DDRS Feasibility Study

Phase 2 Report Technical Appendix

Welsh Government, April 2022, Ref: 5356

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1 Introduction

This Technical Appendix is provided to accompany a report produced by Resource Futures commissioned by Welsh Government entitled 'Digital DRS Feasibility Study - Phase 2: End-to-end system design. This Technical Appendix provides additional technical information for **two research areas** presented in the main report. These are:

1. How to verify material quantities collected and recycled (page 26 of Phase 2 report)
2. Quantifying and comparing the value of consumers' time under RVM-DRS and DDRS (page 27 of Phase 2 report)

The main Phase 2 report provides a summary of each of these research areas. Additional information is presented in this Technical Appendix to provide further clarity on the research findings and any calculations undertaken to produce quantitative estimates in the main report.

2 Verification of material quantities collected and recycled

Verification of material quantities is a crucial aspect of a successful DDRS and can provide an evidence base to ensure high quality in-scope container takeback and prevent fraud. Verification refers to a set of processes that generate the proof of return of the correct (in-scope) containers, by using various criteria specific to the in-scope containers, such as material composition, volume, weight etc. In addition to tracking the quality and quantities of containers returned and recycled, verification may be used to prevent fraudulent practices and to encourage recycling behaviour among users.

Systemic changes resulting from upcoming EPR and DRS legislation are also likely to necessitate administrative and technological modifications to the existing waste management system and infrastructure. In the following sections, verification processes used in traditional RVM-based DRS and the current kerbside collection system in the UK are separately reviewed in detail to understand how verification might work under a DDRS.

2.1 Verification processes in an RVM-based DRS.

1.1.1 Flow of in-scope material post-collection

The material and financial flow of a traditional RVM-based DRS, based on DRS models in five European countries, Germany, Denmark, Sweden, Finland and Estonia, is summarised in Figure 1[1].

[1] Eunomia 2011, Options and Feasibility of a European Refund System for Metal Beverage Cans https://bit.ly/3seM0pj

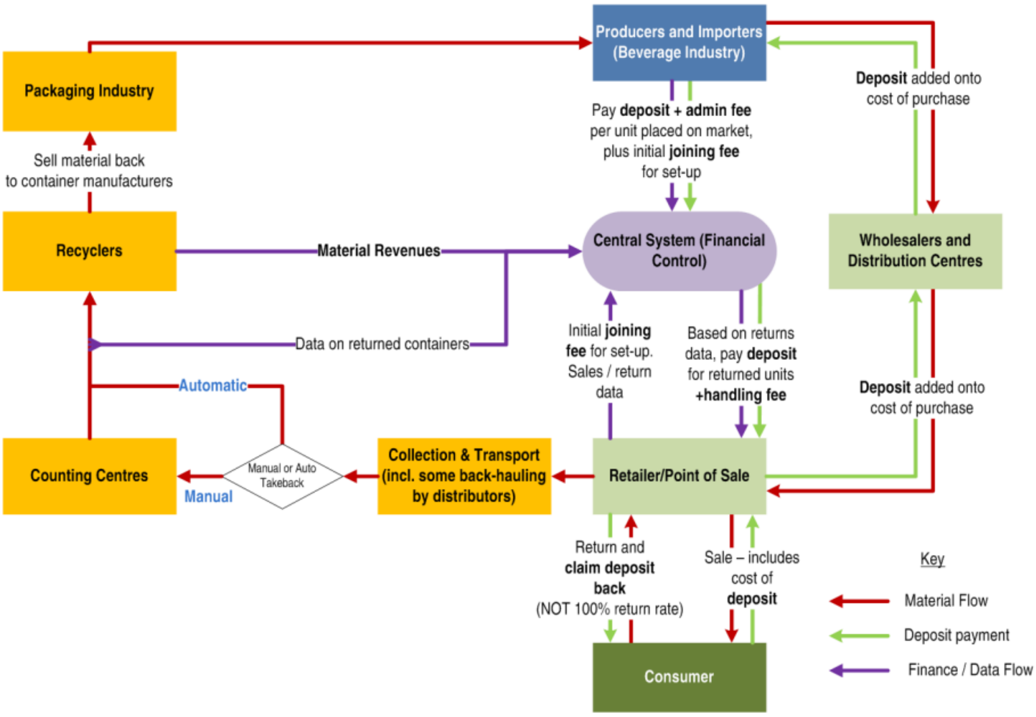

Figure 1: General DRS model (Source: Eunomia)

