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Report describing the potential of new ways of transporting plastic waste

Interreg
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plasticityproject.eu

Summary

This deliverable investigates the current situation in terms of **plastic waste collection** and recycling in Ghent, The Hague, Southend-on-Sea and Douai. The report describes how different countries and cities operate, where the **challenges** and **constraints** are, and what initiatives already exist. From this basis, **new ways** for plastic waste collection and transport are presented and recycling scenarios are explored, identifying advantages, potentials, drawbacks, challenges, barriers, and potential strategies to overcome them. For each city, a suitable scenario taking into consideration the city-specific context, resources and constraints is described. The potential of these small-scale case studies for scaling-up is discussed, and recommendations for the case study cities and other towns are presented.

The report also flags the **political dimension** of the problem with lost plastics: there is a lack of enforceable laws and regulations, allowing the recycling industry to operate in opaque and potentially eco-ineffective ways and thereby harming the environment as well as society.

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1. Introduction

It is undisputed that plastic is a fantastic material: cheap, lightweight, easy to process, flexible yet resistant, and very durable - yet this durability is our major problem. Inadequate collection and disposal of plastics aggravates irresponsible post-consumption behavior and results in unfathomable amounts of plastics finding their ways into the Oceans, harming marine life, affecting tourism, and rising up the food-chain into human bodies.

As a result, plastic waste is one of the most urgent challenges of today. Societies must find ways to collect and recycle plastics, leaking less plastic waste into nature. This report aspires to make a contribution to address this challenge at a local level with focus on the Interreg-2-seas area. It does so by: a) mapping potential news way of transporting waste and recycling waste discussed in academic literature or piloted in ongoing European projects and ; b) exploring existing and new plastic waste collection and recycling strategies in the cities of Ghent, The Hague, Southend-on-Sea and Douai, taking into account their similarities (e.g. handy access to waterways; historical town-centers with narrow streets and restricted access) - as well as their differences in terms of size, organization, ingrained practices, laws and other aspects.

This report does not claim to provide a complete, ready-to-use solution to the whole problem of plastic waste collection, but it hopes to help create a better understanding of this multifaceted problem while suggesting ideas that may lead to better solutions for the future. Let's take care of our Planet together - it's the only one we have!

2. Literature review

This chapter reviews existing literature on waste collection and transport in general and the collection and transport of plastic waste in particular. It relates to other European projects that are relevant to PlastiCity and introduces existing ideas for logging and tracking waste.

2.1. Mapping other relevant large-scale projects

In Europe, we currently use 16 tonnes of material per person per year, of which 6 tonnes become waste. Although the management of that waste continues to improve, the European economy currently still loses a significant amount of potential 'secondary raw materials' such as certain types of plastics present in waste streams, with the majority of plastics being landfilled or burned. Turning waste into a resource is key to unlock a circular economy. In alignment with the EU commitment to zero waste, since 2010, the EU has prioritized incentives to trigger transitions towards a more circular economy: where waste is either eliminated through redesign of products and processes or transformed into new products; and resources are used in an efficient and sustainable way. Supporting this on-going vision towards establishing a strong circular economy, the EU has funded and promoted much research. We review some of those relevant to our project in this section, including Upcycle Your Waste, COLLECTORS, REPAiR, URBAN WASTE, Room Living Lab, STRAIGHTSOL.

Upcycle Your Waste Project

The first relevant project to ours is the Upcycle Your Waste[1] project (2019 - 2022). This project is funded by Interreg 2 Seas Mers Zeen, and is to accelerate the adoption of circular business cases by SMEs that transform waste flows into resources at the local level. SMEs in particular experience difficulties in adopting circular practices, due to limited organisational, technical and financial capacity. According to the Upcycle Your Waste project, only 25% of SME waste is currently repurposed, and circular measures like re-design of products and processes and green procurement could further bring EU SMEs economic benefits of 3–8% of annual turnover.

Specifically, the project conducts six pilots working with groups of SMEs in a specific business area, facilitating the adoption of circular business cases based on collective waste stream analysis, procurement and contracting of waste management; develops protocol for SMEs on procurement for upcycling – showing how SMEs can design and organise collective procurement of waste services to introduce (innovative) circular solutions at local level, design training and

1 https://www.interreg2seas.eu/nl/Upcycle%20Your%20Waste

capacity building programme for SMEs on regulation, waste stream analysis, circular business cases and procurement, and upcycling guidance for local authorities and business district managers on working with SMEs to adopt circular business cases. In summary, this project aims to develop and to introduce knowledge, tools and facilities that enable SMEs and local authorities to make circular economy transitions.

COLLECTORS Project

The second project that is relevant to ours is the COLLECTORS[2] (2017 - 2020), which is an EU Horizon 2020 project aiming to identify and highlight existing good practices of waste collection and sorting. It focuses on three waste streams: paper and packaging, waste electrical and electronic equipment (WEEE), and construction and demolition waste (CDW). More specifically, the main objective of the COLLECTORS project is to harmonize and disclose available information on different waste collection systems, to gain better insight into the overall performance of systems, and to support decision-makers in shifting to better-performing systems via capacity-building and establishing implementation guidelines.

To reach this goal, COLLECTORS plan to work in three phases (Figure 1: Three Phases of COLLECTORS (Source: COLLECTORS)):

Inventory: map, harmonize and disclose existing information on waste collection systems throughout Europe for packaging and paper waste, WEEE, and CDW. The resulting inventory of waste collection practices will be disclosed on a web-based platform to help decision-makers find systems that are in line with their needs.

Assessment: assess the overall performance of waste collection systems in different geographical areas based on comparable data for twelve case studies (four per waste stream), using life-cycle assessments and cost-benefit analyses.

Implementation: stimulate the successful implementation of better-performing waste collection systems by providing implementation guidelines for the collection of the three waste streams,

2 https://www.collectors2020.eu/

which include tailored instructions per type of location. COLLECTORS will also provide policy recommendations on aligning the different policy levels involved. To this end, multi-criteria decision making is to be applied as participatory learning exercises together with regional

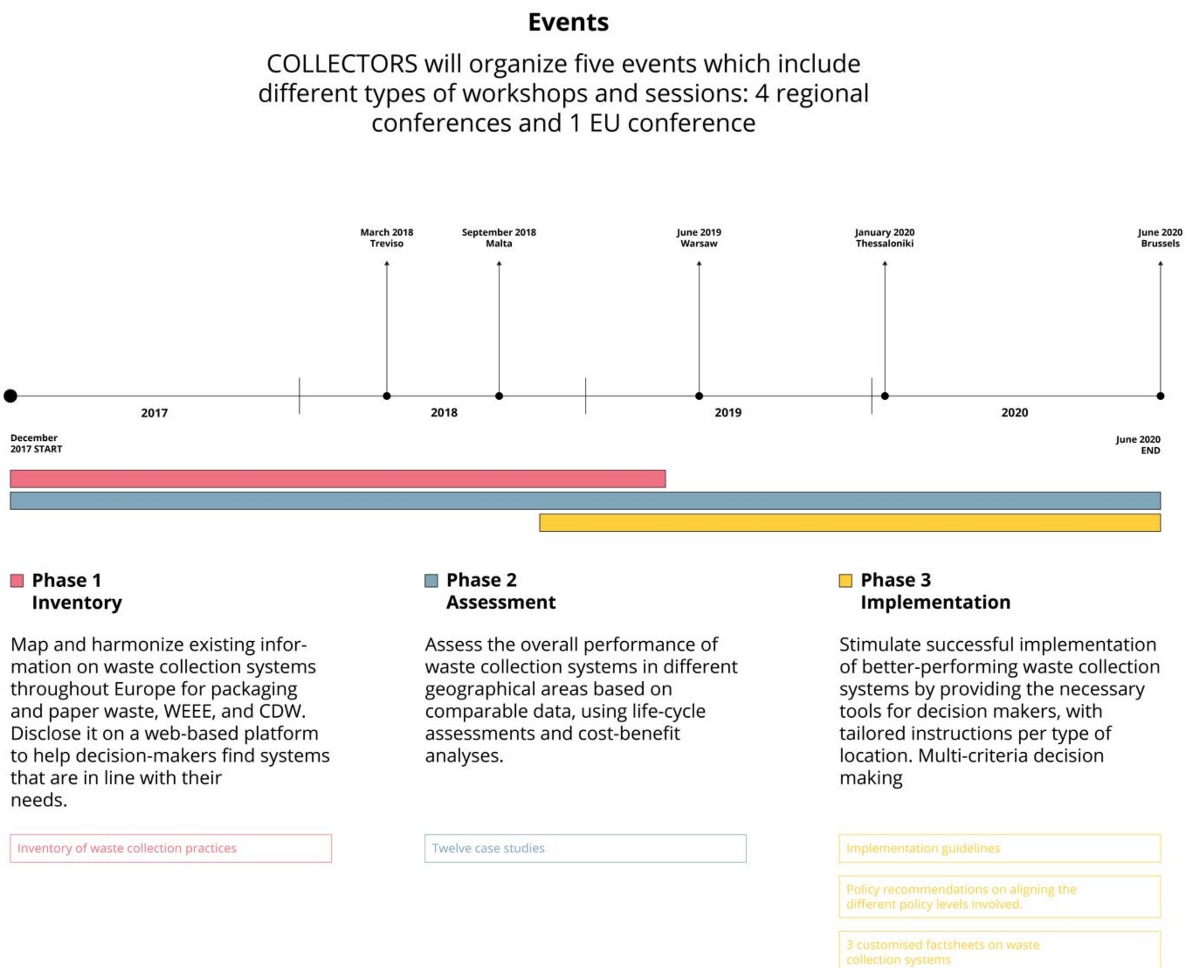


Figure 1: Three Phases of COLLECTORS (Source: COLLECTORS)

decision-makers in the COLLECTORS project[3].

REPAiR Project

3 https://www.collectors2020.eu/wp-content/uploads/2018/04/COLLECTORS-Leaflet-Final.pdf

REPAiR[4] is relevant to Plasticity city in that it allows creating integrated, place-based eco-innovative spatial development strategies aiming at a quantitative reduction of waste flows in the strategic interface of peri-urban areas. This can provide local and regional authorities with an innovative transdisciplinary open source geo-design decision support environment (GDSE) developed and implemented in living labs in six metropolitan areas. These GDSEs further promote the use of waste as a resource, thus supporting the on-going initiatives of the European Commission towards establishing a strong circular economy.

According to REPAiR, the integrated models and methods enable local and regional stakeholders to use the GDSE within a workshop setting to develop fast and reliable alternatives for spatial sustainable development strategies, and the REPAiR is to demonstrate the feasibility and validity of the GDSE as a tool for enhancing waste and resource management.

URBAN WASTE Project

Focusing on touristic cities, the URBAN WASTE[5] project, which is funded by the European Union's Horizon 2020, helps to develop strategies aimed at reducing the amount of municipal waste production as well as strategies to develop further re-use, recycling, collection and disposal of waste. The socio-economic impact of tourism is extraordinary in cities, but it also brings a range of negative externalities, including high levels of unsustainable resource consumption and waste production. In comparison with other cities, tourist cities have to face additional challenges related to waste prevention and management due to their geographical and climatic conditions, the seasonality of tourism flow and the specificity of the tourism industry and tourists as waste producers. Therefore, URBAN-WASTE adopts and applies the urban metabolism approach to support the switch to a circular model where waste is considered as a resource and reintegrated in the urban flow.

Importantly, the project develops eco-innovative and gender-sensitive waste prevention and management strategies in cities with high levels of tourism including Florence, Nice, Lisbon,

4 http://h2020repair.eu/

5 http://www.urban-waste.eu/

Syracuse, Copenhagen, Kavala, Santander, Nicosia, Ponta Delgada, Dubrovnik – Neretva County, Tenerife. These strategies will facilitate the reintroduction of waste as a resource into the urban metabolism flows and address waste management, risk prevention and land-use as an integral part of urban development.

CITYLAB Project

The CITYLAB[6] project, which is funded by the EU Horizon 2020, is to develop knowledge and solutions that result in up-scaling and roll-out of strategies, measures and tools for emission-free city logistics in urban centres by 2030. The participating cities include Amsterdam, Brussels, London, Oslo, Paris, Rome and Southampton. Compared to other projects, CITYLAB focuses on four axes for intervention: highly fragmented last-mile deliveries in city centres; large freight attractors and public administrations; urban waste, return trips and recycling; and logistics facilities and warehouses.

The core of the CITYLAB is a set of living laboratories, where cities work as contexts for innovation and implementation processes for public and private measures contributing to increased efficiency and sustainable urban logistics. Linkages are then established between the different living labs for exchange of experiences and to develop methodologies for transfer of implementations between cities and between companies. The outputs from the living labs include best practice guidance on innovative approaches and how to replicate them. According to CITYLAB, it lays the groundwork for roll-out, up-scaling and transfer of cost-effective policies and implementations that lead to increased load factors and reduced vehicle movements of freight and service trips in urban areas.

STRAIGHTSOL Project

STRAIGHTSOL[7] was another EU-funded project that is related to ours. It ran from September 2011 to August 2014.

6 http://www.citylab-project.eu/

7 http://www.straightsol.eu/

The three-year project concludes seven demonstrations involving stakeholders (such as freight carriers TNT Express, DHL Supply Chain and Kuehne+Nagel) in Brussels, Barcelona, Thessaloniki, Lisbon, Oslo and the south of England. The demonstrations include replacing vans with bicycles, monitoring rail freight with GPS, remote bring-site monitoring for sustainable logistics, information sharing in last-mile distribution, night distributions, as well as new technologies for the management of loading and unloading places.

According to the project coordinator, Jardar Andersen, from Norway's Institute of Transport Economics, the demonstrations have focused on reducing the societal problems associated with freight transport, while also emphasising efficiency, business models and financial viability. "We will evaluate the environmental and financial impact of each of the demonstrated solutions, and focus on which solutions can be best implemented by other companies and in other cities across Europe and elsewhere," he says.

The UK Plastic Pact and other similar plastic pacts

The UK Plastic Pact[8] is a collective initiative that aims to generate a circular economy for plastics. The Pact was launched by WRAP in April 2018, in partnership with Ellen MacArthur Foundation in order to implement the first national strategies for a new plastic economy. With this pact, different businesses in the plastic value chain will act together with the UK government and NGOs to overcome problems related to plastic waste. In this respect, the Pact will encourage different actors to create innovative models to cut down the overall amount of plastic packaging. Additionally, it will help policy makers and businesses to form a better recycling system where each party takes more responsibility for its own waste, and effectively recycle plastic packaging to make new products. In 2018, WRAP promoted the Recycle Now campaign and reached around 18 million people. In focused plastic campaigns, the main goal was to engage citizens on reducing and reusing plastic waste.

Currently, the UK Plastic Pact has around 80 business members from the retail, hospitality, manufacturing, plastic recycling and plastic supply sectors. WRAP estimates that these members

[8] https://www.wrap.org.uk/content/the-uk-plastics-pact

combined produce and use 80% of the plastic packaging on goods sold in UK supermarkets. Moreover, they are also responsible for half of the plastic packaging found in the UK market (WRAP, 2019). Due to the fact that packaging makes up to almost 70% of all plastic waste in the UK, the main focus of the Pact is packaging. Accordingly, by the end of 2020, eight types of single-use plastic items targeted to be eliminated (WRAP, 2020).

The UK Plastic Pact has set four main targets to be achieved by 2025. In the Roadmap to 2025 (WRAP 2019), these targets were stated as:

1. Eliminate problematic or unnecessary single-use packaging
2. 100% reusable, recyclable and compostable packaging
3. 70% of plastic packaging effectively recycled or composted
4. 30% average recycled content in plastic packaging

In order to achieve each target, a number of key activities will be undertaken before the end of 2025. For instance, reviewing all materials with suppliers, updating the criteria for the problematic materials and items together with the adoption of high profile citizen engagement campaigns will be helpful to minimise unnecessary single-use packaging. For producing 100% reusable, recyclable and compostable packaging, new pack designs will be discussed and each member retailer of the Pact will bring at least two inventive reusable packaging to the market. Additionally, for better understanding of recyclable and compostable packaging, there will be more detailed staff training.

For the third target (i.e. 70% of plastic packaging effectively recycled or composted), local authorities and waste management companies will be supported for more effective waste collections. In this respect, financial investment will be provided to the waste management sector. Similar to the first target, high profile citizen engagement and intervention campaigns is another key activity to achieve the third target. Finally, putting recycled content in all products sold by the UK Plastic Pact members and installing additional capacity by waste and recycling sector members will be key activities to have 30% average recycled content in plastic packaging by 2025.

While achieving these targets plays a key role to overcome many problems related to plastics, there are also various challenges the Pact members have to face. For example, there will be a lot of short-term costs of producing more recyclable plastic items and producing new packaging may require more time. Besides, in order to increase recycling and waste management capacity in a relatively short period, new planning and investment schemes have to be implemented. However, innovative and alternative projects highlighting key opportunities for recyclable and compostable products, collaboration between business, investment communities and local authorities together with the government leadership to support the targets of the Pact can be underlined as some of the potential solutions to deal with these challenges.

In addition to the UK Plastic Pact, a number of plastics pacts have been developed in different parts of the world. In Europe, the Netherlands, together with France, is one of the earliest countries to initiate a plastic pact. The Plastic Pact NL is an initiative with more than 70 organisations and supported by the Ministry of Infrastructure and the Environment. The main goal of the Pact is to use 20% less plastic by 2025 and increase the plastic recycling rates. In order to reach that objective, the Pact supports circular products and systems.

The European Plastics Pact is the first regional initiative to join the Plastics Pact network. The Netherlands and France started the Pact, but there are more than 80 organisations all around Europe that helped to shape the Pact. The Pact aims to use 20% less virgin plastics, increase recycling rate by 25%, use a minimum of 30% recycled plastics in new plastics and design 100% recyclable and reusable products before the end of 2025. Further details of the Pact and these objectives will be discussed in the first annual meeting that will be organised in October 2020.

In South America, Chile is the first Latin American country to join the Plastic Pact Global Network initiated by Ellen MacArthur Foundation. The Chilean Plastics Pact, which is led by the Ministry of Environment, was signed in April 2019 with the purpose of bringing together all actors in the plastic value chain. The pact has four main commitments defined for 2025: Eliminate single-use plastics that are problematic or unnecessary; make 100% of plastic containers and packaging recyclable, reusable or compostable; recycle, reuse, or compost around 1/3 of both domestic and non-domestic plastic containers and packaging; use and average of 25% recycled material to produce plastic containers and packaging. In this respect, the Pact released the Roadmap in January 2020.

In North America, the U.S. Plastics Pact is organised by Ellen MacArthur Foundation, The Recycling Partnership and WWF. The Pact targets to reduce the use of virgin plastics by 2025 by achieving the following targets for plastics packaging: Define problematic or unnecessary plastic packaging and eliminate them; make all plastic packaging completely recyclable, reusable or compostable; effectively recycle or compost 50% of all plastic packaging; increase the average recycling content in plastic packaging to 30%.

In Africa, South Africa is the first country to initiate a plastic pact and the only country to join Ellen MacArthur Foundation's Plastic Pact Global Network. Similar to the other pacts, the SA Plastics Pact aims to positively change the country's plastic packaging sector by 2025 by taking actions on unnecessary or problematic plastic packaging, making all plastic packaging recyclable or reusable, recycling 70% plastic packaging and producing plastic packaging with at least 30% average recycling content.

Other relevant small-scale projects

Wong (2010) conducted a study on household plastics recycling in the UK region of Yorkshire and Humber using a comprehensive life cycle inventory analysis. The key findings include that there are not enough recycling facilities in the UK, and some are in the wrong locations, away from where the large quantities of plastic waste are generated. Additionally, instead of working with local recyclers, some councils - who are the main plastic waste collectors in the UK - send their materials to companies that are hundreds of kilometers away. Also, local authorities often do not know what happens to the collected plastics (are they exported?), as there are many small traders who conduct their business in isolation, without council oversight or reporting / tracing.

2.2. Reviewing the status-quo in waste collection transport and logistics

The environmental consequences of plastic solid waste are visible in the ever-increasing levels of global plastic pollution both on land and in the oceans. Although there are important economic, social and environmental incentives for the plastics recycling, the current recycling rates are incredibly low (20-30%) in the 2S region. Within the urban environment, a lot of 'lost plastics' is available that would be eligible for recycling but is not effectively validated, partly because the economic opportunities are not fully known and understood, collection logistics not fully developed, and the sorting facilities not well equipped or stakeholders not fully engaged.

These are all barriers to realise the full potential of plastic in the circular economy and need to be overcome in delivering the EU strategy for plastics in the Circular Economy. In this section, we briefly review the current status of waste collection modes and how literature in waste collection logistics attempt to make a cleaner world and investigate ways to reduce cost, fuel consumption and emission in waste transportation activities. As highlighted in Beliën et al., (2012), the collection logistics activity accounts for approximately 80% of all costs associated with waste disposal.

Currently, there are several waste collection service models used across the globe. The most common form of waste collection is the door-to-door collection (Botti et al., 2020, Kaza et al., 2018). In this model, trucks or small vehicles are used to pick up garbage outside of households at a predetermined frequency. In certain localities, communities may dispose of waste in a central container or collection point where it is picked up and transported to final disposal sites (Kaza et al., 2018). These waste collection services involve large expenditures as well as severe operational problems, such as being expensive to operate in terms of investment costs (i.e. vehicles fleet), operational costs (i.e. fuel, maintenances) and environmental costs (i.e. emissions, noise and traffic congestions) (Mohajeri and Fallah, 2016).

These trucks or small vehicles are often designed as a speciality vehicle, with self-compactors, with considerable operating expenses, are usually delegated to collect urban waste. Hence designing efficient collection strategies is vital not only to reduce operating costs and vehicle emissions but also to maximise the amount of recycling, while minimising traffic congestion associated with refuse collection vehicles (RCV) operations (McLeod and Cherrett, 2008). During loading and unloading bins, trucks have to keep their engines running, producing constant exhaust emissions, and it also causes noise and traffic congestion. The portion of time spent loading and unloading typically depends on different factors (the technology employed, the size and location of the collection operation, etc.). However, in case of urban waste in cities with high population density and high traffic congestion, the non-transportation time, which includes time spent for load-unload operations and other idle times can reach 50% of the total time (Faccio et al., 2011). This consideration highlights the importance not only to optimise the vehicle route in order to reduce the transportation time but also to propose alternative transportation modes and to explore another low-carbon vehicle.

Battery Electric Trucks (BEVs) and Hydrogen vehicles are often considered as the future transport modes that have potential environmental benefits to promote sustainable urban transportation, which has huge integration possibilities in waste collection systems. In particular, Hydrogen vehicles are powered by fuel cells, which use catalysts to combine hydrogen and oxygen to produce water and electricity (Service, 2009). Their ability to generate electricity without CO2 has spawned recurring visions of a carbon-free hydrogen economy. However, the price of fuel cell vehicles is still high because of the high costs of the fuel cells and onboard hydrogen storage systems (Contestabile et al., 2011). Future research is called to reduce the price and improve the durability of fuel cells and onboard hydrogen storage systems, as well as the hydrogen distribution and refuelling system (van den Bulk and Hein, 2009)

Another recent innovation, particularly suitable for congested urban waste collection situations, is the e-cargo bike, which is a robust bike with a sturdy box at the front. It costs almost nothing to run, does not emit any pollutants and unlike vans and cars, helps contribute to cleaner air (Hess and Schubert, 2019). A recent application is with Plymouth City Council. In February the Council submitted a bid about £200,000 to the Energy Saving Trust for a fleet of electric cargo bikes. The companies involved in this project can receive financial support towards the cost of an e-cargo bike. As Cabinet Member for Street Scene and the Environment said[9], the e-cargo bike[10] provides "better air quality, reduced CO2, cheaper running costs and less congestion - that's got to be better for business as well as the rest of us!". In Table 1 and Figure 2, we present a comparison of the economic and environmental vehicle parameters as aforementioned. We extend the discussion in Section 3.

