Proceedings of the Operational Research Society Simulation Workshop 2023 (SW23)
C. Currie and L. Rhodes-Leader, eds.
https://doi.org/10.36819/SW23.016

PLASTICITY SCENARIOS AND MODELLING: PLASTIC WASTE COLLECTION IN URBAN ENVIRONMENTS

Dr Regina Frei

University of Surrey
Stag Hill, Guildford, UK
r.frei@surrey.ac.uk

Prof. Diego Vazquez-Brust

University of Portsmouth
Portland Street, Portsmouth, UK
diego.vazquez-brust@port.ac.uk

Dr Mengfeng Gong

University of Sussex
Falmer, Brighton, UK
mengfeng.gong@sussex.ac.uk

Dr Virginie Litaudon

University of Portsmouth
Portland Street, Portsmouth, UK
virginie.litaudon@myport.ac.uk

ABSTRACT

Within the scope of PlastiCity, an Interreg2Seas project (2019-2022), a set of scenarios were developed for the collection of plastic waste in the urban environments of Ghent (Belgium), Douai (France), The Hague (The Netherlands), and Southend-on-Sea (UK). This included the exploration of alternative vehicles like CargoBikes and electro-vans, in comparison to conventional diesel-powered refuse collection vehicles. For each city, we developed an individual scenario and executed optimisations to compare different collection strategies and frequencies in terms of distance travelled, time used, as well as costs and emissions generated. We used OptiFlow, a logistics optimisation software made available by Conundra, a startup from Ghent University. The main challenge was the unavailability of realistic data on plastic waste volumes for different types of small and medium businesses and organisations in these urban environments, which was at least partially due to pandemic restrictions. Thus, our modelling is mostly to be understood as ways to explore different scenarios and constraints, such as a very limited loading capacity on CargoBikes.

Keywords: Plastic recycling, Waste collection, Sustainability

1 INTRODUCTION

The PlastiCity project[1] aimed to capture plastic waste lost in urban environments, focusing on the cities of Ghent (Belgium), Douai (France), The Hague (The Netherlands), and Southend-on-Sea (UK). This included the development of a mobile processing unit to demonstrate newly developed recycling technology for dealing with multi-material films, the creation of products made from the recycled materials, and plastic waste collection scenarios.

The initial scenario development (PlastiCity Consortium, 2020) looked at reverse logistic solutions that might fit the four cities from a more abstract perspective; what might be possible in the future? The subsequent modelling was more concrete, applying sophisticated logistics optimization software to test scenarios looking at numbers and costs for doing the collections of plastic waste with different vehicles.

A limitation of this work is that calculations are only as good as the data they are based on. When input data or assumptions change, the outputs change. Therefore, these scenarios should be seen as a tool to support thought experiments rather than as evidence-based solutions. The optimisations are not capable of providing exact answers or reliable numbers, given that they are based on many assumptions - some of them more realistic, others more hypothetical, depending on the data available. When the input data changes, e.g. vehicle emissions, waste owner addresses or waste quantities, the results

[1] https://www.plasticityproject.eu

change. Even when all inputs stay the same, the outputs may vary as the optimisations are not entirely deterministic. This is reflected in reality: for instance, traffic conditions change continuously. However, the key aspect of the optimisations is the like-to-like quantitative comparison between alternative scenarios, and - all other things being equal - the optimisations allow to identify the best (e.g. less cost and less pollution) scenarios developed from a set of assumptions. These best scenarios provide the starting point for developing real-world strategies for reverse plastic logistics in each city.

A lot of the data required to build realistic scenarios were unavailable at the time of execution, due to a variety of reasons including the pandemic. Therefore, the modelling must be seen as thought experiments, reflecting the ideas present in each PlastiCity city. They are all different; different types of stakeholders are involved, and different types of data to reduce emissions and costs are available. The overall goal is always collecting plastic waste in an efficient and sensible way, adapted to the local situation.

