Increasing Recycling Sustainability in Finland

Cost Analysis of the Methods of Increasing Recycling FINAL REPORT

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Report for SYKE on behalf of Finnish Ministry of Environment

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1.0 Introduction

Eunomia Research & Consulting (Eunomia) is part of a consortium led by SYKE that was commissioned by the Finnish Ministry of Environment to investigate approaches to increasing the recycling of municipal waste. Finland is currently an average performer on municipal waste recycling within the European Union (EU), and the recent Early Warning Report produced by Eunomia for the European Commission concludes that Finland is at risk of not meeting future recycling targets.[1] The municipal waste recycling targets under consideration here are:

- a 50% recycling rate by 2020 is stipulated by the Finnish Waste Decree, transposing the requirements of the Waste Framework Directive (WFD); and
- those set out in the Circular Economy Package (CEP) to increase recycling targets further to:
    - 55% by 2025;
    - 60% by 2030; and
    - 65% by 2035;

  this package became adopted legislation in May 2018 following a decision by the EU Council of Ministers and becomes legally binding from 4 July 2018.

While the 2020 50% target can be measured in one of four different ways, the CEP also specifies a single measurement method against which all Member States' municipal waste recycling rates should be calculated. Finland currently uses Calculation Method 4, where municipal recycling rates are calculated as the quantity of municipal waste recycled divided by the quantity of municipal waste generated.[2] This method is the one that is most similar to the method prescribed by the new CEP.

The Early Warning Report discussed, amongst other things, two key issues in Finland:

1) the plateauing recycling performance, at around 40% in 2015; and
2) the fragmentation in the waste management system in terms of both institutional responsibilities and collection operations.[1]

Finland was included in the Early Warning project of the European Commission because it was identified as at risk of missing the 50% target under its selected measurement method. However, the new measurement method will be significantly more stringent in measuring recycling at the point of entry into the physical recycling process. As a result of this, it can be expected that under this method Finland's current recycling rate would

[1] Hogg, D.D., Elliott, T., Burgess, R., and Vergunst, T. (2018) *Study to Identify Member States at Risk of Non-Compliance with the 2020 Target of the Waste Framework Directive and to Follow-up Phase 1 and 2 of the Compliance Promotion Exercise*, March 2018

[2] Commission Decision of 18 November 2011 establishing rules and calculation methods for verifying compliance with the targets set in Article 11(2) of Directive 2008/98/EC of the European Parliament and of the Council (2011/753/EU) (OJ L310/11)

reduce. It therefore seems uncontroversial to make the observation that the current waste management system in Finland is unlikely to be fit for purpose for meeting a 55%, let alone a 65% target under the new CEP measurement method.

The main objective of this current research has been to investigate how the measures proposed in the Early Warning Report to increase the recycling of municipal waste could be implemented in a way that suits Finnish legislation and conditions. This report (WP1.3) is part of Work Package 1 on increasing recycling sustainability, and fits in to the wider project as follows:

- WP1.1 ways to increase separate collection and the effects on the recycling rate;
- WP1.2 an estimate of the required changes to legislation;
- **WP1.3 cost analysis of the methods of increasing recycling**;
- WP1.4. analysis of sustainability studies on the separate collection and treatment of biowaste from the perspective of possibilities of increasing sustainability.

Work Package 2 (WP2) will subsequently assess in more detail the producer responsibility system for packaging, and cost-effective methods of increasing the separate collection and recycling of waste under producer responsibility. The results contained within this report relate closely to, and feed into, WP1.1 and WP2.

1.1 Background and Purpose

The current waste management system in Finland has for some time focused on separate collection of paper, paperboard/cardboard packaging, metal, glass packaging, and biowaste. In addition, more recently the separate collection of plastic packaging has been introduced. Where materials are collected directly from properties (referred to as door-to-door collections), this is typically carried out with a separate vehicle for each material, with many of these schemes undertaken by or on behalf of producer responsibility organisations (PROs). In addition, PROs offer an extensive system of 'bring sites', where people can deposit their recycling in a container located in a public area such as a car park or on the street. Until now, door-to-door collections have been offered predominantly to urban apartment blocks through communal collection points, while separate houses and row houses are predominantly covered by the bring system. Overall, there is limited door-to-door collection of recycling. Each PRO has exclusive financial control over the material that they are responsible for, no matter how it is collected or who collects it.

Municipalities, on the other hand, are responsible for mixed waste and biowaste collections, which are carried out almost exclusively door-to-door, and the treatment of this waste. As per the most recent revision of the Waste Law, the role of municipalities is limited only to households and municipal waste from municipal services. This report focusses on these waste streams, in particular household waste. Other waste from commerce and services (referred to in this report as 'commercial waste') is not within the remit of municipality or PRO waste collections, and is discussed in more detail in Section 2.3.

For waste from households and municipal waste from municipal sources, the Early Warning Report highlighted this apparent institutional fragmentation, with PROs being responsible for recycling while municipalities are responsible for mixed waste and biowaste, as a potential barrier to reaching high recycling rates. In part this is as of results an economic disconnect in the waste management system:

- municipalities do not have adequate incentive to reduce residual waste by introducing more door-to-door collections. Although they make savings from not having to treat or dispose of the waste that is recycled by PROs, this reduced residual disposal cost is not enough alone to fund separate door-to-door collection while the separately collected materials have no value to them; and
- producers do not have enough incentive to avoid their products entering the mixed waste stream, because municipalities are responsible for the collection and disposal cost associated with mixed waste. For PROs, the primary incentive is to comply with the packaging waste recycling targets at the lowest cost to producers.

The hypothesis put forward by the Early Warning Report is that the low rates of 'leakage' of recyclables into mixed waste that are necessary for high recycling rates to be achieved cannot realistically be met without addressing these fragmentation issues.

In addition, the Early Warning Report highlighted the possibility that, although efficient within their currency system boundaries and performance, the predominant collection approaches in Finland may not be optimised for higher performance. In particular, the typical approach in Finland of collecting each material on a separate, single compartment vehicle was highlighted. This was contrasted with many other EU Member States where multi-compartment vehicles are common, allowing multiple streams to be collected on the same 'pass'. The Early Warning Report suggested that the limited use of these types of vehicles in Finland might in part be a consequence of institutional fragmentation, with each PRO and municipality being directly responsible for only one or two streams.

The purpose of this project is therefore to test the propositions of the Early Warning Report that significant change in the collection system would drive performance improvement towards the new CEP targets and that reduced fragmentation in institutional responsibilities and collection operations would support the efficient delivery of targets.

2.0 Methodology

2.1 Research Objectives

The Early Warning Report sets out some options for different institutional arrangements that may be improve the prospects of reaching high recycling rates in Finland. In particular, it is proposed that the way in which PROs and municipalities work together needs to change, with the ultimate objective being to reduce the current institutional fragmentation. Based on the four options proposed in Early Warning Report, the policy approaches to be considered in this research were integrated and narrowed down to two policy option packages for modelling purposes:

1) Policy Option 1 involves delegating many more responsibilities directly to municipalities. Combined with setting mandatory recycling targets for each municipality (or group of municipalities), and supporting these targets with financial sanctions, this gives municipalities both the responsibility and the means to reach higher targets; and
2) Policy Option 2 involves introduction of mandatory 'tri-party collaboration' between the PROs, municipalities, and collection companies. Driving cooperation and efficiency across all elements of waste services reduces operational fragmentation in delivering further requirements to sort waste. This is driven by the expansion of the current landfill tax, and is further supported by the creation of a national funding organisation.

In both of these options there is much more cooperation between municipalities and PROs such that the economic disconnect that currently exists is eliminated, and parties work together for the best overall outcome in terms of both overall system cost and performance.

The role of waste collection companies under both policy options is essentially simply contractual, with services being commissioned by the PROs or municipalities. However, under Policy Option 2 the procurement process is assumed to be regulated in such a way as to lead to PROs and municipalities *jointly* commissioning services from waste collection companies – hence the concept of 'tri-party collaboration'. The assumptions made regarding these policy options are described in more detail in Appendix A.1.1.

At the operational level, there are then different ways in which those institutional arrangements implemented in order to reduce operational fragmentation. Waste collections where each material is collected on a separate vehicle can be optimised within the bounds of the current system, but may not be the optimum solution if door-to-door collections are offered to many more households. There are many different configurations of collection containers and vehicles in operation in the EU and further afield. For example, there are systems where source separated materials are collected in different compartments on the same vehicle; as well as a variety of systems where successively larger numbers of materials are mixed in together ('co-mingled') in the same container by the household, and then separated again in a material sorting facility.

So, the objective here is to look at how the higher recycling performance may actually be delivered operationally, because this is where most of the cost is, and also where high performance is driven. Six collection options are modelled:

1) **Multi-stream** – based on the current system with a separate bin and vehicle for each material, but with door-to-door collection offered to more households;
2) **Four-compartment bins** – a system where each household has two bins with multiple compartments so that different material streams can be kept separate (as they currently are), and the vehicle lifts the bin and empties each compartment into separate sections of the vehicle;
3) **Two-compartment bins** – each household has three bins with two compartments, which are again emptied automatically onto a vehicle with two sections. In order to only collect six streams, plastics and metals are assumed to

be mixed together (leaving paper, cardboard, glass, biowaste, and mixed waste as the other five streams);

4) **Three-Stream** – in addition to plastics and metals being mixed, paper and cardboard are now also mixed to reduce the number of dry recycling streams to three (with glass being the third dry recycling stream) and the total number of streams to five (with biowaste and mixed waste);
5) **Two-Stream** – mixing glass in with the plastics and metals reduces the dry recycling down to two streams: one for containers (plastics, metals, and glass) and the other for fibres (paper and cardboard). The total number of streams here is reduced to four (with biowaste and mixed waste); and
6) **Fully Co-mingled** – mixing all the dry recycling fractions (paper, cardboard, plastics, metals, and glass) is referred to herein as a fully co-mingled collection system, with only biowaste and mixed waste collected separately.

For more clarity, these options are shown graphically in Table 19 in Appendix A.3.0.

In Options 2 to 6, bins with compartments and vehicles with multiple sections (for each material compartment) may not be appropriate for many apartment blocks. Therefore, we assume that many of these apartments would continue to have multi-stream collections with different bins and vehicles for each material. We also assume that packaging and non-packaging wastes of the same material are collected together – both will require collection to reach higher recycling rates, but separate bins for each would be unworkable.

If a more integrated approach to recycling were taken in Finland, then new ways to affect behaviour change would become available. For example, reducing collection frequencies (to three- or four-weekly) for mixed waste would begin to have a direct and tangible impact on system cost and performance. Under the current system, where the focus is on separate collections from communal bins and apartment blocks, the collection logistics (be that with respect to frequency or collecting multiple materials on the same pass) have little impact on public behaviour because bins are shared. This would change in future options where households with door-to-door collections have greater responsibility for their individual bins. Here, reducing the collection frequency of a certain stream directly reduces the effective capacity over a given period that is available to the resident for that material. In the case of mixed waste, this would incentivise the resident to produce less mixed waste and recycle more. This becomes especially pertinent when recycling coverage is expanded to include suburban and rural households, and is easier in options where mixed waste is collected on a separate vehicle.

Each collection option beyond Option 1 requires PROs, municipalities and collection companies to work together more closely. This starts with simply collecting different material fractions on the same vehicle, but extends beyond this as more material fractions are mixed together and require sorting. Finland currently has a very limited sorting plant market, so sorting infrastructure would need to be developed if a collection route is chosen where more materials are mixed. However, even in Collection Option 1, where each material group is collected separately, co-operation between PROs and municipalities is still required to share the liability of managing the co-collected packaging and non-packaging wastes.

Thus, the objective of this work is to model the cost of each of the policy options, along with different operational approaches to reaching the 55% and 65% recycling targets. Through this, simulations are run to test both the institutional and the operational sides of reduced fragmentation.

2.2 Modelling Approach

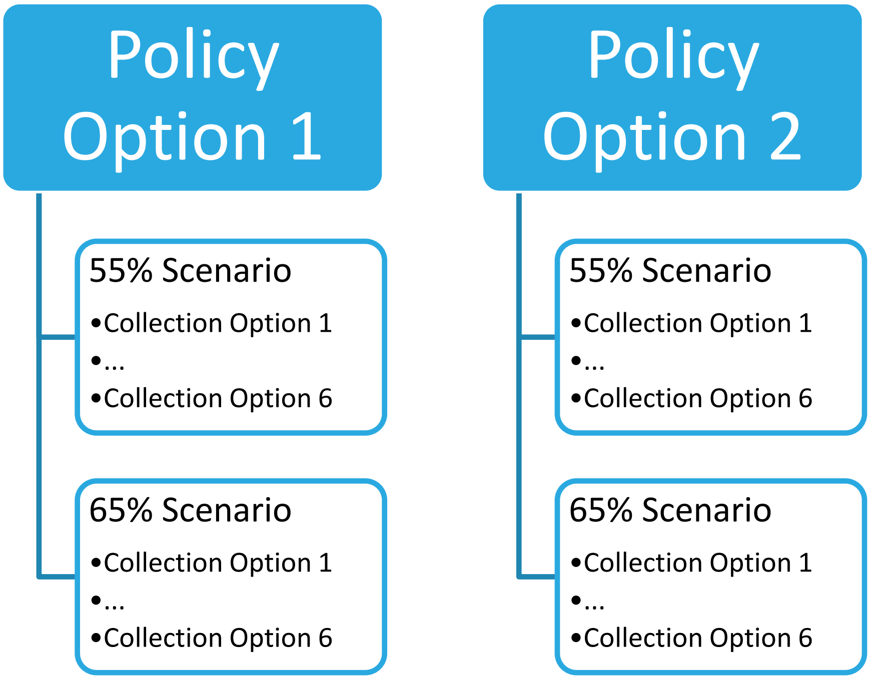
In order to meet the research objectives, the modelling has three key components:

1) the cost of implementing the **policy approaches** models the two broad options outlined in Section 2.1 above, and is a high-level cost model of the operation and administration of the policies;
2) the **waste flow model** includes all municipal waste counted under current and future (CEP) recycling metrics, and shows what performance is required to reach the 55% and 65% targets; and
3) **waste collection modelling** is undertaken using Eunomia's collection modelling tool Hermes2.0 to compare the cost of the current collection system to six possible alternative systems involving more door-to-door style collections from households.

In practice, a number of important simplifications had to be made to narrow the boundaries of the research to be within realistic limits given the resources available. As such, difficult decisions had to be made about which areas to focus the research upon. For example, we assume that both Policy Options 1 and 2 have equal potential to reach both the 55% and the 65% targets. This means that potential differences in performance between these options is not tested, with the same waste flow model used for each policy option. Discussion of these study limitations is summarised in section 2.3.

Details of these three modelling components and the assumptions made can be found in Appendix A.1.0, A.2.0, and A.3.0 respectively. Figure 1 shows a pictogram of how these three key modelling components are combined. The two policy options are modelled for each of the two waste flow scenarios, with each of six possible collection options.

Figure 1: Pictogram of Three Key Modelling Components



The aim of cost modelling is to calculate, as far as possible, the change in whole system costs in Finland. As discussed in Section 1.1 above, the division of activities in Finland has resulted each party (municipalities, PROs, waste collection companies) optimising their costs within the part of the system that is under their control. However, as a key research hypothesis is that this may not be achieving the lowest cost approach overall, we therefore model the whole system costs, including collection, treatment, disposal, income from sale of materials, and administration.

2.3 Key Assumptions and Limitations

In order to undertake modelling of this magnitude, a number of simplifications are required. This section summarises some of the key issues and implications of our modelling approach. More detail on the modelling methodology, assumptions and limitations can be found in Appendix A.1.0, A.2.0, and A.3.0 for the policy modelling, the waste flow modelling, and the collection modelling respectively.

Recycling performance of Policy Options 1 and 2 – the assumption is made that both policy options have equal potential to reach both the 55% and the 65% targets. We use a bottom-up approach where the starting point is a waste flow model that is designed to quantify the changes in waste flows that would be required to hit the targets. As such, this is a ‘goal seeking’ exercise, with the starting assumption being that the targets are met.

This changed waste flow is then inputted into the operational logistics model that simulates the collection of the waste in different ways; and we assume that these changed waste flows and collection systems can be achieved under both policy Options 1 and 2. This is a significant scope limitation, as in effect it means that the two important matters have not been tested: the relative potential of each policy option to achieve the new EU recycling targets and their potential to do so by employing different, more integrated collection methodologies.

It is likely in practice that the two policy options would perform differently in these respects, but to investigate these differences would require a significantly wider scope for the study. It would be necessary to carry out further research and analysis to understand these issues properly, including designing the policy options in much more detail, as currently both the operational design and costing of both options is high-level and illustrative. The cost modelling for the administrative and other direct costs of the policy options is included for completeness, but is very high-level.

Marginal cost modelling and cost allocation – the reason for modelling marginal costs relative to the baseline (i.e. relative to current costs), rather than total costs, is that modelling the total current cost of the waste management system in Finland would be a very significant undertaking and is not necessary to draw the kinds of broad conclusions that are the objective of this project. By modelling marginal costs, we are able to focus on the elements of the system that will change, allowing us to test the implications of moving to a different policy or collection option without becoming absorbed in the enormous task of accurately modelling the whole current costs. This has still required a baseline (intended to reflect current costs) for the elements of the system that would be subject to change, but this baseline excludes a large number of costs (for example overheads) that would be unlikely to change significantly. This does mean though that comparison of the modelled baseline to other sources of 'current cost' data is unlikely to be meaningful.

A limitation of the modelling is that it does not attempt to address where responsibility for those marginal costs or incomes is allocated (e.g. between municipalities, householders, central government and producers/PROs). This will depend on the details of the policy option and how they are implemented that go beyond the scope of this project. The focus here is in considering 'whole system cost' (at least within the system boundaries that have been set) and not to stray into the complex questions of precisely how these costs are allocated to different actors.

Cost modelling approach – given the focus on the marginal costs associated with achieving the targets, it is important to recognise that some costs have not been considered, including:

- managing the DRS (deposit return system) for beverage packaging and collecting material from DRS facilities;
- collecting material on campaign routes;
- collecting material from recycling stations (also known as container parks or civic amenity sites); and
- collecting material from commerce and services (referred to as commercial waste).

In the first two cases (DRS and campaign collections), these systems are modelled to have constant performance in future options, because they are already performing well. As such, they can be excluded on the basis that the baseline and future costs will be very similar. In the third case (recycling stations), recycling performance is assumed to improve, but the overall tonnages collected do not change, and thus it is assumed that operating costs will be similar. Therefore, these omissions were not deemed detrimental to the accuracy of the modelling at this stage, although the approach to recycling stations is acknowledged as an oversimplification that should be considered in more detail in future research. The omission of commercial waste is discussed in more detail below.

Collections of commercial waste – a significant limitation is that the modelling includes waste from commerce and services (referred to as commercial waste) in the waste flow models, but these commercial waste tonnages are excluded from the cost modelling.

The potential for municipal waste from commerce and services (referred to as commercial waste) to contribute to municipal waste recycling targets is clearly significant. This waste is not under direct municipal responsibility in Finland but does come under the definition of municipal waste for the CEP targets. As such, given the very significant tonnages involved, commercial waste has the potential to be decisive in whether or not Finland meets its future targets for municipal waste. However, Finnish data is particularly limited in this area, precluding any sophisticated analysis from being carried out in this project. Obtaining data and investigating action in this area should be a priority for future work.

In terms of waste flows, commercial recycling performance in this work is assumed to mirror that of waste from households in order to reach future recycling targets. In all likelihood, enforcing regulation upon businesses can lead to higher recycling performance in commerce than in households as so this assumption is considered to be somewhat conservative. Overall, placing more of the burden of meeting municipal waste targets on commerce may be more cost effective and perhaps more politically palatable than the route presented in this research. However, the focus of this research is not on answering that question and in any case lack of available data prevents these options being modelled with confidence.

Estimation of the additional costs to businesses is beyond the scope of this project, but should also be a priority area of investigation in the future. In all likelihood, the costs of collecting commercial waste would increase across scenarios as a greater level of waste separation is required. The additional costs would be likely to continue to be passed on to businesses directly through the fees paid for collection, as occurs today, with no additional costs being borne by local or national government.

We acknowledge that this introduces a significant inconsistency in the system boundaries between the waste flow modelling and the cost modelling. The approach taken should therefore be considered as primarily focusing on waste from households, but with the waste flow model incorporating commercial waste as well in order to at least provide a more complete picture on the ways in which tonnage flows would need to change to meet the two municipal waste recycling rates modelled.