9 https://www.plymouth.gov.uk/newsroom/pressreleases/workingbringmoreecargobikesplymouth

10 https://energysavingtrust.org.uk/ecargo-bike-grant-fund-awarded-to-local-authorities-and-businesses

Table 1: Comparison of Different Transport Modes. Note that the theoretical maximal speed of the vehicles, with the exception of the CargoBike, is irrelevant as speed restrictions in Europe are much lower.

	Diesel	**Battery electric**	**Hydrogen-electric**	**E-cargo bike**
Examples	 Heil Trucks	 BYD trucks	 E-truck Europe	 E-Cargo
Primary power unit	Diesel Engine	Battery	Hydrogen Fuel Cell	Battery
Est. Range	1500km	200km	700km	N.A
Est. Fuel consumption	30L/100km	120kwh/100km	15kw/100km, 2kg/100km	N.A
Fuel price	130 p/litre (average in 2019 uk)	10p/kwh	10p/kwh, £ 7/kgH_2	N.A
Speed (highest)	300 km/h	105 km/h	105 km/h (assumed)	20 km/h
Refuel/ Charging time	15mins	9hrs AC (/2.5hrs DC/1.5hrs DC)	15mins	2mins (battery Replaceable)
Loading capacity	20m^3	20 m^3	20 m^3	0.48 m^3
Payload	16 000 kg	16 000 kg	16 000 kg	125 kg
CO2 emission	132g CO2/km	0(*)	0(*)	0(*)

(*) Note that the emissions of electrical vehicles are zero where the energy is consumed (e.g. in the city centre); however, depending on how the energy is generated, there may be emissions elsewhere.

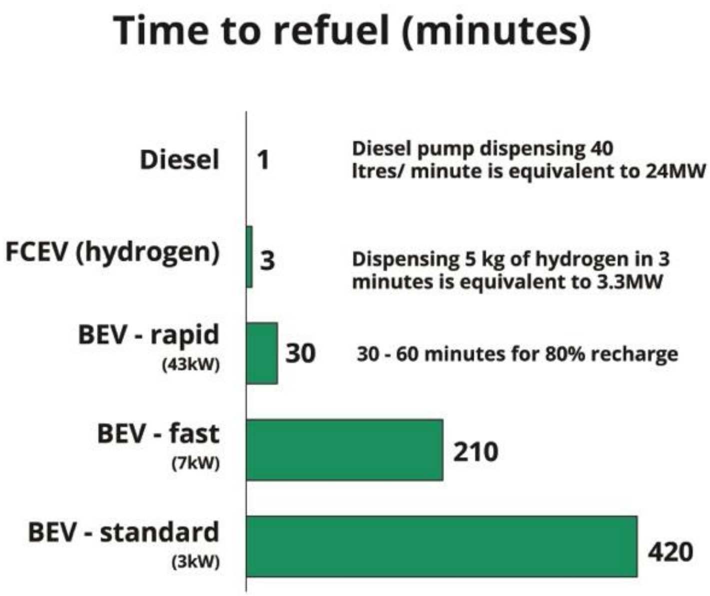


Figure 2: Comparison of Refuel Time of Different Types of Energy

In the past, the waste collection was carried out without a real-time analysing of demand, and the construction of the routes was mainly static. However, because of the ongoing urbanisation, the importance of an efficient collection system only increases. Modern traceability devices, like volumetric sensors, identification RFID (Radio Frequency Identification) systems, GPRS (General Packet Radio Service) and GPS (Global Positioning System) technology, permit to obtain data in real-time basis, which is fundamental to implement an efficient and innovative waste collection logistics model (Faccio et al., 2011). Optimally, a method integrating traditional vehicle routing problem (VRP) solutions and real-time analysis that tries to optimise economic, environmental and social cost is to be developed.

Against this backdrop of new types of transport modes and electric or alternative fuel vehicles being proposed to minimise the emissions, a new challenge to integrate VRP and real-time analysis is where we have recharging or refuelling decisions in lieu of emptying decisions (Markov et al., 2016). In 2011, Conrad and Figliozzi considered the recharging VRP (RVRP), where electric vehicles can recharge at collections locations with time windows. Schneider et al. (2014) contribute to the traditional VRP analysis by solving the electric VRP with time windows and recharging stations (E-VRPTW). The problem features variable recharging times based on remaining battery charge and a hierarchical objective function minimising the number of vehicles first and travels distance second. Schneider et al. (2015) combine recharging and reloading facilities in the VRP with intermediate stops (VRPIS).

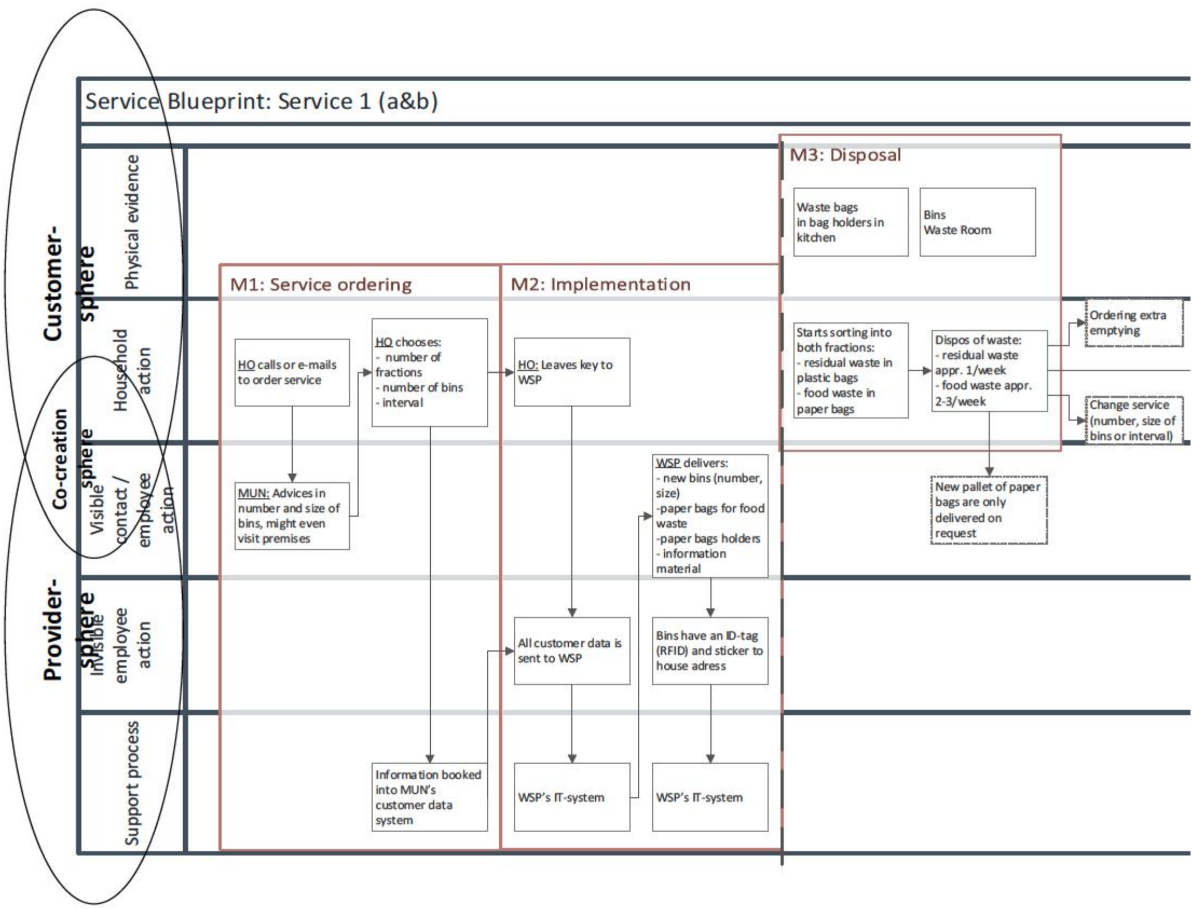


Figure 3: Modular logistics (1/2) from Wehner and Halldorsson (2019)

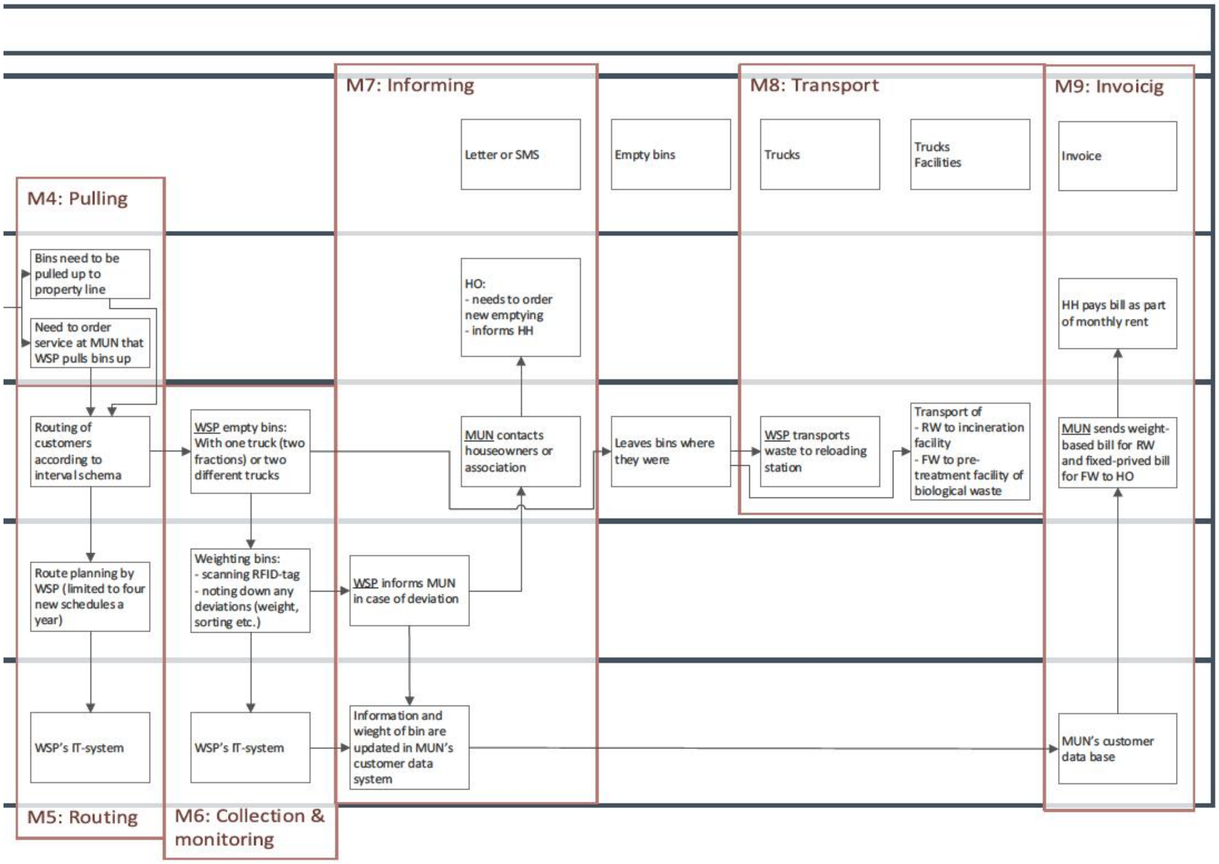


Figure 4: Modular logistics (2/2) from Wehner and Halldorsson (2019)

In Plasticity project, we develop a modular logistics model as an integrated way to improve the service efficiency, which incorporates the analysis spans from traditional VRP analysis, new ways to transport plastic waste inside the four project cities, and new approaches to logging and tracking plastics from source to destination.

Modular Logistics (Lin and Pekkarinen, 2011; Basek et al., 2011; Lin et al., 2010) is a concept for structuring logistics services into a series of service modules. Wehner and Halldorsson (2019) applied this to waste collection logistics services, as illustrated in **Error! Reference source not found.** and Figure 4. These service modules can then take different forms, depending on the implementation case. The advantage of modular approach is that service efficiency can improve, and that there is more flexibility to change one module and keep the others as long as the interfaces stay intact. Furthermore, the modular concept provides a certain abstraction to the logistics problem, facilitating the design of service variations across different cities and countries.

2.3. Reviewing trends and innovations in logging and tracking

2.3.1. Plastic sorting in urban environments and automated plastic sorting technologies

In general, manually sorting waste in cities can be considered as a difficult process as it requires thorough training and too much human capacity and resource. However, thanks to rapidly developing technologies, sorting different types of waste including plastic in urban environments becomes much easier. Accordingly, different types of sorting methods are still emerging and waste companies have already started to implement various sorting techniques to separate waste items more carefully and effectively. For example, in reverse vending machines (RVM) systems (Figure 5), waste recognition and sorting is done through automatic identification of waste based on the material or shape of the container, or the barcode attached to it (Kokoulin et al., 2019).

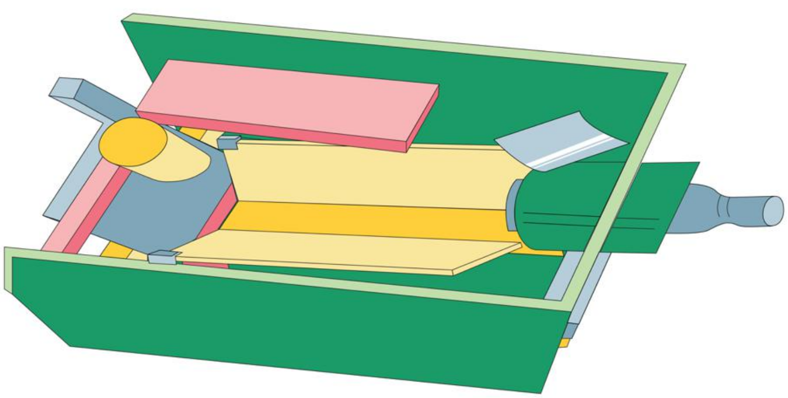


Figure 5: Traditional Reverse Vending Machine (Source: Kokoulin et al., 2019)

Besides, reverse vending machines (RVM) are also used to positively influence consumer behaviour by leading them to correctly sort different types of plastic waste. In this system, after a person puts an object into the waste collection point, that person gets rewards (e.g. shopping vouchers) as a form of incentive. To a certain extent, RVM technologies nudge individuals to correctly sort and dispose of their recyclable waste. Therefore, RVM is both beneficial for consumers and waste management companies.

Other than RVM, near-infrared (NIR) enabled technologies have also appeared as important technologies for automatically sorting recovered plastics from general waste. In this respect, NIR spectroscopy can be highlighted as a highly suitable technique to detect polymers and auto sort different forms of plastic.

In their research, Wu et al. (2020) used NIR spectra (Figure 6) to sort four varieties of recovered plastic, namely acrylonitrile butadiene styrene/polycarbonate (ABS/PC), acrylonitrile butadiene styrene (ABS), polystyrene (PS) and polypropylene (PP). Applying NIR spectra together with distinct classification methods, the authors found that PP, PS, ABS and ABS/PC may have high levels of separation despite the fact that it is not possible to fully separate PS, ABS and ABS/PC in some situations.

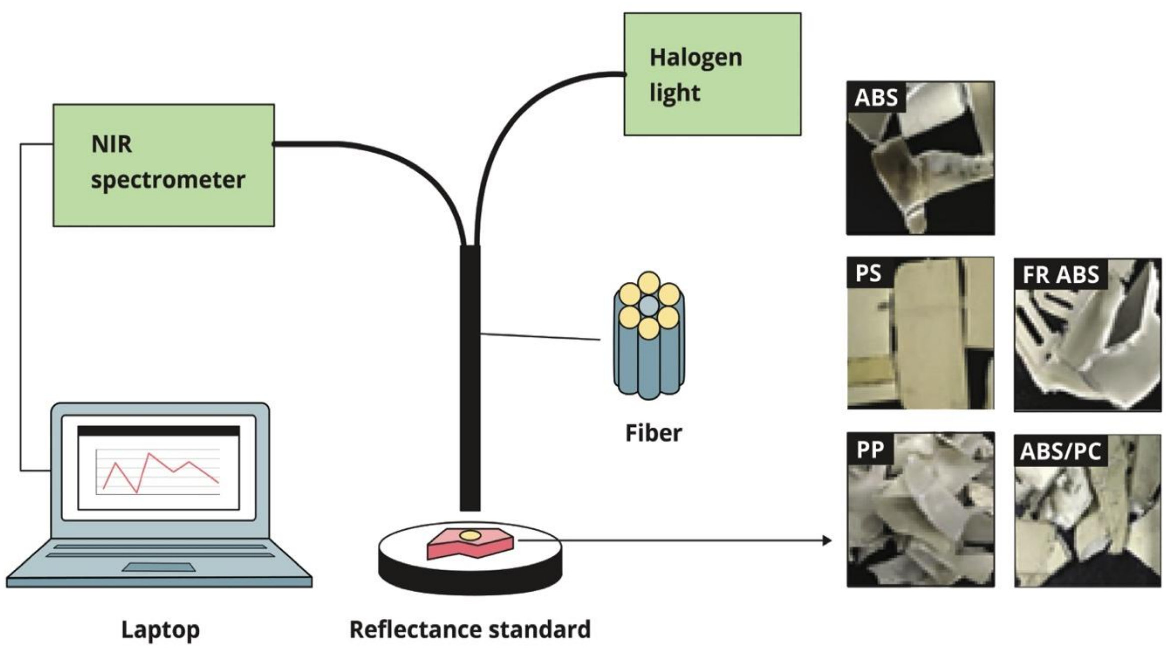


Figure 6: NIR spectrum acquisition platform and waste plastic flakes (***Source:*** Wu et al., 2020)

Although there are many efficient methods and techniques to sort plastic waste, tracking of plastic and plastic waste is still problematic in the majority of the world especially in urban areas. Because of the issues related to correct description and categorisation of waste, lack of data exchange between different parties (e.g. end-users and recycling companies) in the overall waste management process and lack of highly accurate waste tracking technologies, waste managers usually fail to efficiently track plastic waste. Because of this problem, only around one third of the total plastic waste in urban environments is recycled each year. This situation also generates the 'lost plastic' issue in many countries. However, in order to increase plastic recycling rates and minimise the amount of lost plastic in urban platforms, it is crucial to track the movement of plastic waste generated in land in addition to the marine environments.

2.3.2. Plastic tracking technologies

Existing studies covering the topic of plastic tracking have mostly focused on tracking of plastic litter in the marine context and adopted numerical modelling techniques such as probabilistic approach (e.g. Hinata et al., 2020), 2D Lagrangian model (e.g. Maes and Blanke, 2015; Liubartseva et al., 2018) to understand how to track microplastics found in the lakes, seas and oceans.

On the other hand, a number of studies have suggested different technologies including barcodes, radio-frequency identification (RFID) and internet-of-things (IoT) for tracking waste produced in land.

2.3.2.1. Barcodes

Barcode technology can be used to label bulk polymers. By applying direct barcoding, barcoded polymer particles may ease to track steps in product processing (Paunescu et al., 2016). In this sense, graphical, optical and chemical sequence encoding are the three barcoding techniques employed by scientists to track and trace product particles including polymer (see Figure 7 for barcoding and encoding of bulk polymer). Paunescu et al. (2016) also contended that applying one of these encoding methods to track particles might help both consumers and waste managers to learn more about product life cycles and waste creation. Thanks to this, more sophisticated technologies to track different types of plastic waste such as non-degradable plastic packaging in more environment-friendly ways can be developed.

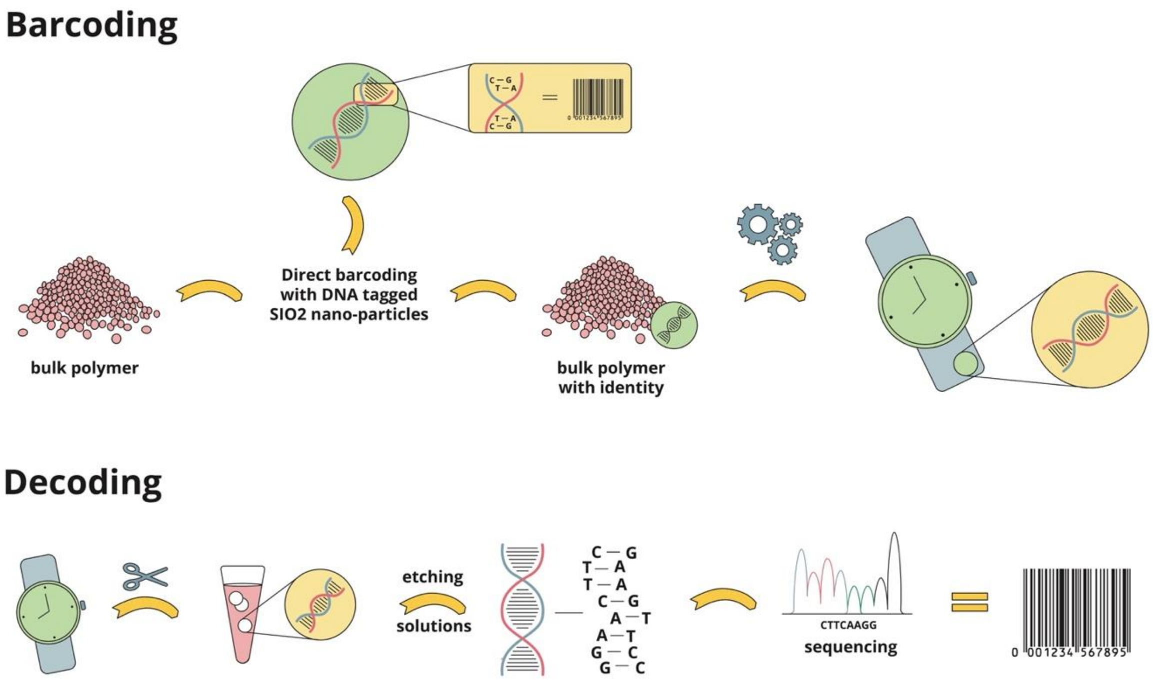


Figure 7: Barcoding and encoding of bulk polymer for particle tracking (***Source:*** Paunescu et al., 2016)

2.3.2.2. RFID and GPS

RFID is one of the most commonly used technologies to manage municipal and household solid waste. In some situations global positioning system (GPS) tools are integrated with RFID to create powerful tracking tools for waste. In their study, Phithakkitnukoon et al. (2013) highlighted that attaching RFID tags to products and tracking those products with an GPS-enabled RFID helped them to track more than 1100 tagged waste items in 110 different locations. They also managed to separate the waste into six categories including landfill and recycling (Figure 8). In another study, Hannan et al. (2011) designed a system with RFID reader and GPS for waste trucks to monitor waste collection from RFID tag attached solid waste bins. They found that the new monitoring system increased the efficiency of waste tracking and collection. RFID and GPS technologies are frequently used for electrical and electronic waste (WEEE or e-waste) tracking as well. Accordingly, in order to minimise illegal and undocumented e-waste trade, Lee et al. (2018) carried out an experiment by using 17 cathode ray tube (CRT) monitors in 15 e-waste collection centres in California to track e-waste. They explored that using RFID together with GPS was a good method for e-waste tracking and policy makers can use location tracking to avoid ineffective

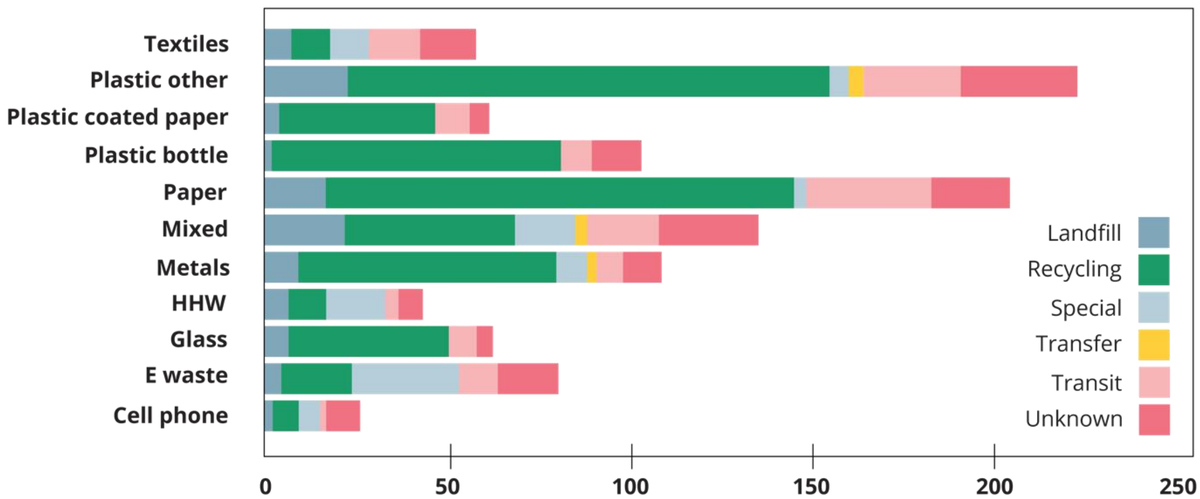


Figure 8: Destination types for different trash categories (Source: Phithakkitnukoon et al., 2013)

and/or illegal waste management.