We developed individual scenarios for each city, depending on how the involved stakeholders (waste collection companies, city councils, etc.) see the situation. For Douai, the optimisations are based on a client database provided by a waste collection company, and we investigated the lorry trips required to collect Ampliroll containers from client locations. For Southend, three scenario optimisations were conducted: two milk-run collection tours executed by Ford E-Transit vehicles and the lorry trips required to serve the 10 mini-hubs distributed across town. For The Hague, we considered three circular bands around the city centre: up to 1km from the city centre, CargoBikes would collect waste and drop it off at the hub; between 1 and 3km a Nissan e-nv200 would collect plastics and drop them off at the hub; and between 3 and 5km from the city centre a diesel lorry would be used, dropping off the waste at a local waste processing company. Finally, for Ghent, we explored the use of alternative vehicles and checked the necessary collection radius for gathering a certain amount of plastic waste, e.g. 5 tonnes.

The overall goal was always to determine a sensible approach to plastic waste collection that minimises emissions, impact on pedestrian zones, and costs, whilst keeping plastics in the best condition possible (e.g. compaction only, no shredding before quality-assured sorting).

2 RELATED WORK

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 plastics recycling, recycling rates remain low. 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.

When searching for alternatives to traditional waste collection vehicles, one of the possible solutions are CargoBikes (Sheth et al., 2019). Besides significantly reducing congestion (Cairns and Sloman, 2019), they are also able to access narrow roads in town centres more easily and may be allowed to enter pedestrian zones. CargoBikes are often powered by human muscles assisted by batteries which can be exchanged easily. Many models have small boxes or crates, e.g. to hold food for delivery. Those used for waste collection require larger loading containers and are ideally equipped with a compactor.

The CargoBike used by The Hague in the PlastiCity project is powered by a replaceable battery and has a loading volume of 2.2m3. About 7m3 of plastics in their original state can be compressed down to fit into the CargoBike. The electrical van is assumed to be a Ford e-Transit[2] with a loading volume of 15m3, with a press for compacting plastics on-board.

Research by Eunomia (2020) concluded that it is favourable to replace diesel waste collection vehicles by electrical ones: " (...) switching the UK's fleet of diesel powered refuse collection vehicles (RCVs) for electric trucks would have multiple benefits. These include reducing UK greenhouse gas emissions by 290 kilotonnes of CO2 each year – the equivalent of recycling almost 16 billion plastic bottles – eliminating associated exhaust fumes, and saving local authorities money in the long run." An

[2] https://www.autocar.co.uk/car-news/new-cars/new-electric-ford-e-transit-revealed-217-mile-range

additional benefit is that electrical vehicles are far less noisy than diesel powered ones, contributing to a better life quality especially in cities.

In 2018, Veolia trialled the conversion of old diesel RCVs (26t) into electrical vehicles, powering them with energy gained from the incineration of non-recyclable waste. In 2021, they announced the launch of a new fleet of electric RCVs in the City of London and in Westminster, where also electric sweeping vehicles and trikes for collecting recycling. The trikes are similar to the CargoBike used in PlastiCity but aimed at collecting street recycling.

There are challenges with electrical vehicles. Their high purchasing prices are high due to the cost of batteries. Assuming a lithium-ion battery capital cost equal to 90 €/kWh, acceptable pay-back periods (about 6 years) were obtained (Calise et al., 2019).

Most importantly, end-of-life solutions for the batteries are urgently required. Battery recycling is complicated and expensive, and there is a risk of batteries being sent to developing countries where health and safety regulations are less stringent and less enforced. Car manufacturers are legally obliged to recycle the batteries and first pilot recycling plants are operational, some going beyond the (very low) obligation of recycling 50% of the metals. It is also possible to give car batteries a second life before recycling, using them for energy storage which is required for many renewable energy sources.

The advantages and downsides of small and large vehicles with alternative power sources, such as LNG, LPG, biogas, biodiesel and hydrogen were discussed. We concluded that for the purpose of the modelling, the fuel did not matter, only the type of vehicle and its loading volume. Once the optimisations were concluded, the emissions generated can be calculated for various fuel types.

The literature, discussed in PlastiCity Consortium (2022), provides a strong case for environmental gains to be achieved by reducing emissions when switching to electric vehicles (large and small). However, the actual impact on wheel-to-wheel emissions depends on the country's energy mix. In countries where the generation of energy is heavily dependent on fossil fuels, the use of electric vehicles does not reduce the country's total emissions (Woo, Chong, Ahn, 2017). In the UK this could be the case, while in France electric vehicles will deliver substantial gains. Natural Gas vehicles (CNG and LNG) do not bring significant improvements. Hydrogen vehicles are potentially the most environmentally beneficial but there is not yet evidence to support the most optimistic claims.