Rurality, demographics, and housing type – the limitations of waste data at the regional or municipality level means that the waste flow modelling was undertaken based on Finland-wide averages. However, in reality, different socio-demographic groups, as well as different rurality and housing types, produce different types of waste and engage with recycling collections to differing extents. For example, houses with large gardens will produce more biowaste in the form of garden waste, and elderly people who still read more newspapers may produce more paper than younger people in the population.

A more detailed modelling exercise could be undertaken to resolve some of these differences using more detailed data from sample municipalities or from other countries – this might be of interest to Finland to investigate if the targets will be more difficult for some municipalities to reach than others. However, until more detailed data becomes available across Finland, it will not be possible to measure performance against targets. Therefore, the implementation of a more comprehensive waste data system should be a top priority for Finland. This is likely to be required irrespective of the policy option chosen, because more detailed reporting will be necessary for future targets, relating to both municipal waste and packaging waste.

More detailed data will also allow further investigation of operational issues such as testing where different systems would work. For example, the assumption on the cut-off between door-to-door and bring collections in different areas is based on Finland-wide rurality classifications, which are quite high-level. Similarly, the cut-off between where multi-stream collections should continue in apartment buildings in the situation where more co-mingled system are implemented for separate houses is based on national housing type data. These assumptions could be refined significantly in a more detailed study.

Waste and housing growth – waste growth was not modelled in this piece of work, as the primary objectives related to modelling the impact of changes in institutional and collection regimes and so introducing such a variable would have made presentation of the results more difficult. It is plausible that waste arisings will continue to grow in Finland, for example broadly in line with population and economic growth, meaning that the differences in cost calculated versus the baseline would likely to increase over time. Future research could look to incorporate this as a sensitivity in order to more accurately establish the likely financial cost impact of the changes modelled over time for budgeting and impact assessment purposes.

Approach to modelling infrastructure – the cost modelling includes a cost per tonne (i.e. a ‘gate fee’) for the sorting of mixed dry recycling materials based on high specification sorting equipment elsewhere in Europe. This is intended to include both the cost of financing the capital investment in the sorting infrastructure and the on-going operating costs. However, this is a high-level assumption and the details of how this might work in practice have not been considered. For example, the number and location of sorting facilities was not considered, with the obvious implications for logistics and economies of scale of larger or smaller numbers of sorting facilities excluded from the modelling.

It should also be noted that the cost per tonne of sorting may need to be higher in future in order to meet increasing material quality standards in the constantly evolving secondary material markets. The approach that Finnish sorting facilities take to achieving high quality outputs and low loss rates from sorting plants in respect of manual (human) versus mechanical effort will also have an impact on cost, losses and quality. These are complex technical issues that have not been addressed here.

In addition, if materials are mixed for collection, in particular for the fully co-mingled collections, then all parties will need to be satisfied that the materials are being collected, sorted and marketed transparently. Thus, there may be more monitoring required to satisfy PROs that the recycling rate for their material fractions are being optimised. The potential additional cost of all parties working together to develop and oversee appropriate sorting infrastructure has not been considered.

Similarly, for options that continue with separate collections of each waste fraction, but on the same vehicle, an optimised set of infrastructure has not been developed as part of this project. It may be beneficial to relocate, share, expand, or close existing waste infrastructure such as depots and transfer stations to meet the future needs of operations that meet the targets. We have included a high-level cost assumption for infrastructure (e.g. depots and waste transfer) in all options, but details of this have not been modelled.

Biogas markets – With a maturing biogas market, experiencing more consistent use of digestate and better separation of incoming biowaste, it is also reasonable to expect that the costs of biowaste treatment would come down from what are currently relatively high levels by European standards. Development of the biogas treatment market might therefore be expected to deliver some savings to the overall system cost and the means of achieving this would warrant further investigation.

3.0 Modelling Results

Since the modelling is based on a bottom up approach:

- where the starting point is a waste flow model that hits target;
- feeding into an operational model that collects the waste in such a way as to meet those targets; and
- we assume this can be done under both institutional models;

the modelling results are presented in a similar order. Section 3.1 presents the results of the waste flow modelling; Section 3.2 presents the results of the cost modelling including the policy options (Section 3.2.1) and the collection options (Section 3.2.2); Finally, Section 3.3 presents the results of the environmental modelling, the employment modelling, and a number of sensitivity analyses.

3.1 Waste Flow Modelling Results

The contributions of each material to the over-arching recycling rate scenarios are presented in Figure 2. The majority of the increase to 55% results from:

- reducing reject rates of separately collected materials;
- replacing much of the existing low-performing bring site coverage with higher-performing door-to-door coverage; and
- improving performance of recycling stations (container parks or civic amenity sites).

In addition to those listed above, three further actions bring about the additional recycling required to achieve 65%. These are:

- further geographical expansion and improved performance in household door-to-door collection system;
- performance improvement at recycling stations; and
- greater enforcement and sorting imposed upon commercial premises.

In both scenarios, consideration is given for the fact that the most rural areas of the country are the most challenging, and most environmentally uncertain areas to operate door-to-door collections in. This is done by exempting households in these areas from the collection system changes detailed above, and allowing them to continue with the existing, predominantly bring site systems. The exemption applies to fewer households at 65% than at 55% as more recycling tonnage is required to hit the higher target. This approach is explained in more detail in Appendix A.2.2.2.

Figure 2: Material Contributions to Baseline and Future Scenarios

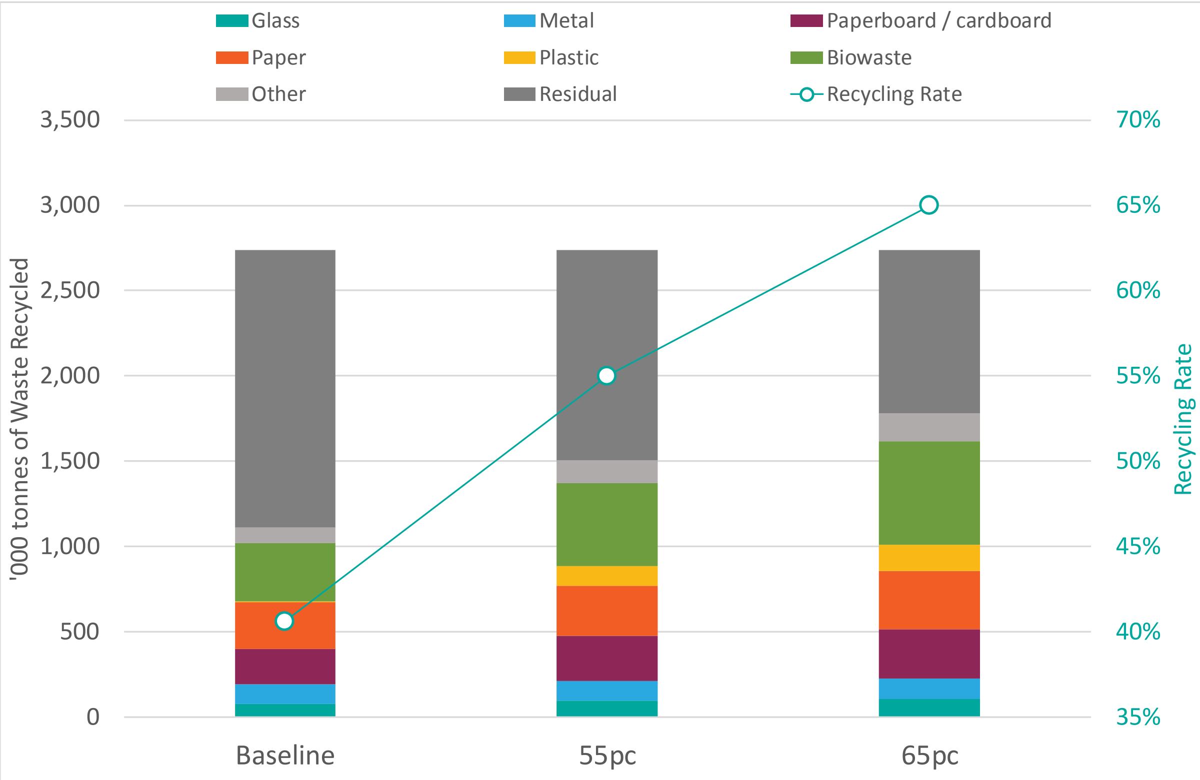


Figure 2 includes the tonnes from all collection sources:

- household door-to-door,
- bring sites,
- recycling stations (also known as container parks or civic amenity sites),
- campaign collections,
- Deposit Return System (DRS), and
- commercial door-to-door.

As discussed above, the modelling assumes that both the household waste and commercial waste streams reach roughly the same recycling rates. There is likely to be scope for Finland to require higher performance of its commercial sector than is being modelled here, even at 65% recycling. Other nations impose stringent requirements upon businesses as a relatively straightforward route to higher national performance. Going forward, Finland should look to gather data on the operations of the commercial waste management systems as they stand in order to facilitate a more thorough exploration of how best to improve performance here.

The tonnage collected through the DRS is assumed not to change. This collection source is currently achieving high return rates, and we assume this would continue into the future.

Recycling stations are assumed to reach higher recycling rates than the overall targets, without any change to the tonnages being received. According to SYKE data, Finnish recycling stations currently recycle (or prepare for reuse) around 60% of the municipal waste they receive. This is relatively low compared to the highest performing recycling stations in Europe, even though they fulfil similar roles in the waste management systems in terms of collecting awkward waste streams such as bulky and hazardous waste. This work assumes that through improvements in sorting practices, recycling at these stations increases to 66% in the 55pc scenario, and to 75% in the 65pc scenario. It is worth noting that performance could be even higher with the right policies and implementation.

Finally, the recycling of 'other' materials is assumed to increase quite significantly, some of which is likely to be via campaign collections, which are often responsible for collections of lower-yielding waste streams such as WEEE and textiles. However, the performance of campaign collections is not modelled explicitly because waste data is currently reported at too high a level to resolve the materials and tonnes collected via this route.

3.2 Cost Modelling Results

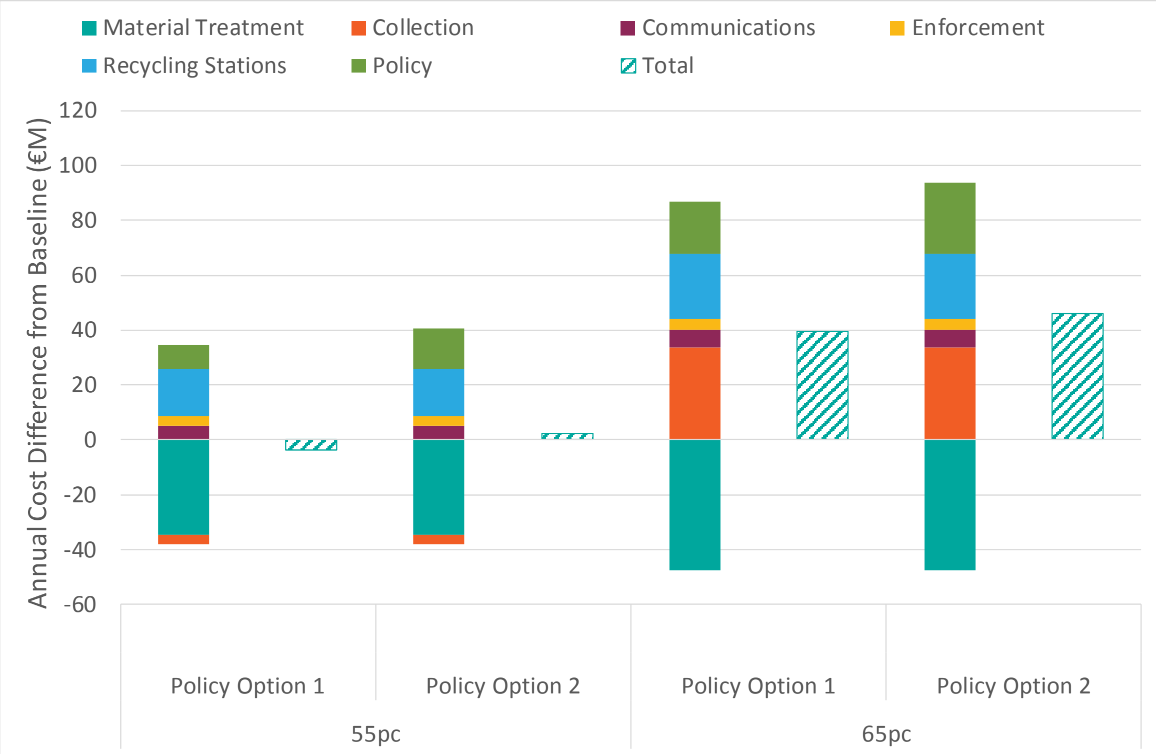
The primary focus of the cost modelling was to represent the marginal costs in achieving future targets. In general terms, the scope of the calculations includes the policy considerations in addition to calculations for:

- waste collection,
- waste treatment,
- collection infrastructure, and
- other staff costs.

The results of the cost modelling are summarised in Figure 3. The modelling shows that, relative to the current system, achieving 55% recycling does not need to be associated with significant additional cost. Savings in material treatment and disposal largely offset the increase in costs associated with expanded collections, improved infrastructure, and additional staff.

However, to achieve 65%, further savings from material treatment do not compensate for the additional costs associated with other areas of the waste management system such as collections, and this scenario has a net annual cost around €40M higher than the 2015 baseline system. The parties who would fund these additional costs depends largely on the detail of the policies that would be put in place.

Figure 3: Summary Cost Results

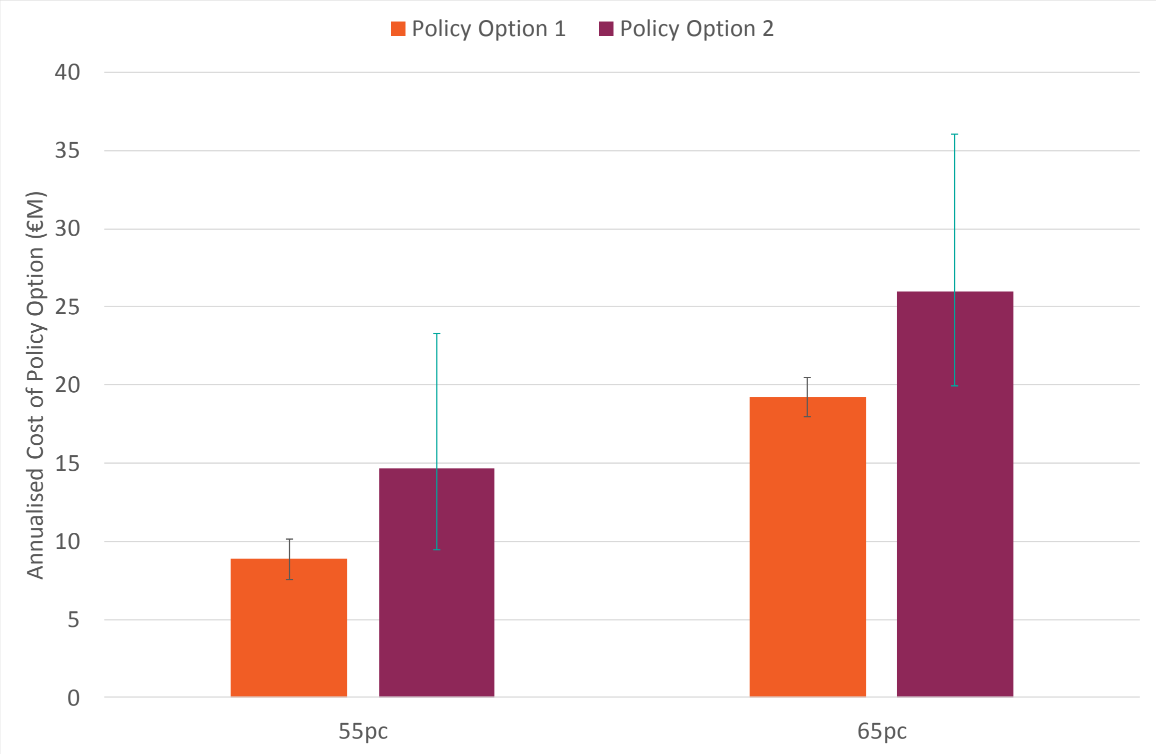


3.2.1 Policy Modelling Results

The cost results of the policy modelling are presented in Figure 4. Policy Option 2 is modelled as being more expensive than Policy Option 1, both in terms of one-off costs of policy implementation as well as ongoing operational costs, but the modelling is high-level and the differences relatively marginal.

The policy option costings in Figure 4 have been built from the bottom up as a series of high, central, and low estimates for each policy component – these are shown as range bars in this figure. Only the central results for each policy option were taken forward as contributors to the overall cost modelling presented in Figure 3 above. The range of possible costs is significantly broader for Policy Option 2, driven predominantly by uncertainty around the costs and scope of setting up a national funding organisation. This organisation is designed to provide research and support bespoke to the Finnish waste context, helping stakeholders responsible for Finnish waste management achieve the best outcomes both economically and environmentally. Its costs are drawn from similar organisations in operation across Europe (discussed in more detail in Appendix A.1.2).

Figure 4: Policy Modelling Results



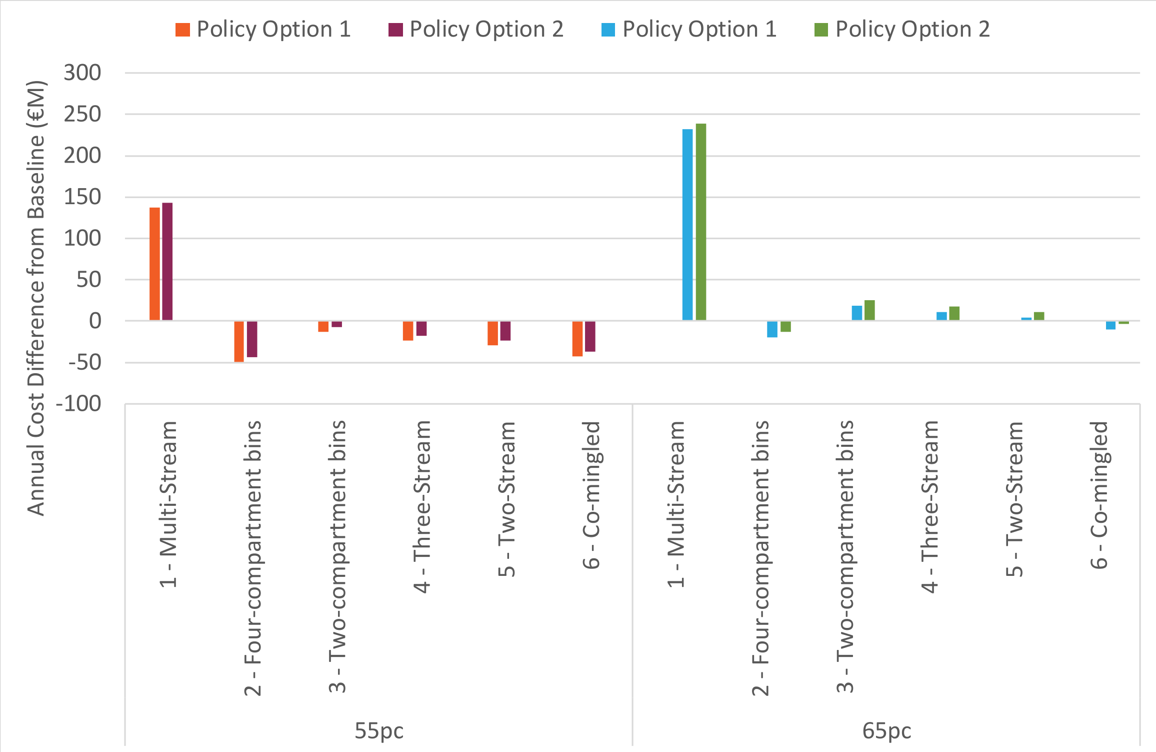
It is also worth noting here that in context of the total costs in both options, as well as the option differential, the cost of implementing the policy options is fairly small compared to the overall system costs. More details on the policy modelling results can be found in Appendix A.1.3.

3.2.2 Collection Modelling Results

The cost results of the collection modelling are presented in Figure 5. This includes the operational costs (vehicles and staff) for each of the different collection systems, as well as the different material incomes and sorting costs. The results show that expanding the current collection system – Option 1 (multi-stream) where each material is collected in a different bin on a different vehicle – to more households is unlikely to be the most cost-effective solution.