In addition to GPS, different location tracking technologies have been adopted by individuals to generate RFID-based systems for waste tracking. For instance, Arebey and colleagues (2010) developed a solid waste system with RFID, geographic information system (GIS), general packet radio services (GPRS), and a low cost camera to track solid waste bins and waste trucks (**Error! Reference source not found.**). Their system provided Arebey et al. (2010) important information about the amount of waste and real-time status of the waste bin. Therefore, they could reallocate the bins in order to collect and recycle waste more accurately.

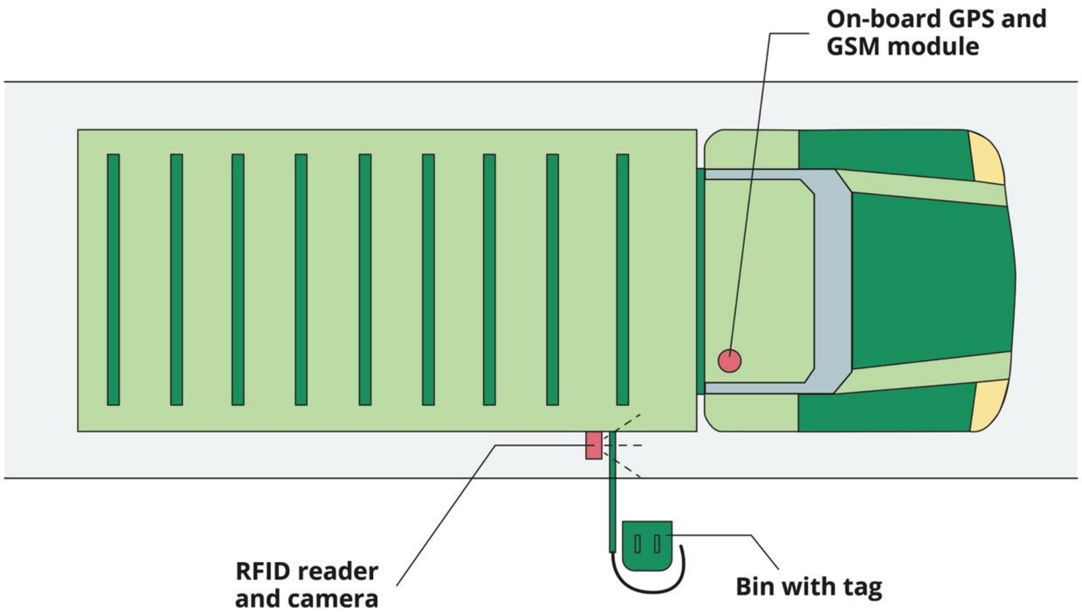


Figure 10: Proposed RFID system for waste management (Source: Arabey et al., 2010)

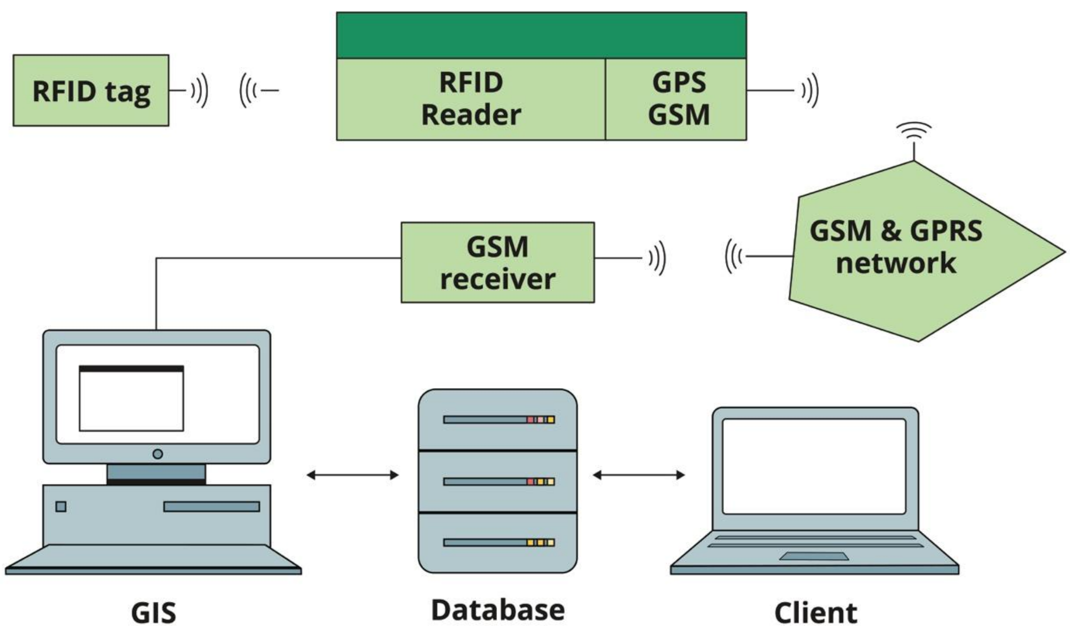


Figure 9: Architecture of the proposed waste monitoring and management system (Source: Arabey et al., 2010)

Furthermore, real-time information collected with GPS, GIS and RFID can be used to prepare more enhanced pay-as-you-throw (PAYT) systems, and therefore better plans for waste recycling. When waste trucks are loaded with an RFID reader and GPS, waste managers may optimise the routes for these trucks as they could identify the amount of waste in each specific bin and manage waste bins more accurately (Purohit and Bothale, 2011). Similarly, Wyld (2010) argued that RFID-enabled waste bins might increase the effectiveness rates of PAYT systems by offering more recycling incentives to consumers. Encouraged consumers might put more effort to separate and sort recyclable waste and make it easier for waste management companies to track different kinds of solid waste. According to Gnoni et al. (2013), RFID-based traceability system is highly feasible to implement and it has potential to increase the effectiveness of the PAYT system and overall process of waste tracking.

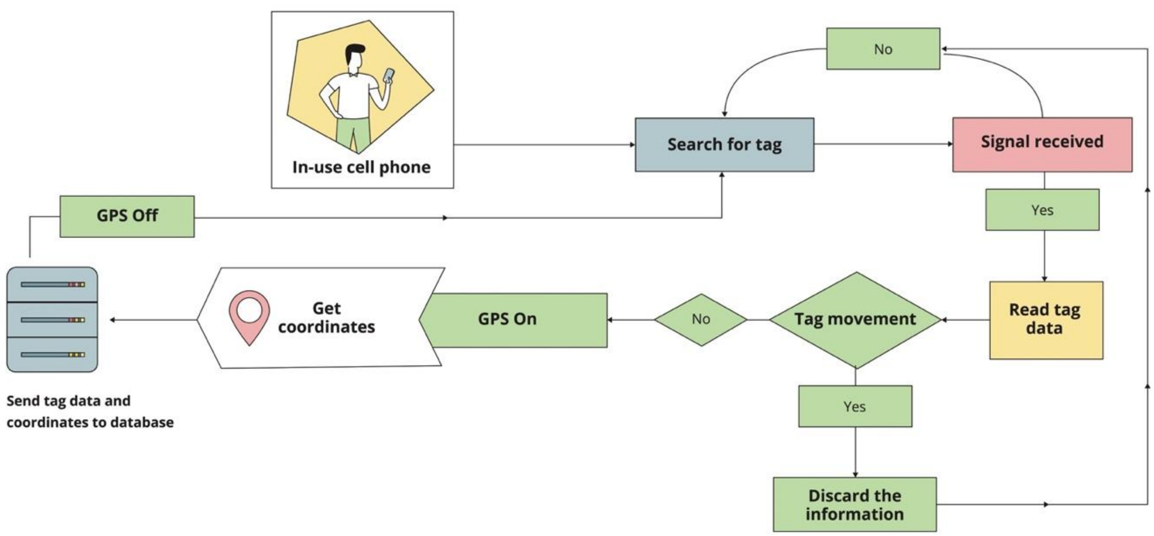


Figure 11: Proposed RFID-based system for cell phone tracking (Source: Ullah and Sarkar, 2018)

As RFID makes it possible to store more data on the targeted items and products, this technology plays a key role for optimising supply chains and reverse logistic processes, which lead to higher recycling rates (Nunes et al., 2006). In the automotive industry, for example, RFID can increase the overall recycling rate by helping waste managers to more efficiently track recyclable plastic and lowering logistics costs (Nunes et al., 2006). Ullah and Sarkar (2018) recommended to manufacture cell phones with RFID tags embedded to improve waste management by increasing the return rate of recyclable phones from general waste in the reverse logistics system (see Figure 11 for the proposed tracking system). In other words, tracking any plastic part used in cell phones becomes easier with RFID technology.

From a similar perspective, Stankovski et al. (2009) suggested an in-mould labelling (IML) robot to automatically track products in different phases of life cycle. With IML technology, each plastic part is labelled before they are assembled. After attaching an RFID tag to products, IML robots may track the number of mould cycles and automatically save the significant data on the RFID tag. Hence, this procedure enables information update about the actual situation of the product for tracking purposes.

Moreover, in some cases, RFID technology is applied to create a knowledge hub for waste recycling. In their study, Atkins et al. (2008) proposed a system to combine RFID and wireless imagery technology to verify data in the knowledge hub and predict the logistics of waste (i.e. plasterboard) to recycling centres. By using this technology, they aimed to track the appropriate disposal and recycling of the materials.

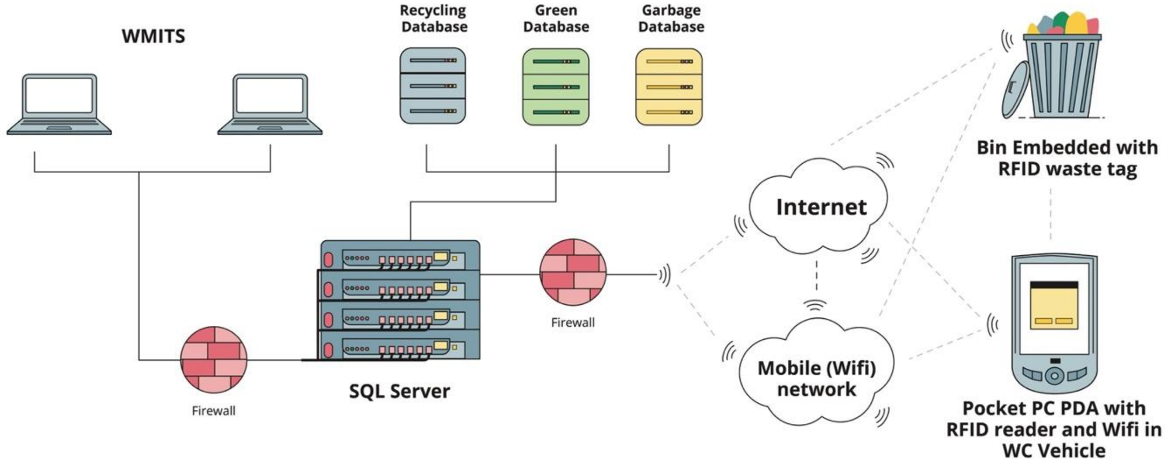


Figure 12: RFID-enabled multi-layer waste management system (Source: Chowdhury and Chowdhury, 2007)

In order to track waste, RFID technology can be used with different computer applications. According to Sun et al. (2013), for electrical and electronic product waste management, RFID tags with detailed e-waste information guide waste managers to check the situation of the products when RFID is used with a specific application (i.e. GREENet). Likewise, for hazardous waste tracking including plastic, RFID-enabled cloud computing can be implemented to facilitate smart recycling systems (Namen et al., 2014). This system is very useful especially for accurate waste delivery destinations. Furthermore, a multi-layer architecture using RFID technology integrated with computer application (Figure 12) has potential to improve the effectiveness of real-time waste tracking and management systems (Chowdhury and Chowdhury, 2007).

2.3.2.3. Smart Waste Bins: Internet-of-Things (IoT) and RFID-enabled IoT waste systems

In the recent years, various IoT-based (i.e. smart) technologies have been developed and implemented to track general and plastic waste. For higher levels of consumer integration and engagement in the waste management process, policy makers and waste managers have adopted a number of smart applications.

Accordingly, technologically enhanced mobile technologies provide good potential for individuals to share a significant amount of data with waste managers to support the overall process of waste tracking. For instance, Nagendra et al. (2019) did a pilot study with Public Affairs Centre (PAC) waste tracker, a mobile application used by municipalities in India to improve citizen science, in order to show the effectiveness of this application in waste tracking. In PAC waste tracker, individuals spot the uncollected waste and put a complaint about the waste into their mobile phones. Following this, the information is uploaded to a cloud server. Finally, city councils ask waste collectors to collect the waste. Figure 13 below demonstrates the overview of this system. The authors added that this system has the potential to overcome many issues related to waste tracking.

Esmelian (2018) also argued that involving individuals in the waste management process and collecting information from them is an essential part for IoT-based waste technologies to work sufficiently. Similarly, for increased transparency of information regarding waste and better waste information exchange between parties in the waste management system, decentralised blockchain applications can be used (Laouar et al., 2019). Blockchain databases might give opportunity for both individuals and waste managers to access waste information without restrictions. Thus, different types of waste including plastic can be more smoothly tracked.

Figure 13: Overview of PAC waste tracking system (Source:Nagendra et al., 2019)

IoT-enabled, smart waste bins are usually recognised to be very useful technologies for waste classification, detecting and tracking. Salimi et al. (2018) designed a smart waste bin robot to visually classify different organic and non-organic waste. In this process, the smart robot moved autonomously to scan waste in public locations. With the application of Kalman filter to track waste objects, the authors managed to accurately detect and track distinct waste items.

Additionally, Crisnapat et al. (2019) proposed an IoT-based smart trash tracking system (STTS) to accurately monitor and track waste with a web technology. They proposed to attach a smart device to each waste bin that could collect the data and send it to the cloud server automatically (Figure 14)

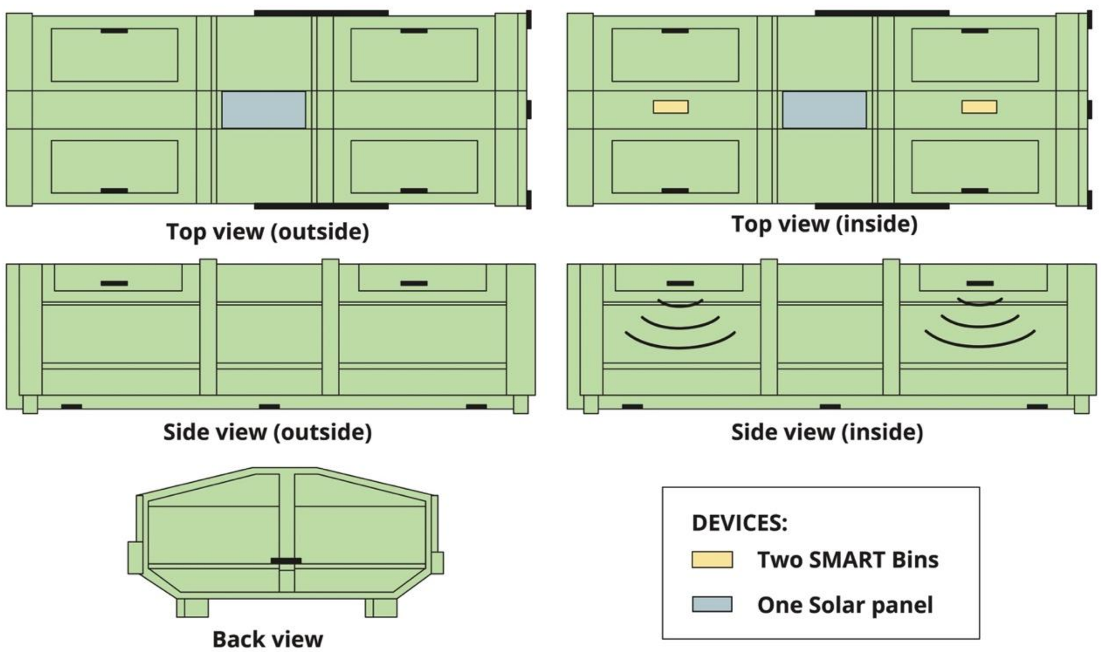


Figure 14: Smart trash tracking system installed waste bin (Source: Crisnapat et al., 2019)

As discussed earlier, RFID is one of most commonly used technologies for accurate waste management. Additionally, RFID has potential to bring many benefits to many IoT systems used in waste management.

In this sense, many scholars have argued that integrating RFID technology may improve the effectiveness of IoT-based, smart waste management technologies particularly for waste identification and tracking. For instance, Costa et al. (2015) stated that a smart waste system using RFID technology has the potential to correctly track the waste items in the reverse logistics process. When the RFID tags are attached to different items of the products, the RFID reader receives information about the actual situation of a specific part and sends that information to another software for profile mapping.

Furthermore, in their smart waste management design, Glouche and Couderc (2013) proposed to attach a RFID tag to each item such as plastic water bottles (Figure 15) except non-recyclable, organic waste items. By attaching the tags, each waste item becomes smart and can be detected by RFID-enabled smart bins more easily based on the information stored in the tags.

This system is argued to be highly practical for providing information about waste in a specific bin and guiding waste managers to optimise waste tracking. Multiple tags can also be attached to objects in order to overcome any potential low levels of detection probability (Margaret and Sridhar, 2017).

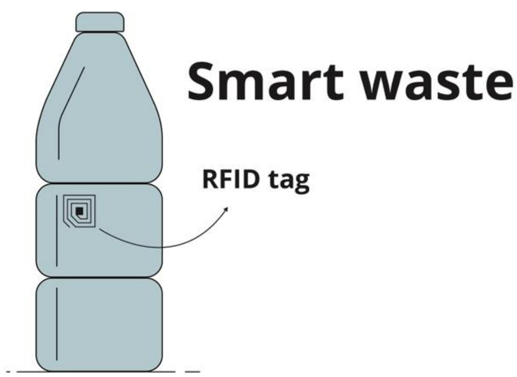


Figure 15: Smart plastic bottle with RFID tag
(Source: Glouche and Couderc, 2013)

Moreover, Figure 15 illustrates the architecture of the RFID-enabled smart recycle bin proposed by Wahab et al. (2014) was aimed to nudge consumers to dispose of their waste correctly into the dedicated bins (i.e. orange bin for plastic products) by offering them points as a reward. To be more specific, after a user throws a plastic bottle to the orange recycling bin, RFID reader automatically identifies the product and if it is disposed in the correct bin, the user is given points depending on the weight of the disposed item. This system showed that it would be possible to track different waste items with less effort. Similarly, Amritkar (2017) underlined that RFID-enabled smart waste management systems have potential to help facilitate selective sorting by identifying waste items correctly which in return might help waste managers to recycle more waste.

Based on these technologies, Table 2.2 below displays different tracking alternatives together with a brief description, advantages, disadvantages, drivers, barriers and examples of implementation of each alternative.

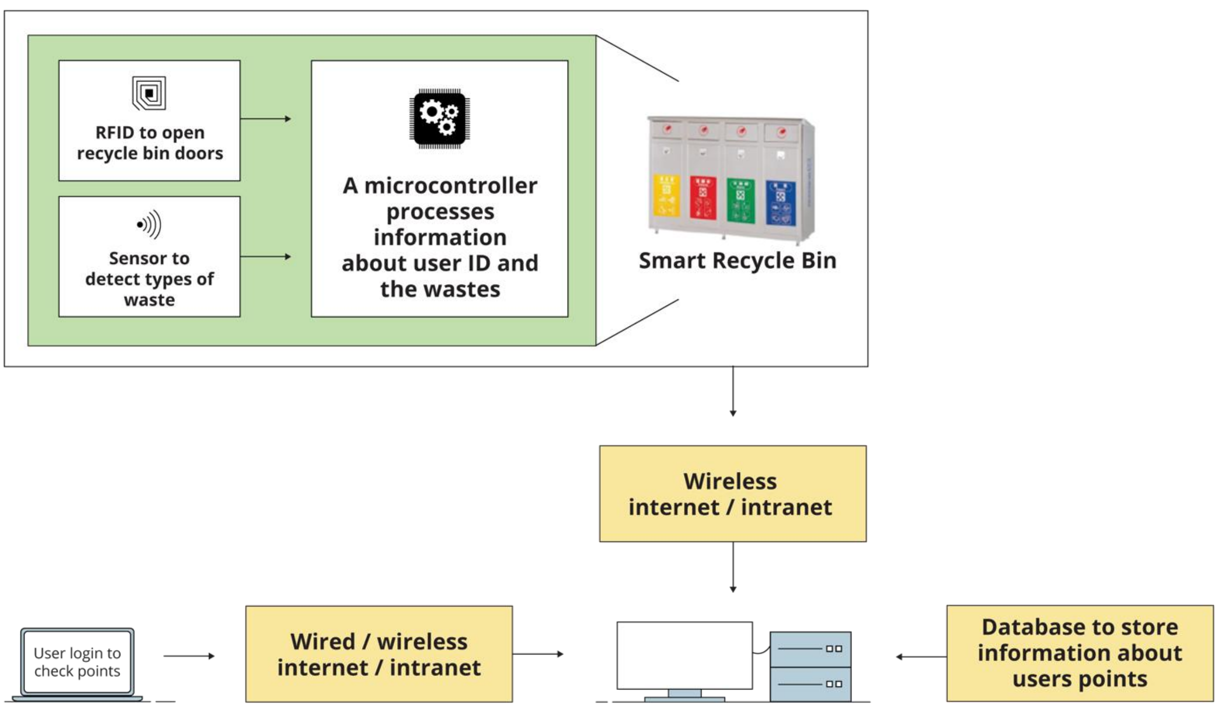


Figure 16: Proposed architecture of RFID-enabled smart recycle bin (Source: Wahab et al., 2014)

Table 2.2: Overview of logging and tracking technologies

Tracking Alternative Reference(s)	Brief Description	Advantages	Disadvantages
Barcode Technology (Paunescu et al. (2016))	* Using barcodes in polymer particles to track track these particles * Graphical, optical and chemical sequence encoding * Using powders as taggant	* Abilitiy to track information of very small particles * Identfying different products in the life cycle * Increased product value and manufacturer responsibility	* Complex chemical procedures * Might be very costly to implement
RFID with GPS, GIS and GPRS Phithakkitnukoon et al. (2013) Hannan et al. (2011) Lee et al. (2018) Purohit and Bothale (2011) Arebey et al. (2010)	* GPS, GPRS and GIS integrated/enabled RFID technologies to track waste * Attaching RFID tags and installing GPS, GIS, GRPS devices to waste bins, collection trucks, etc.	* Real-time information * Ability to track wider areas * Highly operational in extreme conditions. Resistible to environment hazards	* Attaching RFID tag to each bin may be time consuming * Design of a different hardware/software for every waste management company * Reliance on the truck driver (in some cases) * Sometimes, product journey may take couple of months. This technology may fail to track items for longer periods of time
RFID embedded technologies Stankovski et al. (2009) Nunes et al. (2006) Ullah and Sarkar (2018)	* Manufacturing products/parts with RFID tags embedded for more efficient tracking in reverse logistics system	* Higher return rates of recyclables * Easier information update by automatically saving data * Ability to track specific items with less effort * Lower logistic costs	* These technologies may require high sum of initial investment * Problems related to tag memory capacity * Some data has to be written on the database instead of RFID tag * Problem of standardisation of RFID tags
RFID and imagery technology Atkins et al. (2008)	* Combination of RFID and imagery technology to create knowledge hub, verify data in the hub and predict the logistic of waste	* Higher prediction rates * Detailed real-time information	* May not work well to identify different plastic types * Not a commonly use technology. May require substantial initial investment