3 SCENARIO SETUP AND FINDINGS FOR EACH CITY

Each city adopted a very different concept for its plastic waste collection, and hence the results are not directly comparable. The software used to explore various logistic scenarios is OptiFlow[3], a commercial logistics optimisation platform that is mostly used by companies organising deliveries. OptiFlow can process a maximum of 2000 deliveries or collections at a time, which meant that we had to split the bigger cities (The Hague and Ghent) into strategic areas. The software allows for analysing transport time and distance, presenting the most efficient routes and schedules. It is non-deterministic, meaning that it can produce different outputs for the same inputs. However, the outputs are not generated through a random search process. Below is a summary and some highlights of each set of scenarios based on three key strategies: the fetch, milk-run and concentric strategies, as well as an improved combination. Details are available in PlastiCity Consortium (2020, 2022).

3.1 The Fetch Strategy in Douai

The PlastiCity partner in Douai is Theys Recyclage, and hence our modelling was designed from their perspective. Theys provided access to databases with actual volumes of waste collected yearly from their clients. As a result, the strategies produced have a business perspective and will provide particularly useful insights for plastic waste business models. Theys is currently building an innovative recycling sorting plant at their base, expanding their existing capacity. Theys has a distinctive waste collection strategy as part of their business model. We call this the "fetch strategy". Their clients notify Theys when the ampliroll containers are (almost) full, and according to contract, Theys needs to collect them within two days. Our modelling uses Theys' client database in anonymised form. However, only the collection frequency per client per year was recorded, not the dates when the collections happened.

[3] https://www.conundra.eu/optiflow-route-optimization-software

Hence it was not possible to run optimisations taking into account collection distribution over time. Instead, we assumed all collections needed to be done subsequently, in random order, and calculated the time required, distance travelled, emissions generated and costs incurred.

Due to the nature of ampliroll containers, each requires an individual trip, and a milk-run scenario is not possible. However, the literature suggested potential cost and emission efficiencies when lorries with trailers are used. Lorries with trailers are not suitable for collecting waste in city center areas with narrow and twisty streets but Theys clients do not operate in old central areas. This suggested that while Theys is using lorries without trailers, substantial gains could be obtained if they changed this. Thus we compared the calculations on their current basis (lorries without trailers) to a situation where all lorries pull trailers, and can hence transport two ampliroll containers at the same time.

Theys' database contains 108 clients with a varying number of collections. Collectively, they generate 2700 orders. As OptiFlow allows for a maximum of 2000 orders to be calculated simultaneously, not all orders could be included in the modelling. However, this should not influence the validity of the results; e.g. if using trailers could save 50% of distance travelled, this applies whether 80% or 100% of the orders are considered. The base scenario includes 5 lorries without trailers. We compare this against scenario 1, where the 5 trailers travel with trailers. In scenario 2, we use only 4 lorries with trailers.

3.1.1 Fetch Strategy Findings

Figure 1 shows an example of a scenario calculated for Douai, in this case using 5 lorries with trailers. Our results agree with common sense: adding a trailer, the distance travelled and operational costs incurred are roughly half. However, the time is only reduced by 40%. This is mainly due to the time it takes to load and unload, which remains the same, whilst travelling is reduced and the time added to manoeuvres by handling the trailer. An additional factor to consider is that trailers require a capital investment as well as further training for drivers, as they require a special driving license for operating lorries with trailers.

Our conclusion is that if the goal is to reduce costs, emissions and distance travelled, scenario 2 is the best choice. However, scenario 1 requires fewer days to complete the waste collection, given that there is one more lorry, and still reduces costs, distance and emissions compared to 1. When the business model is based on speed of collection, scenario 1 would be the best choice.