This method of collection works well for apartment blocks where a number of properties share larger bins, but for row and single houses it takes a lot of time to collect one bin from each house and so collecting them all separately is less efficient. In addition, the rurality of some of the areas in Finland that are currently not covered by door-to-door collections means that there are also long 'drive times', leaving less time available for collections; as a result, vehicles may not fill up and the collection capacity is under-utilised. By collecting multiple materials on the same vehicles, either in separate compartments or mixed together, both of these issues can be better resolved.

Figure 5: Collection Modelling Results



The mean average cost of the six collection options was taken forward to contribute to the overall cost modelling presented in Figure 3. Although a simplification of the data that has a large range, this approach did not preclude a valid analysis of the overall system costs.

However, the collections options comparison can also be taken as a distinct analysis that is of interest in its own right. The collection options show similar trends in both policy options and both waste flow scenarios. More details on the door-to-door collection modelling results can be found in Appendix A.3.3, and other collection sources (bring, sorting stations, etc.) in Appendix A.3.3.2.

3.3 Other Modelling

This section presents the results of additional modelling undertaken to calculate the environmental impact of the future recycling and collection options (Section 3.3.1), the resulting employment changes (Section 3.3.2), waste flow modelling sensitivities (Section 3.3.3), and cost modelling sensitivities (Section 3.3.4).

3.3.1 Environmental Modelling Results and Sensitivity

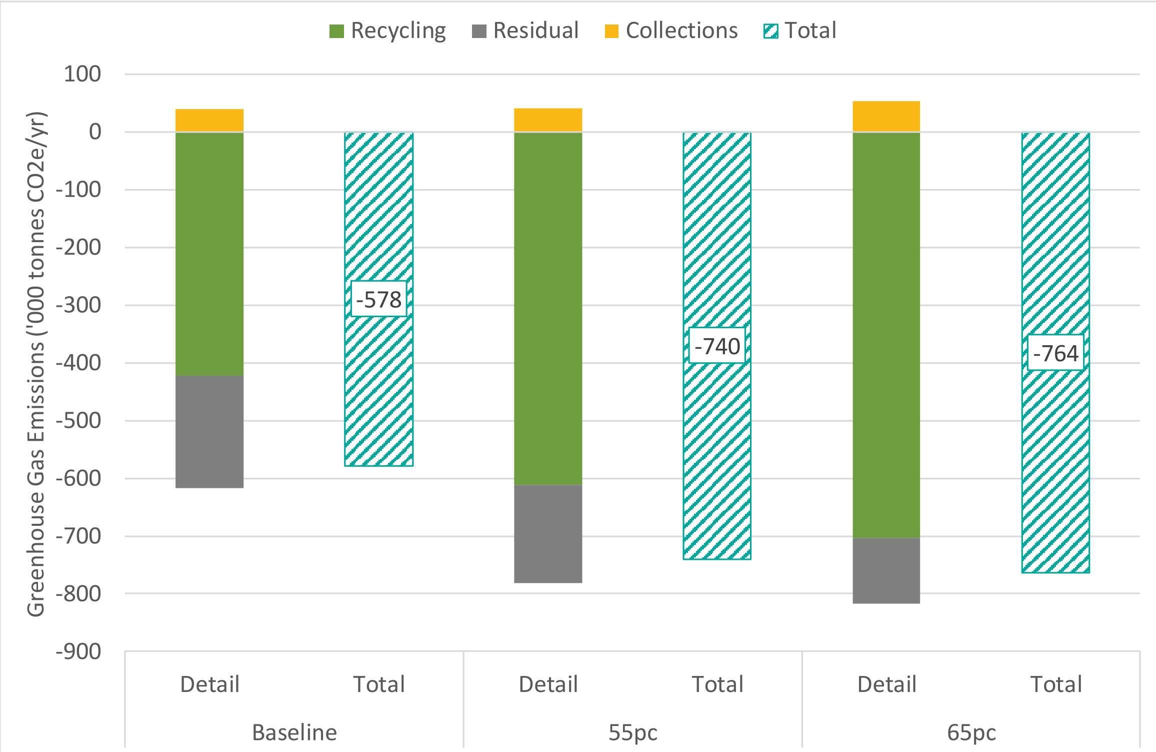
The scope of the environmental modelling was to quantify greenhouse gas emissions from waste collection, processing, and treatment for all waste streams including recycling, biowaste and residual. The results of the environmental modelling are presented in Figure 6. This figure shows that the current waste management system provides net greenhouse gas emissions benefits. This is predominantly a result of recycling (leading to avoided virgin material production) and from residual waste incineration (generating electricity and heat that is less carbon intensive than that of the Finnish baseline).

The results also show that progressing to 55% recycling will further reduce Finland's emissions from waste management, driven largely by increased plastic recycling. The increase to 65% recycling saves further net greenhouse gas emissions.

Expanding the coverage of the household door-to-door collection system results in an increase in the fuel consumed by the fleet of waste collection vehicles in both scenarios, but the additional emissions associated with this increase are far outweighed by the climate change benefits from increasing material reprocessing and reducing residual disposal.

More detail on the modelling methodology, assumptions, sensitivity, and limitations can be found in Appendix A.4.0.

Figure 6: Summary Environmental Results



The results shown in Figure 6 assume a different environmental benefit from biowaste treatment in the baseline and future options. Since the current biogas market is not mature, the benefits of the digestate may not be fully realised. In Finland, all digestate is applied to land as this is a prerequisite to count it as recycling, but it is not clear to what extent these products truly displace synthetic fertiliser. As such, it appears that the environmental benefit of biowaste treatment is currently less than it could be. In the future when biowaste collections are more widespread, biowaste markets are expected to mature, although some interventions may be required to support this process such as more robust quality standards and stronger proposition of the benefits of digestate use to agriculture through pilots, case studies, awareness raising and more directly addressing concerns and prejudices.

An environmental sensitivity, assuming that a more mature market is available in the baseline as well, was carried out in order to facilitate a more direct comparison between the three recycling rate scenarios. This sensitivity improves the environmental performance of the baseline by 25 ktCO_2e/yr, closing the gap to the future options. The cost implications of a maturing of the biogas market are also investigated in Section 3.3.4.

3.3.2 Employment Modelling Results

The employment modelling results are shown in Figure 7. Each future option is associated with an overall increase in employment, with 933 additional full-time equivalents (FTEs) supported at 55%, and 1,716 additional FTEs supported at 65%.

In both scenarios, there is a reduction in operational staff collecting waste as a result of reducing fragmentation of the collection system, but this is more than outweighed by the gains made in treating the waste and managing new contractual obligations.

The number of people who actually benefit from this increase is likely to be higher than the quoted figures because the calculations are in terms of FTEs, and in reality, employees take annual leave or may work part-time. Even so, at 65%, this could reduce the number of unemployed Finns by at least 0.7%.[3]

Figure 7: Employment Changes in Future Scenarios

[3] Based on a total of 227,000 currently unemployed. Statistics Finland (2018) Unemployment rate 8.4 per cent in December 2017, January 2018, https://www.stat.fi/til/tyti/2017/12/tyti_2017_12_2018-01-25_tie_001_en.html

More detail on the modelling methodology, assumptions and limitations can be found in Appendix A.5.0.

3.3.3 Waste Flow Modelling Sensitivities

The central waste flow modelling assumes the same material is recycled independent of the collection system chosen. In other words, we assume that the systems where more material fractions are mixed together, and is subsequently sorted in regional sorting facilities, results in the same level of recycling as systems where waste is collected source separated.

Based on systems elsewhere in Europe, data suggests that the more material fractions are mixed together for collection, the more non-target or non-recyclable material (referred to as contamination) is collected. This contamination then needs to be sorted out and sent for energy recovery or disposal by the sorting facility. Due to the imperfect nature of the sorting process, some target material inevitably ends up being disposed of with contamination, and some contamination ends up in the material products reducing the quality of the materials sent for recycling.

This tendency is modelled as a sensitivity in the waste flows, where we assume that more contamination is collected, but that some of the target material is then not recycled due to the nature of the sorting process. Modelling typical figures found in other European countries suggests that this may have an impact of up to 1.4 percentage points in the 55pc scenario (reducing the recycling rates modelled to 53.6%), and 1.9 points in the 65pc scenario.

3.3.4 Cost Modelling Sensitivities

Mature Biogas Markets

As discussed above in Section 3.3.1, the fact that the biogas market is relatively immature in Finland means that the environmental benefits of biogas treatment in the baseline is less than it could be, and we assume that this will improve in the future. Another implication of this is that the gate fees for biogas should reduce. If digestate is being fully utilised to add value to land, and more consistent end-destinations for the compost product of the biogas process are found, then this should also reduce the input gate fee of the collected biowaste.

If, for example, the gate fee for biowaste treatment were to reduce from the current level of €92 per tonne (see Table 11 in Appendix A.2.2.3) to €50 per tonne, which would be representative of more mature biogas markets in Europe, then this would save a total of €9.4M across Finland in the baseline, €15.5M in the 55pc scenario, and €17.7M in the 65pc scenario, based on the tonnes modelled. These are significant savings, in addition to the environmental benefit as well. Thus, investing in developing the biogas and digestate (fertilizer) markets in Finland should be a priority for Finland.

Open-Market Waste Collections

One of the fragmentation issues within the current market for household waste collection in Finland that was raised in the Early Warning Report relates to the fact that some municipalities opt for an open market for waste collection in their area. In most municipalities there is one collection operator that visits all households for each waste fraction. In municipalities that opt for the open-market approach, there are competing collection operators, and residents can choose which to sign up with (in a similar way to choosing a mobile phone service provider). By 28% of the Finnish population live in municipalities that operate these open market collection systems, alongside a small proportion of municipalities who operate a dual system.

Additional savings of €11-16M per year are estimated to be available were all municipalities to shift to the predominant system of a single service provider covering all households. These savings have not been included in any of the results presented above. However, if they were to be included, they would bring the cost of the 55pc options to below the cost of the current system in Finland overall, and would reduce the marginal cost of the 65pc options by almost 50% (see Figure 3).

These estimates were informed by work on free-market inefficiencies carried out by Eunomia for the Republic of Ireland.[4] Data from across the world was reviewed, finding that 'competition-for-market' municipalities regularly achieved significant savings over similar 'competition-in-market' municipalities. These findings are discussed in more detail in Appendix A.3.3.2, but relate primarily to more efficient use of resources (economies of density in collection logistics, fleet management, etc.).

4.0 Discussion and Summary

The work presented in this report seeks to take a constructive approach to considering challenging options for reform of institutional and operational arrangements for the collection and treatment of waste materials in Finland, particularly from households. A number of key themes can be discussed as a result:

- Much of the analytical effort was focused on modelling future options for collection that might meet the 55% and 65% targets for municipal waste under the revised Waste Framework Directive. This work shows that:
    - A significant area of focus will have to be on growth in door-to-door collection in suburban areas, small towns and villages and rural areas if these targets are to be met;
    - As door-to-door coverage increases, the system that is currently predominant, under which a separate bin is provided for each material stream and collected by a separate vehicle, appears to be the most expensive way to meet targets;
    - This is because, although the current system is well optimised within each separate material stream, significant optimisation opportunities are lost:

[4] Eunomia Research & Consulting (2009) *Costs of Household Waste Collection in Ireland - A Discussion: Annex to the Policy Review*, Report for Department of Environment, Heritage and Local Government, Ireland, July 2009

        - Time in the working day tends to be the limiting factor in determining when a collection vehicle has to stop working and return to its depot. As door-to-door collections become more spread out in rural areas, vehicles for some separate materials have to return to the depot with significant unused capacity;
        - The time spent stopped outside each collection point becomes increasingly important as smaller quantities of material are collected at a time under door-to-door collection from single houses and row houses. Where the number of these incidents can be reduced by collecting multiple materials each time the vehicle stops, optimisation benefits can be achieved.
    - It appears that for many areas of Finland, multi-compartment vehicles do look like a good option for door-to-door collections, with use of several vehicle types appearing to be significantly lower cost overall than using a separate bin and vehicle for each material. Differentiating accurately between these options would require more detailed work, for example modelling a representative range of Finnish municipalities in fine detail. However, the conclusion that multi-compartment vehicles are likely to be most efficient in many circumstances appears to be robust.
    - The modelling also illustrates a number of advantages and disadvantages of co-mingling some materials and sorting them subsequently:
        - Greater savings can be made on the cost of collection, as the benefits of collecting multiple materials each time the vehicle stops can be achieved without the downside of the filling up of a particular separate compartment becoming the limiting factor;
        - However, the sorting costs associated with co-mingling increase as a factor within the overall costs as more materials are mixed and these sorting costs are likely to offset the collection savings, even reaching the point where co-mingling actually costs more;
        - And at the same time, as material quality becomes more and more important both to find good markets for recyclables and to meet stricter measurement methods for recycling, the losses of target materials in sorting plants seem likely to be a significant inhibitor of ability to meet particularly the 65% target;
        - Overall then on co-mingling, it would be a major decision for Finland to go in this direction on a large scale. Finnish citizens are already used to separating materials and although co-mingling can make services easier to use and more convenient, the risks that costs will actually be higher ands that future drivers will push towards un-mingling seem significant.
    - Overall, the modelling concludes that the 55% and 65% targets can be met with relatively little additional investment in collection where a ‘whole system cost’ approach is taken. At high performance levels, savings on optimising collection and avoiding disposal costs, alongside revenues from material sales largely offset the cost of separately collecting a wider range of materials from many more households. This

will be counter-intuitive to many, but demonstrates that the economics of a system designed to meet a 65% recycling rate are very different to one designed to meet 40-50%.

    - The conclusions on collection that can be drawn from this work may be challenging for Finland's waste management industry, which is rightly proud of its achievements in terms of efficiency and performance within the boundaries of the current system. Overcoming industry preconceptions will require more than this high-level analysis, including:
        - Modelling of a sample of municipalities using detailed operational data reflecting all variables more accurately;
        - Pilot schemes for different collection and vehicles systems;
        - Promotion of the results of this future work through professional associations, publications, conferences and training; and
        - The provision of technical assistance to disseminate best practice across operational practitioners.
- The work on collection also drew attention to various infrastructure-related issues that could only be addressed at a very high level:
    - The number of depot and bulking points where materials can be tipped has a significant bearing on drive times. This becomes more important as door-to-door collection expands and spreads to more rural areas. Optimising this infrastructure could offer significant benefits, but also involve other institutional change. Most municipalities already work collaboratively on waste management, but it may be that the existing partnerships are more a result of historic factors and do not reflect the optimum logistical configurations. Even within the existing collaborations, the infrastructure may not be optimised. This could quite easily be studied alongside the more detailed collection modelling suggested above. Optimisation of infrastructure may be strongly driven by producers and the PROs where a more integrated approach is taken under Policy Options 1 or 2, as producers apply pressure to ensure that the overall system is as cost optimised as possible.
    - Another area of infrastructure development that it may make sense for producers/PROs to drive more directly is that of sorting plants. The current capacity of sorting plants in Finland is very limited, but as can be seen from the analysis here, the alignment of sorting facilities and collection is crucial. The apparent capacity gap provides government and industry with the opportunity to design the policy and operational frameworks to avoid many of the pitfalls that other EU Member States have fallen into with misaligned collection systems, infrastructure and markets.
    - To a lesser extent, the same will go for the development of additional biogas and other biowaste treatment infrastructure. The right balance between wet and dry anaerobic digestion, in-vessel and open windrow composting will be driven by the supply of material from collection and vice versa. A key consideration will be the extend of co-collection versus separate collection of food waste and garden waste. In addition, the

environmental benefits than can be achieved from biowaste management will depend on the detail of the pattern of infrastructure developed and the end uses of the products generated.

- Related to this, across all material streams the role of market development is also likely to be crucial. As a relatively small and geographically isolated economy, Finland has some disadvantages in developing a circular economy. However, it also has many advantages, with high-tech engineering and manufacturing and excellent sea transport links, as well as strong political commitment amongst these. As tonnages separately collected become larger and recycling rates increase well beyond 50%, the cost and revenues associated with the end uses of materials become ever more economically important. There may well be potential to generate higher revenues per tonne for materials than has been assumed here and certainly with further development of the biogas market, especially for the use of digestate on land, the assumed gate fees for anaerobic digestion could be lowered. However, greater exposure to global market forces introduces larger risks as well and so market development should be an increasing focus of government and industry as the strategy for delivering a high recycling economy continues to develop.
- Regarding the institutional models considered in Policy Options 1 and 2, both would clearly require significant reform that would be challenging to design and deliver. However, it does appear form the work on collection and treatment costs that a more intergraded system would be capable of meeting Finland's obligations to the EU, and its ambitions for a more circular economy, at lower cost and with significant greater environmental and economic benefit than business as usual.
- Policy Option 1 is more orthodox in that it reflects the approach in a number of high-performing EU member States, but to implement it would push against the direction of travel regarding the allocation of responsibility to municipalities. Policy Option 2 is certainly likely to be more complex and ground-breaking and may not in practice be much more politically straightforward. The questions raised by the modelling, not least of which is the key omission from this study regarding the likelihood of the different policy options actually succeeding in meeting the EU targets, require significantly more work to resolve. However, it seems clear that substantial reform of packaging EPR will be required in Finland, both as a means to meeting future recycling targets and to comply with the EU's more stringent requirements for EPR design under the Waste Framework and Packaging and Packaging Waste Directives. As such, 'business as usual' is not an option and something along the lines of these policy options or some other approach to significant reform will be required.
- There are a number of other observations that can be made from the analysis that are worth noting:
    - It seems reasonable to conclude that the implementation of a more comprehensive waste data system should be a top priority for Finland. This work has been limited by the lack of high quality, detailed and readily available waste data and this situation will hamper Finland in the future as the Government seeks to make the right strategic and policy decisions

and industry and municipalities seek to invest in the right infrastructure and services. Traceability and quality of evidence in all senses seems likely to continue to grow in importance and the Finnish Government, municipalities and producers will all have to invest more in good systems and data. This should be within a robust national framework developed with a long-term outlook.

  - According to our analysis, additional savings of €11-16M per year may be available were all municipalities to shift to the predominant system of a single service provider covering all households. These savings could bring the cost of the 55pc options to below the cost of the current system and reduce the marginal cost of the 65pc options by almost 50%. Although the political challenges of reform in this area are acknowledged, it may be right to consider this issue within a wider package of reforms.

- Overall, the analysis presented here makes a compelling case for achieving high recycling rates in Finland on economic grounds as well as in respect of environmental benefits and compliance. Indeed, if the market development challenges outlined above can be overcome, it may well make sense for Finland to seek to exceed the EU's 65% target well in advance of the 2035 target year. However, this work is clearly high level in a number of areas and includes significant omissions due to scope and resource constraints. As such, we hope that it provides a step towards a robust strategy for Finland whilst acknowledging its limitations.

APPENDICES

This technical appendix is intended to support the main project report. It contains little of the contextual considerations explored in that report, but instead aims to detail the data, assumptions, and methods used to obtain the results explained in the modelling, as well as the results themselves. The structure of this appendix largely mirrors the main report. First, the methodology and results of the waste flow modelling is explored in Section A.1.0. Collections modelling using Hermes2.0 is then explained in Section A.3.0, followed by an explanation of our approach to environmental modelling in Section A.4.0, and our approach to employment modelling in Section A.5.0.

A.1.0 Policy Modelling Technical Appendix

Finland's current policy framework is thought to require reform in order for Finland to reach future municipal waste recycling targets. Therefore, two alternative policy options have been modelled, informed by work carried out in preparing the Early Warning Report and by discussions between Eunomia, SYKE, and the Ministry of Environment. Each option is assumed to be equally capable of reaching future municipal waste recycling targets.

However, each requires different changes to how Finnish waste management operates today. This section explains the assumptions regarding how each policy option would be implemented, and what each of those components would cost. In all cases, expanding the scope of existing waste policy comes at an additional cost. However, in all cases these costs are at least partially recuperated by savings in material treatment and disposal.

These changes are described below in Sections A.1.1.2 and A.1.1.3 for the two policy options respectively; changes included in both policy options are described in Section A.1.1.4. The quantitative assumptions are detailed in Section A.1.2, and further details of the results (in addition to what is in the main report) is presented in Section A.1.3.

A.1.1 Methodology

A.1.1.1 Rationale for the Policy Options

The Early Warning Report put forward four main options for reforming the policy and institutional framework for municipal waste. These options were developed at a high level and included components that were not mutually exclusive. It appeared rather that they were designed to illustrate a range of approaches that could be taken, all of which would require significant further consideration to convert them into detailed, implementable options.