RFID and computer applications Chowdhury and Chowdhury (2007) Sun et al. (2013) Namen et al. (2014)	* Using RFID with special computer applications and new system architecture to develop RFID-enabled cloud computing	* Facilitate smart recycling * Very useful for accurate waste delivery destination * Easy to connect system (access via internet) * No human intervention	* Fraud and security concerns (user privacy, etc.) * Requires sophisticated system designs
IoT technologies for collaboration between different parties Esmelian et al. (2018) Nagendra et al. (2019) Laouar et al. (2019)	* IoT-based mobile applications, waste technologies and blockchain databases to increase user involvement in the overall waste management process for more effective tracking	* Important for the creation of smart and sustainable cities * May facilitate data exchange between users and recyclers * Full transparency of the process * Faster digital archiving of waste	* Reliance on data from users (individuals may provide false information) * Less secure * Some stages of the process are not handled by professionals
Smart waste bins Crisnapat et al. (2019) Glouche and Couderc (2013) Amritkar (2017) Margaret and Sridhar (2017) Wahab et al. (2014)	* IoT-enabled waste bins to automatically identify and classify different types of waste. Each bin is attached a smart device. In many cases, RFID technology is integrated into these systems to increase their effectiveness * Smart wastes with RFID tags attached (i.e. self-describing objects) *** Instead of RFID, QR codes can be applied. If this option is used, individuals have to scan each item before they bin it. This option is less convenient than RFID (Glouche and Couderc, 2013)	* Easy access through web interface and android devices * Real-time information from each bin * More accurate sorting may lead to faster recycling rates * Assisting user in waste classification * Better plan waste collection	* Accuracy of the sensors is still not very high * Full reliance on digital information attached to waste items (in the case of smart waste and no sensors are required)

Tracking Alternative Reference(s)	Drivers	Barriers	Examples of Implementation
Barcode Technology (Paunescu et al. (2016))	* Technological advances in powder technology * Knowledge to synthesise and analyse unique features of particles	* Need for strong chemistry knowledge * Costs	* Various commodity products
RFID with GPS, GIS and GPRS Phithakkitnukoon et al. (2013) Hannan et al. (2011) Lee et al. (2018) Purohit and Bothale (2011) Arebey et al. (2010)	* Low implementation cost * Developed mobile network connectivity to support this system * Independence of GPS technologies * Potential to build trust between recycling partners * Clearer poicies and more transparency * Information about collection time and area * Potential for better bin distribution * Overcoming management issues (observing performance of contractors, observing waste generation characteristics of particular area etc.)	* Relatively high cost of these technologies and data service * In some cases, there is lack of collaboration between different parties (i.e. e-waste * Falsified information issue * Choosing the appropriate tag and reader technology * Complexities related to data management (high volume of data)	* Different types of trash including textile, plastic, paper, metals, etc. * General solid waste * E-waste tracking with cathode ray tube (CRT) * Solid waste bin and waste truck tracking with low-cost camera * Enhancement of pay-as-you-throw (PAYT) systems via installation of the system on the waste bins
RFID embedded technologies Stankovski et al. (2009) Nunes et al. (2006) Ullah and Sarkar (2018)	* Collaboration between users and manufacturers * Potential to have proper recycling of certain products and reach higher recycling rates * Easy integration of additional stakeholders into the system	* National regulations * Lack of knowledge about techical infrastructures	* RFID embedded automative parts * In-mould labelling (IML) robot with RFID tag for tracking product life-cycle * RFID embedded mobile phones to track them and separate from general waste
RFID and imagery technology Atkins et al. (2008)	* Government support and incentives when used for recycling hazardous waste	* Costs * Legal requirements	* Integrating RFID technology and digital imagery to save records including construction material, location,

	* Cooperation between users and waste management companies		volumes and weight, container movement and delivery tracking inventories and scheduling into the knowledge hub
RFID and computer applications Chowdhury and Chowdhury (2007) Sun et al. (2013) Namen et al. (2014)	* Availability of different cloud technologies * Cost savings in the long term * Incentives (especially for hazardous waste tracking)	* May take too much time to design the system * No clear guidelines, lack of standarisation	* Multi-layer system architecture with RFID to facilitate automation and streamlining waste identification * RFID tag, reader and cloud computing to track hazardous waste
IoT technologies for collaboration between different parties Esmelian et al. (2018) Nagendra et al. (2019) Laouar et al. (2019)	* Potential to co-create value * Green behaviour intentions * Collaboration among different parties including designers, manufacturers, scientists, consumers, etc. * Reduced costs (based on the volunteer system)	* Laws and regulations regarding personal data * Users' lack of knowledge of different types of waste * Specific requirements for each waste type * Lack of financial and human capacity * Lack of communication within stakeholders	* Public Affairs Centre (PAC) waste tracker in India. When citizens see waste they inform city councils via IoT-enabled system. Then, city councils ask waste management companies to collect and recycle waste
Smart waste bins Crisnapat et al. (2019) Glouche and Couderc (2013) Amritkar (2017) Margaret and Sridhar (2017) Wahab et al. (2014)	* Incentives and rewards for users (Waste to Wealth - Wahab et al., 2014) * Collaboration between users and waste management companies * Individuals' motivation to recycle * Reduced human time and effort * Providing help to users to correctly sort and dispose waste	* Lack of awareness among users about different types of waste * Additional cost of attaching RFID tag to each waste (are these tags reusable?) * High cost of RFID readers	* Smart bin application based on information self-contained in tags associated to each waste item. The wastes are tracked by smart bins using a RFID-based system without requiring the support of an external information system

2.3.3. Conclusion on logging and tracking

In conclusion, waste tracking is a complicated process and implementing effective tracking systems is one of the most important things in order to increase the success rate of the overall waste management chain. Fortunately, many RFID and IoT enabled waste management technologies have potential to help individuals and waste managers to classify, identify, sort, collect and track different waste items more accurately and efficiently.

Nevertheless, most of the existing waste management technologies are not designed or used to track specifically plastic waste. While there are certain tracking methods developed to track plastic in marine environments, technologies for land waste management are mainly used for identification and classification of waste products in general rather than focusing on plastic. Accordingly, although the existing systems may automatically identify different types of plastic waste, their accuracy is still far below from the expected levels. Besides, the majority of the waste management technologies can only identify waste items once they are disposed of in bins. Therefore, identification and tracking of waste items that are not properly disposed such as plastic bottles or any other type of plastic waste on the streets are still very limited.

Considering these gaps in waste tracking, Section 4.1 discusses ideas for potential new technologies and ways of logging and tracking plastic waste in urban environments.

3. The situation as it is now in the four cities

This chapter is dedicated to describing plastic waste recycling as it is currently done in the four project cities.

3.1. Plastic waste collection constraints

Most European cities share similar constraints: they have narrow streets, especially in old town centres; many inner-city streets are reserved to pedestrians for certain hours of the day; lorries are kept out of the city centre as far as possible; and there is very limited space for recycling containers to be placed.

In all countries involved in PlastiCity, waste collectors need a licence for transporting waste. The only way around this is to use reverse logistics, i.e. sending plastics back to where they came from, without declaring them waste. Waste treatment needs a separate licence. Furthermore, companies are obliged to pay for having their waste collected in all countries, with the exception of the waste assimilated to household waste being collected from companies for free in France within the limit of 1200 liters per week all type of wastes included and within the framework of public contracts for the collection of household waste.

On the other hand, the details of the regulations for the separation and collection of recycling vary widely between countries, even within the EU. Many companies accumulate their recyclables in mixed containers, often together with other waste; some separate plastic wrapping films.

In France, the household recyclable waste (including paper and cardboard, glass, metals, plastics, etc.) are mainly collected as a mixed bunch, and sorting happens after collection. It's direct neighbour Belgium, however, has one of the more sophisticated approaches, where recyclables are separated at source and collected in separate, colour-coded bags or in containers.

This makes sense, as sorting plastics according to types is a challenging task, especially when it comes to composite films. Sorting is currently mostly a manual task that requires extensive training. Automated approaches are still under development, with prototypes available.

But even with proper separation of plastics at source, and avoiding contamination, not all plastics can currently be recycled economically.

Plastics tend to have very low density, which makes transportation in uncompressed state inefficient. Compressing them for transportation makes retrospective sorting rather more difficult. A potentially better solution could be to sort them at source and shred them before transportation. There are indeed recycling providers that take this approach with PET bottles. However, for other plastics, recyclers are worried that the purity of shredded plastics would be compromised if they give away control over sorting.

3.2. The situation as it is now in Ghent

3.2.1. Background information and mobility

With about 262,000 inhabitants, Ghent is a medium-sized European city. It is located at the crossing of the rivers Scheld and Leie and next to the southern part of the North Sea Port.

Ghent has a dense historical center with a large pedestrian zone and 2 ring roads: R40 and R4.

In 2017, Ghent drastically changed the traffic flow in the city (within the R40), by introducing the so called "circulatieplan" [11]. The major driver for his plan[12] is to have less motorized vehicles in the city, more use of alternative transport modes like bicycles and public transport and to have a car-free zone in the centre. Ghent has a website[13] with a variety of publicly available data on mobility.

This plan has an effect on the 'distance traveled' and - to a lesser extent - on the average speed on a trip within the R40 (CityCentre). E.g. if one wants to ride from Coupure (SW of the City Centre) to Steendam (North East), one would originally find a straight line, north-east-bound. Current regulation will require vehicles to take the R40 ring road (see Figure 17). In 2020, Ghent introduced a Low Emission Zone within the R40 which means that vehicles with Eur 4 engines or older no longer have access to the city Center from 2020. From 2025, vehicles with Eur 5 engines

11 https://stad.gent/nl/mobiliteit-openbare-werken/mobiliteit/plannen-projecten-subsidies-cijfers-scholenwerking/het-circulatieplan/kaarten-circulatieplan

12 https://thesquare.gent/leisure/circulation-plan-gent/

13 https://data.stad.gent/explore/?disjunctive.keyword&disjunctive.theme&sort=modified&refine.theme=Mobiliteit

or older no longer have access. Commercial vehicles can reach the commercial and historical pedestrian area with a permit only and between 6 pm and 11 am.

The GentLevert[14] initiative is aimed at improving the sustainability of goods transportation in Ghent, supporting the transition towards efficient and sustainable last mile logistics. It is a public/private consortium of forwarders, logistics service providers and receivers who seek for improvements in line with the priorities of the "Trias Logistica" shown in Figure 18, which defines the following priorities:

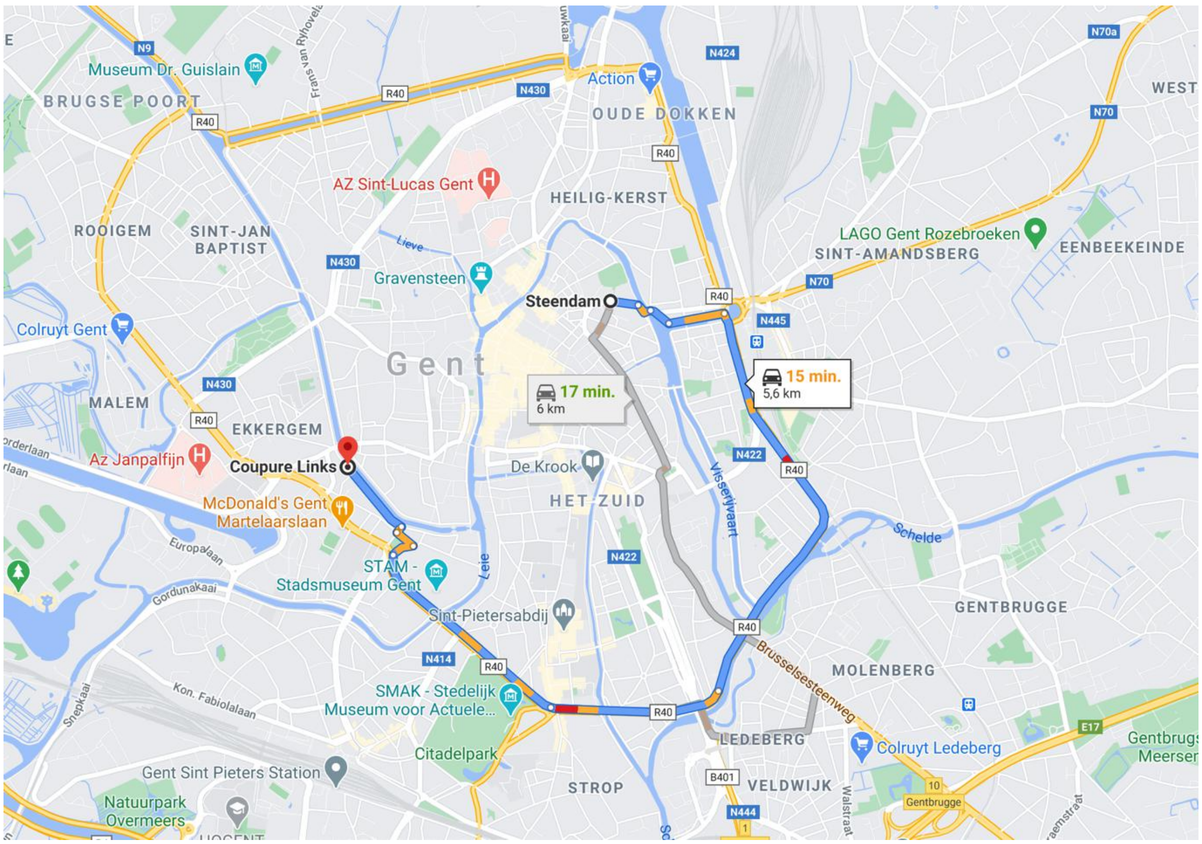


Figure 17: Map of Ghent with ring road

14 https://www.gentlevert.be/en

1. **Avoid trips**: aims to discourage single entry/low load deliveries in the city centre and encourage to use local last mile carriers.
2. **Perform smarter trips**: aims to deliver at the right time, with a vehicle fit for the city centre
3. **Perform clean transport**: drive with environmentally friendly vehicles.

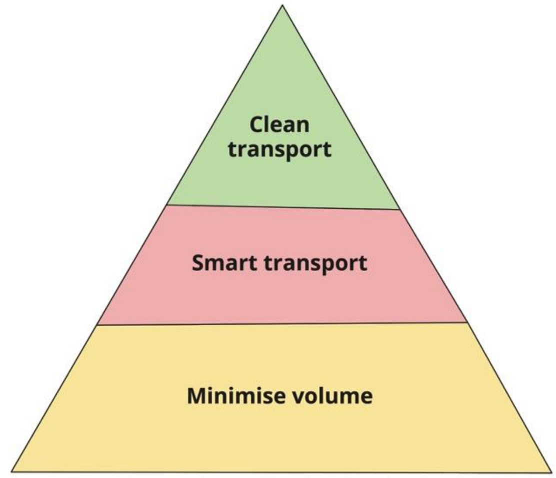


Figure 18: Trias Logistica by GentLevert

Logistics service providers adhering to the GentLevert membership rules, and applying principles of Trias Logistica, are entitled to exemption of access restrictions.

The pilots running under GentLevert mostly focus on consolidating freight flows in urban logistic hubs and performing highly efficient and sustainable last mile milkruns from those hubs. One of the projects has proven that, when the last mile is subcontracted to a local last mile logistics service provider, the last mile trajectory is reduced from 3.3 km to 2 km, through the effect of bundling of freight.

3.2.2. Waste collection and sorting

An overview of solutions that the Flemish government focuses on, including a chapter on mobility, is provided in Flanders Environment Agency (2019).

The following information can be used to calculate the cost of waste transport

For low to medium traffic (no driver's license C, which is the type of driver's license required to drive lorries):

- Labor cost: 20 à 24 €/hour
- Travel cost: 0,41 €/km (all vehicle costs / van)
- Pollution data: depends on the vehicle used

- Average speed: depends on the area, route, time of day

An overview of the total amount of plastics waste produced by industry and households, as well as a flow diagram showing the plastic waste flow from origin to destination, and an overview of the major collection and recycling firms, see the study by VITO (2018).

The brochure "Sorting waste: your obligations as a company" clarifies that companies in Belgium are obliged to individually separate 21 types of wastes, including different types of plastics. Corresponding information is available[15] in Dutch.

Since 2018, industrial waste regulations in Belgium prescribe the separation of recyclables, including three types of plastics that need to be collected separately (in addition to PET bottles, Tetrapaks, etc. which has been established for a long time and is not considered in this project):

- Polystyrene
- Rigid plastics
- Plastic films

The collection of these three plastic streams is organised individually, as follows:

- Processors of polystyrene organise the selective collection, mainly separated in bags collected in open-top hooklift containers or by covered lorries.
- The collection of films is organised by waste transportation companies.
- Bigger companies with large amounts of films are served by open-top hooklift containers with a loading volume of 30-40m³ (see Figure 20) or compression hooklift containers with a loading volume of about 25m³ (**Error! Reference source not found.**)

15 https://www.ovam.be/iksorteer

Figure 20: Compression hooklift container

Figure 20: Open-top hooklift container

- Companies with small or medium amounts of films will use colour-coded bags (Figure 22) for accumulating their plastics. The bags are then collected with a compression lorry, combined with the collection of paper. At the recycling plant, the bags are sorted automatically. The bags containing films are made of the same material and can therefore be recycled together with the content. In all other cases, the bags are removed and recycled separately. There are five colours of bags:

  - Transparent (white) for clear films
  - Blue for coloured films
  - Red for hard plastics
  - Orange for EPS
  - Black for the rest, including contaminated plastics

- Companies with films as production waste (on rolls, unused, released during production processes): these are collected on pallets by a covered lorry.

Figure 22: Colour-coded bags for the collection of paper and plastic films

Figure 21: Wheel containers

- There are pilot projects for households with bags collected by a compression lorry on separate collection routes.
- The collection of rigid plastics is also organised by waste transport companies:
- Companies with rigid plastics as production waste (unused, released during production processes) are served by open-top hooklift containers (Figure 20)
- Companies with small or medium amounts of rigid plastics use colour-coded bags that are collected by a compression lorry, combined with the collection of paper. Some bigger waste collection companies like Renewi and Suez have recently introduced wheel containers (240-1100L) shown in Figure 21.

Companies are obliged to pay for having their waste collected. Separating plastics will reduce the amount of residual waste, and hence the collection costs will decrease.

The collection frequency is determined together with the waste producer, based on the volume of waste produced; typically, collection happens one to four times per month. Upon collection, the waste is transported to the nearest recycler in that area. As the waste is compressed upon collection, the lorry's capacity is determined by weight. However, plastic films have a very low density, only 500kg / 30m3, so the volume limits the loading capacity in this case.

To create some traceability (e.g. to be able to sensitise waste producers about contamination), some bags and containers carry ID labels.

Three project partners operate in Ghent

GRCT is a waste management company that collects and sorts recyclable waste

Van Werven is a plastics recycling company that recycles high quality hard plastics

DPL is a plastics recycling company that recycles plastic films from production waste (as opposed to post-consumer films)

Figure 23 provides a very clear overview of which vehicle types and energy sources are currently used in consumer and industrial waste collection. This graphic was developed by the City of

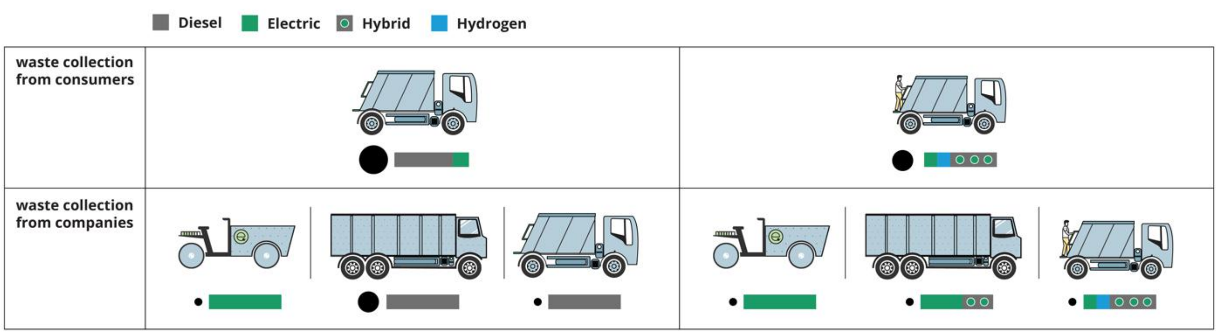


Figure 23: Vehicles used for waste collection 2019 and predicted for 2025, where grey represents diesel, green stands for electric, grey with a green dot means hybrid, and blue stands for hydrogen. Source: Rotterdam (2019)

Rotterdam and is applicable to other Belgian cities.

Diesel-powered trucks, often with compression mechanisms, are used predominantly for collection. These trucks perform a typical milk-run starting from the collection hub and returning either to the collection hub for trans-shipment, or dropping off at the plastics waste recycling site. Those milk-rounds can be considered efficient, because the providers are driven to plan milk-runs with full truckload returns. Vehicles powered by cleaner energy (hybrid, hydrogen or electric) are only expected to reach mass market introduction by 2025-2030 according to Rotterdam (2019).

Emissions of CO^2, NOx and particulate matter are significant in relation to their market share of the total fleet of vehicles in the street. While vans and lorries (blue and green in Figure 24) only represent around 11% of vehicles on the road, they represent 34% of CO2, 62% of NOx and 39% of small particulate matter emission.