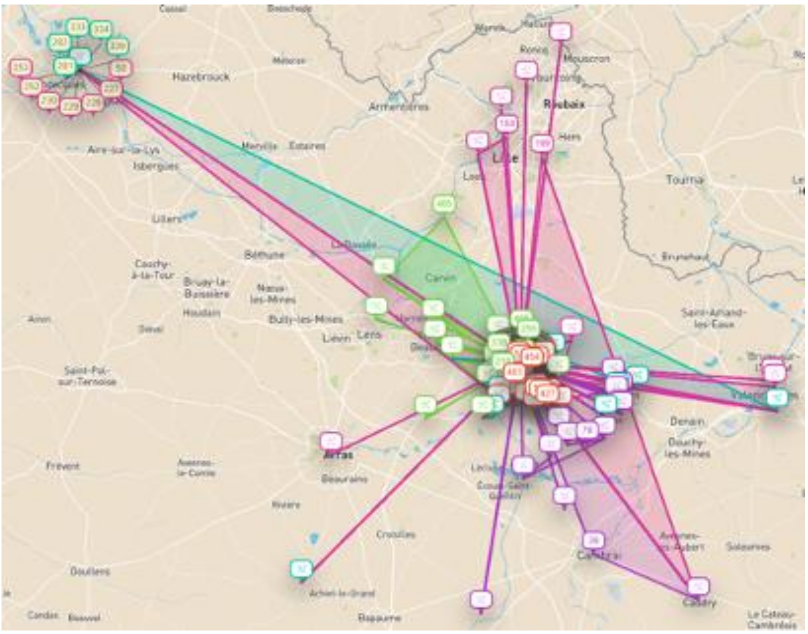

Figure 1 *Possible routes for Douai with 5 lorries with trailers*

3.2 The Fetch Strategy for Mini-hubs and the Milk-runs Strategy in Southend

Southend-on-Sea Borough Council (SBC) is the local PlastiCity partner in the UK and interested in improving plastics waste logistics in various ways. Three scenarios were built to explore a concept with 10 mini-hubs distributed across the town, each with a roll-on/roll-off container requiring individual lorry trips similar to the scenario in Douai, based on a “fetch strategy”. We compared the use of 3 different waste management companies to service the mini-hubs; one company is located out of town, the second is within the outskirts of town, and the third is in town.

However, the scenarios are more complex because Southend wanted to explore the use of electric vehicles, which present substantial reductions in emissions compared to fuel-based vehicles. Accordingly, the other two scenarios in Southend are milk-runs executed by electrical vans: one route in an industrial area called Temple Farm and one route in the town centre, where a CargoBike is used additionally. Both locations also host a mini-hub, where the collected plastics can be accumulated. Southend’s town centre includes a high street with lots of small and some bigger shops, restaurants and cafes as well as a shopping centre. The shopping centre also hosts a mini-hub. The high street is reserved for pedestrians during the day, hence a CargoBike is used for serving this location. The town centre milk-runs are executed once a week or once a fortnight. SBC provided us with a list of businesses in their town centre. As there is no data on waste volumes, random numbers were used. We assume the collections are executed by a two-person crew.

3.2.1 Combined Strategy Findings

Unsurprisingly, the mini-hub service could save considerable time and reduce emissions by operating via the waste management company located in town. This may need to be weighed against prices charged by each company as well as whether it is desirable to use (and hence support) a waste treatment plant in town, with its space requirement and the noise, smell and traffic generated.

Figure 2 *Southend Temple Farm, possible route for monthly collections with triple waste volume and one container at the mini-hub*

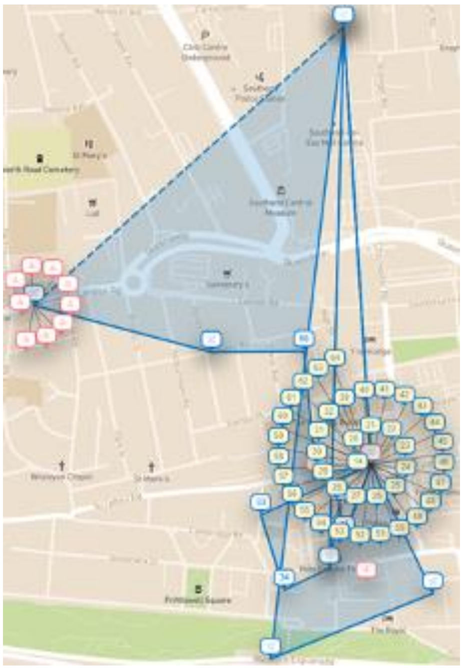

Figure 3 *Southend town centre, possible route for one vehicle*

For the Temple Farm milk-run (Figure 2), we explored weekly, fortnightly and monthly collections with assumed single, double and triple waste volumes and two different local drop-off locations. We found that with higher waste volumes, it is necessary to have more than one container available at the mini-hub to receive the collected waste. Also, for certain situations, a number of collection orders remained unfulfilled, meaning that the vehicle had run out of time.