The two policy options assessed here draw on all four of the options put forward in the Early Warning Report and take these ideas forward to the next stage of development, but are still far from fully developed. Most project resources have been focused on modelling the collection arrangements that are actually assumed to be common to both options and so there is considerably more work to do to fully develop these policy options. However, it was necessary to make assumptions regarding the costs (and therefore some of the details) of the policy options and so these are presented here.

Overall, the two policy options are intended to illustrate two ends of a spectrum, ranging from quite a conventional approach across the EU (Policy Option 1) whereby municipalities are given responsibility for commissioning the whole collection system, with funding provided from PROs to support costs of collection and sorting; to a much more innovative approach (Policy Option 2) which attempts to simulate the benefits op Policy Option 1 in terms of addressing fragmentation whilst avoiding the complete transfer of financial and operational responsibility to municipalities. Although all elements of Policy Option 2 find some precedent in other EU Member States, the whole system as described here is not used in any other country.

A.1.1.2 Policy Option 1

The first policy option is based around the introduction of mandatory recycling targets for each municipality. Municipalities are given full responsibility for the collection system and so can change any of the relevant services in order to meet the targets. In addition, they are given responsibility for the costs of sorting and revenues from materials, as well as the retaining responsibility for the costs of treatment of mixed waste and biowaste. As such, municipalities would have physical and economic responsibility for all key aspects of the waste management system as it relates to waste from households, although they would exercise this responsibility by using the private sector as service providers/contractors.

Targets could be uniform across all municipalities, or could vary to reflect differences in ‘difficulty’ of meeting targets based on current performance, housing stock, rurality, or waste composition, for example. As occurs in some EU Member States today, financial penalties would be introduced for missing the targets, such that the recycling targets policy becomes the primary driver to ensure that action is taken. Policies in respect of municipal waste from commerce and industry would need to be well aligned to ensure that the system is optimised and the overall targets are met.

To put this policy in place, the Finnish Government would first have to amend the Waste Act or introduce other legislation to change the responsibilities of municipalities and PROs, and to include the mandatory targets. This would require time both from senior civil servants and probably some external contractors.

The operation of this option would require additional resource in municipalities to manage new contracts for new collection services. Municipalities already manage the collection and treatment of mixed municipal waste and biowaste, and therefore have many existing relevant skills. However, there would be further effort needed to specify additional services, define what the contractor must offer in their tender, evaluate wider tender responses, and monitor activities during the contract phase. Data on how municipalities currently undertake this task is not available so it is challenging to accurately estimate the cost from this component of the policy option, but an estimated additional requirement of 0.1 to 0.2 FTEs per municipality has been used.

Finally, to ensure compliance, the Finnish Government would be required to carry out some additional enforcement activities.

Overall, this option would be broadly cost-neutral for municipalities. Any additional costs from biowaste or residual collections would be recovered from citizens through local waste fees, while any additional costs from packaging collections would be offset by EPR fees. The costs to PROs would therefore likely increase overall, with increased EPR fees outweighing the savings obtained through managing a smaller bring site network.

A.1.1.3 Policy Option 2

From an institutional point of view Policy Option 2 involves introduction of mandatory 'tri-party collaboration' between the PROs, municipalities, and collection companies. In this option there is strong cooperation between municipalities and PROs such that the economic disconnect that currently exists is eliminated, and parties work together for the best overall outcome in terms of both system cost and performance in each geographic area.

In practice this means that the municipalities and PROs would be responsible for procuring a package of services for a given area that optimised cost of collection and sorting, cost of treatment and disposal and revenue from sales of recyclables. PROs would fund the cost of managing the end of life materials for which they are responsible, net of the revenues generated by sales of recyclables. The role of waste collection companies would essentially be simply contractual, with services being commissioned jointly by the PROs and municipalities – hence the concept of 'tri-party collaboration'.

There are several possible approaches to this joint commissioning, but the key objectives would be to ensure that optimised solutions are procured across the whole system and that producers, through the PROs, only contribute the necessary level of funding based on the procurement of efficient services. To achieve this, new contracting authorities structured as joint venture companies could be set up, with municipalities and PROs on the board. Alternatively, municipalities or municipality-owned companies could be the contracting authorities but with the PROs participating in the development of the service specification and evaluation of tenders. These service commissioning activities would occur in the context of joint strategies developed by PROs and the municipal sector at national and regional level.

To make this work effectively, the Finnish Government would develop a suite of guidance documents, including model procurement and contract documentation, some of which would be mandatory and some voluntary in order to provide flexibility where appropriate. These model processes and documents would provide the basis for governing the relationships between municipalities, PROs and contractors. An arbitration process would be used to resolve disagreements between the parties.

The reform of responsibilities would be supported by a package of economic instruments and policies designed to ensure that:

- those responsible for recycling collections are incentivised to avoid the cost of disposal; and
- the costs of disposal are at an adequate level to make the business case for investing in new recycling services and infrastructure attractive, thereby ensuring recycling levels increase.

The tri-partite contracts would provide the economic link between avoided cost of disposal and investment in recycling services. To make this as effective as possible, the scope of 'full cost recovery' under Finland's producer responsibility system for packaging would be extended to include the cost of treatment and disposal of packaging in residual waste. This would ensure that the costs of disposal, currently paid for by the municipalities, influence the PROs who have primary responsibility for increasing packaging recycling rates.

Increasing the cost of mixed waste disposal would be achieved primarily by extending the landfill tax to include incineration. This tax would work in the same way as the current landfill tax, except that the scope would be broadened to include waste to energy incinerators. Any person delivering waste to an incinerator would be charged the tax based upon the measured mass of waste delivered. These taxes would then be paid to the national tax agency on a regular basis.

In theory, these measures alone could be enough to see levels of recycling increase to meet future targets, and it is worth noting that the tax would also affect non-household wastes, driving increases of recycling activity in respect of waste from commerce and industry too. However, to make the outcomes more certain, two further policy measures have been included:

1) the introduction of an enhanced minimum service standard; and
2) the establishment of a national funding organisation.

Firstly, minimum service standard would serve to provide a broadly consistent level of service for different housing types and ruralities across the country, as well as ensuring that performance levels are likely to be adequate. This might cover, for example, collection frequency or limits on bin size, although care would have to be taken so as to leave room for innovation and consideration of local context.

Secondly, a funding and support organisation would be set up to facilitate the transition, to provide national public communications services, to provide technical advice on how to meet national requirements, and to help to develop markets for recyclates through funding of infrastructure and development of standards and specifications for secondary materials and products, perhaps as well as compost and digestate from biowaste treatment.

A.1.1.4 Both Policy Options

In addition to the components above, both policy options are likely to require the introduction of weight-based pay-as-you-throw (PAYT) systems to ensure adequate public participation to achieve high recycling rates. Such instruments are capable of outstanding results,[5] and are likely to be needed to drive performance up to 65pc. It is assumed that this system operates as an extension of the current household fees system. Although not designed in detail within the scope of this project, the cost of the PAYT systems modelled includes provision for:

- RFID tags for collection containers;
- weighing equipment for vehicles; and

[5] Dri, M., Canfora, P., Antonopoulos, I.S., and Gaudillat, P. (2018) *Best Environmental Management Practice for the Waste Management Sector*, Report for European Commission. Luxemboug, May 2018

- administration of household data such as bill payments.

In addition, a new and improved waste information system would be required for both policy options. Under Policy Option 1, this would be necessary to accurately report and monitor the performance of each municipality, potentially against different mandatory targets where a national uniform target is not adopted. Under Policy Option 2, the waste information system would be necessary to ensure that municipalities, PROs and the Finnish Government can effectively monitor and report on performance to ensure that EU recycling targets are met.

It seems likely that such a system will be necessary in order to comply with the revised Waste Framework Directive which requires Member States to “establish an effective system […] of traceability of municipal waste”.[6] In effect, Member States will have to track waste from sources to final recycling process, taking into account losses through the management chain. The likely cost of such a measure, detailed in Section A.1.2 below, is informed by estimates compiled for the European Commission.

The components required for each policy option to operate effectively were explored and costed using high, low, and central assumptions where necessary; the results in the main report only show the central results. These costs draw on a variety of sources which are detailed in Section A.1.2. Each component was assigned a label of either ‘one-off’ or ‘ongoing’ costs, which were totalled separately. The metric for option comparison was an annualised total cost, representing the ongoing costs of operation added to the one-off costs of policy implementation annualised over 10 years at a 4% discount rate.

A.1.2 Assumptions

The assumptions used to cost Policy Options 1 and 2 are shown in Table 1. One-off costs are assigned the letter O and ongoing (annual) costs are assigned the letter A. As discussed above, the cost of the current waste management system is unknown, and developing a model to calculate these costs is beyond the scope of the current project. Therefore, these are all marginal costs relative to the baseline. In other words, they are additional costs to set up and administer the new waste management systems being proposed for each policy option. The operational cost of waste collection is modelled separately and detailed in Section A.3.0.

[6] (2018) Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste, *Official Journal of the European Union*

Table 1: Low, Central and High Policy Option Assumptions for One-off (O) and Annual (A) Costs

Component	Requirement	Option	O/A	Unit	Low	Central	High
Waste Data System	Development Time	Both	O	€M	2.0	3.5	5.0
PAYT System[1]	Implementation			€/hh		5	
PAYT System[1]	Maintenance		A	€/hh		4	
Communications[2]	Material Development and Distribution			€/hh		2	
Updating Waste Act	Senior Civil Servant	1 Only	O	Days	75	113	150
Updating Waste Act	Consultancy			€k		100	
Contract Management	Contract / Service Managers		A	FTE/mun	0.10	0.15	0.20
Enforcement	Junior Civil Servant			Days	20	110	200
Enforcement	Senior Civil Servant			Days	5	28	50
PRO Role Reduction	PRO Staff			FTE		- 12	
Contract Template	Civil Servant	2 Only	O	€k	200	300	400
Developing Economic Instruments	Civil Servant			€k	200		
Developing RTS	Senior Civil Servant			Days	75	113	150
Developing RTS	Consultancy			€k	100		

Component	Requirement	Option	O/A	Unit	Low	Central	High
Arbitration Process	Court Staff	2 Only	A	€k	50	175	300
Contract Management	Contract / Service Managers			FTE/mun	0.10	0.15	0.20
Administering Economic Instruments	Civil Servant			€k	50		
Funding Organisation[3]	Staff			€/cap	0.2	1.0	2.6
Notes:	[1] Note that the PAYT costs apply only at 65pc [2] Communications costs increase to €3/hh at 65pc [3] The scale of the funding organisation increases at 65pc to reflect greater demand						

PAYT costs were informed by published work on similar systems in Europe.[7] To obtain national figures, the costs (per household) shown in Table 1 were multiplied by 1,607,990 (the number of street-level Finnish households, i.e. not in apartment blocks). This is because PAYT systems do not work with communal bins (although PAYT systems for flats are being developed and may be something that is implemented in the future) and because the costs relevant to commercial waste collections are out of scope. The ongoing operational costs of these systems are relatively high as the equipment is difficult to maintain.

Communication costs per household were multiplied by 2,933,713 (the total number of Finnish households). This is because effective communications will be necessary to improve recycling performance in all Finnish residences.

The savings associated with a reduced PRO role were estimated by assuming that 6 PROs employing approximately 3 FTEs apiece could be replaced by one larger PRO employing 6 FTEs. It should be noted that this estimate, alongside several others in this section, is intended as much to highlight the changes necessary in each policy option as to actually affect the cost estimates. In context, reducing PRO employment contributes little to the overall costings.

The cost of running a funding organisation in Policy Option 2 was informed by the costs of similar organisations across Europe, namely OVAM and Vlaco[8] in Belgium as well as WRAP in the United Kingdom. Spend per resident values were calculated for each organisation and scaled up by the population of Finland.

The assumptions above, shown in terms of days required, were converted to FTEs by dividing by 253, the number of working days in Finland.[9]

Assumptions shown in Table 1 in terms of FTE/mun (FTEs per municipality) were converted to FTEs by multiplying by 311, the number of municipalities in Finland. It is acknowledged that most municipalities already participate in cooperation arrangements with neighbouring municipalities, either through formal regional partnerships or through ownership of waste management coordination companies. As such, further economies of scale may be able to be achieved in practice but this more cautious approach was taken to the modelling due to the high-level nature of the work and uncertainties regarding the detail of these arrangements.

FTE requirements were costed according to wages relevant to the staff grade, as shown in Table 2. A further 35% on-cost assumption was used to determine staff costs, taking into account additional costs such as holiday cover and employer contributions to social security.

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[7] European Reference Model on Municipal Waste Management

[8] Vlaco (2017) *What does Vlaco do?,* Accessed 6th June 2017, http://www.vlaco.be/over-vlaco-vzw/wat-doet-vlaco-vzw

[9] *Business days calculator in Finland,* Accessed 6th June 2017, http://finland.workingdays.org/

Table 2: Staff Cost Assumptions

Staff Grade	Wage (€/FTE/yr)	Cost (€/FTE/yr)
Junior Civil Servant	45,000	60,750
Senior Civil Servant	60,000	81,000
Contract / Service Managers	50,000	67,500
PRO Staff	40,560	54,756

No accounting of additional income from the expanded disposal tax in Policy Option 2 has been attempted. This is because it forms a cost in one part of the waste management system (e.g. for the municipalities) and an income in another part of the waste management system (e.g. for central government). These new tax revenues could either be re-invested in the system to improve performance, or be used for other purposes.

A.1.3 Results

Table 3, Table 4, and Table 5 show details of the low, central, and high policy modelling results respectively. Each table shows the total one-off costs modelled (in italics), which are then annualised over 10 years at a 4% discount rate. The tables also show the total ongoing costs modelled, which are added to the annualised one-off costs to calculate the total annualised costs shown in the main report. The central results in Table 4 are the central results carried forward to the overall modelling results, and the low and high modelling results are shown as range bars in Figure 4.

Table 3: Details of Low Policy Modelling Results (€M). Total Annualised Cost shown in the Range Bars in Figure 4

	55pc		65pc	
Policy Option	**1**	**2**	**1**	**2**
Total One-Off Costs	*2.1*	*2.5*	*10.2*	*10.6*
Annualised One-Off Costs	0.3	0.3	1.3	1.3
Total Ongoing Cost	7.3	9.1	16.7	18.6
Total Annualised Cost	**7.6**	**9.4**	**17.9**	**19.9**

Table 4: Details of Central Policy Modelling Results (€M). Total Annualised Cost shown in Orange/Purple Bars in Figure 4

	55pc		65pc	
Policy Option	**1**	**2**	**1**	**2**
Total One-Off Costs	*3.6*	*4.1*	*11.7*	*12.2*
Annualised One-Off Costs	0.4	0.5	1.4	1.5
Total Ongoing Cost	8.4	14.1	17.8	24.4
Total Annualised Cost	**8.8**	**14.7**	**19.2**	**25.9**

Table 5: Details of High Policy Modelling Results (€M). Total Annualised Cost shown in the Range Bars in Figure 4

	55pc		65pc	
Policy Option	**1**	**2**	**1**	**2**
Total One-Off Costs	*5.1*	*5.7*	*13.2*	*13.8*
Annualised One-Off Costs	0.6	0.7	1.6	1.7
Total Ongoing Cost	9.5	22.6	18.8	34.3
Total Annualised Cost	**10.1**	**23.3**	**20.5**	**36.0**

A.2.0 Waste Flows Technical Appendix

The waste flow model determines how much waste requires collection and treatment to reach future EU municipal waste recycling targets. The modelling was done with consideration for the current Finnish context and for precedent in other EU countries.

To put this into practice, a bespoke waste flow model was created that models the three key scenarios: baseline, 55% recycling, and 65% recycling. Thus, for the waste flow modelling, this appendix presents:

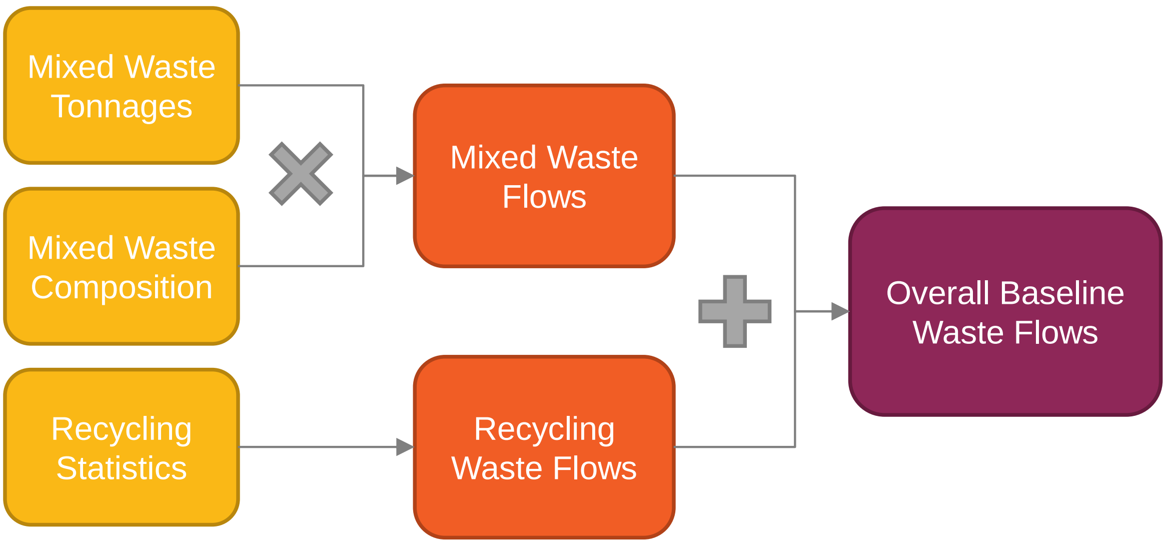
- the methodology (Section A.2.1),
- baseline data and future assumptions (Section A.2.2), and
- results of the modelling (Section A.2.3).

In addition, we model a sensitivity for co-mingled collections in each of the two future options (Section A.2.4). Finally, key modelling limitations are explained (Section A.2.5).

A.2.1 Waste Flow Modelling Methodology

The first steps in any waste flow model is to ascertain how much waste exists within the system, and what it is composed of. In Finland, annual statistics are released reporting the tonnages of each recyclate fraction collected in the country. However, as is the case in virtually all countries, mixed waste tonnages are only summarised as a total tonnage figure. In order to know how much recyclate is available, a recent mixed waste composition was applied to the mixed waste tonnages. The recycling and mixed waste mass flows were summed to arrive at a set of baseline waste flows representing all of the waste produced in Finland. This approach is summarised in Figure 8.

Figure 8: Method for Generating Baseline Waste Flows



Within the model, the baseline and future recycling waste flows were calculated as a product of three variables:

- **service coverage**, defined as the percentage of all Finnish households (or businesses) with access to the collection service;
- **yields per household** (or per business), defined as the mass of a certain material fraction arising in a single household's collection stream each year, and measured in kg/hh/yr (or kg/bus/yr); and
- **reject rates**, defined as the percentage of waste collected through recycling streams which does not end up getting recycled.

In the baseline, data (described in Section A.2.2.1) was used to inform each of these variables and 2015 data regarding national waste flows was used to calibrate the model.

In the future options, each of these data points was revisited and benchmarked against other waste management systems in Europe, with consideration for the system already in place in Finland, in order to obtain recycling waste flows compliant with future municipal waste recycling targets. The recycling waste flows in each option were then taken away from the baseline total waste arisings to leave behind the waste still destined for residual treatment.

In so doing, these models determined the quantity of each material type collected, the route by which they were collected, and the final destination of each of these materials, either to a residual treatment plant or a recycling reprocessor.

The material fractions modelled were:

- biowaste,
- paperboard/cardboard,
- glass,
- metal,
- paper,
- plastic, and
- other material.

The last fraction (other materials) is a catch-all for a variety of other waste streams (including textiles, batteries, electronics, etc.), both recyclable and non-recyclable. It is a necessary approximation in the waste flow modelling given the resolution of the composition data available. In terms of collection sources, those considered were:

- household door-to-door,
- bring sites,
- recycling stations,
- campaign collections,
- Deposit Return System (DRS), and
- commercial door-to-door.

All modelling was done at a national level, however we acknowledge the many of these variables (composition, yields of recycling, total waste arisings) will vary for different municipalities (based on their housing types, rurality, demographics, etc.). Using data and assumptions from Finland and other countries in Europe, it would be possible to develop a model and investigate this at a more detailed level (e.g. regional or municipality); this could form the basis for additional research.