The system is managed by a central Deposit Management Organisation (DMO), which sets the requirements and standards for RVMs and counting centres. Container returns may be automated (via RVMs) or manual. Most current DRSs use RVMs that have to be DMO approved and have advanced capabilities to scan and record information regarding the collected containers. The data collected are shared with the DMO, often in real time. Approved collections made through RVMs are often directly sent for recycling without any interim stops. In contrast, manually collected collections are bagged in RFID tagged bags, which enable the tracking of these bags as the material is transported through following stages. These collections are first sent to counting centres that are equipped with bulk counting RVMs or industrial RVMs. These RVMs must also be system approved and are capable of scanning and recording verification information. The information scanned and recorded by the RVMS (including industrial RVMs) is used by the DMO for verification.

1.1.2 Verification methodology for automated (RVM-based) and manual collections

Typically, verification is based on multiple data points pertaining to the in-scope containers. Producers are required to submit this information, as part of a registration process, prior to placing their products on the market. The data points include:

- Standard product barcodes
- Expected volumes of sale
- Number of containers actually placed on market (POM)
- Physical samples for size and dimensions
- A range of weight of individual containers with and without residues

Thus, verification is based on both the count and average weights of individual containers. System approved RVMs scan and record the data that is reconciled with the registered details to facilitate container verification. Ineligible containers are rejected by the RVMs. In addition to the standard product barcode used in many countries, a DRS-specific identification or 'deposit mark' may also be used (e.g., Norway) to distinguish between deposit bearing material and those not in scope. RVMs are usually capable of reconciling container information in real time with data from the DMO. They also have compaction capabilities to prevent fraud, by not allowing redemption of a container more than once. Manually collected containers are routed via counting centres to be counted in industrial RVMs that also share real time data with the DMO.

According to TOMRA[2], the data management and reporting responsibilities of the DMO in high-performing states include:

- maintaining a central database of all product barcodes (to be provided by the producers)
- aggregating all data from manual and automated collection points
- clearing deposits at different trade levels and
- administering handling fees and compensation

1.1.3 The role of counting centres

The primary role of counting centres is to count returned containers and verify the count matches that reported by the RVM, or manual takeback point to prevent fraud. The way that this is done can vary depending on whether the container takeback is done via RVMs or manually (and in RVMs without compaction). The collections from manual collections and RVMs without compaction are sent to counting centres to be counted in industrial RVMs and compacted. Additional functions include sorting and baling of collections.

In many DRSs (e.g., Germany), compaction is obligatory and usually takes place in the RVMs. Compacted containers are then directly sent for recycling. In some cases, RVMs may not be capable of compaction. In such cases, the collected material is bagged (system approved) in a RFID tagged bags to be taken to counting centres for compaction.

1.1.4 Material quantity, losses and margins of errors

In the DRS system operated by TOMRA in Germany, both the count and an average weight are used to verify returns. Verification is based on information provided by producers to the DMO during registration (see section 1.1.2). Additionally, container samples are also provided for proof of physical dimensions of containers. The counts of collected containers, received from RVMs and counting centres, are matched by the DMO with the data submitted by the producer during registration, resulting in the identification of any losses of containers.