For the town centre, shown in Figure 3, we found that it is necessary to define a strategy for how to deal with cases where a shop has waste volumes that are above the CargoBike's loading capacity: Will the CargoBike take as much as possible and return, or will a larger vehicle be called instead?

3.3 The Concentric Strategy in The Hague

The Hague conducted a waste collection trial to get an idea of plastic waste quantities. The targeted business types were based on a survey conducted in Ghent at the beginning of the project to find out how much plastic waste can be found at different types of NACE[4] codes. The results suggested focusing on retail and offices. However, due to the pandemic lock-down, offices were not occupied and therefore did not respond to our query. Therefore, waste could only be collected from retail businesses, and the number of participants was small. The trial was conducted over a period of 6 weeks, with weekly collections, but some companies were closed during some weeks and hence did not have any plastics to collect. Whilst this trial gives a glimpse of possible waste numbers, there is not enough data to provide typical waste volumes per retail business type, or even for retail as a whole.

The core idea of the scenario for The Hague was to explore the use of different vehicles for different circular zones around the city centre. We call this strategy: "the concentric" strategy. The local partner is the city council. They supplied a database with businesses in the city, which was filtered for relevant potential waste owners per zone.

Within a radius of 5km (Zone 1) from the assumed centre point, a CargoBike would be used to collect plastic waste only. The drop-off point is the Hub. Within a radius of 5-10km (Zone 2), an electrical van would be used, and in Zone 3, from 10 to 15km from the center point, a diesel lorry would be used. In Zones 2 and 3, mixed recyclables would be collected. However, it turned out that these radii were too big for The Hague. To focus on the city and its immediate agglomeration only, the zones were defined as up to 1km, 1-3km, and 3-5km, instead. Two waste treatment facilities in the outskirts of The Hague were considered as drop-off points. The electrical van assumed to be used is a Nissan E-NV200, with one van available for collecting plastics. The loading space is 4.2m3. We established three scenarios to be able to make comparisons between the vehicles, with weekly collections:

- Scenario 1 (base line): all by diesel lorry
- Scenario 2: zone 1 collection of plastics by CargoBike, zone 2 and 3 by diesel lorry
- Scenario 3: zone 1 collection of plastics by CargoBike, zone 2 by electro-truck, zone 3 by diesel lorry
- Scenario 4: zone 1 collection of plastics by CargoBike, zone 2 and 3 by electro-truck

3.3.1 Concentric Strategy Findings

A trial-and-error approach was used to determine a suitable number of vehicles in each scenario, as shown in the example of Figure 4. The calculations showed us that the intuitively nice idea of concentric circular zones is not very practical in reality, as streets and activity zones rarely follow this pattern.

Very unsurprisingly, emissions are lowest for electrical vehicles. But of course, the wheel to wheel (WTW) emissions are only lowest for electricity-powered vehicles if we assume that the electricity is fully generated by renewable energy sources. Otherwise, the emissions are just moved out of the city. As noted before, a country-specific analysis of the energy generation mix is needed to assert the extent to which electric vehicles produce less emissions than diesel vehicles. We do not have quantitative information about WTW emissions of cargo bikes vehicles in Woo et al. (2017) for the Netherlands, but we know that in 2021 The Netherlands was ranked 27th out of 27 European countries in share of renewables, and has the highest rate of emissions per KWH generated. 46% of its energy mix came from oil (38%) and coal (11%) with a further 38th from natural gas and only 11% from nuclear, wind, solar, hydropower and geothermal.[5] Such an energy mix is unlikely to result in gains in emissions from

[4] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=NACE_background

[5] US International Trade Administration 2021: Netherlands, Country Commercial Guide, Energy.

the use of electric vehicles compared to diesel, and very likely to result in electric vehicles contributing more than diesel vehicles to emissions.