A.2.2 Waste Flow Modelling Assumptions

This section contains waste flow modelling assumptions for:

- baseline data (Appendix A.2.2.1);
- the future scenarios (Appendix A.2.2.2); and
- material incomes and treatment costs (Appendix A.2.2.3).

A.2.2.1 Baseline Data

Firstly, to the extent possible with the data available, the baseline performance of Finland's municipal waste management system in 2015 was replicated in the model. Modelling in this way, as described in the methodology section (A.2.1), required a synthesis of data from a wide variety of sources, of which the quality and quantity limited the precision of the model.

Baseline coverage of door-to-door collection services was calculated as a percentage of all Finnish households (including all housing types, i.e. apartments, row houses, single houses, etc.), determined separately for each waste fraction (see Table 6). The data largely came from an analysis of waste regulations in each municipality, although an assumption of 35% was used for coverage of other material and of plastic waste, in line with the average for the other waste fractions.

Plastic waste collections, although relatively new in Finland, do exist and are growing in coverage. The coverage figure used here (shown in italics) is higher than what was occurring in Finland in the baseline year for waste flows (2015). However, we model this because it can be thought of as a business-as-usual figure, relevant to the timeframe in which major decisions will be made. The figure was consistent with a packaging waste coverage estimate provided by RINKI. Including a 'current' coverage for plastics is important for the cost modelling presented in Section A.3.0 below, so that we do not penalize the future options by including cost of collections that have already been or are being rolled out at the moment; and the tonnages can be calibrated to still match the 2015 figures and recycling rate.

Regarding the paper coverage, we are aware that the Waste Act requires paper producers to provide collections to households in certain areas from a reception point provided by the property holder. The coverage figure in Table 6 may therefore seem low, but it is based on a strict reading of this legislation. The assumptions detailed here are aligned with the data provided to Eunomia by SYKE which are, in turn, based on the Waste Act requirements above. They assume 100% coverage for all apartment blocks and row houses, but 0% coverage for single houses, amounting to 49% overall. We acknowledge that since the coverage is based on the legislation rather than the actually number of households receiving collections, they may in fact be under-stating coverage.

Better data would need to be made available by the producers delivering the collections in order to improve the accuracy of the modelling.

The coverage for other recycling collection sources (i.e. bring sites, recycling stations, etc.) and for residual waste collections was assumed to be 100%.

Table 6: Baseline Door-to-door Coverage Data

Material	Household Coverage
Biowaste	44%
Paperboard / Cardboard	27%
Glass	23%
Metal	25%
Paper	49%
Plastic	*35%*
Other	35%
Residual	100%

Baseline reject rates for collected source-separated waste were taken directly from published Statistics Finland data, and are shown in Table 7.[10] These numbers reflect the percentage of source-separated waste that does not end up being recycled, and can be a result of contamination, imperfect sorting, or market forces.

We note that some of these figures seem unexpectedly high. Indeed, improving reject rates forms the basis of one approach to improving recycling rates, as described in Appendix A.2.2.2.

For example, the paperboard / cardboard reject rates are higher than would normally be anticipated. However, no alternative data sources are available in Finland at this time, and these values are used in the nationally published recycling rate, so in order to calibrate the baseline we use the same.

Similarly, the plastic reject rate is above what we would expect to see. It is worth noting that this data precedes the wider introduction of separate plastic collections for household recycling. It is only based on the 42 kt collected in that year, most of which would have been collected for energy waste. However, as for paper, in order to replicate

[10] Espo, J. (2016) *Waste Treatment in 2015*, accessed 25 September 2018, https://www.stat.fi/til/jate/2015/jate_2015_2016-12-20_tau_001_en.html

the baseline recycling rate for 2015 (and in the absence of alternative data sources), it was necessary to accept and use these figures.

This is slightly inconsistent with the business-as-usual approach used for the plastics coverage above because the context here is slightly different. However, while it is possible with coverage to calibrate waste yields per household to match the baseline overall, reject rates cannot be calibrated in the same way because of how they affect the overall recycling rate.

For both paperboard/cardboard and plastics, better data be needed in order to understand exactly what is currently being recycled and rejected. And improved data reporting system, as discussed above in the context of the policy options (Appendix A.1.1.4), for example would mean that materials are traceable through the collection and recycling process, and issues regarding contamination and rejects can be addressed specifically where and when they arise. In the absence of this sort of information, we make general assumption based on the high-level data provided.

Table 7: Baseline Reject Rates

Material	Reject Rate
Biowaste	6.4%
Paperboard / Cardboard	15.1%
Glass	9.2%
Metal	0.0%
Paper	0.0%
Plastic	88.6%
Other	35.0%

Material yields came from a variety of sources. For example, the capture associated with Finland's DRS was taken directly from the organisation's website. Many of the other household yields were guided by previous analysis carried out by the Finnish Ministry of Environment,[11] itself a collection of data from a number of different sources.

In addition, the lack of data available regrading yields of campaign collections meant that these were not modelled explicitly in the baseline (and future options). In other words, the tonnage is included in the model since it contributes to the overall recycling rate in Finland, but it was not clear from the data provided where this tonnage is classified and

[11] *Municipal Waste Recycling Model,* 2018. Sahimaa, O. Ministry of Environment, Finland.

what materials it covers; it is likely that it is included in the 'other' tonnage collected door-to-door. This was not deemed of detriment to the accuracy of the model since these campaigns largely involve collections of more minor waste streams and would likely be modelled with consistent performance in future options. However, if data were to become available regarding the performance and logistics of these campaigns, it would be interesting to fully analyse how they could work in the context of the future scenarios.

Finally, published data from Statistics Finland was used to calibrate the baseline tonnages of waste collected and disposed to recreate the 2015 municipal waste recycling rate of 40.6%. The baseline municipal waste flows are summarised in Table 8. This shows the total amount of MSW reported as recycled and disposed of by Finland, including commercial waste from commerce and business.

Table 8: Baseline Waste Flows Replicated (t/yr)

Material	Recycling	Residual	Total
Biowaste	341,234	508,635	**849,869**
Paperboard / Cardboard	207,370	176,668	**384,038**
Glass	76,977	38,947	**115,924**
Metal	114,371	44,715	**159,086**
Paper	272,302	123,905	**396,207**
Plastic	4,777	327,685	**332,462**
Other	94,534	405,959	**500,493**
Total	**1,111,565**	**1,626,514**	**2,738,079**

A.2.2.2 Future Assumptions

In order to model future scenarios, a number of assumptions were made on how Finland's waste management system could evolve.

Assumptions regarding overall coverage are shown in Table 9. The baseline figure is an average of all recycling streams, derived from the data shown in Table 6. Future expansion of door-to-door collections applies equally to all recycling streams, and for households was informed by rurality data, considering that collections from the most rural parts of Finland is challenging. This 83% coverage in the 55pc scenario is roughly based on the fact that 17% of Finnish households occur in the two most rural categories according to 2018 data.[12] Based on the waste flow modelling undertaken, it was determined that 55% recycling could be achieved without providing relatively resource-intensive door-to-door collections to these households.

Similarly for 65pc the door-to-door collection system is expanded to include all but the most rural households, such as those that live in Lapland. The limit of this expansion was guided by the same rurality data used in the 55% scenario, but now only excludes only the most rural category.

The details of which households would be covered in which municipalities is beyond the scope of this project, but the overall message is that the coverage of door-to-door collections needs to increase significantly relative to the current collections. In particular, collections need to expand to include more row houses and single houses than it currently does. In order to reach the targets, only the most rural municipalities, or the most rural households within municipalities, can be excluded from the collections offered, and we assume that the coverage needs to increase more to reach the 65% target than the 55% target.

Table 9: Door-to-door Coverage of Household Recycling Collections

Scenario	Baseline	55 Percent	65 Percent
Average Coverage	49%	83%	94%

The same collected yields (kg/hh/yr) are assumed for each collection system (i.e. multi-stream, three-stream, two-stream, etc.) because benchmarking in other countries suggests this is similar irrespective of the exact system in place. Yields were further calibrated by comparing capture and recognition rates with those observed in other established door-to-door collection systems. The yields and capture rates modelled in the baseline and both future options are presented in the results sections below.

A sensitivity regarding the material actually recycled under a co-mingled system is explored in A.2.4. Again, assuming the same yield for all households in Finland is a simplification – there will be differences based on demographics, for example, but not enough data is available to model at this level of detail.

Improved reject rate assumptions, shown in Table 10, were informed by experience of municipal waste management systems elsewhere in Europe, and the figures typical in more established recycling markets. In particular, we note that the reject rate for plastics is particularly high in the baseline (see discussion above in Section A.2.2.1 and Table 7), and the change in the future options is the most significant. The same reject rates are applied to all collection sources.

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[12] 2018 data from the National Land Survey of Finland via the Finnish Environment Institute working with METLA, MMM, MML, VRK, and Statistics Finland. Data provided by SYKE.

Table 10: Baseline and Future Reject Rates

Material	Baseline	55pc	65pc
Biowaste	6.4%	6.4%	
Paperboard / Cardboard	15.1%	3.0%	
Glass	9.2%	3.0%	
Metal	<0.1%	3.0%	
Paper	0.0%	1.0%	
Plastic	88.6%	15.0%	
Other	35.0%	35.0%	

The Finnish DRS already performs well across the country so no change was modelled in any future options. The overall tonnage was assumed to be constant in both future options, although future work could look to incorporate waste growth in line with household growth projections.

A.2.2.3 Treatment and Disposal Cost Modelling Assumptions

In the current waste management system, the PROs responsible for the collection of recycling also manage the material after collection. This means that they pay any relevant gate fee or receive any income from the sale of materials. In the current modelling, we are interested in the total system costs, which includes the costs of both recycling treatment and residual disposal.

Material treatment costs vary with collection system because of the level of sorting required and the quality of secondary stream produced. For example, a fully co-mingled system (where all materials are mixed together for collection and then separate again in a sorting facility) requires more sorting than a multi-stream system (where materials are collected in separate compartments on the vehicle); the different collection systems modelled are discussed in more detail in Section A.3.0. In particular, the glass produced from this sorting rarely achieves the same price when sold than glass that is separately collected due to the degradation in quality as a result of the processing. The assumptions used for material values (Table 11) and sorting costs (Table 12) are detailed below.

Table 11: Household Door-to-Door Collected Material Costs (+ve) and Incomes (-ve). Units: €/t. See Section A.3.0 for Definitions of the Collection Systems Modelled

Collection System	BL	1	2	3	4	5	6

Collection System	BL	1	2	3	4	5	6
Biowaste	92	92	92	92	92	92	92
Paperboard / Cardboard	-80	-80	-80	-80	-80	-80	-80
Glass	-13	-13	-13	-13	-13	0	0
Metal	-100	-100	-100	-100	-100	-100	-100
Paper	-100	-100	-100	-100	-100	-100	-100
Plastic	-77	-77	-77	-77	-77	-77	-77
Other	0	0	0	0	0	0	0
Residual	143	143	143	143	143	143	143

Table 12: Household Door-to-Door Collected Material Sorting Costs (€/t, +ve = cost); See Section A.3.0 for Definitions of the Collection Systems Modelled

Collection System	BL	1	2	3	4	5	6
Biowaste	0	0	0	0	0	0	0
Paperboard / Cardboard	0	0	0	0	23	23	130
Glass	0	0	0	0	0	25	130
Metal	0	0	0	100	100	100	130
Paper	0	0	0	0	23	23	130
Plastic	0	0	0	100	100	100	130
Other	0	0	0	0	0	0	0
Residual	0	0	0	0	0	0	0

The material value of plastic (Table 11), specifically, was calculated by taking an average value of the main plastic types recycled in Finland. This includes the valuable bottles obtained through the Finnish DRS, as well as other less valuable plastics (e.g. pots, tubs, trays) obtained through the kerbside system. The quality of the waste flow data did not justify the separate modelling of bottles from the rest of the plastic stream. This figure is in line with market averages in recent years.

The values in Table 11 and Table 12 only apply to material collected from households in the door-to-door system. Baseline (BL) costs are applied to all non-door-to-door waste because we assume waste continues to be collected separately for each stream. Recycling stations, for example, will continue to collect source-separated waste.

Given that details of commercial waste collections are beyond the scope of the modelling in this phase of work, secondary materials produced from commercial collections were assigned material values of €0/t. In reality, the same logic regarding the impacts of waste fraction mixing on material values and sorting costs holds true for commercial waste as it does for household waste, and it is anticipated that the cost differences in the commercial collection system will be passed on to businesses directly. In other words, we would assume that the changes to material incomes and gate fees from commercial waste is passed through to the customer via the pricing mechanism for these waste collections. As discussed in Section 2.3, not evaluating these impacts is undoubtedly a limitation of the study. Future work should look to gather data on commercial waste operations and seek to quantify the possible impacts of higher recycling, although the detail of modelling pricing mechanisms of commercial waste operators is likely to be a complicated exercise and future work should initially focus on whole system costs as we consider here for household waste.

A.2.3 Results

In this section, the results of the waste flows modelling for the two future scenarios are presented. Summary results are contained in Section 3.0 of the main report, and this section contains more detail:

- First, each of the future recycling rate scenarios are explored in detail in Appendices A.2.3.1 (55pc) and A.2.3.2 (65pc), presenting the waste flows modelled and describing the changes made to reach the recycled tonnages required.
- Then, key parameters for households and sorting station performance are presented in Appendix A.2.3.3, alongside baseline figures for comparison.

A.2.3.1 55 Percent

Reaching 55% recycling in Finland requires a 14.4 percentage point increase on current performance. The majority of this increase is modelled as arising from three main areas:

- reducing reject rates of separately collected materials,
- replacing much of the existing low-performing bring site coverage with higher-performing door-to-door coverage, and
- improving performance of recycling stations (container parks).

The reduction of reject rates is most significant for plastics and for paperboard/ cardboard. Applying European average reject rates results in an increase in recycling of over 2 percentage points from the baseline performance. We understand that there is a level of debate as to the baseline figures but, as discussed in Appendix A.2.2.1, no alternative data sources are available. As such, improving reject rates remains the sensible first step in improving municipal recycling rates.

Coverage of household recycling was increased from 49% to 83% (Table 9), displacing the bring site network in the newly covered areas. As a general starting point, we assume that new households that are offered door-to-door collections behave in a similar way to existing households, and therefore the yield of recycling would be similar. For some fractions the yields were then adjusted up or down based on the waste composition and arisings.

For example, some yields (e.g. paper) were adjusted down if there was not enough recyclable material in the mixed waste stream. On the other hand, some were adjusted up where current performance was low (e.g. plastics) under the assumption that more complete and cohesive recycling services available to households, supported by coherent communications campaigns nationally, would result in better performance.

In the case of biowaste, collection coverage increases by almost 40 percentage points (from 44% in the baseline, Table 6, to 83% in the 55pc scenario, Table 9) but yields per household are assumed to remain constant. This assumption was made for two reasons:

- Firstly, based on the available data, it looks like biowaste yields per household are already relatively high when compared to elsewhere in Europe. To assess whether this would be likely to increase further with the wider roll-out of door-to-door collections, a more detailed analysis would need to be undertaken on the split of food waste and garden waste in the biowaste stream.[13]
- Secondly, the yield would only likely be increased by way of communications campaigns, which are more efficient to carry out on larger scales. So, the coverage was expanded at 55% and yield improved at 65%. Although both could conceivably be carried out at 55%, and the implementation of PAYT may also have a positive impact on yields, this was not necessary to reach the targets given the other actions taken in this scenario. However, it is worth noting that implementing both simultaneously could provide an alternative route (not modelled here) to achieving future recycling rate targets.

Overall, the yields modelled are in line with other well performing systems in Europe, within the limits of what is available in the waste arisings based on Finnish compositions.

Finally, a performance floor is introduced for recycling stations nationwide, assuming that all sites begin to capture at least 75% of each waste fraction, with the exception of 'other' materials which is capped at 50% due to the unknown nature of this waste. Where captures are already higher, they are maintained. Details of the capture rates for

[13] More rural, single houses, for example, are likely to yield more garden waste than row houses in urban areas. Analysis of this kind may be of interest in municipality-specific modelling, but is not possible at the high-level undertaken here.

each material in the baseline compared to the future scenarios are shown in Table 16 in Appendix A.2.3.3 below.

Overall, this increases the recycling rate at sorting stations from 60% to 66%. High performing recycling stations across Europe can be used as examples for this type of performance, and there are relatively straightforward measures that can be taken to achieve this. For example, we have included costs for improving signage, expanding the range of materials accepted, and additional staff to meet customers and enforce recycling policies. Sometimes, significant site redevelopment will be required. The costs of these initiatives are explored further in Section A.3.4.2.

The final waste flows for this scenario are shown in Table 13, compared to the equivalent for the baseline shown in Table 8 above, and again shows the modelled total amount of MSW recycled and disposed of by Finland. The overall capture rates of each fraction (a slightly different representation of these same tonnage results) are shown in Table 17, compared to the current baseline and 65pc scenario.

Table 13: 55pc Final Waste Flows Modelled (t/yr)

Material	Recycling	Residual	Total
Biowaste	486,644	363,255	**849,869**
Paperboard / Cardboard	265,398	118,640	**384,038**
Glass	93,851	22,072	**115,924**
Metal	116,225	42,861	**159,086**
Paper	295,412	100,795	**396,207**
Plastic	113,036	219,426	**332,462**
Other	135,378	365,116	**500,493**
Total	**1,505,943**	**1,232,135**	**2,738,079**

A.2.3.2 65 Percent

Reaching 65% municipal waste recycling requires a 24.4 percentage point increase on current performance, and a further 10 point recycling increase on the 55% scenario. The changes listed in this section are assumed to be additional to the changes made above to reach 55% recycling, given that 55% recycling is a necessary step en route to achieving 65% recycling. The additional performance in this scenario arises from three main areas:

- further geographical expansion and improved performance in household door-to-door collection system,
- performance improvement at recycling stations, and

- greater enforcement and sorting imposed upon commercial premises.

Firstly, as discussed in Section A.2.2.2 above, coverage of household recycling was increased from 49% to 94%, displacing the bring site network in the newly covered areas. Greater capture is also modelled within this door-to-door collection system. The introduction of a weight-based pay-as-you-throw system, as explored in Section A.1.0, will be the main driver in achieving this additional performance, but a level of improvement would also be expected just from residents acclimatising to the new system with the support of continuous (but varied) communications.

As with the 55pc scenario, the recycling rate at sorting stations is further increased to be in line with the best performing facilities in Europe. The overall recycling rate is modelled at 75% (from 60% currently, and 66% modelled in the 55pc scenario), meaning that the capture rate of each fraction is increased above this level to account for the large amount of 'other' materials that cannot be recycled.

Finally, as discussed in Section 2.3 of the main report the levels of recycling within commercial premises is increased significantly in this scenario, bringing performance in line with that of households in Finland. Realistically, it is probably easier to enforce more stringent requirements to sort upon, and achieve higher recycling rates with businesses than with households. However, given the lack of data around the management of commercial waste in the free-market system, performance was only levelled with households to remain conservative. It is worth emphasising that this approach is a product of data limitations rather than what may be most effective (and most cost-effective) in reality. Going forward, more precise data gathering in this area should be prioritised in order to properly ascertain the possible impact of these measures.

The final waste flows for this scenario are shown in Table 14, compared to the current baseline waste flows in Table 8 and the 55pc modelled waste flows in Table 13.

Table 14: 65pc Final Waste Flows Modelled (t/yr)

Material	Recycling	Residual	Total
Biowaste	607,940	241,929	**849,869**
Paperboard / Cardboard	290,296	93,741	**384,038**
Glass	102,393	13,530	**115,924**
Metal	121,333	37,753	**159,086**
Paper	341,654	54,553	**396,207**
Plastic	152,111	180,351	**332,462**
Other	164,024	336,469	**500,493**
Total	**1,779,751**	**958,328**	**2,738,079**

As part of this scenario, a greater level of recycling in the 'other' waste fraction was required. It is likely that textiles, WEEE, and other recyclables make up some of this stream, but with little data to back this up, this assumption remains a weakness in the modelling – as previously stated, one of the first steps in waste flow modelling is to work out what the waste is actually composed of. This issue can be resolved by carrying out more frequent and more detailed composition studies, and as performance improves, this will become increasingly pressing for Finland. It is worth noting, though, that this is a problem globally, and many nations will have to do the same as the world approaches a more circular economy.