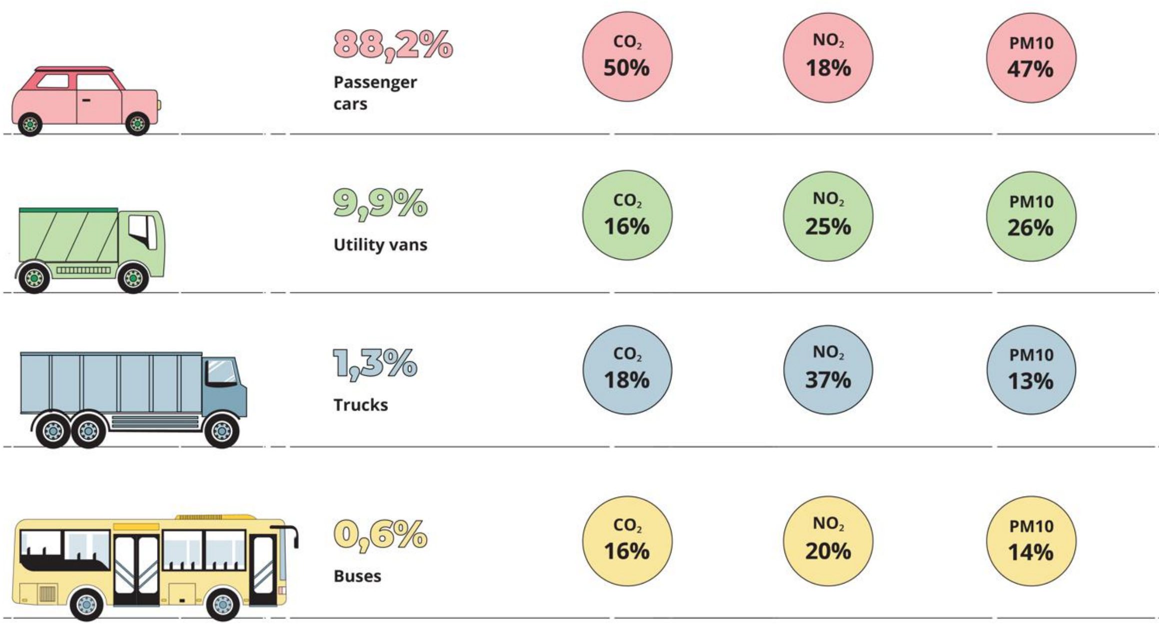


Figure 24: Vehicle emissions per type of vehicle on roads in The Netherlands. Source: Rotterdam (2019)

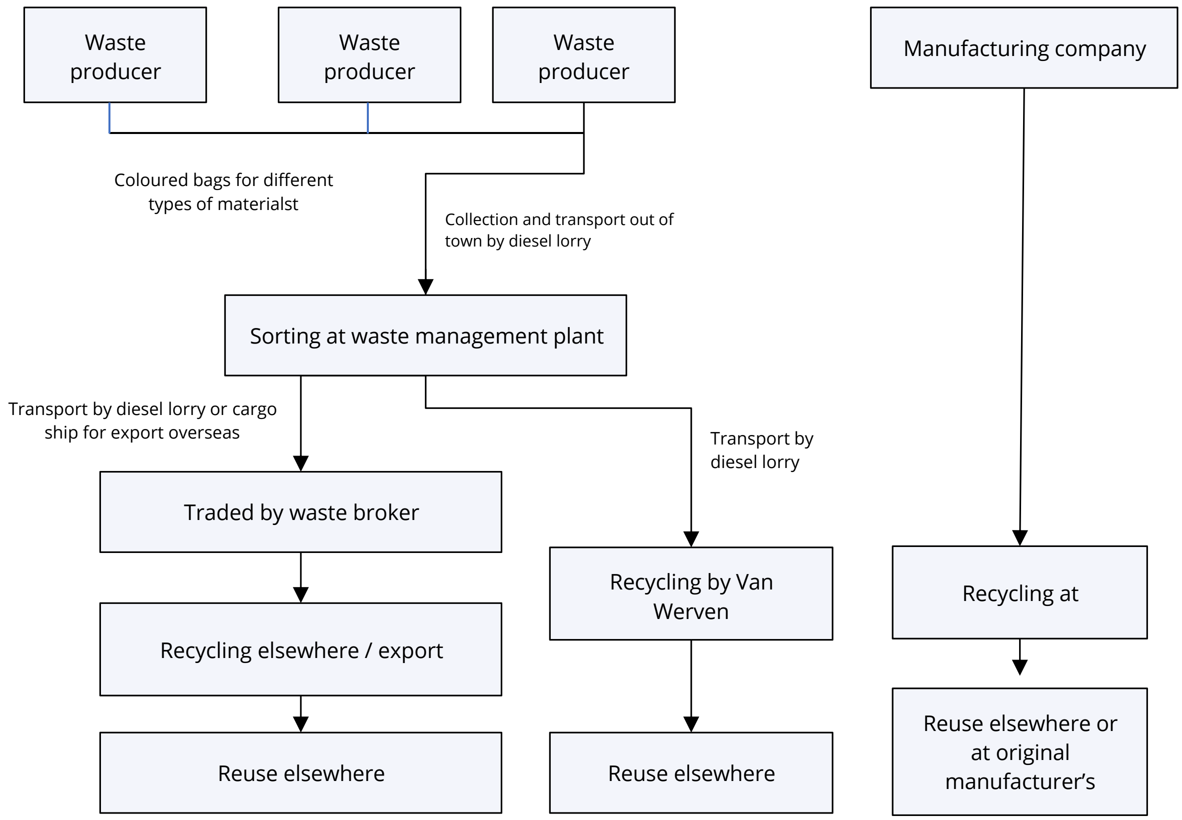


Figure 25: The current plastic waste flow in Ghent

3.3. The situation as it is now in The Hague

With about 545,000 inhabitants, The Hague is the biggest city in the PlastiCity project, located on the North Sea coast of the western Netherlands. A number of canals leaOpd through the city.

Figure 27 shows the low emissions zone in the city centre, and Figure 26. the pedestrian zone. It is operational from 11.30 hrs every morning. Waste collection lorries and delivery vans are allowed to drive in the pedestrian area until this time only.

In the Netherlands, all companies (including schools) are obliged to procure a waste collection and treatment contract. Very small companies that only produce waste that equals household waste are allowed to use the municipality's household waste collection service.

Figure 26: Pedestrian zone in the Hague (source: https://www.denhaag.nl/en/in-the-city/getting-there-and-around/getting-downtown/ban-on-motor-bikes-in-downtown-pedestrian-area-for-part-of-day.htm)

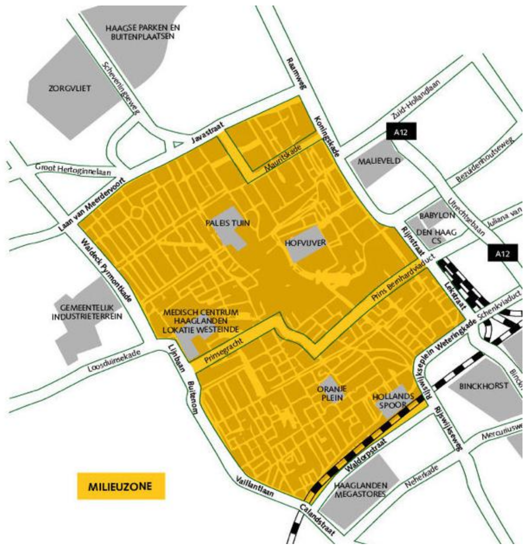
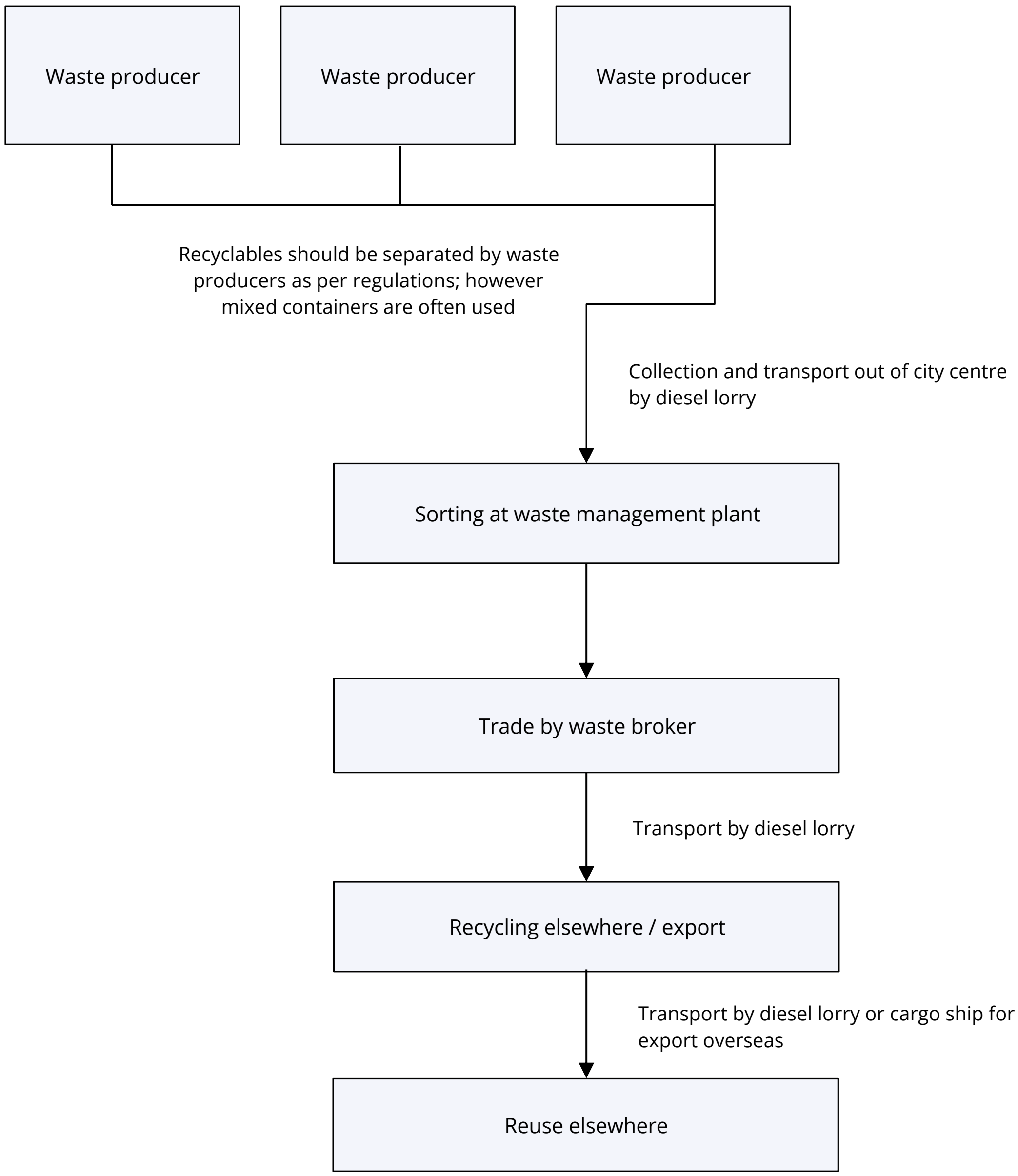


Figure 27: Low emissions zone in The Hague (source: https://urbanaccessregulations.eu/countries-mainmenu-147/netherlands-mainmenu-88/den-haag)

Companies are required to separate their recyclables (including electronics, paper and cardboard, aluminium foil, other metals, kitchen waste, garden waste, textiles, polystyrene, plastic cups, other plastics, car tyres, etc); however, it is unclear how far this is enforced. Many companies have all their waste collected at once, in a mixed container.

The city of the Hague is the lead partner in another Interreg2Seas project (Upcycle Your Waste project), which is described in Section 2.

Figure 28: The current plastic waste flow in The Hague



3.4. The situation as it is now in Douai

Douai is a small city in the north-east of France with just below 40’000 inhabitants and is part of an agglomeration of 160,000 inhabitants and of an urban area of 325,000 inhabitants and 98 cities. It is located between Lille and Arras, as shown in Figure 30 and Figure 29. The river Scarpe and a canal cross Douai.

Figure 29: Douai in the region “Hauts de France”

Figure 30: The urban region regrouping 3 inter-municipal authorities

Figure 31 and Table 2 the areas around Douai which can be reached by a lorry within 10, 20 and 30 minutes.

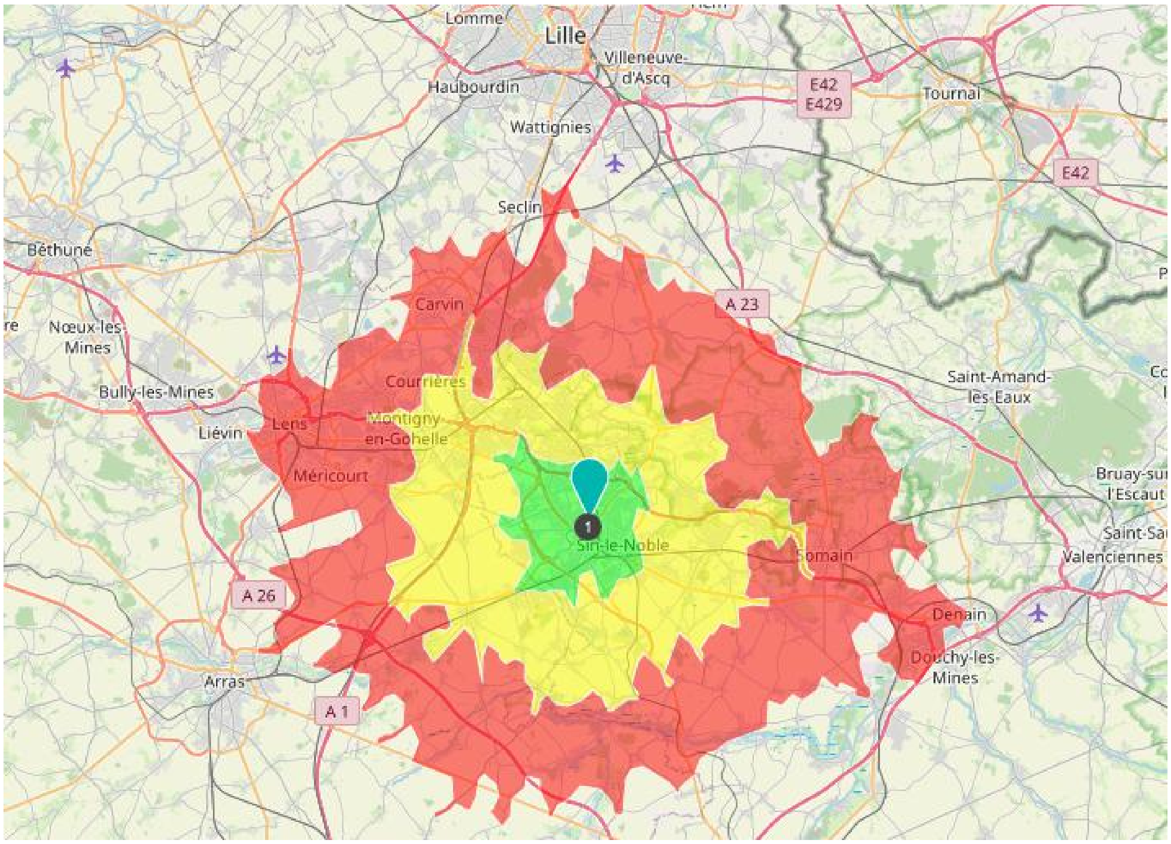


Figure 31: Isochronous with trucks - green area : 0-10 minutes; yellow area 10-20 minutes; red area : 20-30 minutes from Douai

Currently, there are no traffic restrictions linked to air quality or zones prohibiting the use of vehicles perceived as polluting. However, the agglomeration of Douai (Douaisis Agglo) has started studies to determine an action plan to improve air quality. Thus, they launched a call for projects for the design, construction and operation of a service station with clean energies. They also signed up for a call for projects for the use and promotion of hydrogen vehicles. Finally, the household waste collection trucks in the densest towns of Douaisis Agglo now use compressed natural gas and are equipped with container lifts and an electric compaction system. The Theys Group is involved in all of these projects.

In France, each community exercising jurisdiction over household waste management can decide to allow entities other than households to use the public household waste collection services and set a limit in terms of waste volume above which commercial waste collection services need to be contracted. It depends on how taxes are collected and on political decisions. The waste must have the same characteristics as household waste and be collected at the same time and with the same equipment. Beyond the limit, the waste is not collected or is the payment of a fee will be required “Entities other than households” are not obliged to use this service and can use commercial waste management companies.

Time frame	Area	Population
10min	56.53mk2	82516
20min	332.62km2	245558
30min	940.91km2	577781

Table 2: Details about isochronous areas around Douai

In the agglomeration of Douai, companies can have 1440 l / week of “household waste” collected for free, or to be more precise, included in their local taxes. For any waste above this quantity, or not qualifying as household waste, companies need to arrange collection through one of the waste management companies operating in the area; Theys Recyclage is one of them. Five types of industrial waste should be sorted at source, in accordance with the law known as “décret Tri5flux” (“decree Sorting5flows”), and plastics (of any type) are one of them. However, most companies usually accumulate all their waste in one container, and the recyclables need to be separated and sorted afterwards. Companies that generate large quantities of waste may collect recyclables in separate containers that will be collected individually.

The management of household recyclable waste in France is partly financed, oriented and harmonized by a private company created by the French state and named CITEO. CITEO collects the tax paid by each consumer (individual and company for example) using packaging and graphic papers and transfers this money in the form of subsidies and support after having signed contracts with each community exercising the competence of waste management. 70% of packaging is currently recycled and 57% of graphic papers.

To increase their results, CITEO launched a project called "extension of sorting instructions". This is to simplify sorting by now collecting all plastic types in the recyclable flow. Indeed, before, some plastics (such as yoghurt pots, films and polystyrene for example) were excluded from collection. This resulted in a lot of mistakes and wasted plastics.

Project partner operating in Douai:

Theys Recyclage is a waste management company that collects and sorts recyclable waste; there are plans for adding automated sorting and some recycling processes in the future.

Automated approaches to plastic waste sorting in France can be divided into three main fields:

Technologies used to help members of the public to improve their sorting gestures, like a “chatbot” that explains in which container people can drop their waste (Trizzy[16] [17]), or a

16 https://trizzy.io

17 “Developed by the French agency Mr Bot, Trizzy is a chatbot that can be used by local authorities and environmental conservation organisations on their websites. The conversational assistant can advise and inform users about adopting eco-friendly habits. In particular, it answers questions on waste sorting and recycling.

Trizzy can be quickly and easily installed and customised to any website and enables organisations to create a direct link with users. The app collects and analyses conversational data to gather statistics (most popular questions, frequent requests etc), which helps organisations to run more targeted communication campaigns. Trizzy can also relay messages with a particular community and so local recycling initiatives can be highlighted more effectively.” (https://startup.orange.com/en/start_up/trizzy) "connected" and "intelligent" recycling bin, from the most elaborated, like the Réco Kiosk[18] from Suez, often present in supermarket lots, to small bins like R3D3[19].

Optical recognition with aeraulic ejection, and which is now coupled with AI, like Tomra[20] or Pellenc ST[21] devices, mainly present in waste sorting centres. These devices generally cost several hundred thousand euros with IR and X-ray recognition, but some smaller devices, based on small cameras, are coming onto the market.

Robotic arms and gantries[22] are currently being tested at several sites in France, with waste collection and treatment companies like Veolia[23] or Paprec[24], using solutions from foreign companies like BHS, Max AI or Zen Robotics. A number of other projects[25] exist.

18 https://www.reco-france.com

19 https://www.environmental-expert.com/products/green-creative-model-r3d3-sorting-bins-641235

20 https://www.tomra.com/en-gb/sorting/recycling

21 https://www.pellencst.com/markets/plastics-recycling

22 https://www.recyclingtoday.com/article/recycling-robots-ai-sorting

23 https://www.veolia.com/en/csr-natural-resources/innovative-waste-sorting-better-materials-recycling

24 https://www.paprec.com/en/understanding-recycling/recycling-plastic/sorting-plastic-waste

25 https://anasasorter.com

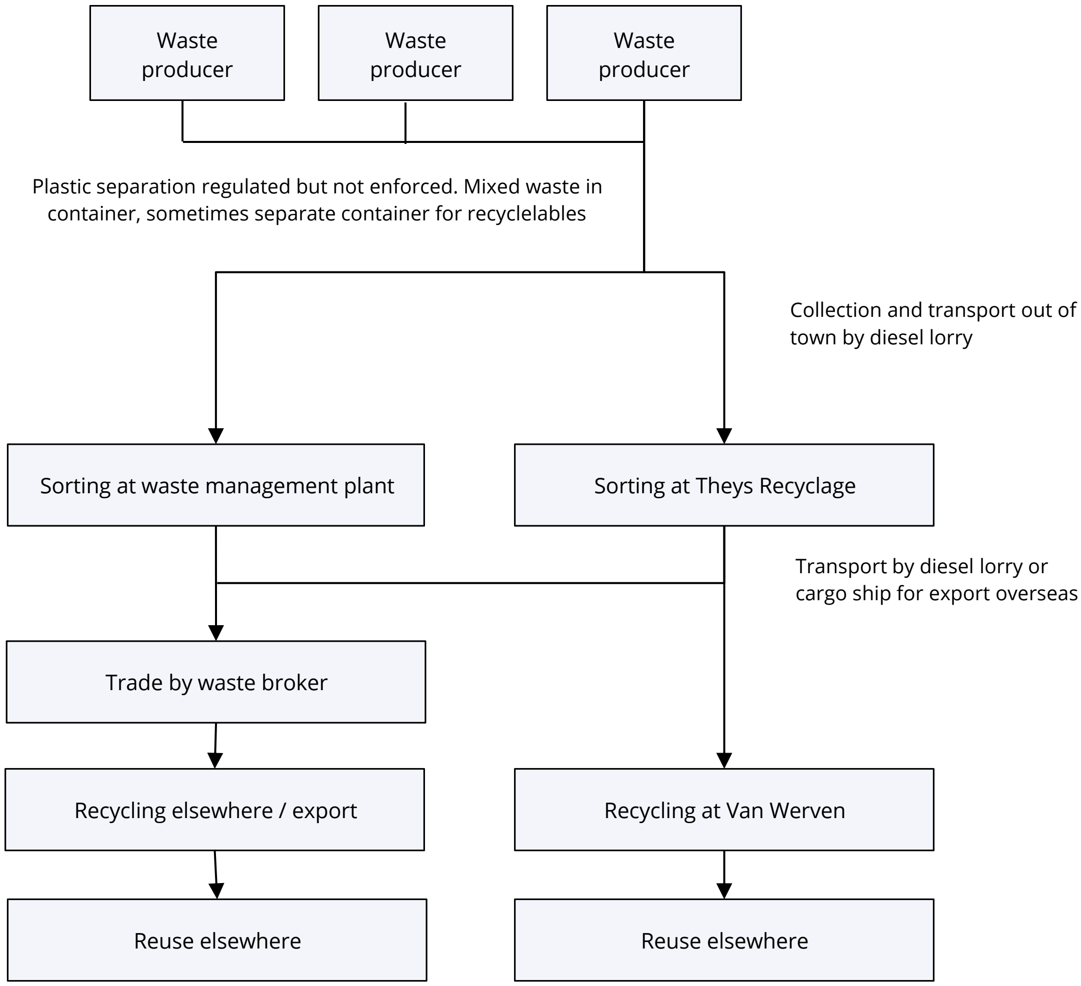


Figure 32: The current plastic waste flow in Douai

3.5. The situation as it is now in Southend-on-Sea

Southend has about 183,000 inhabitants, but as a "beach location" in the Thames river delta, the town typically hosts approximately 6 millions of tourists over the summer months, generating very large amounts of waste. Figure 33 shows Southend town centre, including the pedestrian high street marked in red. The 'Town Centre Ring Route' is a network of on-road / off-road shared cycle paths that form the main cycle route in Town Centre. It connects key locations in the Town Centre to the two main cycle routes in the Borough, Prittlebrook Greenway and Seafront Cycle route.

Figure 33: Southend's town centre

As the largest town in Essex, Southend lies 40 miles east of central London with direct rail and road links to the capital. Good transport links helped Southend to historically establish itself as a popular visitor destination and this remains Southend's primary role at a regional level. The town is also a centre for higher education with a new University of Essex campus. The town lies within the Thames Gateway and in this context plays an important role being a focus for jobs and employment growth.

A recent Residents' Survey showed that the provision of recycling, waste and street cleaning services is rated highly. Residents agree that street cleaning is important and focussing resources on high priority areas such as the beaches, seafront and main shopping areas are essential.

Given the special situation of this Borough geographically, ecologically and environmentally, Southend-on-Sea Borough Council declared a Climate Emergency in September 2019, including committing to action to achieve net-zero carbon by 2030.

In the UK, there is no law obliging companies to separate their waste. Generally, plastics are collected together with other mixed dry recyclables (MDR) from smaller businesses. Bags of MDR will be collected by a compaction vehicle, similar to the dust carts that collect household waste.

Some larger businesses will be provided with a compactor. The MDR bags will be taken to a Material Recycling Facility (MRF) where they will be machine and manually sorted into separate material streams.

Most large companies retailers will use reverse logistics to 'backhaul' clean films (secondary or tertiary packaging) from stores back to their depots. They use tall metal wheeled cages to transport goods to the stores and will refill these with clean high quality secondary and tertiary plastics and cardboard and load them back onto the lorries. These will go back to their regional distribution centres, where they will bale them up and sell them.

Manufactures often have compactors and balers for single stream packaging. They will use these to bale and compact the more valuable and uncontaminated films. Other materials e.g. bottles and single use plastics will generally be bagged and mixed with other recyclables.