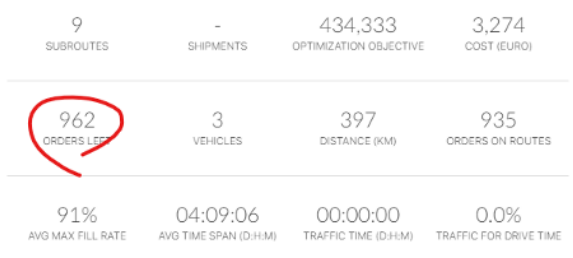

Figure 4 *Optimisation result data for The Hague*

Figure 5 *Possible route for The Hague scenario 3.2, using six vehicles: 2 CargoBike (z1), 2 electro-lorries (z2) and 2 diesel lorries (z3)*

A scenario where only cargo bikes are used could result in less emissions but our modelling approach shows that such a scenario is unfeasible. The cheapest scenario is that with all electric vehicles. However, the savings compared to the second cheapest scenario - all diesel vehicles- amount to only € 1000/year, suggesting savings are not significant from the operational cost of view. However, there is, as noted during the interviews carried out for sensitization, a significant difference in acquisition costs between electric vans and diesel lorries, with the former being more pricey. This suggests that policy intervention subsidizing costs of electric vehicles may be needed to scale up its use. However, our preliminary WTW emissions analysis based on Woo et al. (2017) suggests that such interventions may be counterproductive if the country does not radically change its energy mix to reduce dependence on oil, coal and gas. Further calculations are required to determine the actual WTW emissions produced by using electric vehicles, taking into account the actual WTW emission factor for cargo bikes and electric vehicles vans in the Netherlands.

3.4 Leveraging Previous Knowledge About Fetch, Milk-run and Concentric Strategies in Ghent

The knowledge acquired from the previous scenarios based on the fetch, milk-run and concentric strategies was applied to a more complex scenario in Ghent. The optimisations conducted for Ghent include 7 different scenarios including weekly, fortnightly and monthly collection and alternative transportation modes and alternative vehicles like the CargoBike. To determine plastic waste quantities, a waste collection trial was conducted in Herentals, Belgium, amongst retail businesses. Two collections were executed: the first collection in the period of July-August 2020 and the second one in the period from Sept 2020 to January 2021. It is not known for how long the businesses were accumulating the waste collected in the first round - potentially 1-2 months, but the waste collected in the second round was likely accumulated during 1-5 months. This wide variation makes it impossible to create typical values for waste volumes. For the sake of the exercise, we shall assume 2 months on average, and hence the volume for a monthly collection would be half.

The database used for the scenario calculations contained 10136 entries in total. Those without plastic waste volume data and those with 0.000 tons per year (which might be zero because of rounding) were removed. 9930 addresses remained in the database. Out of these, three zones were defined for the modelling, based on the shopping areas. The PlastiCity Hub is situated at Farmanstraat 40, a site in the southern part of the North Sea Port district, situated in the middle between the historical city centre with a lot of retail and gastronomic venues and the major companies along the harbor.

We assume that there is space for a 40m3 container to receive the collected plastics at the mini-hub locations. These containers then get taken to the hub at Farmanstraat in scenarios 5/6/7. The building at Farmanstraat can be reached by road, tramway (there are rails next to the road) and boat.

3.4.1 Improved Combined Strategy Findings

The very high density of businesses in Ghent city led to visualisations as shown in Figure 6. The fact that the (assumed) waste quantities cannot fit into the smaller vehicles at once needs to be discussed when deploying them. Possible solutions are:

- Call for a larger vehicle, especially in case of large items
- Revisit this business
- Collect more frequently
- Increase the loading volume of the CargoBike, potentially by adding a trailer
- Encourage the business to be a mini-hub where a larger container can be placed, hence also serving the neighbouring businesses