A.2.3.3 Parameter Results

Hereunder, Table 15, Table 16, and Table 17 show results for some of the key parameters underpinning the household and sorting station performance modelled. These reflect the current baseline data as well as the modelling results for the 55pc and 65pc scenarios. The full results for each of the future scenarios are explained in more detail in the preceding sections.

The household yields in Table 15 are an indicative output, calculated by the model. This table shows the kilograms per household receiving a door-to-door collection (referred to as coverage) per year. As discussed in the sections above, the yields is combined with an increase in coverage in each option to produce the total tonnes modelled. The yields were used as key parameters against which performance could be calibrated.

In most cases the yields increase as the modelled recycling rate increases. Where this is not the case (e.g. paper), this is due to limitations in the waste composition. In other words, there is not currently enough paper in mixed waste to assume the paper yield in the future scenarios the same as in the baseline; the increase in coverage alone would have resulted in negative tonnes of paper in mixed waste. Therefore, the yield is assumed to decrease slightly under the assumption that new households being given door-to-door collections produce less paper than those that already have collections.

This is slightly counterintuitive, because the new households being given collections are mostly single houses, which we would expect to have larger families than the flats and row houses that already have collections. Therefore there may be an issue with the baseline data – as discussed above it may be that the baseline coverage for paper (49% in Table 6) is incorrect. More and better data would be needed to correct this. However, although some of the variables may be incorrect, the overall tonnes have been calibrated based on the composition such that the error is likely to be small.

Table 15: Yield (kg / covered household / year) of Door-to-Door Collections

Waste Fraction	Baseline	55pc	65pc
Biowaste	137	137	141
Paperboard / cardboard	26	41	47

Waste Fraction	Baseline	55pc	65pc
Glass	11	15	15
Metal	4	8	9
Paper	116	100	90
Plastic	6	24	30
Other	0	26	24

Table 16 shows the capture rate of each waste fraction at sorting stations. The capture rate is defined as the percentage of waste arising that is recycled. The baseline figures in Table 16 are based on a SYKE analysis of waste flows from three different recycling station datasets from 2015, in combination with a compositional analysis for the mixed waste collected. Some of these values look lower than we might expect for the baseline (e.g. 14% for paperboard/cardboard, 7% for glass, 0% for paper). However, this is based on the calibrating the nationally published statistics, so again a better data capture system might need to be put in place to understand exactly what is currently happening at sorting stations across Finland. In the future scenarios, again, these parameters were used to improve and calibrate performance against other waste management systems internationally.

Table 16: Capture Rates of Each Fraction at Sorting Stations

Waste Fraction	Baseline	55pc	65pc
Biowaste	98%	98%	98%
Paperboard / cardboard	14%	75%	89%
Glass	7%	75%	96%
Metal	90%	90%	90%
Paper	0%	75%	83%
Plastic	0%	75%	82%
Other	50%	50%	65%
Overall	**60%**	**66%**	**75%**

Finally, aggregate capture rates are presented in Table 17. This is a different representation of the total tonnage results presented Table 8, Table 13, and Table 15 for the three options respectively. Here again, the baseline figures are taken directly from

Statistics Finland data. These outputs were used more indicatively, to calibrate the model rather than to amend performance.

Table 17: Overall Capture Rates of Each Fraction from Household Collections

Waste Fraction	Baseline	55pc	65pc
Biowaste	44%	72%	82%
Paperboard / cardboard	46%	62%	76%
Glass	76%	88%	92%
Metal	68%	74%	77%
Paper	79%	88%	88%
Plastic	11%	37%	49%
Other	26%	41%	50%

A.2.4 Co-mingled Sensitivity

This section presents a co-mingled sensitivity, where we test what might happen if recycling materials were collected mixed together in one bin instead of separated into multiple streams:

- Section A.2.4.1 presents the methodology and assumptions; and
- Section A.2.4.2 presents the results.

A.2.4.1 Methodology and Assumptions

In contrast to the largely source-separated dry recycling system that exists in Finland today, co-mingled dry recycling collection systems are associated with higher contamination rates and higher reject rates. This section illustrates how these properties of co-mingled collection systems might impact upon final recycling rates, for the same levels of material capture. These are important considerations when assessing the different collection systems analysed in Appendix A.3.0.

Contamination refers to material that is collected in the recycling bin that is not recyclable. For example, contaminating material may be wrongly identified as recyclable by the resident, or simply placed in the wrong container for collection. It also refers to target material that is no longer recyclable due to being contaminated, for example paper that is wet from food or drink waste (e.g. the remains of drinks in bottles, or food in tins) and therefore cannot be recycled. Data from other European countries where such systems are more common suggest that as more waste fractions are co-mingled, more contamination is collected.

In addition to non-target material being collected, sorting is an imperfect process. The objective of sorting is to separate the contamination from the recyclable material, but often also results in the removal of some target or recyclable material from the waste stream. In other words, the imperfect nature of the sorting process results in some recyclable material being disposed of as rejects, or sorted into the wrong product stream, after the sorting process. For example, in fully co-mingled systems, small pieces of glass often end up mixed with the paper and other products sold by the sorting facility. This results in some recycling streams obtained from co-mingled collection systems being of lesser value than the source-separated equivalent (see Section A.2.2.3).

These considerations were dealt with in a sensitivity for both future scenarios, informed by experience of co-mingled systems in the UK. In the results below, the 'core scenario' represents the fully source-separated system prevalent in Finland today. In the main report, the central results for the future options assume that the same amount of waste is recycled independent of the collection system and how many material streams are mixed for recycling – here is test what might happen if this were not the case.

Thus the core scenario is compared against a 'co-mingled sensitivity' where all dry recycling is collected together in a single container, and contains more contamination as discussed above. In addition, this sensitivity results in more material being rejected due to the imperfect nature of sorting.

Both options assume the same capture rate of targeted materials at the point of collection, but alternative contamination and reject rates are used (Table 18). These assumptions are applied to the dry recycling waste flows of both the 55% and 65% scenarios, and resulting changes to overall municipal recycling rates are presented.

Table 18: Co-mingled Assumptions

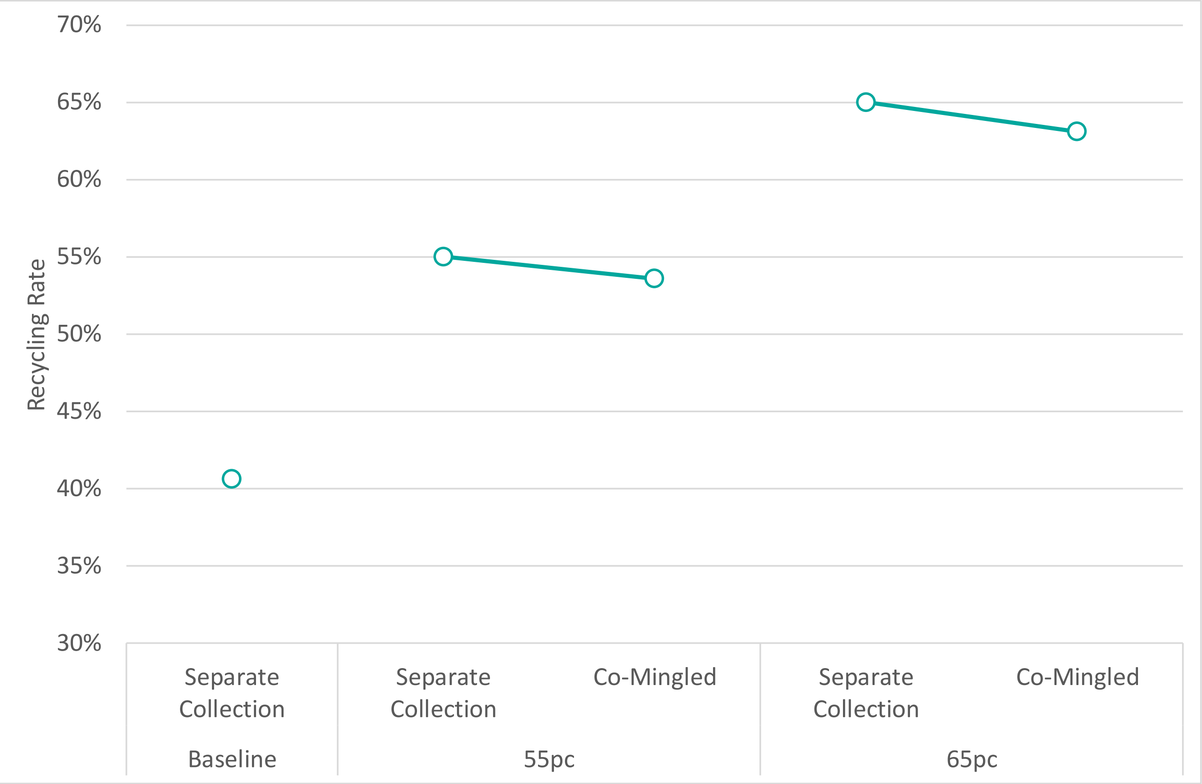
Sensitivity	Core Scenario	Co-mingled Sensitivity
Contamination Rate	0.0%	10.0%
Average Reject Rate	10.0%	15.5%

These sensitivities aim to illustrate the impacts of co-mingled collections on recycling rate, but the associated economic and environmental costs have not been derived in detail. The economic cost differences are incorporated at a high-level in the cost modelling, via the differential sorting costs and material values. However, the differential impact of market trends (such as the recent changes in China) on co-mingled versus separately collected materials are not modelled, but should be considered when making a decision regarding what type of collection system(s) to implement in Finland.

A.2.4.2 Co-mingled Sensitivity Results

Applying these assumptions, typical of a co-mingled system, to the dry recycling waste flows of each core scenario leads to a reduction in overall municipal recycling rate in both scenarios, as illustrated in Figure 9. In the 55% scenario, the modelling of a fully co-mingled dry recycling system results in a recycling rate reduction of 1.4 percentage points, while in the 65% scenario the decrease was slightly greater at 1.9 percentage points. This level of loss of material becomes increasingly important as recycling targets increase.

Figure 9: Recycling Rates in Co-mingled Sensitivities



Although relatively simplistic, this sensitivity clearly demonstrates the risks associated with adopting a co-mingled collection system. These should be considered against the benefits of the system's simplicity. It is possible that this could increase engagement from households, although evidence in other European countries suggests that this does not lead to higher capture rates and this does not outweigh the issues around contamination and rejects. These considerations are beyond the scope of this report.

A.2.5 Limitations

It is worth noting that, as Finnish recycling performance improves, it will become increasingly necessary to address shortcomings in the data as it exists. Priority areas include:

- more detailed compositional analyses and more detailed reporting of tonnages collected and recycled in order to fully understand the recycling potential of material currently categorised as ‘other’;
- more detailed reporting at the regional or sub-regional level such the differences in demographics and rurality can be accounted for;
- improved accounting of waste from more minor collection routes such as street cleansing and campaign collections; and
- improved accounting of tonnages of municipal waste arising from commercial premises.

Such limitations have not held back the high-level modelling carried out in this project, but more detailed analyses would require more detailed data, collected regularly through an improved waste information system. The need for such a system is also addressed in Section A.1.0.

A.3.0 Collections Modelling Technical Appendix

In most countries, the majority of waste collection costs are borne by those operating the residential door-to-door collections. In this work, these costs were calculated using Eunomia's recently updated proprietary model, Hermes2.0:

- Section A.3.1 introduces the methodology used and the options modelled;
- Section A.3.2 presents the key assumptions made; and
- Section A.3.3 contains the modelling results.

Other collection costs were estimated as described in Section A.3.3.2; this includes the other collection sources included in the waste flow modelling (see the methodology described Section A.1.1): bring sites, recycling stations, the deposit refund system (DRS), campaign collections, and commercial collections.

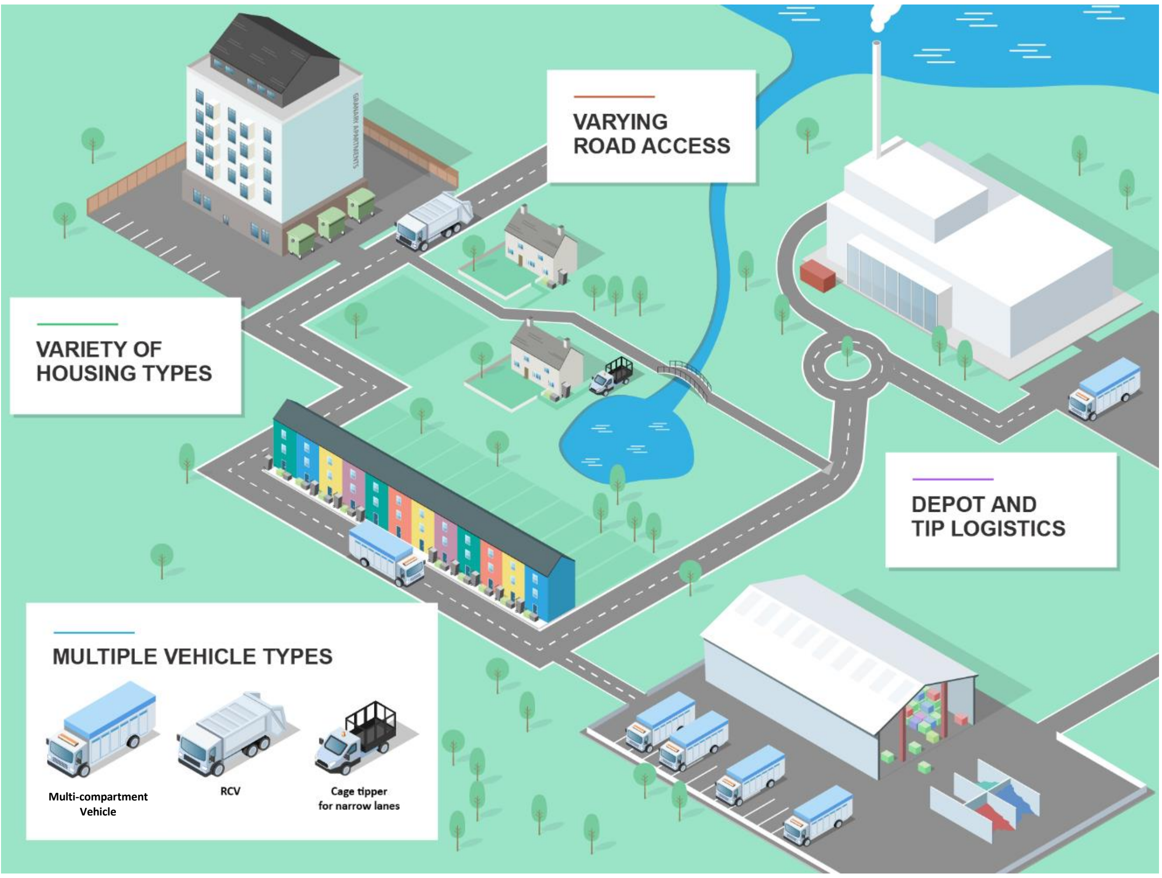
A.3.1 Household Door-to-door Collection Methodology

Eunomia has been using and developing its proprietary waste collection model, Hermes, for approximately 15 years. Hermes2.0 was released in early 2018, and involved a major redesign of the model. Improvements to the model have increased the scope and flexibility, thus increasing the accuracy and allowing the user to model multiple scenarios more quickly and easily than ever before.

The scope of Hermes2.0 is to estimate costs of waste collection from each household to the tip only. This includes the vehicle, staff and container costs directly involved in collection, as well as material incomes and treatment/disposal costs for each waste stream. Infrastructure costs for depots and waste transfer stations can be included where relevant.

Figure 10 shows a graphical representation of the flexibility of Hermes2.0. We are able to model different vehicle types (e.g. multi-compartment vehicles, standard RCVs, smaller/bespoke vehicles for difficult territory), different housing types (e.g. row houses, apartment blocks), varying road access and rurality, and different logistics in relation to the locations of depots and tips. This allows us to build bespoke models for each client, depending on the territory that is in scope for each project. This varies from single municipalities, to groups of municipalities working together, to whole countries – as we are modelling here.

Figure 10: Graphic Demonstrating the Flexibility of Hermes2.0

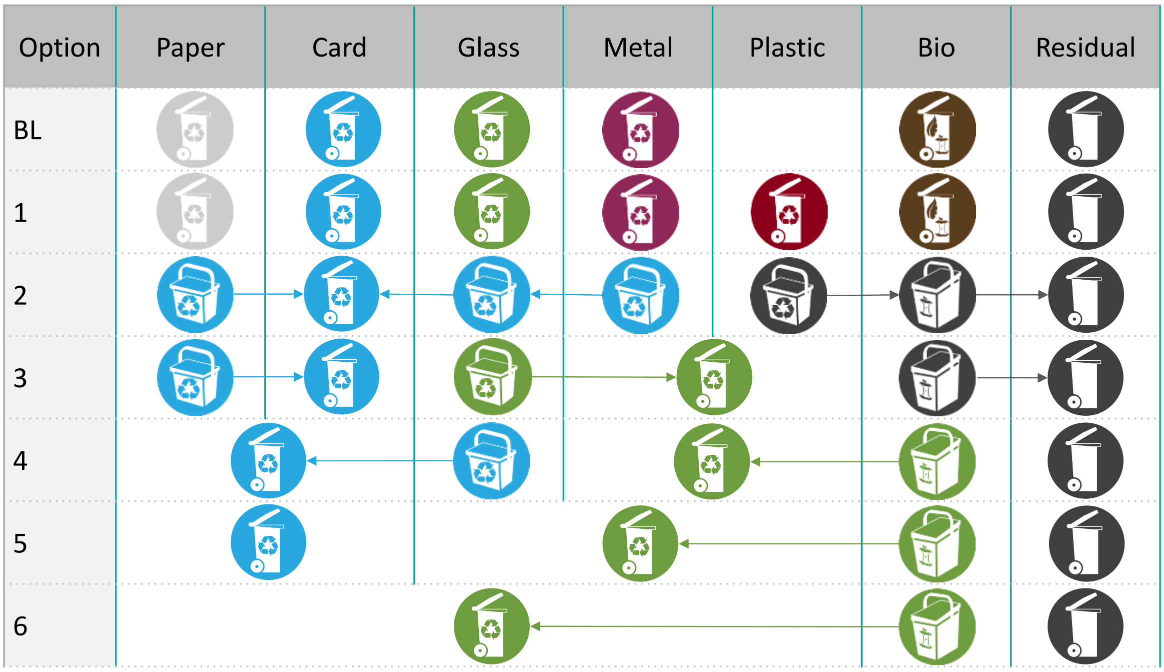


The options modelled are defined in Section 2.1 of the main report. Table 19 and Table 20 show two alternative representations of the list of options. In particular, Table 20 shows which materials are assumed to go into which compartments of the bins.

Table 19: Description of Door-to-Door Collection Options Modelled

Option	Name	Description
Baseline		Separate pass for everything – current (low) coverage
1	Multi-stream	Based on baseline system – higher coverage
2	Four-compartment bin	2 bins with multi-compartments
3	Two-compartment bin	3 bins with two compartments in each
4	Three-stream Recycling	2 two-compartment bins + separate residual bin
5	Two-stream Recycling	1 two-compartment bin + 2 separate bins
6	Co-mingled Recycling	1 two-compartment bin + separate residual bin

Table 20: Pictogram of Door-to-Door Collection Options Modelled Illustrating which Waste Fractions are Collected on the Same Vehicle (by colour) and which are Mixed in the Container (merged cell)



A.3.2 Household Door-to-door Collection Assumptions

The collections costs calculated vary with the system because of different numbers of vehicles and containers required to operate the system. Staff costs are based on those published by Eurostat for transportation and storage HGV drivers and waste management labourers. These are calibrated against staff costs in the categories and waste collection crews in the UK, as the Eurostat values seemed quite high. The total unit costs modelled, including all on-costs such as pensions and social security are €40,000 for drivers, and €35,000 for loaders/operatives.

Table 21 shows the vehicle cost assumptions. The unit capital cost is assumed to be annualised over eight years with 3% interest. In addition, we add just over 13% to cover maintenance, insurance, and any vehicle taxes required to operate collection vehicles.

Table 21: Vehicle Cost Assumptions (€)

	Unit Capital Cost	Annualised Unit Cost
Standard RCV	184k	51k
Two-Compartment	250k	69k
Four-Compartment	300k	82k

The cost of infrastructure requirements such as depots for the collection costs was modelled as an additional 16% of collection costs,[14] and so also indirectly depends on option.