Skips are used for hard plastics.

Several waste management companies are operating in Southend, including Veolia and Biffa. The collected waste then goes to waste sorting companies such as James Waste Management, who prepare the materials for further processing / export.

Examples of recycling processing plants in the UK include:

- Biffa Seaham for PET
- Biffa Redcar[26] for HDPE
- Van Werven Selby[27] for high quality hard plastics

26 https://www.biffa.co.uk/about-us/waste-journeys/plastic-recycling

27 https://www.recyclingplastics.co.uk/our-facilities/selby

Research of current systems suggests that 7% of businesses could be taking waste home or taking it to the Household Waste Recycling Centres (HRWC). Therefore, the Council has identified a potential need for recycling hubs, sites where businesses could bring their plastic waste to be recycled, as described in Section 4.4.

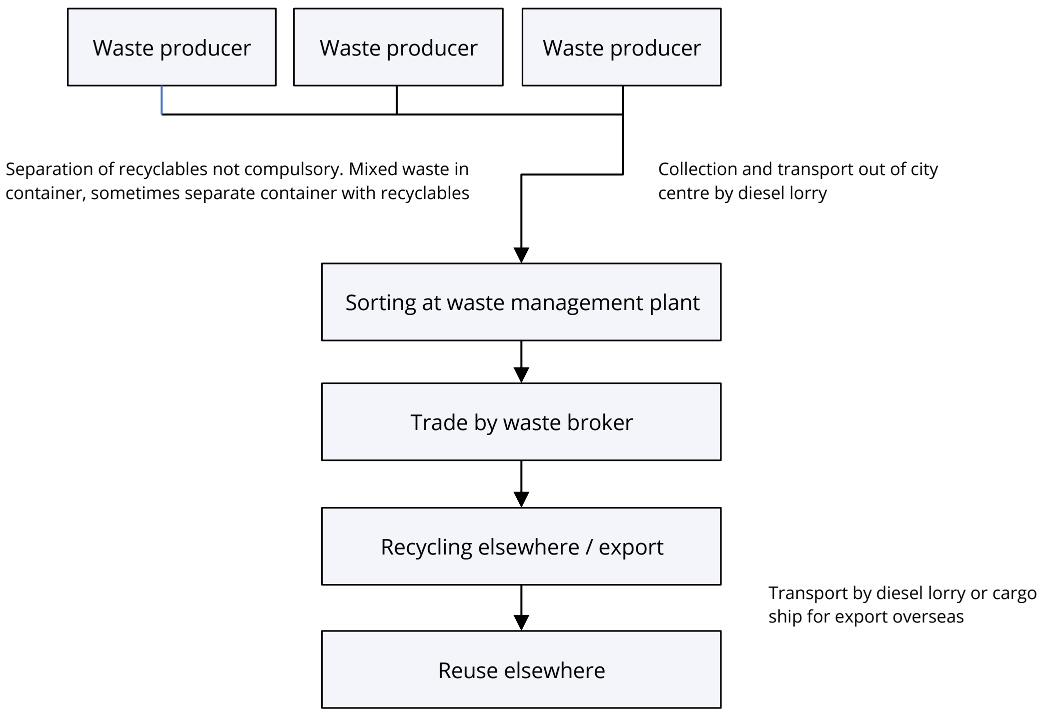


Figure 34: The current plastic waste flow in Southend

3.6. Locations and capabilities of plastics recycling plants

Plastics that are collected and sorted then need to be recycled somewhere. Ideally, this would happen locally, to minimize transportation and to ensure the responsibility for proper treatment. The Media keep reporting on recycling from European countries being exported to developing countries for "recycling" which often means the materials get dumped illegally or burnt illegally; see BBC (2020) for instance. Table 3 summarizes where the recycling currently happens / is supposed to happen for the four cities, showing the project partner companies only. It also shows the current recycling capabilities of our project partner companies.

Table 3: Locations of plastics recycling plants and recycling capabilities of our project partners

	Transportation and sorting	EPS	Hard plastics	Printed films	Clear films	The rest / contaminated
CITIES						
Ghent	(GRCT)	-	Van Werven	DPL	DPL	-
The Hague	-	-	Van Werven	-	-	-
Douai	Theys	-	Van Werven	-	-	-
Southend	-	-	Van Werven	-	-	-
RECYCLING COMPANIES						
GRCT	yes	-	-	-	-	-
VanWerven	-	-	Yes, for all of Europe (*)	-	-	-
DPL	-	-	-	yes	yes	-
Theys	yes	-	-	-	-	-

(*) Van Werven:

“We work in countries where a legal framework has been installed as well as a good collection structure; preferably built by a solid local partner who knows the local culture. For example, we have concrete partnerships with GRCT, Theys and other parties that do smart collection, pre-sorting and a high-quality final delivery of used hard plastics to our installation that is as often as possible located in the region. For GRCT and Theys, this is currently our Belgian location in Lanaken.

We transform nearly 150.000 tons of used plastics into 50 different high-quality material flows in currently 6 installation locations: Ireland, UK (Selby & Nord Ireland: Belfast region), Poland, Sweden, The Netherlands (headquarters) and Belgium. We also have an extensive participation network in Germany, the Czech Republic, Slovakia and others. These material flows are in turn also sold locally as much as possible to solid partners who also know the local culture.”

4. New ideas to explore

The following are ideas that have emerged from brainstorming as well as careful analysis of what currently exists and what is needed to address problems.

4.1. Logging and tracking

4.1.1. Scale

Existing tracking solutions are at a large scale. Logging and tracking we need here additionally is more at a "local" scale, meaning that plastic items would have their barcode scanned when they are placed in the container, and a log would be created, such that we know what is in each container and where it comes from... that log could then be processed in parallel with the plastic being processed, and hence we know which item (or which container) goes where, and what is happening to it

4.1.2. Tags:

Attach an RFID tag to each plastic item and implement a smart waste system to identify different types of plastic. Automatic elimination of non-recyclable ones

4.1.3. Bins

RFID-enabled, smart waste systems that reward users when they dispose of the correct type of plastic in the designated bins. When users bin their plastic waste, a smart bin may add points to that individual's account in the online application. These points might be redeemed for cash, reduction on electricity bill, etc.

4.1.4. Data

A general database for waste management companies to see and exchange information about plastic waste in cities. Collaboration between different companies potentially leads to faster and more accurate tracking of plastic waste. Smart bin automatically saves information to the database that is obtained from RFID tags attached to the waste items. A general management system will inform a specific company to collect and recycle the waste. Each company will be provided information about the situations of the plastic bins in different locations of the city

4.1.5. Procter & Gamble's 5 pillars

Procter & Gamble overall aim is to reduce the use of virgin plastics by 50% before 2030. Therefore, the company developed a five-pillar strategy. Pillar One is reduction in packaging and designing packaging for more circularity. In 2019, P&G joined the On-Pack Recycling Label scheme (OPRL) to decrease the amount of landfill waste (Bairstow, 2019). Figure 35 shows an example of a label.

Figure 35: Example of On-Pack Recycling Label

Collection of waste and people's knowledge of how packaging can be recycled is still problematic. Pillar Two and Pillar Three focus on generating more effective collection systems of packaging and educating consumers about recycling. With the recycling platform, Loop, consumers can buy refillable packages of everyday goods online. In the process, the company called TerraCycle will collect the empty products from individuals' homes and refill them. Damaged packages will be sent for recycling.

In terms of product development and innovation, in Pillar Four, P&G plans to put digital watermarks on packaging which can be identified by key stakeholders (edie, 2019). For a successful recycling process, special sorting lines and cameras will read these digital watermarks. Consumers could also see those watermarks via their smartphones and get more information about the packaging of the specific product.

The key purpose of Pillar Five is better separation of various types of materials including dyes, odours and any other type of waste from the plastic to increase the quality of the recycled plastic with the help of PureCycle. This way, the recycled plastic can be more conveniently used in new packages. This method is used in the manufacturing of recycled plastic bottles, which are almost identical to bottles made from virgin plastic (Interpack, 2020).

4.1.6. Digital support for sorting Household Recycling in Shanghai:

Starting from July 2019, Shanghai residents are asked to separate their waste into four different bin categories: Wet, dry, hazardous and recyclable. Accordingly, Alibaba developed an app to identify different types of trash for ease of separation and correct disposal of waste. After individuals scan the waste item using their smartphones, the app tells them which bin they should dispose of the waste item in (Cheng, 2019). Moreover, individuals can get more information about their waste by using certain apps (e.g. WeChat) in situations where they are not sure about how to dispose of it. Some of these apps are able to identify thousands of types of trash items (Liao, 2019).

Additionally, in order to facilitate and speed up waste tracking and collection processes, Alipay provides around 70 applications that help consumers to sort their trash and sell recyclable items from their residences (Li, 2019). As Liao (2019) argued, more than two million Chinese residents have used Alipay's platform to sell recyclable material. In several locations in China, residents attach QR codes to their waste bags to let municipalities to trace where the waste comes from. As an incentive, municipalities give around 1.5 cents per day to residents who separate and organise their trash correctly.

4.1.7. Blockchain for Recycling

In blockchain, agreed parties use smart contracts to automatically move to the following stage of the agreement once they meet the terms of the contract. Smart contracts help different parties of the process to control certain steps such as data share, payment information, etc. more easily. Parties set the specific rules as well as penalties of the agreement via smart contracts. Therefore, there is no need for any external party to enforce any punishments when the rules are not followed (Gupta and Bedi, 2018).

Every partner included in the system is able to reach any available information and keep track of any problems that may occur because of lack of compliance. As the digital information in the blockchain system is checked and validated by different partners in every transaction (Chidepatil et al., 2020), the system is highly resistant to any potential abuse and misconduct.

Like many other sectors, blockchain allows everybody in the recycling chain to get all the necessary information by facilitating the information flow from one party (e.g. recycler) to another (e.g. manufacturer). In more sophisticated supply chains, individuals can track the movement of recycled materials between different destinations. Hence, by giving responsibility to each member of the recycling chain to share data, blockchain can be used to effectively track a product's lifecycle which would result in better recycling processes (Staub, 2019). Besides, according to Peshkam and Dubois (2019), blockchain technology may also provide various significant information about the packaging of a product including the amount of virgin and recycled plastics and the origin of the specific material.

In many developing countries (e.g. Haiti, Indonesia) consumers use blockchain-based applications and smart contracts on their mobile phones to gain credits by bringing their plastic waste to designated collection centres (Peshkam and Dubois, 2019). Similarly, in Brazil, after taking recyclable waste items to collection points, households receive credits (i.e. Green Coin) in the form of social currency that can be used in local shops to purchase products (Franca et al., 2020).

4.2. Modular logistics applied to PlastiCity

The modules required for plastics waste collection and recycling are shown in Figure 36.

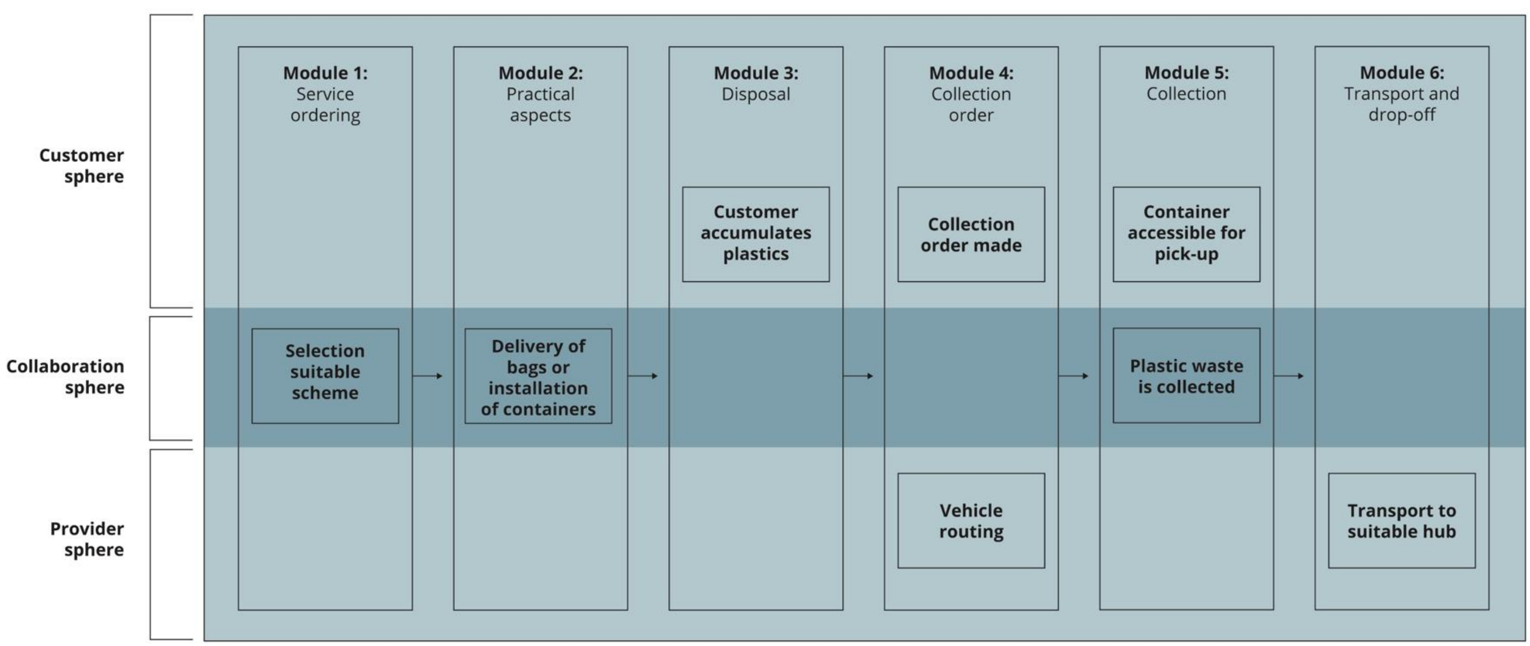


Figure 36: Modular logistics applied to PlastiCity (modules 7 and 8 are not shown.)

4.2.1. Module implementations

Each module can take a number of different implementations, depending on the case. Those of special interest for PlastiCity logistics scenarios are: 1, 5, and 6. For selecting which version to choose, criteria need to be elaborated and tested by simulation. Variables to optimise through simulations include: cost, emissions, accessibility and other factors.

Module 1: Service ordering and customization

This includes strategies to encourage or incentivise companies to join local plastic recycling schemes like proposed in the PlastiCity framework. This could include for small businesses in a high street to take their waste to the local hub, or for companies in an industrial area to contract the same PlastiCity collection services as the neighbouring companies. The best suited solution needs to be agreed with each company that subscribes to the service.

- If a local "milk-run" type collection is available (e.g. in a high street) and the volume of plastic waste generated per period of time is below a certain threshold, the company should be encouraged to join.
- If a local hub is available (e.g. in a shopping centre) and the volume of plastic waste generated per period of time is below a certain threshold, the company should be encouraged to take their plastics to the hub, from where it will be collected. This could include a sorting and compacting (potentially also shredding) service at the local hub.
- If none of the above are available or suitable, the company will use the general collection service.

Module 2: Practical arrangements - delivery of bags, containers, instructions, etc.

The collection of recyclable waste in Belgium typically happens in colour-coded bags. These need to be redistributed regularly.

In Douai, The Hague and Southend, containers are used to accumulate waste. Smaller containers are then emptied into collection vehicles, whereas larger containers are taken away full and empty replacement containers are provided. In Southend, there are “mini-hubs”: containers distributed across the city that are connected to an app (for details see Section 4.5).

Module 3: Disposal of plastics into containers / bags, at company or local hub

- In Den Haag, it is assumed that plastics are accumulated separately.
- In Ghent, plastics are separated into categories.
- In Douai, recyclables are kept in mixed containers.
- In Southend, recyclables are mixed. Companies will be encouraged to bring their plastics to a local mini-hub container.

Module 4: Collection order (periodical, sensor-activated, manual notification, etc.)

Collection typically happens periodically (typically varying between twice a week and once every 6 weeks), but can also be requested depending on fill-levels and via a manual order or a sensor-triggered notification.

Module 5: Collection from company or local hub

The plastics could be picked up inside the colour-coded bag, inside a container (meaning that a new container needs to be provided), or transferred from a stationary container into the vehicle container (e.g. as is the case with the CargoBike).

The choice of vehicle will depend on a number of factors, including the type of scheme (milk-run, local hub, individual collections), the pickup location, the volume of plastics to be collected, and the degree of separation at source (mixed recyclables / only plastics but mixed / plastics separated by type).

- If located in the historical town centre and the volume is under a certain volume, select CargoBike, otherwise ElectroTruck.
- If located in a residential area, select ElectroTruck.
- If volume over a certain threshold, and located in a remote area, select diesel lorry (hydrogen-powered if available).
- Large containers, such as used at local hubs, will always need to be collected by lorry.

Module 6: Transport and drop-off at main hub or waste recycler plant

The collected waste is transported either to the main hub (The Hague and Ghent), or a waste recycler (Southend and Douai).

Module 8: Processing of plastic waste

The collected plastic then requires processing, including sorting and recycling or alternative disposal, whereby export, landfill and incineration are the least desirable options. Some plastics will be clean and pure enough for recycling, whereas others will be too contaminated or impure. Especially mixed material films are rarely recycled, and therefore, alternative solutions should be considered locally, such as pyrolysis. Alternative ways to deal with otherwise unrecyclable plastics are discussed in Section 4.6.

4.3. New ways of collection and transport

4.3.1. Transport using waterways from the city centre

All four cities have shippable waterways and could use boats for transporting plastics out of the city centre. Ideally, the recycling hubs would be directly at the boat mooring places; otherwise they then need a logistical connection to the hub or directly to shops, which potentially requires a second mode of transportCompared to other types of deliveries (i.e. road, rail and plane), transporting goods on waterways (i.e. rivers, channels, etc.) offers many benefits. As many water transport technologies are highly efficient in terms of fuel consumption, they are also considered as more environment-friendly, economical and sustainable transportation options (e.g. Fathoni et al., 2017). To be more specific, inland water transport uses almost 20% less energy than road transport and 50% less than rail transport per km/ton of each transported good (European Commission, 2020).

Last year more than five millions tonnes of goods were transported on the Thames. This number kept around 270,000 off from London's highly crowded and clogged roads (Port of London Authority, 2020) and helped authorities in the city to reduce CO2 emission and overall pollution levels. According to European Commission (2020), over 37,000 kilometres of waterways connect many industrial areas and cities in Europe. Moreover, 13 EU States have interconnected waterway networks. Therefore, different practices and innovations have been implemented in various European countries to improve city logistics by water. In this respect, the focus has been shifted to the development of electrically powered ships and boats to transport goods to and from city centres through canals and rivers in many European cities.

In Utrecht, the Beer Boat is used to deliver items into the city centre. While the Beer Boat was initially diesel powered, it now works as a fully electricity powered inland ship. The Beer Boat has a hydraulic crane and multiple rolling containers that make it able to deliver the freight to the quays without damaging the historic centre of the city. The vessel's electric engine is charged with green energy and the vessel can sail all day long on a single charge. In terms of accessibility, the Beer Boat can reach more than 80% of the canals in Utrecht. In addition to serving a number of breweries, the vessel also carries both frozen and fresh goods in special containers. More importantly, it can transport many waste items from houses, shops and restaurants in the form of reverse flows (Maes et al., 2015). The amount it can carry can go up to 20 tonnes (Trojanowski and Iwan, 2014). While the Beer Boat can move freely without any traffic congestion, this reduces traffic problems in Utrecht and increases the accuracy of transportation and delivery of goods.

Other than the Beer Boat, The Amsterdam City Supplier is another electrically-propelled vessel that has been used to transport goods on the canals of Amsterdam since 2010. In Amsterdam, the goods are transported on road until they arrive in the city centre, but the last mile of the transport is done over water. Similar to the Beer Boat, The Amsterdam City Supplier also transports various waste (in addition to other products such as food) from different locations (e.g. shops, restaurants, etc.) to a processing plant in order to produce biofuel. Thanks to its electrical engine, the vessel requires less energy to operate and generates low levels of PM10 and CO_2 emissions (Maes et al., 2015).

In Amsterdam, DHL also provides its services over water via its floating service centre. Navigating through the major canals of Amsterdam, DHL's ship collects the mail it is supposed to deliver from specific locations in the morning and in the evening the collected mail is transferred to DHL's regular network. DHL uses nine couriers with bicycles and only two vans. Carriers with vans are used to transport parcels that cannot be transported by bicycles. By reducing the number of vans from 10 to two, DHL managed to reduce its annual fuel consumption by approximately 12,000 litres (Maes et al., 2015).

Another project developed in the Netherlands to transport goods over water is the Dutch Distrivaart project. In this project, it is planned to use 40 ships to transport goods from 17 distribution centres via inland navigation. Moreover, it is also expected to transport above 40 million pallets of goods in this project (Maes et al., 2015). One benefit of this project is to connect rural areas to large cities and transport the goods (e.g. grain) produced in rural areas to cities over water. Furthermore, as each vessel is able to carry up to 20 truckloads of goods, Distrivaart could also reduce the traffic congestion and CO2 emissions in the country.

Since the mid-2000s, an inland ship has been used to transport waste paper from Paris to a recycling plant in Rouen. Once the recycling process is completed, recycled paper rolls are shipped back to Paris in order to print magazines and newspapers. Besides, Vert Chez Vous (i.e. France-based Logistics Company) uses floating warehouses on Seine. In their system, the company first loads the vessel with goods and tricycles. After that, each tricycle is loaded on board with the sorted goods. When the ship arrives at the ports, the tricycles distribute parcels lighter than 30 kg to the designated locations (Trojanowski and Iwan, 2014). Furthermore, SUEZ (i.e. France-based Utilities Company) aims to develop its river transport system in Greater Paris to carry household, construction and industrial waste from the city centre to recycling plants over water (SUEZ, 2017).

In Lille, more than 200,000 tonnes of urban waste is transported to recycling plants by water annually (Maes et al., 2015). In Bordeaux, vessels are used to collect recyclable waste over the river as well. Moreover, in Lyon, SUEZ uses River'Tri, a water-borne mobile waste collection centre to provide waste management service to the residents located in the city centre. As River'Tri has potential to replace 16 waste collection trucks in Lyon (SUEZ, 2017), it can help to reduce traffic congestion in the city centre.

Considering these examples, bringing the goods to the city centre over the water with an electricity-powered vessel from the city borders is one of the potential options we can implement in the PlastiCity project. While this might help us to protect the historical city centres, it would also reduce the negative environmental impacts of rail or road transportation. In this sense, a small storage centre outside the city centre may be required to temporarily store the goods before the electric vessel collects those (Maes et al., 2015). Likewise, interim container stations with lower capacity storage spaces can be installed in waterways (Trojanowski and Iwan, 2014). In addition to this option, shared container transportation with IoT-enabled vessels can be adopted to transport goods or waste over water more efficiently. In the shared container transportation mode, each container is scheduled with an app to reduce the waiting time of containers, and eventually reduce energy consumption (Huang and Zhao, 2019).

Practical aspects explaining why waterways remain largely unused for waste transport

- Changing to another mode of transport may lead to extra manipulation, which lowers the quality of the materials due to the increased risk of contamination. A way around this would be to transport the plastics in containers that get loaded from one mode of transport to the next, which requires infrastructure such as docks with cranes and suitable boats or ships (depending on the scale).
- To be financially worthwhile, large volumes of a monostream would be needed. The density of plastics tends to be too low to make it interesting, whereas e.g. construction materials are much heavier and therefore waterways become a viable option.
- The situation on the roads would need to be very bad for the waterways to become attractive. This is currently the case in Antwerp, where the waterways are increasingly being used because of the serious traffic jams.
- On the short-term, waterways are too expensive; the situation may change on the long term.

4.3.2. CargoTrams to collect waste

This section is based on Lin (2020).