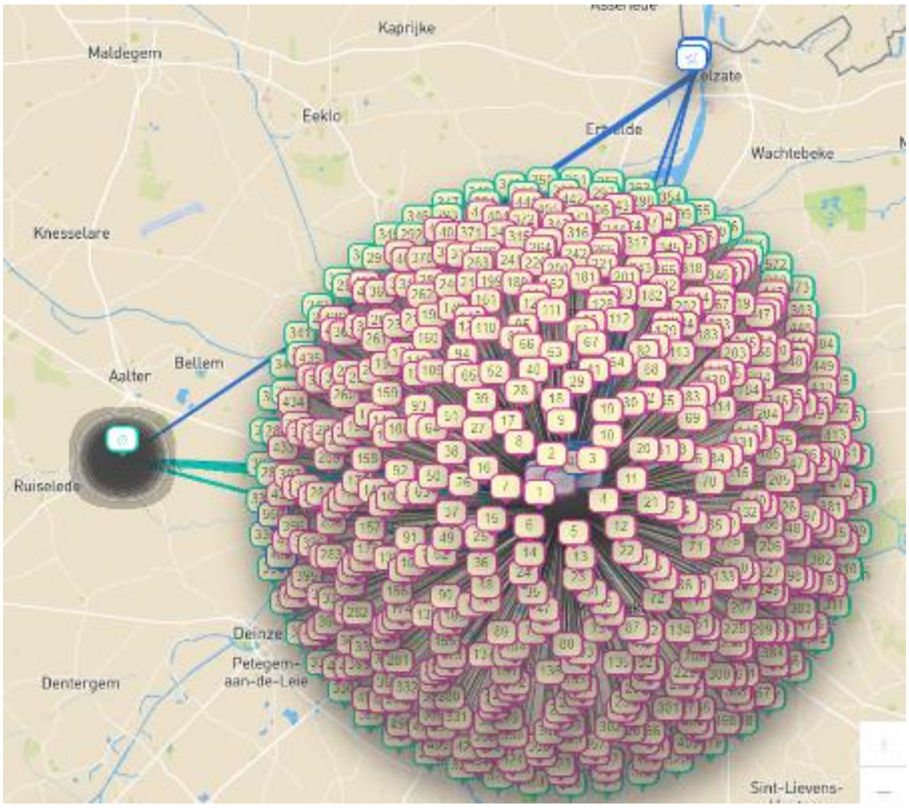

Figure 6 *Possible routes for a Ghent scenario in 'Zone South' with fortnightly collections*

4 DISCUSSION, CONCLUSION AND RECOMMENDATIONS

Each city needs to make individual decisions. How companies handle their waste depends on many factors, including whether they are individual locations or part of a chain. For instance, one chain of electronics equipment with many shops in the Netherlands, Belgium, Germany and Luxembourg stated that they separate their recyclables (paper, cardboard and plastic) locally and then take them to the main location for proper disposal. It is possible that the reason behind this strategy is that they need to pay for their recyclables to be collected, and it is cheaper to do this in one location, only, even if it requires company-internal transportation. It may make sense from an environmental perspective as well if the company can benefit from reverse logistics, that is, for the forward distribution to take the recyclables back.

Large companies often use reverse logistics in this way. Some even include the customers in the chain, by asking them to return certain items or materials to the store. For instance, the British supermarket chain Tesco collects post-consumer soft plastics (plastic films of any type) for chemical recycling, as councils in the UK currently do not collect these materials and they would end up in landfill / incineration otherwise.

The scenario considered for Douai is very simple, and the conclusion from it is equally clear: to reduce emissions and costs in the long run, lorries picking up large containers should run with trailers. It would be interesting to explore further possibilities for this town, considering also companies that do not host their own 40m3 container, and using a milk-run approach for collecting their waste. This could be an interesting project for an MSc student, for instance. In addition, policy makers in Douai should actively encourage the use of electric vehicles. The positive impact of EV in emissions reductions depends on each country's energy mix. France's energy mix is heavily dependent on nuclear and renewable energies, and results in the lowest emissions per KW of electricity generated in Europe. In such conditions, the use of EV could result in 60-70% less emissions of reverse logistics than diesel lorries and 80% less than gasoline lorries. Our cost analysis in the other cities suggest that the costs of using electric vehicles in Douai will not be substantially higher than current alternatives. However, acquisition costs are steep and would need policy intervention, for instance with subsidies.