In addition to the operational requirements of the waste management system, the changes required to drive increases in performance in Finland also come at a cost. Increased resident communications are estimated at €1.73/hh/yr and €2.30/hh/yr for 55pc and 65pc scenarios, respectively.

A.3.3 Household Door-to-door Collection Results

This section contains detailed results of the collection modelling undertaken to investigate the impact of changing the style of collection as well as the coverage, in order to reach higher recycling targets:

- Section A.3.3.1 contains the central results presented in the main report, and
- Section A.3.3.2 contains a sensitivity related to the free market collection systems comparted to competitive tendering.

A.3.3.1 Central Collection Modelling Results

Figure 11 show the total annual collection costs modelled for the baseline (BL), 55pc and 65pc scenarios. This includes only the vehicle, staff and bin costs.

Option 1, where the coverage of the current system is expanded to include more single houses in suburban and rural areas close to urban areas, the collection costs increase significantly. This option assumes that a different vehicles is used for each material, since it mirrors the current service where different PROs are responsible for each material and thus there are many fleets of vehicles. Thus the cost increase is not surprising – it is due to the increased number of vehicles and staff required, and the longer distances driven to collect from all these additional households.

Interestingly, the other five options are all similar in cost to the baseline. In all of these options, we assume more cooperation between municipalities and PROs, such that different materials are collected together, either in separate compartments on the same vehicle, or mixed together (co-mingled) into a reduced number of waste streams.

Thus, Option 2 where the same number of streams is collected as in Option 1, but in different compartments on the same vehicle, becomes more efficient than collecting each stream on a separate vehicle. Although the capital cost of each vehicle is higher, fewer vehicles are needed to collect waste in this way compared to Option 1.

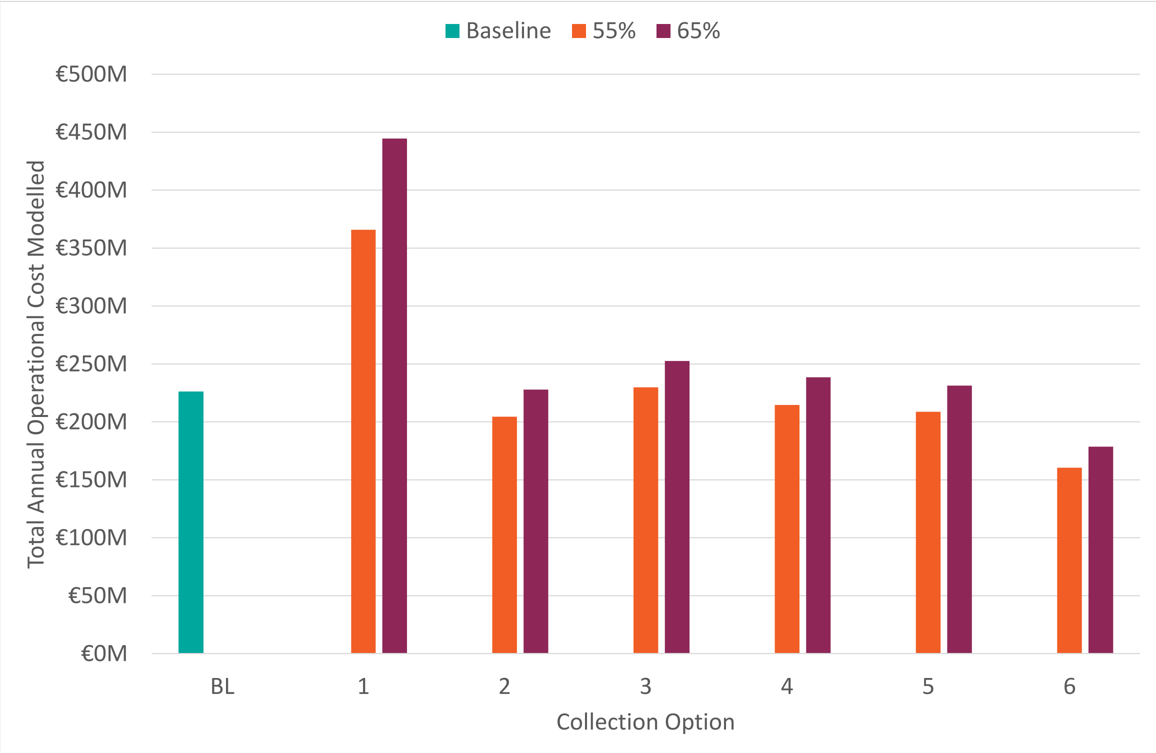
[14] This figure is a standard Eunomia estimate informed by significant experience and expertise in modelling prospective and existing waste collection systems.

In general, the options with more co-mingling of materials have lower collection costs. So from Option 3 to 6 where increasing numbers of materials are mixed together, the collection costs drop. This is because as more materials are mixed, the vehicles and bins need to have newer compartments and thus cost less.

Note that in all options we assume that there are some apartment blocks that will continue to have separate collections for each material on a separate vehicle. This is because they are assumed to have larger (e.g. 1100 litre) bins that cannot be emptied onto the same vehicle as, for example, bins with four compartments. However, some blocks, e.g. with only a small number of apartments, will be able to have the same bins as row houses and single houses, and this can be collected on the same vehicles.

We assume that about 40-60% of apartments can be collected with row and single houses, depending on the rurality. At the low end of the range, 40% co-collection is assumed possible in the urban areas because apartment blocks are generally larger with more people sharing larger bins, while 60% co-collection is assumed possible in more rural areas where apartment blocks are smaller and thus smaller bins can be used. The rest will need separate dedicated collections. The exact split will vary for each municipality, and surveys will need to be undertaken to determine coverage of each system if a service change is implemented.

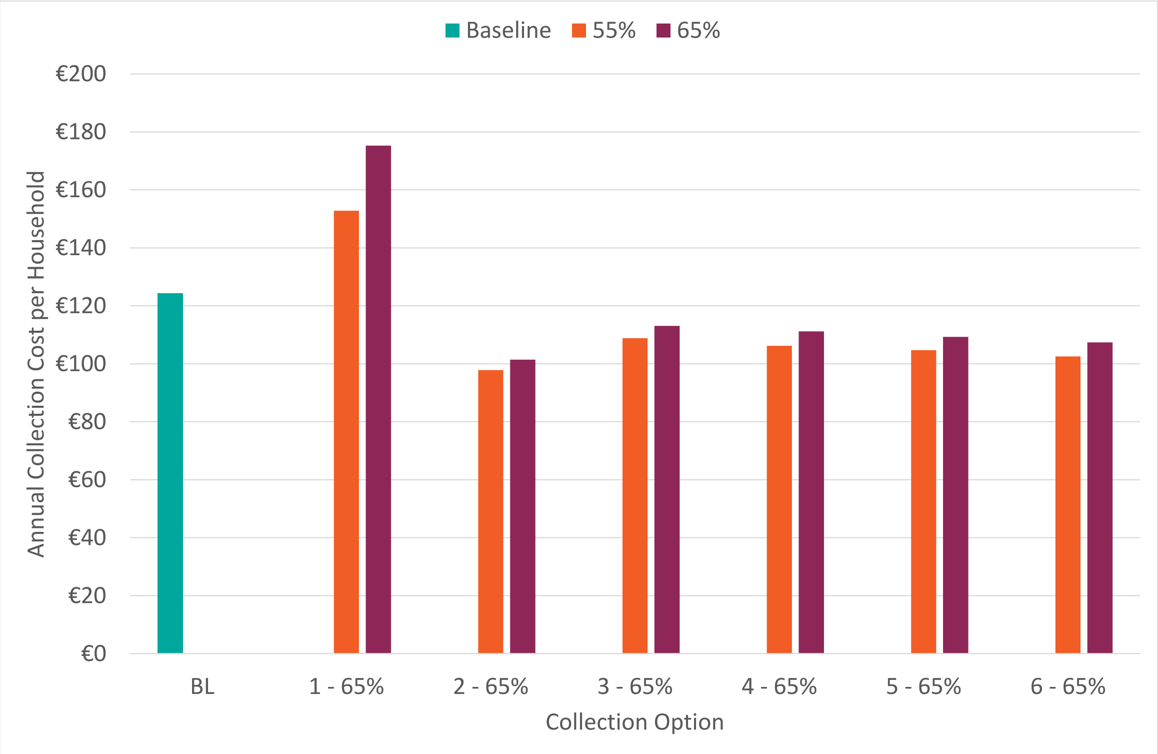
Figure 11: Total Annual Operational (Vehicle, Staff, Bins) Cost Modelled for 55pc and 65pc Options Compared to the Baseline (BL)



Since the results above are only the operational costs, they do not include the cost of sorting the material that is collected mixed together. The cost of sorting is obviously only applied to the tonnage that is collected mixed, but as more materials are mixed together the total cost of sorting increases. In some cases, the value of the materials collected also reduces (see Section A.2.2.3 above for material value and sorting cost assumptions). Therefore, although the collection costs drop as dry recycling is collected more co-mingled, the total cost including sorting remains more constant for each option (2-6).

Figure 12 shows the annual collection cost per household, now also including material incomes, sorting costs, biowaste treatment, and mixed waste disposal. Here we can see that the costs of each of the future collection options, excluding Option 1, are very similar. Thus, the choice of collection system may depend more on local circumstances, and the appetite in Finland to for municipalities PROs to collaborate to the extent of developing the sorting infrastructure required for some of the latter options. Since the costs are similar, it may be more politically palatable to implement one of the options where less co-mingling is required.

Figure 12: Total Annual Collection Cost Cost Modelled for 55pc and 65pc Options Compared to the Baseline (BL)



Similar to Figure 12, Table 22 shows the cost per tonne. Since each household produces just under half a tonne of waste at the kerbside, these values are roughly double those per household. As discussed in Section A.2.2.2, the coverage of bring sites is assumed to reduce as a result of kerbside collections being introduced more widely and waste being collected there instead. Thus the tonnage used in this table increases from 1,353,134 in the baseline, to 1,432,428 in the 55pc options, and to 1,471,126 in the 65pc options.

Although it would be nice to differentiate by waste stream, as was done for the baseline data Eunomia received, this is not possible for the future options where material streams are grouped for collections. When comparing to baseline data in Finland, we must also be careful of scope differences. For example, these values do not include any corporate overhead and profit margin that a contactor working for the municipality may charge.

Table 22: Cost of Waste Collection and Treatment (€/t)

Option	BL	1	2	3	4	5	6
Baseline	270	-	-	-	-	-	-
55pc	-	312	200	222	217	214	210
65pc	-	350	202	226	222	218	214

A.3.3.2 Free-market Inefficiency Sensitivity

Research for the Republic of Ireland indicates that savings of up to 48% can be achieved by changing from free-market collection systems to systems with competitive tendering.[15] These savings arise primarily from more efficient collection routes and reduced spend on vehicles and infrastructure, but the tender process itself is also helpful as it allows municipalities to actively seek value for money. Importantly, this review also found that there was no significant evidence to suggest that cost savings were attributable to reductions in service quality.

The review cites a variety of studies from across the world, but of particular relevance is a Finnish study carried out for the OECD. This indicated that collection costs were 20-25% higher in regions where there was competition in the market as opposed to competitive tendering.[16] Studies from the Republic of Ireland, as another of the more rural Member States, are comparable to the Finnish context. Here it was found that average cost savings of 30% had been achieved by contracting out services to a single provider.

According to KIVO data, 28% of the Finnish population live in municipalities which operate fully privatised free-market systems for collections of mixed waste and biowaste. In addition, another small proportion live in municipalities that operate mixed systems. Therefore, our sensitivity analysis assumed that these efficiency savings could be applied to around 30% of the baseline costs for residual and biowaste collections costs, which were calculated as €179M in the baseline (see Section A.3.3.1).

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[15] Eunomia Research & Consulting (2009) *Costs of Household Waste Collection in Ireland - A Discussion: Annex to the Policy Review*, Report for Department of Environment, Heritage and Local Government, Ireland, July 2009

[16] Darryl R Biggar (2000) Competition in Local Services: Solid Waste Management, *OECD Competition Law and Policy*, Vol.28

Efficiency savings of 20% and 30% were tested, relating to the results detailed above. These resulted in estimated available system cost savings of €11-16M (Table 23).

Table 23: Free-market Inefficiency Sensitivity Results

Sensitivity	Efficiency	Cost Saving (€M)	Case Study
High	30%	16.1	Republic of Ireland
Low	20%	10.7	Finland

If better data became available on the scale of competition present in each of the free-market municipalities, this sensitivity could be refined in the future.

A.3.4 Other Collections

A.3.4.1 Bring Collection Cost Modelling

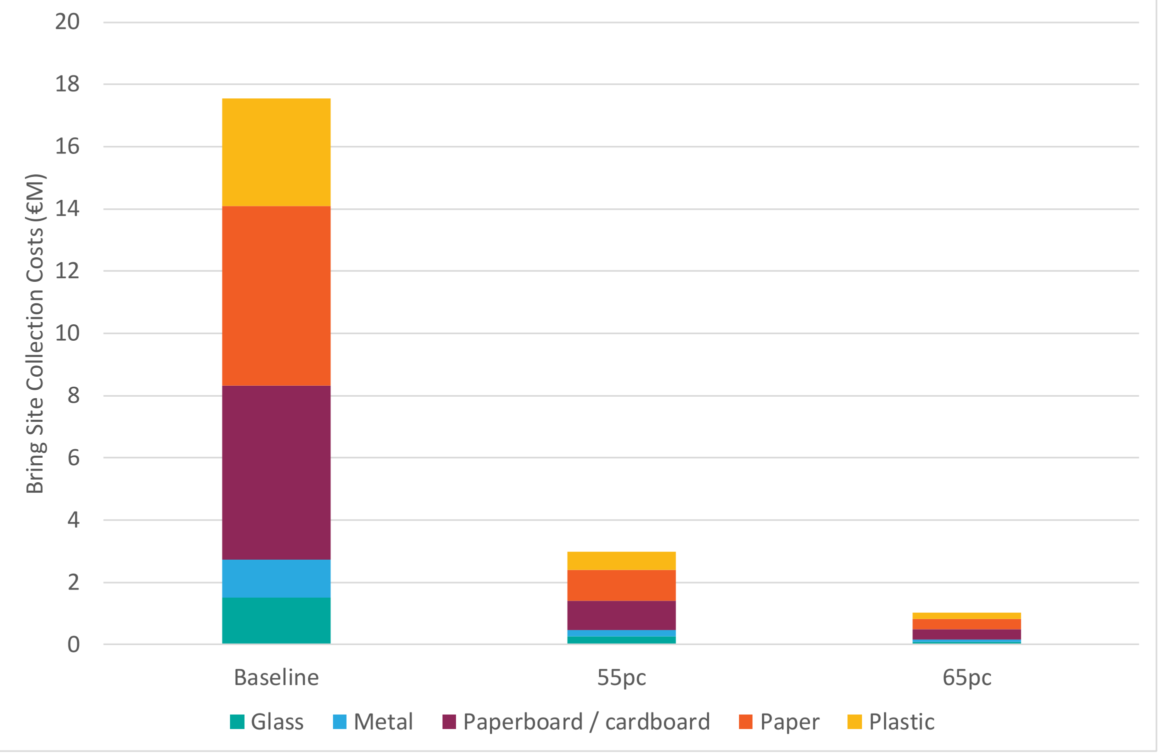
Collections from bring sites were not modelled using as sophisticated a logistical model because of the considerable variability in their collection routes and vehicles, and their relatively low contribution to overall costs. Instead, per tonne assumptions (Table 24) were used to approximate the costs of taking material from a bring site to a tip, taking into account the different densities of each waste fraction.

Table 24: Bring Site Collection Cost Assumptions

Waste Fraction	Collection Costs (€/t)
Biowaste	89
Paperboard / Cardboard	89
Glass	71
Metal	89
Paper	89
Plastic	450
Other	37
Residual	89

These were multiplied by the bring site waste flows in each scenario to get the results detailed in Figure 13. Significant savings are made in collections from bring sites in the future options as the bring site network is mostly replaced in with the higher-performing door-to-door system. Between the baseline and the 65% scenario, these savings total over €16.5M/yr.

Figure 13: Bring Site Collection Costs



The costs of transporting bulked materials from transfer station to disposal facility were excluded from all modelling, primarily because there was not adequate data available to accurately model the typical distances involved. In the absence of that information, it would be impossible to model any significant differences in this area given that overall arisings do not differ in any of the scenarios. This logic also applies to collections from container parks so those were also put out of scope for this phase of work.

Lack of data prevented any modelling of the costs associated with Finland's complicated commercial collection network, whilst the costs of campaign collections and collecting from DRS facilities were also excluded from consideration given that performance was assumed to remain constant across all scenarios.

A.3.4.2 Recycling Station Cost Modelling

A list of bring sites and recycling stations was provided by SYKE. It was not possible to split this into the two types of sites, so an approximation had to be made. To split out the number of recycling stations, we selected only sites that collected hazardous waste, wood, and WEEE, plus at least seven other materials. This was done in conjunction with looking at photographs of sites to check that these assumptions were generally valid. This left just over 200 sites classified as sorting stations – about 2% of the sites on the list.

Upgrading Finland's approximately 200 recycling stations has been calculated at €22.8M and €31.7M for the two future scenarios respectively. This includes costs for infrastructure improvements and additional staff:

- infrastructure changes include improving signage, adding reuse facilities, and some site redevelopments; and
- extra staff are needed to meet and monitor residents as well as to manage commercial waste operations and the sites themselves.

The full assumptions regarding infrastructure investment and staffing are detailed in Table 25 and Table 26, respectively. These assumptions have been informed by similar work undertaken by Eunomia determining national waste policy in Wales.

The costs presented in Table 25 have been annualised to reflect typical public sector funding mechanisms. The salaries detailed in Table 26 are subject to the same 35% on-costs as described in Section A.1.2. The modelling assumes that, unlike the infrastructure improvements, all sites require additional staff.

Table 25: Additional Recycling Station Infrastructure Assumptions

Improvement	Sites Requiring Improvement		Cost (€/yr/site)
	55pc	65pc	
Signage and Small Infrastructure	70%	85%	460
Minor Works	60%	65%	13,208
Major Works	20%	30%	99,063

Table 26: Additional Recycling Station Staff Assumptions

Staff	FTEs Required per Site		Salary (€/yr/FTE)
	55pc	65pc	
Residual Waste Monitor	1.0	1.3	35,000
Meet and Greet	0.5	0.7	35,000
Commercial Waste Manager	0.5	0.7	35,000
Site Manager	0.3	0.5	50,000

A.3.4.3 DRS Cost Modelling

Additional costs, such as the estimated €320M[17] cost of managing Finland's DRS system, were not included in the modelling because they are not expected to change so contribute nothing to the marginal impacts of future options.

A.3.4.4 Campaign Collection Cost Modelling

Campaign collection costs are not modelled, because there is not enough data available on how they are currently operated or the tonnage that they collect. Thus, the assumption is that the cost would remain similar to current costs, although we acknowledge that the waste flow modelling implicitly suggests more tonnage collected via this collection source.

A.3.4.5 Commercial Collection Cost Modelling

As discussed in Section 2.3, although commercial collection costs would likely increase across scenarios as a greater level of waste separation is enforced, it is not anticipated that any additional administrative burden would be placed directly on local or national government. Instead, it is anticipated that additional costs would be passed on to businesses directly through the fees paid per collection, as occurs at the moment. Estimating the costs to businesses is beyond the scope of this project, but would be worthy of investigation in the future. We note that by evaluating collection cost differences from households and not commerce, but including tonnages recycled from both, we are introducing an inconsistency in the model's system boundaries. This is necessitated by the lack of data available on commercial collections.