Instead of being stationary, recycling hubs can also be mobile, shortening the paths for companies to drop off their waste. As an example, Zürich uses a tram (Figure 37) converted from two carriages to collect electronic (e-tram) and bulky (cargo-tram) waste in sensitive and car-free areas of the city (McLeod et al., 2008).

Figure 37: Zürich Cargo-Tram (source: https://www.stadt-zuerich.ch/vbz/de/index/die_vbz/services/cargo_tram_und_etram.html)

It travels on a pre-planned route and stops briefly at some stations to collect the electronic and bulky waste in a container for later sorting and disposal. During non-working hours, the cargotram will stop at a fixed location to serve as a stationary waste collection container or a local hub (Wong, 2018). To improve the convenience of e-Cargotram in charging and unloading, Zürich also built a recycling centre with tracks in the west of the city and equipped trucks with two containers that allow carrying large cargo (Neuhold, 2005). The daily cost of operation amounts to about €1000 (Eltis, 2015).

Both The Hague and Ghent have tramways that could be used for waste collection. There are four urban tram routes passing through the city centre of Ghent, and the total length is about 30km (Tundria, 2016). The Hague's tram network has a total length of 12 lines covering 117km (Urbanrail, 2019).

4.3.3. Alternative vehicles and land transport modes

The alternatives presented include modes of transport identified in section 2.2 and futuristic thought experiments.

CargoBike

Cargo bikes are especially suitable for transporting low volumes of plastic in urban environments with restricted access, such as old city centers. The Hague has an electric bike with a compactor press. The volume it can carry is approximately 200kg or 2m3.

The number of catering bins filled with compressed plastic that can be carried depends on the weight of the full bins. A full bin contains two packages of compressed plastic. With an average density of 28kg/m3 of uncompressed plastic, a full bin with 2 cycles of compressed plastic weighs 6,7 kg. This means that with 28 bins a total weight of 188kg of plastic is stored. A weight of 188kg of plastic is close to the maximum load-bearing weight of the container 191kg (250kg payload of the container, minus the weight of the press, 59kg). It will have to be examined by trial and error whether a higher number of bins filled with compressed plastic and therefore, a higher weight can be carried. That is why the storage capacity in the container in relation to weight is classified up to a maximum of 28 clearing bins.

Electrical pickup trucks

Electrical pickup trucks are especially suitable for transporting medium volumes in urban environments. Similarly, there are lorries powered by hydrogen or biogas, considerably lowering emissions.

Autonomous vehicles

Some autonomous waste vehicles such as Volvo’s and Renova’s autonomous refuse truck are being tested in urban environments in Sweden. And some vehicles like Komatsu America Corp.’s semi-autonomous construction-class dozers and excavators are being utilized at landfills and materials recovery facilities. In 2018 Atlanta based waste company Rubicon patented an integrated driverless collection system (Figure 38). Rubicon proposes potential scenarios in which an automated vehicle drives down a street and sends a signal to a "plurality of transporters," which would then autonomously bring receptacles out for collection. In 2019 the company announced pilots in partnership with local authorities in Santa Fe, Atlanta and Columbus. The majority of Rubicon's business is in the commercial sector, particularly small business. Waste industry executives have been skeptical about autonomous collection in the near future. However, the impact caused by COVID-19 pandemics in waste collection services has reignited interest and research in these technologies. Receiving recyclable materials has a high rate of interaction with the public, as a result, many locations around the world have temporarily halted collection of a portion or all recyclable materials. Recycling operations must make the most with the material they receive, with fewer workers. In China and USA "advancements have been made in sorting circuit automation at both front and back ends, which have helped recycling operations

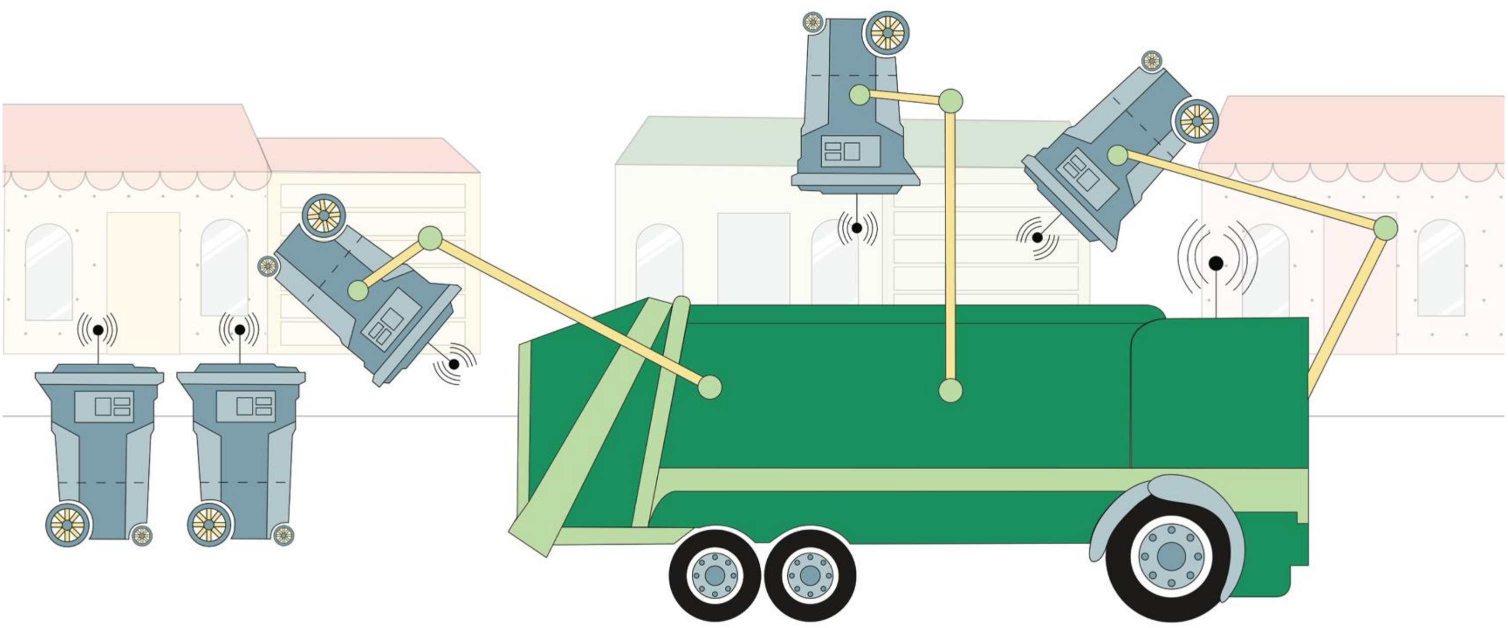


Figure 38: Rubicon Automated waste collection vehicle (WasteDive, 2018).

decrease the number of manual sorters while increasing material purity."[28]

28 https://waste-management-world.com/a/tomra-new-sorting-technology-can-help-overcome-recycling-disruption-from-covid

Drones

Certain types of drones can carry heavy loads (up to several hundreds of kg) but are the moment best suited for small, valuable cargo. Advances in the technology, increased usage of autonomous drones during the pandemics and changes in regulation can expand their potential. Drones and Artificial intelligence are currently used to collect plastic waste in water bodies. For example, Ran Marine Technology is a dutch start-up that since 2016 has been using a waterdrone called water shark to collect plastic from harbour waters in the USA, the UK and the Netherlands. It is the size of an average coffee table and collects up to 1000 pounds of waste/day. WasteShark can be steered manually via remote control or set up to swim autonomously; its collision-avoidance system employs remote-sensing technology called Lidar to spot obstacles, such as buoys and other crafts, and adjust its position accordingly.

Volume reduction

Some collection vehicles are equipped with a press to compact their load. Alternatively, vehicles could be equipped with a shredder, leading to a higher density. However, this only works when the purity of the recyclables can be ensured.

Redesign for combined forward and reverse logistics:

Lorries could be redesigned for combining forward and reverse logistics, making it easier to keep loading and unloading: one way in, one way out, reducing the shifting around of cargo to get access to goods.

4.4. Smart collection and sorting system - the underlying principle

This section is based on input from interviews with Peter Brughmans (Van Werven).

As an underlying principle, all activities of separating, collecting and sorting should be oriented towards the final goal, which is creating a high quality recyclate that can be sold and reused for making high quality products again and again. This makes sense both economically (the recycling activities fund themselves) and ecologically (more plastics neither get dumped nor burned, and less new plastics need to be made, which is all better for the climate as well as flora and fauna). Contrarily, the collection of plastics that will not get recycled (like it is often the case with Tetrapaks, unfortunately, makes no sense (with the exception of the aspect that the population keeps up a good habit, hoping that these materials will be recycled in the future).

Similarly, whilst the compaction of materials for transportation would make sense to reduce the volume and hence save fuel for transportation. However, this should only be done if no further sorting is required, i.e. if the material purity is right for the subsequent processing and purpose. Point in case: some materials that go into the same stream will need to be further separated to create a high quality recyclate, as they come with or without fillers like limestone. By mixing them for recycling, the higher quality (purer) materials will be degraded, and value would be lost. It is also worth noting that such fillers can change the density of plastics, therefore disturbing or disabling automated sorting mechanisms such as water baths, whereby some plastics will float and others will sink. With fillers, or when materials are mixed, this mechanism no longer works. Products and components that remain sufficiently intact for people to recognise what they once were (shape, purpose) are easier to sort by materials; e.g. a fragment of white hard plastic that can be identified as part of a former garden chair is typically polypropylene with limescale filler.

Ultimately, (more) closed-loop recycling is an ideal scenario, as materials remain at the same level of quality and responsibility is clear. With open-loop recycling, materials often go through multiple hands, with many opportunities for contamination, loss, fraud, and other problems.

A downside of more separation and sorting as a function of what will happen to the materials afterwards is that the collection logistics become more complicated, and that there may not always be sufficient volumes of individual streams. The consensus is to separate into 5 streams for collection (EPS, clear film, coloured film, hard plastics, the rest / contaminated plastics), and conduct further sorting and separation afterwards, for instance to remove multiplayer films and mixed materials. There are two rationales for combining plastic waste streams: either because two materials can very easily be separated at the sorting plant, or because they can be recycled together, as a combined material with a specific reuse application afterwards. Sometimes conversations with individual recyclate buyers are required to discover such opportunities.

The sale of recyclates must take place within a fair playing field where circularity does not only depend on price but on the materials' high-quality and sustainable reusability. Also, transparency is required; if certain materials are not being recycled, this should be communicated, such that changes can be made accordingly, e.g. by product designers, plastic producers and waste collectors.

Ideally, the plastic recycling market should remain open to all players, and the creation of exclusive niche markets should be avoided.

Recyclability is often not about the part size, but about its life cycle. High quality long-life plastics (like those used for garden chairs and the shells of appliances) often have different properties than short-life plastics (packaging) and therefore a different smart collection method (bring vs. collect) is preferable.

- For (limited volumes of) long-life plastics, it may be preferable for waste producers to bring their items to a local collection point - a hub. In many regions, such collection points exist for households but not for companies.
- For short-life plastics, which are often accumulated in larger quantities, it may be preferable to organise a collection service.

Further criteria that influence what the best logistics scenario is:

- For locations including shopping centres, office buildings and business centres: organise a local recycling hub where plastics can be placed in distinct containers (separating each stream or creating a "smart mix" for targeted recycling). Each of these hubs should have a person (quality guard) responsible for proper sorting and cleanliness, avoiding contaminations.
- The dismantling of products composed of several materials (e.g. household appliances) could be organised through social employment.
- Social employment works under certain conditions; no time pressure: people can call when they are done disassembling the products, and then they get paid for the work done. This could be a valuable way to engage the local communities. However, for

sorting of plastics under time pressure at the recycling plant, properly trained staff are required.

- Another example: Cork has the same density as PE, making sorting through a water bath impossible; therefore, manual sorting is required, which social employment companies can do.
- The most suitable collection scheme will depend on population density (city vs. village, major shopping mall vs. local highstreet with a few small shops, etc.).

Other ideas:

- Vouchers for people who bring sorted materials to collection points; such vouchers could for instance contribute to working towards rebuilding a forest linked to shares for a new social company. This is community building, and very little money is involved, yet there is a growing value. The idea is based on Lietaer et al. (2012).
- Use delivery couriers for reverse logistics of hard plastics, valuable items; e.g. collect christmas lights once a year, collect specific materials once a month.

Tracking and tracing:

- The waste tracking system should be unambiguous, uniform, and easy to use (for unskilled persons), cheap, easily visible (as a commodity) and without devices.
- Traceability (for example with a quality mark or logo) could be used as a commercial marketing tool, for companies to demonstrate their commitment to upcycling their materials.
- What is relevant for the consumer to know / what information is required:
    - Material content: Yes
    - Used Process: No
    - Reuse future: Yes
- What is important for the local authorities?
    - Care management of the 'source material' and the reuse of it
    - Percentage of recycled content

- Do we need to know what the reuse / recycling circle is? Details are not required by the consumer - just the big facts: Is the material recycled locally or at risk of being dumped in Asia or Africa?
- Different collection systems for different materials and situations:
  - Recycling bin in shops: make shops responsible for the products and packaging they sell and have them collect the waste. (This idea is implemented partially in the UK, where supermarkets collect the type of plastic used for carrier bags; elastic films.)
  - Recycling bin at a hub: people bring their accumulated materials to a local quality control point.
  - Waste bin at a hub: people bring their other waste to a control point to verify that no recyclable material is thrown away in the general waste bin.

4.5. Development of a plastics logistics hub and plastics reuse ecosystem

After collection and treatment, plastic waste can reach 3 destinations, and the logistics cycle is currently organized to operate accordingly:

- Granulates
- Export
- Residual waste reaching the general waste treatment cycle

If the PlastiCity project manages to enhance circularity by finding an alternative treatment, it is important to breach into this current supply chain, gather data, approach the current waste logistics service providers and invite them to reconsider (part of) the current flow, more precisely: the first mile.

If the PlastiCity project aims to apply this circularity on a local/regional scale, a plastics waste collection hub can be considered. Such a hub can have the following functions:

- Local/regional cross-dock for plastics waste
- Sorting plastics
- Home for the (to be) eco-system aiming to re-use of plastics

Logistics of local/regional plastics waste can be optimized according to three axes:

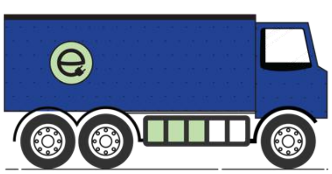
Full truck load through consolidation:

Inner city: current waste logistics service provider subcontracts the first mile to a local logistics service provider specialized in urban freight. This leads to consolidating plastic waste with other freight, hence higher truck fill rate.

Regional: current waste logistics service providers subcontract the first mile to a local logistics service provider.

Smart transport:

Local and regional: Sharing data between waste logistics service providers in order to reach full truck loads.



Clean transport:

Local and regional: performing the waste collection with electric/hybrid or hydrogen driven trucks.

4.6. Other ideas

Alternative logistics

- A "milk-run" scheme can be arranged for companies in a local area, e.g. in a high street. A collection vehicle would visit one company after the other, only returning to the hub when full.
- Reverse logistics can be operated by delivery companies, meaning that they take plastics back to suppliers / delivery hubs / headquarters, as long as the materials are not declared as waste (hence no waste collection licence needed).

Bigger ideas

- Every piece of plastic should have a label specifying what it is, where it comes from and how it can be recycled. This already exists to some degree, as may packaging items carry a recycling sign and a number specifying its material. However, this does not include all information in case of multilayer films.
- With much better and correct labelling, sorting would become much easier, and plastics could be washed and shredded locally. (Problem: plastics from outside of Europe are often not labelled at all).
- The potentially most effective concept would be to introduce a law forcing manufacturers to take back their plastics and reuse them, closing the circle. The manufacturers know what plastic it is and how it can be reused. There might, however, be negative effects generated by otherwise avoidable transportation.

Infrastructure

- Machines for automated sorting and shredding are being developed.
- Local drop points in the floor, with underground containers, already exist in some cities. This reduces the need for overground space, which is scarce in many city centres. As a next step, tunnels that connect them could be added, so that materials can be sucked through. The downside is that this needs large scale construction works and is hence very costly.

- Local hubs could be equipped with presses and shredders; companies drop off their waste there, it gets sorted and compacted (by a trained employee?), and then collected from there to the central hub / recycling company.
- Collection points could be located at various locations throughout the cities, such as fuel stations, car washes, etc.

Public participation and social inclusion

- Networks of volunteers or casually paid workers could be organised for collecting small amounts of plastics from smaller businesses and take them to local collection points. Such a scheme could offer a welcome opportunity to make some cash for rough sleepers etc., similar to selling the Big Issue magazine in the UK. However, quantities might be too big for manual collection, and access to industrial sites might be a problem as well.
- The sorting of plastics could similarly be done by town communities, although people would need access to the sorting site and be trained and supervised.
- Parcel couriers might be able to transport clean plastic waste as well - once their vans are no longer fully loaded.

Designing and marketing recycled products:

- There are websites[29] that promote products made from recycled plastics.
- Promoting products made from recycled materials is important to stimulate the market, as recycling only makes sense if there are enough manufacturers willing to use the recycled materials, and this again depends on consumers actually buying the products.

29 https://www.recyclemoreplastic.org/buyrecycled

4.7. Chemical recycling solutions and similar approaches

PlastiCity focuses on mechanical recycling processes. However, for certain situations, other processes are necessary.

Between mechanical recycling, and when not possible, energetic valorisation (i.e. burning to recover heat), there is a third way investigated by many researchers (academic and industrial) which consists in breaking the big plastic macromolecules into small ones in order to, whenever reachable, go back to the polymer building blocks (monomers), or whenever not, to obtain molecules of interest. This is so-called "chemical recycling" (e.g. Ragaert et al., 2017; Solis and Silviera, 2020).

Although this could be discussed, we do not consider plastic to fuel or plastic to (syn)gas as chemical recycling, but as an indirect means of energetic valorisation.

Chemical recycling covers a large spectrum of possible techniques from depolymerisation to pyrolysis. For instance, CARBIOS, a French start up near Clermont Ferrand has developed a green chemistry process based on enzymatic catalysis to turn PET back to its constitutive monomers; in the same purpose, Dutch teams are also working on PET depolymerisation by Glycolysis. And although food grade PET is the only plastic that can be recycled back to food contact, this is a major evolution because despite waste sourcing (food or non-food, coloured, filled, contaminated or polluted…), the obtained monomers can be used to produce virgin PET, even food grade (Carbios, 2020).

Solvolysis (that is, using solvent in supercritical state, mainly CO2sc or H2Osc) can also be used for chemical recycling for instance to de-vulcanise rubber (e.g. from tires), or for recycling thermosets; in more severe conditions of pressure and temperature, it could also lead to fragmentation of macromolecules into smaller ones (e.g. Keith et al., 2016; Khalil, 2018; Li et al., 2019) .

Pyrolysis, which is broadly used for plastic-to-fuel conversion, can also be used for chemical recycling especially under catalytic control (e.g. Miandad et al., 2016; Pudding et al., 2018): Ineos

Styrolution is working on the installation of a new plant in northern France, near Lens, to achieve chemical recycling of polystyrene and use the obtained monomers for synthesis of new raw Polystyrene; though we have no precise information on their process, it is very probably based on catalyst assisted pyrolysis. This technique could also be used for chemical recycling of mixed plastics, and TEAM2 is supporting two projects of ENSCL (a chemical engineering school in Lille) in this field. In this case the expected output are not mainly monomers, but rather interest molecules that could be used for specialty chemical processes.

Combination of mechanical recycling assisted by chemical or chemical recycling assisted by mechanical process is also investigated, for instance reactive extrusion or supercritical solvent assisted extrusion: in France labs from University of Lyon, IMT Lille Douai and ENSCL are working on these techniques which are promising for decontamination of plastics which could make them suitable for going back to food contact (of course if the waste stream treated is food grade).

According to the European Association of Plastic Converters (EUPC), major oil and gas companies are very interested in chemical recycling of plastics, because in this case they can feed (with almost no additional investment) their existing facilities with monomers from chemical recycling to synthetize plastics instead of fossil sourcing (EUPC, 2020).

To conclude on chemical recycling, we can consider that it covers a family of promising techniques, some mature, some still investigated, that could allow to create new raw plastic material fully equivalent to virgin material from plastic wastes.

More information can be found on the following websites:

- Pyrolysis (works for mixed / dirty plastics) to create diesel: https://www.youtube.com/watch?v=6L7A7wRs1R8
- Gasification (works for mixed / dirty plastics)
- https://theconversation.com/if-we-cant-recycle-it-why-not-turn-our-waste-plastic-into-fuel-96128
- Plastic digesting enzyme https://www.port.ac.uk/news-events-and-blogs/news/engineering-a-plastic-eating-enzyme

- Plastic eating worms - could be kept in an installation at the recycling hub, rather than released into the wild which causes issues for bees! https://www.nationalgeographic.com/news/2017/04/wax-worms-eat-plastic-polyethylene-trash-pollution-cleanup/
  - Dissolution (solvent extraction), mechanical process https://repository.upenn.edu/cbe_sdr/115/
  - Solvolysis and depolymerisation (chemical process, for sorted and clean plastics) http://plastics-themag.com/Chemical-recycling:-the-missing-link
  - Digest impure plastics https://www.goodnewsnetwork.org/factory-uses-enzymes-to-recycle-all-plastics-at-once-backed-by-major-companies/
  - Mixing plastic recyclate with other waste to bind it and use in low-spec applications https://www.goodnewsnetwork.org/israeli-plastic-and-waste-recycling-method-kills-two-birds-with-one-stone/
  - Chemical recycling without losing quality https://www.circularonline.co.uk/news/new-process-allows-plastic-to-be-recycled-without-losing-quality/

5. Developing the individual logistics scenarios

This chapter develops future / hypothetical scenarios for each project city, elaborating strategies for improved logistics rooted in local conditions, constraints and preferences.

5.1. Plastic waste collection scenarios for Ghent

The scenario to be developed in Ghent responds to a centralized urban sorting hub strategy. It will be centered around the hub located at Zeilschipstraat, off Wiedauwkaai, with approximate coordinates (51.077487, 3.717141). This location is close to a waterway that leads out of the city centre.

Purposes of the hub:

- Location of the mobile unit (described in other PlastiCity reports) when it is not travelling around. The unit will perform the necessary tests on the plastics. It will also serve as a showcase location, to invite companies, civilians, policy makers, researchers and other interested persons to see the mobile unit in action and learn from our experience.
- Storage of the collected plastics in different containers. Depending on the collection method (separate or mixed), the lot can also serve as a workspace for sorting and separating the different plastic types.
- The aim of the PlastiCity project is also to use the newly recycled plastics in products, new designed and/or existing products that are now being made of virgin plastics. So the lot at the Wieudauwkaai can also serve as a experimenting zone for design of new/existing products with recycled plastics.

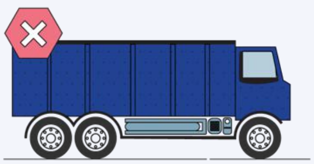
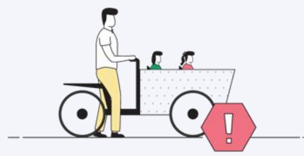
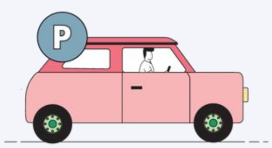
The combining of these different purposes make the Wiedauwkaai a true PlastiCity hub, that will serve as an example and inspiration. This does not exclude the possibility of other (smaller) plastic hubs in the city, but the main focus will be on the Wiedauwkaai. Scenarios will be developed around the plasticity hub at the Wiedauwkaai, with the aim of breaking the current supply chain as described in Section 3.1.

At the hub, the mobile unit will test some of the newly developed recycling processes. For the time being, the large quantities of plastics will continue to go to the industrial waste management and recycling facilities at GRCT, Van Werven, and elsewhere.

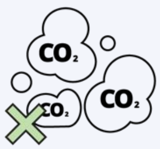
One can look into different kinds of vehicles, separating at the source or at the hub. A first scenario will be the collection with a smaller vehicle by GRCT, transport to the hub and then further treatment.