For Southend, it is difficult to make a qualified recommendation due to the complete lack of waste quantity data when the optimisations were run. However, their idea of creating mini-hubs for accumulating plastics locally certainly makes sense, especially in areas with many small businesses like in high streets, shopping malls and industrial areas with many small and medium sized companies. This idea has been adopted by Ghent. However, the use of a CargoBike with a very small loading capacity is not useful. For the collection service to reach a sensible level of efficiency, it is essential to have the largest loading capacity possible and to have a press on-board. In terms of emissions, the UK energy generation mix is still heavily dependent on fossil fuels, resulting in some of Europe's higher emissions per KW. As a result, the environmental advantages of using EV are minimal.

The modelling conducted for The Hague taught us that "distance from the centre" is not necessarily a useful criterion to organise logistics as streets and neighbourhoods are usually not organised in a concentric way. Most importantly, the waste drop-off location is essential especially when using vehicles with small loading capacities. While the use of cargo bikes seems intuitively appropriate for old areas of the city, cargo bikes will always need to be combined with other means of transport with larger carrying capacity, in what could be called a two step strategy. A combination of bikes and electric vans will result in lower running costs, but increase acquisition costs. Environmentally, since The Netherlands has one of the most polluting energy mix of Europe, the use of electric vans is not advisable. The use of cargo bikes may still have benefits but positive effects are more likely to derive from reductions in congestion. A detailed well to wheel analysis of cargo-bikes emissions in The Netherlands is recommended.

For the Ghent modelling, many of the above-mentioned lessons were taken into account. Collections were arranged by shopping areas, with milk-run drop-off at local mini-hubs which were optimised for the further transportation mode (next to a tramway or river/canal if this modus is considered to empty the mini-hub). The loading volume of the CargoBike used here is larger and it is equipped with a press. However, given that some small companies have waste quantities that still exceed the loading volume, the use of a trailer should be considered. As in the case of France, Belgium has a relatively clean energy mix, where low carbon emitting sources dominate. As a result, the use of electric cargo bikes and larger electric vehicles is definitely advisable from an environmental point of view. Policy incentives should be provided to drive the electrification of waste and reverse logistic companies afloat.

It would make sense for all cities (and rural areas as well) to move away from each waste management company to organise their own logistics. Currently, some streets get visited by 5 recyclables collection vehicles, plus several more for other types of waste. Whilst potentially difficult to negotiate, the use of a joint collection service would reduce emissions, noise and traffic, improving quality of life.

ACKNOWLEDGMENTS

We would like to thank Conundra[6], and in particular Luis D'hondt, for their generous support in allowing us to use the OptiFlow software for free. PlastiCity has received funding from the Interreg 2 Seas programme 2014-2020 co-funded by the European Regional Development Fund under subsidy contract No 1/12/02/2019 16:43:38.

REFERENCES

Cairns, S., & Sloman, L. (2019). Potential for e-cargo bikes to reduce congestion and pollution from vans in cities. Transport for Quality of Life Ltd. Available online: https://www.bicycleassociation.org.uk/wp-content/uploads/2019/07/Potential-for-e-cargo-bikes-to-reduce-congestion-and-pollution-from-vans-FINAL.pdf

Calise, F., Cappiello, F. L., Cartenì, A., d'Accadia, M. D., & Vicidomini, M. (2019). A novel paradigm for a sustainable mobility based on electric vehicles, photovoltaic panels and electric energy storage systems: Case studies for Naples and Salerno (Italy). *Renewable and Sustainable Energy Reviews*, 111, 97-114.

Eunomia (2020). Ditching diesel - a cost-benefit analysis of electric refuse collection vehicles. Available online: https://www.eunomia.co.uk/reports-tools/ditching-diesel-analysis-electric-refuse-collection-vehicles

PlastiCity Consortium (2022). Logistics Simulations Report. Available online: https://www.plasticityproject.eu/downloads

PlastiCity Consortium (2020). Logistics Scenario Report. Available online: https://www.plasticityproject.eu/downloads

Sheth, M., Butrina, P., Goodchild, A., & McCormack, E. (2019). Measuring delivery route cost trade-offs between electric-assist cargo bicycles and delivery trucks in dense urban areas. *European transport research review*, 11(1), 1-12.

Woo, J., Choi, H., & Ahn, J. (2017). Well-to-wheel analysis of greenhouse gas emissions for electric vehicles based on electricity generation mix: A global perspective. Transportation Research Part D: Transport and Environment, 51, 340-350.

[6] https://www.conundra.eu