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[17] (2018) *Deposit-refund system*, accessed 25 June 2018, https://www.palpa.fi/beverage-container-recycling/deposit-refund-system/

A.4.0 Environmental Modelling Technical Appendix

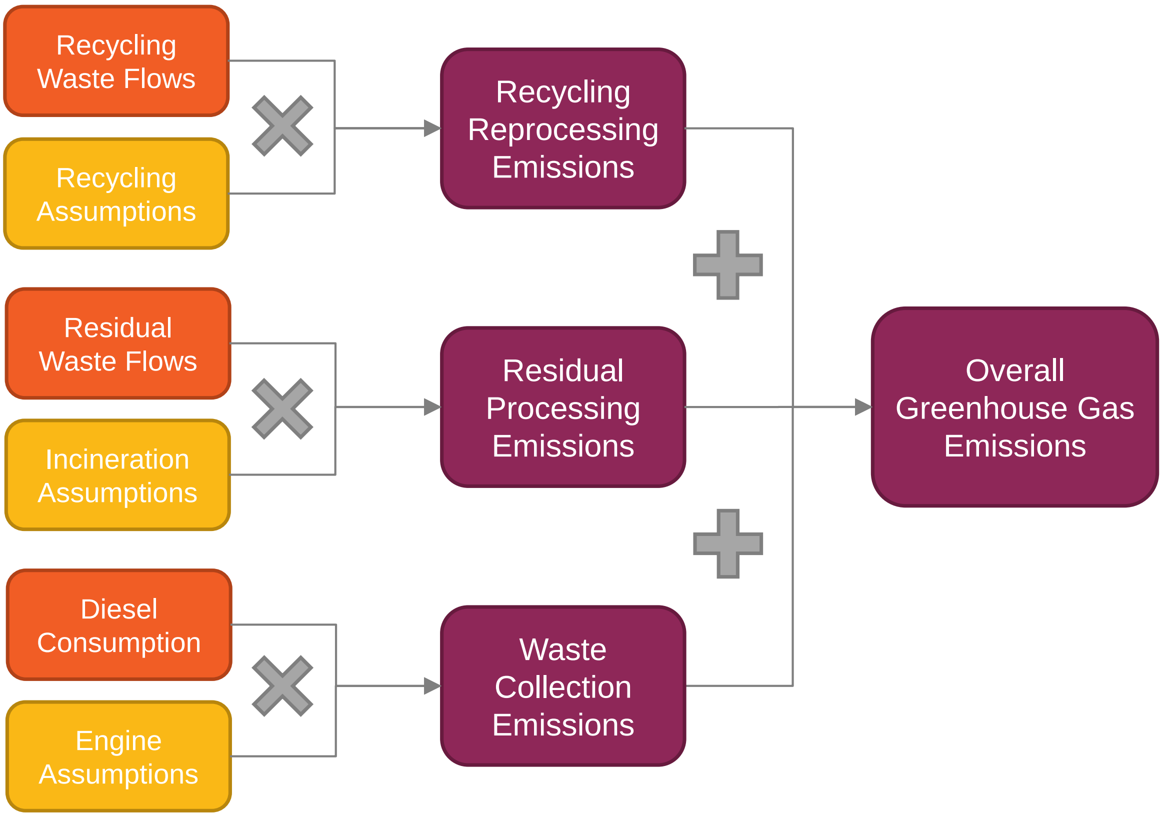
The environmental modelling in this phase of work was limited in scope to account only for the greenhouse gas emissions (GHGEs) from material collection and treatment in each scenario; future work could look to expand this scope to include, for example, air quality emissions. The results are relatively high-level but indicate that achieving higher recycling rates is not only necessary to meet future EU targets but also beneficial from a GHGE point of view.

A.4.1 Methodology

GHGEs were determined as the sum of emissions arising from waste treatment and from waste collection. Waste treatment by recycling results in reduced emissions, by reducing requirements for production of virgin materials. In contrast, waste treatment by residual disposal is not associated with such a reduction. However, where waste is incinerated for energy production, this brings down the need for energy generation by conventional plants (coal, gas, etc.) so a smaller emissions reduction factor is available, depending on the carbon intensity of alternative baseline energy generation in Finland.

Emissions from waste treatment were calculated by multiplying the recycling and residual waste flows by their respective sets of treatment assumptions. These figures, which have been tailored to the Finnish context, are described in full in Section A.4.2. Emissions from waste collection were calculated by multiplying the mean diesel consumption required in each scenario and by a typical emissions factor of a collection vehicle. This approach, summarised in Figure 14, is straightforward and reflects the emissions accounting methodology used by Eunomia during their work to support the European Commission during the derivation of the new municipal waste recycling targets.

Figure 14: Method for Calculating GHGEs



A.4.2 Assumptions

The data and assumptions used in the modelling of GHGE impact of material treatment and of collections are described in this section.

Incineration was the disposal method for around 80% of residual waste in Finland in 2015 and almost 95% of residual waste in 2016, continuing recent trends of displacing landfill as the default waste disposal method. In this modelling, it was therefore approximated that 100% of residual waste in Finland is disposed of by incineration in all current and future scenarios. Further, all of these incinerators were assumed to be generating combined heat and power (CHP).

The assumptions used to model the GHGEs associated with disposal by incineration as well as reprocessing materials, by anaerobic digestion (AD) for biowaste and by recycling for all other material streams, are detailed in Table 27.

Table 27: Material Processing Emissions Assumptions (tCO_2e/t waste)

Waste Fraction	Reprocessing	Incineration
Biowaste[1]	-0.12	-0.14
Paperboard / Cardboard	-0.06	-0.73

Waste Fraction	Reprocessing	Incineration
Glass	-0.20	-0.05
Metal	-2.46	-1.89
Paper	-0.34	-0.66
Plastic	-1.17	0.53
Other	0.00	0.00

[1] The figure given for reprocessing of biowaste is for future scenarios and the baseline sensitivity only - this sensitivity is further explored in Sections A.4.3.

Figures on the benefits of reprocessing are, for the most part, taken from the Scottish Carbon Metric published by Zero Waste Scotland.[18] The source data is based on UK, European and East Asian datasets following a literature review, and is assumed to be generally representative of the current climate change benefits from recycling taking place in Finland.

The assumptions used to calculate the GHGE impacts of waste incineration are summarised in Table 28. Generation efficiency assumptions were obtained from previous work carried out by Finnish specialists LCA Consulting.[19] The figure for electricity demand is taken from CEWEP's survey of 97 facilities,[20] and is in line with data taken from no fewer than 15 UK facilities currently operating.[21] The diesel use figure is taken from a report by the Flemish Institute for Technological Research based upon incinerators operated by Seghers Better Technology.[22] Finally, metal recovery rates are based on a survey of Dutch energy-from-waste facilities.[23] These figures were processed in Eunomia's proprietary incinerator model, alongside assumed baseline carbon intensities of 250 gCO_2e/kWh for heat generation and 200 gCO_2e/kWh for electricity generation, to generate the Finnish carbon factors listed in Table 27.

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[18] Zero Waste Scotland (2011) The Scottish Carbon Metric Carbon Factors, March 2011; Zero Waste Scotland (2013) The Scottish Carbon Metric - A National Carbon Indicator for Waste: 2013

[19] Niskanen, A., and Kemppi, J. (2017) Tool for Calculating the Environmental Impacts and Costs for Household solid Wastes in Different Source Separation Intensities, paper given at Sixteenth International Waste Management and Landfill Symposium, Sardinia, 2017

[20] Riemann I (2006) CEWEP Energy Report (Status 2001-2004): Results of Specific Data for Energy, Efficiency Rates and Coefficients, Plant Efficiency Factors and NCV of 97 European W-t-E Plants and Determination of the Main Energy Results, updated July 2006

[21] Reports available from http://www.ukwin.org.uk

[22] VITO (2000) Vergelijking van Verwerkingsscenario's voor Restfractie van HHA en Niet-specifiek Categorie II Bedrijfsafval, Final Report

[23] Muchova L and Rem P (2008) *Wet or Dry Separation: Management of Bottom Ash in Europe,* Waste Management World Magazine, 9(3)

Table 28: Incineration Assumptions

Parameter	Assumption
Gross Electrical Generation Efficiency	20%
Gross Heat Generation Efficiency	70%
Electricity Demand for Flue Gas Cleaning	78 kWh / t input
Diesel Use by Process	4.7 l / t input
Recycling of Bottom Ash	90%
CH_4 emissions from process	0 kg CH_4 / t
Recovery Rate for Ferrous Metals	70%
Recovery Rate for Non-ferrous Metals	30%

The UK Government has calculated that emissions from diesel consumption from the use of Euro 5 collection vehicles are 2.6 kgCO_2e / L diesel consumed. The differential fuel consumption of each vehicle type was taken into account when calculating the fuel consumption associated with each scenario in Section A.3.0. These figures were multiplied together to estimate the emissions from waste collection in each scenario.

A.4.3 Biogas Sensitivity

The biogas market in Finland is relatively immature and, as such, has a number of differences compared to more established markets elsewhere in Europe with more optimised environmental (and economic) performance. Three key differences are:

- the application of digestate;
- the purity of the input material; and
- the facility type.

In order to count the treatment process as recycling, Finnish biogas facilities are required to apply the digestate product to land. This is not an uncommon requirement across European countries, and improves the economics of biogas by reducing the costs of disposal. However, there is an important nuance here. What is important with regards to the environmental benefits of digestate application is that it is applied to land in order to improve soil fertility and where, otherwise, fossil fuel-derived synthetic fertilisers would have been used. In Finland, there remains a level of opacity as to what extent synthetic fertilisers are actually being displaced by these products. It will be important to ensure that these benefits are genuinely being realised as the market develops.

Household waste Biogas plants are more effective at generating energy when running on pure food waste, but in Finland most biowaste collections allow for garden waste to be collected alongside food waste. In practice, only a relatively small amount of garden waste makes it into the biogas facilities because of the shorter growing season and the current weighting of biowaste collections towards urban households and apartments without gardens. However, increasing the level of food waste separation could still make biogas plants more economically and environmentally productive. This will become increasingly important as biowaste collection coverage expands to include more households producing garden waste.

In addition, 39% of Finnish facilities are designed to generate heat alone, whereas only 30% of facilities are designed for combined heat and power (CHP). More mature markets tend to have greater penetration of CHP facilities.

To reach future targets, it will be necessary for the biogas industry and market to change significantly, both in terms of capacity growth and optimisation of environmental outcomes. The carbon factor of -0.12 tCO_2e/t waste shown in Table 27 is that of a relatively high-performing biogas market as seen in best practice in Europe. However, to reflect the still maturing Finnish biogas markets in the modelling, a reduced environmental performance has been approximated by removing the environmental credit for application of digestate in the baseline scenario, resulting in a lower carbon factor of -0.05 tCO_2e/t waste.

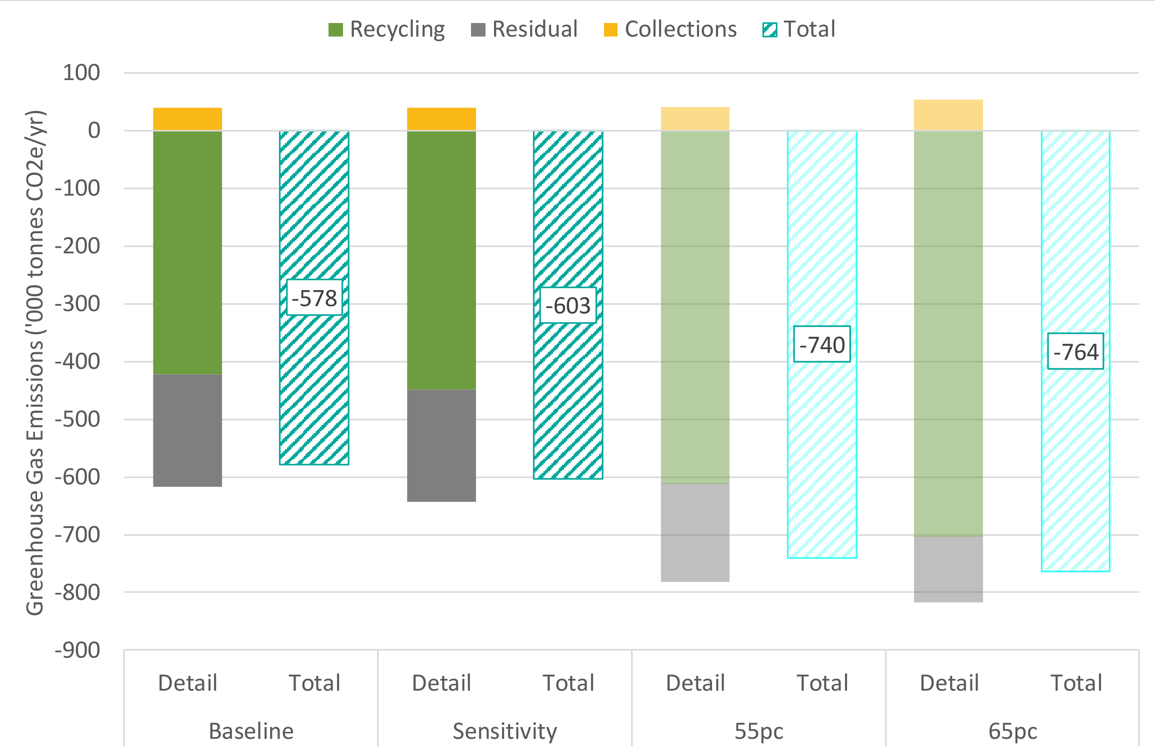
The implication of this is that the environmental assumptions favour the future options. Therefore, a sensitivity has been modelled using the improved biogas carbon factor in the baseline. This sensitivity allows for the benefits from improving waste processing facilities to be separated from the benefits of improving the waste management system up to the point of delivery to those facilities.

A.4.3.1 Sensitivity Results

The results of the biogas sensitivity, modelling an improved biogas market on the baseline waste flows, are presented in Figure 15 alongside the core results for the baseline and for both future results in faded bars. Here we can see that improving biogas markets results in an overall reduction in emissions from waste management of 25 $ktCO_2e$/yr relative to the core baseline scenario.

Maturation of the Finnish biogas market is necessary to facilitate high levels of biowaste recycling and will alone bring with it significant environmental benefits with respect to GHGEs. However, the remaining difference between the totals for the baseline biogas sensitivity and the future options indicate that it is not this market maturation that brings the bulk of the environmental benefits associated with higher recycling, but the higher capture of biowaste and other recyclables into the relevant reprocessing streams.

Figure 15: Environmental Results of Biogas Sensitivity



A.4.4 Limitations

The environmental modelling carried out in this phase of work has a number of limitations which, although unlikely to change the main conclusions of the modelling, could be explored in future options in order to refine the quantitative results.

Firstly, a lack of available data prevented much of the waste transport network, for example, being accounted for. This included emissions from commercial collections, transport of reject material, and the onward transport of materials from transfer stations. However, the contribution of household door-to-door collections to the overall GHGE footprint of the national waste management system, even given the relatively significant expansion of the network modelled in the future options, was not very significant. In addition, it is also likely that increasing vehicle electrification, especially in urban areas, will reduce the impact of collections with regards both to GHGEs and air quality emissions going forward. Therefore, it is not thought that these omissions significantly detract from the accuracy of the environmental conclusions.

Secondly, modelling GHGEs on a scenario basis meant that no considerations of collection system were taken into account. A future phase of modelling at higher resolution could look to quantify the differences in emissions between the options. For example, the mixed-stream options would be associated with emissions from the construction of sorting facilities and the sorting processes themselves, although these emissions tend to be small in scale relative to whole waste management system.

Finally, the input assumptions used to generate the carbon factors for waste incineration would benefit from further examination. There is a high degree of uncertainty around the Finnish heat and electricity generation efficiency figures, in the way that they are calculated and the way that they are presented in the literature. A future priority would be to explore the methods used to calculate these figures as misinterpretation and subsequent miscalculation of these variables is relatively common.

If further investigation resulted in a downwards adjustment of generation efficiencies, even slightly, then it is worth pointing out that the GHGE improvements observed by achieving higher recycling would increase. For example, if electricity and heat generation efficiencies of 15% and 52%[24] are used instead of those detailed in Table 28 then the beneficial impacts of improving recycling increase in scale, as shown in Table 29.

Table 29: Incinerator Generation Efficiency Sensitivity Results

Generation Efficiencies	GHGE savings ($ktCO_2e/yr$)	
	Baseline to 55pc	55pc to 65pc
Literature	-162	-24
Sensitivity	-237	-62

Furthermore, future decarbonisation of baseline electricity generation is necessary for Finland to meet climate change obligations. This will make incineration decreasingly preferable from a GHGE perspective, further favouring recycling as the waste treatment option of choice.[25] By using current carbon intensity of electricity generation, and by using energy generation figures as given, a conservative approach to the environmental modelling has been taken.

Future phases of work would seek to amend and improve upon some of these limitations, especially with regards to the assumptions around waste incineration. However, even employing a relatively conservative approach, the environmental benefits of improving recycling are clear, with GHGE savings of almost 200 $ktCO_2e/yr$ available.

[24] Chosen such that (a) the ratio of heat:electricity figures is consistent with the literature and (b) overall plant efficiency is calculated as 90%, equal to the direct sum of the literature efficiency figures.
[25] Although note that this decarbonisation will also decrease the benefit associated with electricity generated by biogas facilities.

A.5.0 Employment Modelling Technical Appendix

In addition to the financial cost, the change in employment associated with reaching future municipal waste recycling targets has been estimated.

A.5.1 Methodology

The employment calculations include consideration of indirect employment supported in material processing (as a result of waste flows modelled in Section A.2.0). In addition, the total direct employment outlined in the policy modelling and collection modelling sections above (see Sections A.1.0 and A.3.0) is calculated.

A.5.2 Assumptions

Changing waste management systems involves a change in how many drivers and loaders are required to run the collection vehicles. These figures were calculated using Hermes2.0 in Section A.3.0 and vary fairly significantly by collection option. In this calculation, median figures were used as marginal differences from baseline employment, as presented in Table 30.

Table 30: Change in Employment from Waste Collections

	Median Change in Employment from Baseline (FTE)	
Scenario	**55pc**	**65pc**
Driver	-85	64
Loader	-546	-541
Total	**-631**	**-478**

The assumptions underlying the employment calculations around processing recycling and residual waste are detailed in Table 31. These are a standard set of assumptions with broad applicability across Europe. The recycling figures have been compiled from a variety of sources, including a 2008 report by the Tellus Institute.[26] The organic and

[26] LEPU (2004) Jobs From Recycling: Report on Stage II of the Research, London South Bank University; Save Waste and Prosper (SWAP) (1999) Employment in the UK Recycling Industry, National Recycling Forum; Coalition for American Electronics Recycling (2013) Jobs Through Electronics Recycling, January 2013, http://www.ecsrefining.com/Media/Default/Industry_Reports/CAER_Jobs_Study_Report_-

residual waste treatment statistics were published in a 2014 report by Eunomia and the Copenhagen Resource Institute.[27] These figures were multiplied by the waste flows in each option to generate employment figures.

Table 31: Material Processing Employment Assumptions

Material	Treatment	FTE / Kilotonne Material
Biowaste	AD	0.20
Paperboard / Cardboard	Recycling	1.90
Glass		0.42
Metal		0.62
Paper		1.90
Plastic		6.70
Other		2.00
Residual	Incineration	0.10

The approach taken to modelling the waste flows means that all reprocessed tonnage is presented together, irrespective of whether it is actually recycled or reused. Since the vast majority of this tonnage is recycled, it was determined that applying the above assumptions to all reprocessed tonnage was a valid approximation to make. However, a WRAP study from 2011 found that over 52 jobs can be supported for every kilotonne of waste reused, which is significantly greater than the figures associated with recycling.[28] It is therefore likely that the figures presented in Figure 7 in the main report underestimate the actual employment benefits associated with these policy decisions. Any future modelling should look to improve on this approximation, further distinguishing between tonnages for recycling and those for reuse in order to derive a more accurate employment projection for Finland under higher recycling rate scenarios.

Modelling employment benefits at a scenario level means that little consideration of the implications of the different collection options has been made. Future phases of work

_January_2013.pdf; Tellus Institute with Sound Resource Management (2008) More Jobs, Less Pollution: Growing the Recycling Economy in the U.S., http://docs.nrdc.org/globalwarming/files/glo_11111401a.pdf

[27] Eunomia Research and Consulting & Copenhagen Resource Institute (2014) European Reference Model on Municipal Waste Management, Report for DG Environment, http://www.wastemodel.eu/

[28] WRAP (2011) A methodology for quantifying the environmental and economic impacts of reuse, November 2011, http://www.wrap.org.uk/sites/files/wrap/Final%20Reuse%20Method.pdf

could look to account for the employment sustained in sorting facilities in the less source-separated collection options.

In addition to these two operational areas, the policies and changes required to drive the change in national performance also have employment implications, as summarised in Table 32. For example, improving the performance of recycling stations involves additional monitoring and staffing. An average of the employment sustained in each of the two policy options was used in this calculation.

Table 32: Median Change in Employment from Baseline (FTE)

Staff	55pc	65pc
Recycling Station	464	635
Enforcement	98	98
Policy Option Average	44	44