The advantages of this scenario are

The vehicle being smaller

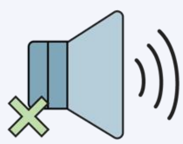
 Ghent has urban areas where no lorries are allowed	 Safety of vulnerable road users (bikes, pedestrians,...)	 Small streets in historic city centre of Ghent
 More easy and efficient to drive and park in city centre	 No lorry driving licence needed	

100% electric

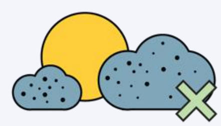


No carbon dioxide emissions in the city

Ghent is a low emission zone



Less noise



Less smog, less small particles in atmosphere

Additional scenarios include that GentLevert could perform an inner city (within R40) or local (within R4) milk run by electric van, CNG truck or CargoBike.

At the hub, there will also be designers and manufacturers, so at least part of the recycled materials will be reused locally, without further transportation.

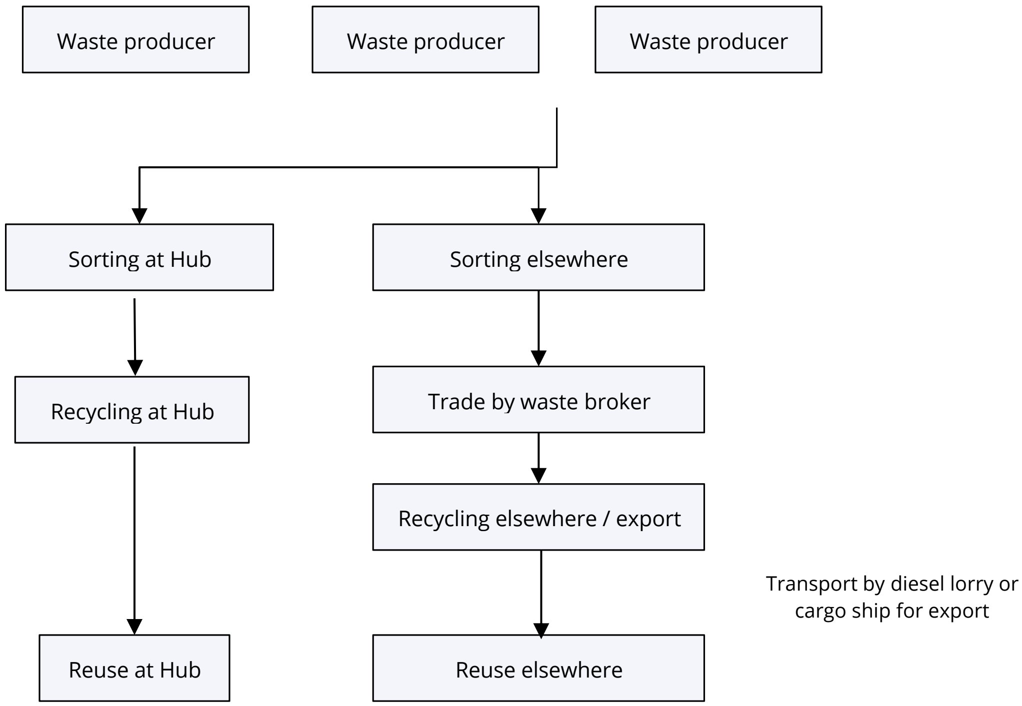


Figure 39: A possible future plastic waste flow in Ghent

5.2. Plastic waste collection scenarios for The Hague

The scenario to be developed in Ghent represents a centralized urban sorting hub strategy with waste collection and transport zonification. In other words, the type of collection and vehicle used to transport plastic waste to the hub will be different in different urban zones. Initially, two zones are considered: one within the boundaries of the city center, the second outside the city center boundaries. In the scenario to be explored, the CargoBike will be the transport mode in the city centre (zone 1). It is also assumed that waste owners will separate plastic for collection by Cargo Bike, In zone 2, outside city center, recyclables may be mixed and an electrical truck may be used, especially in residential areas.

There are two potential hub locations in The Hague:

- De Besturing: Willem Dreespark 312, 2531 SX Den Haag
  This location is next to a canal.
- Energy Academy: Laan van Nieuw Oost-Indië 277, 2593 BS Den Haag
  This location is close to a train station.

The scenario is based on the assumption that waste producers separate their recyclable materials at source, so only (mixed) plastics will be collected.

At the hub, plastics will be sorted and pre-treated / recycled, and new products will be made from the recycled plastics. Once the proof-of-concept is developed, a way to scale it up will be needed. Figure 40 illustrates the plastic waste flow as imagined for the future in The Hague.

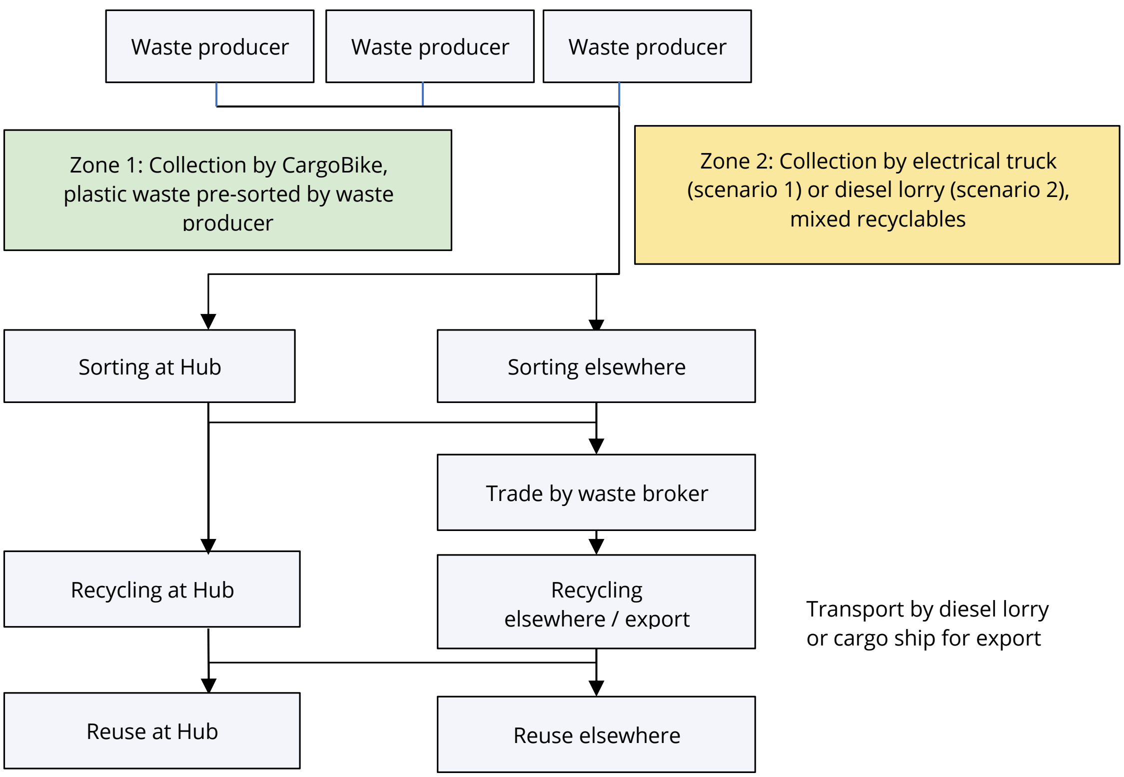


Figure 40: A possible future plastic waste flow in The Hague

5.3. Plastic waste collection scenarios for Douai

The scenario to be developed in Douai, responds to a centralized peri-urban sorting Hub strategy without pre-sorting at the source. In terms of transport we will consider the use of hydrogen-powered lorries for plastic waste collection. The hub is located at the Theys Recyclage at 815 rue du Faubourg d'Esquerchin, Cuincy, where a new sorting plant is being developed with innovative sorting mechanisms. It is expected to become operational in Spring 2021. It is possible that recycling processes will become available at the hub in the future.

The lorries used for collection have a loading volume of 40m3, and hydrogen-powered lorries are roughly three times as expensive as conventional diesel lorries. Additionally, they require special fuel stations.

An additional aspect to explore is the recycling of hard plastics from households (for instance, garden chairs) that the city receives at 20 public "recycling centres" but does not currently recycle. These plastics are estimated at 3kg / inhabitant / year. With 40,000 inhabitants, this is 120 tons of recyclable plastic.

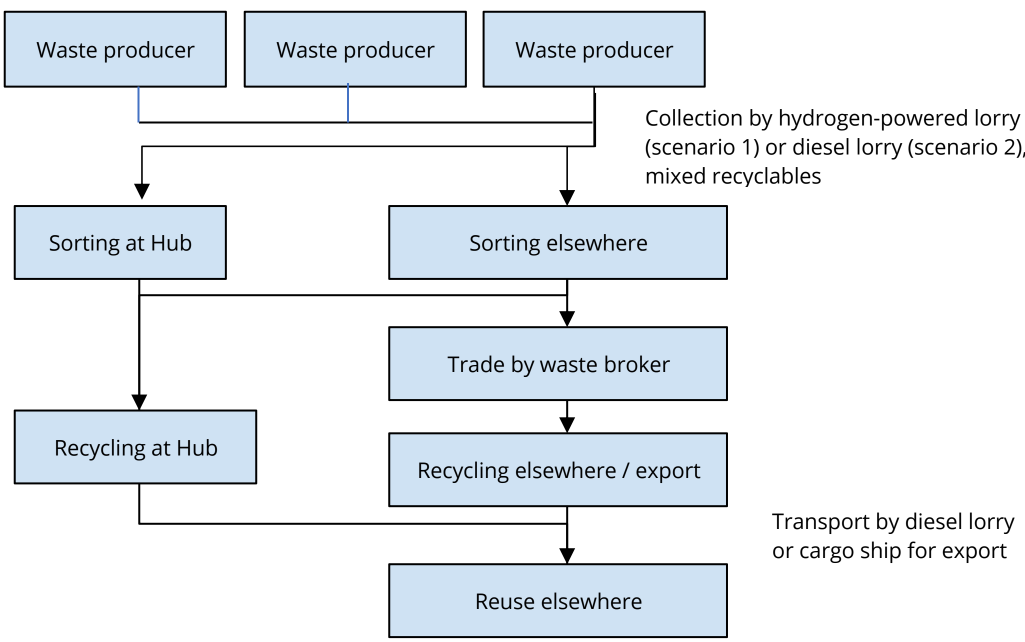


Figure 41: A possible future plastic waste flow in Douai

5.4. 5.4 Plastic waste collection scenarios for Southend

The strategy for Southend departs from the other 3 cities because the city does not have suitable urban locations to install a large centralized recycling Hub. Instead, it envisages several mini-hubs (intelligent plastic collection containers- see section 2.3.2.2) connected to a "virtual central hub", that is, a recycling platform providing information. Businesses with plastics will be able to log in and find their nearest mini-hub or other recycling site for the type of plastic they wish to recycle, with opening hours, capacity, restrictions and payment etc. Some sites might offer a payment for some materials or still usable components, for instance unwanted windows (which nowadays often have PVC frames).

The digital platform will contain a host of information specific for Southend businesses, schools and the community from education, sensitisation, questionnaires, forums, workshops, case studies, material trading, service quotes. Southend already has an urban platform online30, set up by the GIS team in conjunction with a company called ESRI for other council projects. A Southend PlastiCity page is being prepared and will be attached to the existing page. In terms of physical arrangements, Southend will place its "mini-hubs" (plastic collection containers) at ten locations throughout the town, as shown in Table 4. These containers will be specific to certain plastic types, requiring waste producers to sort their plastics.

Table 4: Mini-hubs in Southend

POTENTIAL MINI HUB SITES (SUBJECT TO CHANGE)		
Name	**Address**	**Postcode**
Barons Court Primary School	Avenue Road, Westcliff-on-Sea, Southend-on-Sea, Westcliff-on-Sea	SS0 7PJ

30 https://www.smartsouthend.org

Sacred Heart Primary School	Windermere Rd, Southend-on-Sea	SS1 2RF
Milton Hall School	Salisbury Ave, Westcliff-on-Sea, Southend-on-Sea, Westcliff-on-Sea	SS0 7AU
Heycroft School	Benvenue Ave, Southend-on-Sea, Leigh-on-Sea	SS9 5SJ
The Eastwood Academy	Rayleigh Rd, Leigh-on-Sea, Southend-on-Sea, Leigh-on-Sea	SS9 5UU
Thorpe Hall School	Wakering Rd, Southend-on-Sea	SS1 3RD
Fairways Primary School	The Fairway, Leigh-on-Sea, Southend-on-Sea, Leigh-on-Sea	SS9 5UU
Edwards Hall Primary School	Macmurdo Rd, Leigh-on-Sea, Southend-on-Sea, Leigh-on-Sea	SS9 5AQ
The Royals shopping centre	High St, Southend-on-Sea	SS1 1DG
Victoria shopping centre	362 Chartwell Square, Southend-on-Sea	SS2 5SP
The Pier	Western Esplanade, Southend-on-Sea	SS1 2EE
Civic Centre	Victoria Avenue, Southend-on-Sea, Essex	SS2 6ER
The Forum	The Forum, Elmer Ave, Southend-on-Sea	SS1 1NE
Olympus KeyMed	Keymed house, Stock Rd, Southend-on-Sea	SS2 5QH

Certain locations in town, where many small businesses are located, would have special arrangements. For instance, the Royals shopping centre would offer their facilities for the accumulation of films, bottles,tubs and trays as a mini-hub and then other high street traders would collaborate to organise a milk-run collection system. The agreements would include the day of the week and the materials to be collected. The collection vehicle would preferably be electric and include a compaction press.

The other mini-hub containers will be "bring-sites" (meaning that companies will bring their plastic waste to the container) connected to the digital platform. One idea is to find businesses in Southend with existing recycling facilities that are willing to allow other companies to use them. These sites could be supplemented with a PlastiCity container. The digital hub would allow other businesses to find their nearest 'mini-hub' site, find out materials taken, opening times, parking etc.

Given that there are no known local plastics recycling facilities, sustainable alternative arrangements (like the concept for a local recycling centre) need to be developed.

Figure 42 illustrates the plastic waste flow as imagined for the future in Southend.

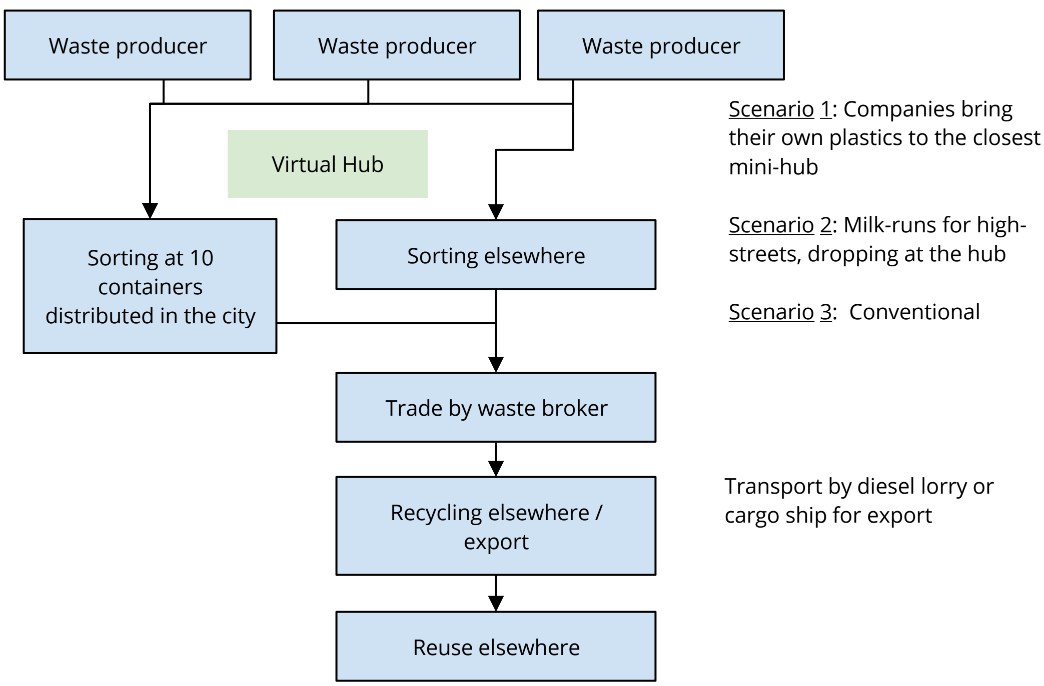


Figure 42: A possible future plastic waste flow in Southend

5.5. Overview of strategies

Table 5 provides an overview of the strategies adopted by each city and indicates under which condition this strategy might be suitable for other cities.

Table 5: Overview of the strategies chose by each city

Hub	Bring / collect	Pre-sorted by Waste-owners	Sorting	Recycling	Strategy Suitable for
GHENT					
Urban: Wiedauwkaai, in the north of the city	Mostly collection	Yes. Colored bags	At the Hub and at GRCT or other waste management companies.	At VanWerven for hard plastics, unknown for all other plastics; a small quantity at the hub	Medium-size cities. Availability of urban location for Hub Enforced pre-sorting schemes.
THE HAGUE					
Urban: City centre	Mostly collection	Yes. In city center zone serviced by CargoBikes. No. outside city center	At the Hub and Waste management companies	At VanWerven for hard plastics, unknown for all other plastics; a small quantity at the hub	Medium size cities Availability of urban location for Hub. Clogged Urban areas with strict transport restrictions. Positive attitudes towards pre-sorting
DOUAI					
Peri-Urban: Outside of city, at Theys	Collection only	No	Outside of city, at Theys Recyclage	At VanWerven for hard plastics, unknown for all other plastics; a small quantity at the hub	Medium-small size cities Lack of availability of urban location for Hub Negative attitudes towards pre-sorting/pre-sorting difficult to enforce

SOUTHEND					
Several small mini-hubs in the city; small-scale arrangements for high streets, shopping centres, etc.	Mainly bring-sites, but small-scale collection schemes for certain locations	Yes	Pre-sorting at mini-hubs	Unknown, mostly export	Medium size with seasonal waste peaks. Lack of availability of urban location for Hub Positive pre-sorting attitude

6. Recommendations and conclusions

This chapter reflects on the situation as it currently is, presented in chapter 3, and the individual scenarios developed in chapter 4. We then derive recommendations for the project cities to move forward as well as a generalization that could help other cities increase their plastic recycling rates.

6.1. Transparency and coordination in the recycling industry

With every town council having their own budget for dealing with waste, it is very difficult to achieve any coordination or economy of scale (Wong, 2010). Regional or even national coordination could achieve significant improvement. Similarly, recycling companies could form cooperatives where they can organise themselves to achieve greater efficiency and offer town councils a more integrated service (Wong, 2010). They may also have more power when applying for government funding to build new recycling facilities to deal with the waste internally, rather than exporting it to developing nations, generating emissions on the way and lacking any reliable information on what really happens with the plastics (landfill, illegal incineration?).

The analysis conducted in PlastiCity reveals that there is a major problem with the secrecy in the recycling industry. It is very difficult to receive any information on where plastics go for the actual recycling. Often, waste management companies that accumulate, sort and condense recyclable materials and remove other waste and contaminated materials call themselves "recycling companies". However, the materials are then sold to third parties, sometimes through the hands of waste brokers, and eventually may or may not be recycled somewhere unknown. The trade with recyclables appears to be a very shady business, and anecdotal evidence hints at rampant corruption.

As one of the project partners put it: "Finding out about commercial and industrial waste is highly frustrating. It is a hugely secretive, competitive and corrupt industry and it needs to be regulated, and regulations need to be enforced."

The UK Duty of Care states:

"As a business, you have a legal responsibility to ensure that you produce, store, transport and dispose of your business waste without harming the environment. This is called your duty of care.

The duty of care has **no time limit**. You are specifically responsible for your waste from when you produce it until you have transferred it to an authorised person. However your duty does not end when you hand over the waste to the next holder. It extends along the entire chain of management of your waste. If you think that your waste is not being managed correctly you must take action to check and prevent this.

You must:

- **segregate, store** and **transport** your waste appropriately and securely, making sure that you do not cause any pollution or harm to human health
- **check** that your waste is transported and handled by people or businesses that are authorised to do so
- complete **waste transfer notes**, including a full, accurate description of the waste, to document all waste you transfer, and keep them as a record for at least **two years.**

If a waste carrier takes your waste away, you need to check that they are authorised to accept it."

However, enforcing this is very difficult and mostly unrealistic, which means that the regulation is pointless. In conclusion, to ensure that plastics are actually recycled rather than dumped or burnt illegally, several steps are needed:

An open database of local recycling facilities and their processing capacities needs to be compiled to gain an overview. This would include all types of plastics recycling, including mechanical and chemical methods, for all plastic streams including Tetrapaks. Most likely, it is necessary to create local recycling capabilities in Europe (or to ramp up the capacities where the facilities already exist).

For the UK, a database with incomplete information exists:

Recoup[31] is an organisation that aims to be the UK's plastic value chain co-ordinators. Their database for reprocessors (companies that actually recycle plastics) contains 145 companies. Some of them seem to be purely recycling companies, whereas others make plastic products (assumingly partially from the recyclate they process).

31 https://www.recoup.org

Also potentially useful for this purpose: the European Association of Plastics Recycling and Recovery Organisations[32], although they have not responded to an enquiry from PlastiCity.

Furthermore, laws and regulations are required to provide a framework for all waste management and recycling companies to operate within. It is essential to forbid the export of any type of waste beyond Europe, as the Duty of Care clearly cannot be enforced elsewhere. It will be challenging enough to implement it even within European countries.

6.2. Ecological and economic sustainability

As discussed in Section 4.4, plastic waste collections make the most sense when they are done in a smart way, which means taking into account how the materials are going to be recycled, and how the recycled materials will be used afterwards. This means treating the plastic waste not as "waste" but as a potentially valuable material that needs to be treated with appropriate care. The idea of Theys Recyclage to also accept solid plastics from households (e.g. garden chairs) via domestic recycling centres, estimated to be 3kg / resident and year, is an example of this principle.

Financial incentives could be a powerful tool for getting companies to separate and sort their waste. This could be either in the form of higher costs for the collection of mixed waste, or by reducing the costs for sorted recyclables.

To ensure that plastics recycling is ecologically sensible, it is necessary to collect data on the journeys that plastics make, from when they are first discarded to when they are actually recycled (or burnt / dumped). The amount of emissions and costs incurred would need to be calculated and compared to any available alternative (potentially more local) solutions. For example, the initiative of certain UK town councils to collect plastic food trays is commendable. However, should it be revealed that these plastics then take a long and erratic journey through many hands and across half the globe to end up being burnt illegally in a developing country, it

32 http://www.epro-plasticsrecycling.org

would have been better for them to be sent to a local (and assumingly properly managed) landfill or incineration site.

6.3. Conclusions

At first, plastics recycling appears a relatively simple matter: accumulate (and sort), collect, sort, recycle, reuse. However, once we look deeper, it is a very complicated, multifaceted problem with a political dimension. Different countries have different laws and regulations, cities have individual constraints and existing commitments, people behave in different ways and based on different moral values.

Developing a single solution and strategy for all four cities is almost impossible. Each strategy responds to a particular configuration of contextual factors; including amount of waste generated, availability of urban locations for a centralized hub, and pre-sorting behavior. As such they provide archetypes or templates to be considered by other cities with similar configurations. On the other hand, the cities do share characteristics that in the long term may lead to converging strategies: besides being in the Interreg2Seas area, they all have shippable waterways crossing their city centers. If the costs of using waterways decrease or the costs of land transport increase, it will make sense the shift towards strategies combining short distance transport by land with longer distance transport by waterways.

This report developed individual plastic waste logistics scenarios for each city. It also pointed out the general problems in the waste industry and the lack of enforceable regulations. The subsequent project phase will generate simulations linked to these scenarios, so optimised local transportation solutions can be identified.

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