As part of data collection during registration, the weights of each type of eligible container with varying levels of residues are used to set a tolerance range to account for contamination. Therefore, some variations in tonnages are expected due to contaminants or residues such as drink residues left in the container. Containers received at the RVMs that weigh heavier than the upper limit of this range are rejected. Differences may also be observed in the weight of the container scanned by the RVMs during collection and the final weight of compacted containers measured at the recycling facilities, due to loss or evaporation of residues. It is likely that the range of weights set during registration accounts for any losses in tonnage between collection and receipt of material at the final recycling site. Figure 2 shows an example

[2] TOMRA 2021, Rewarding Recycling Learnings from the World's Highest Performing Deposit Return Systems https://bit.ly/3HUsEMZ

of the range of weights of containers with and without any residues recorded by the DMO Infinitum in Norway.

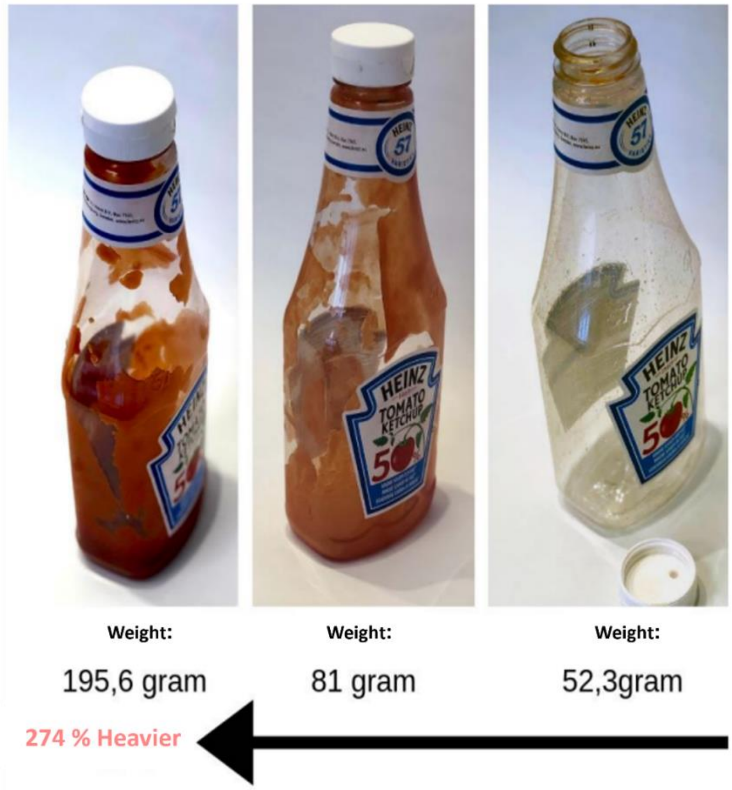

Figure 2: Reporting of tonnage[3]

1.1.5 Additional case studies

Sweden[4,5]

- Returpack is the DMO is responsible for the collection of all ready-to-drink beverage containers (plastic bottles and metal cans). The collection system is 95% automated (RVM take back) and 4% manual (manual take back)
- 5,100 RVMs at 3,100 retailers & 50 Pantamera (the brand operated by Returpack) Express (large deposit machines) at municipality recycling centres. Additional collection at traffic stores, restaurants, pizzerias, camping sites, skiing resorts, festivals, sports clubs (9,500 collectors). 94% of container volumes come from retailers.
- There are two routes for return logistics (Figure 3).
    - The first is planned by Returpack but operated by 3rd party operators – Container returns from retailers are collected in trucks with separate compartments for metal and PET. These are transported to intermediary warehouses for bulking. Here specialised bulking trucks take bulked materials to a single centralised Returpack site which operates as a Material Recovery Facility (MRF), where collections are sorted into their various material streams.

[3] https://bit.ly/3tsxfRz
[4] Returpack 2017, (Information brochure?) https://bit.ly/3HmmMeZ
[5] Reloop 2020, Global Deposit Book 2020 https://bit.ly/34hBpll

- In the second, collections are back hauled by wholesalers and producer. Their warehouses have Returpack pick up points

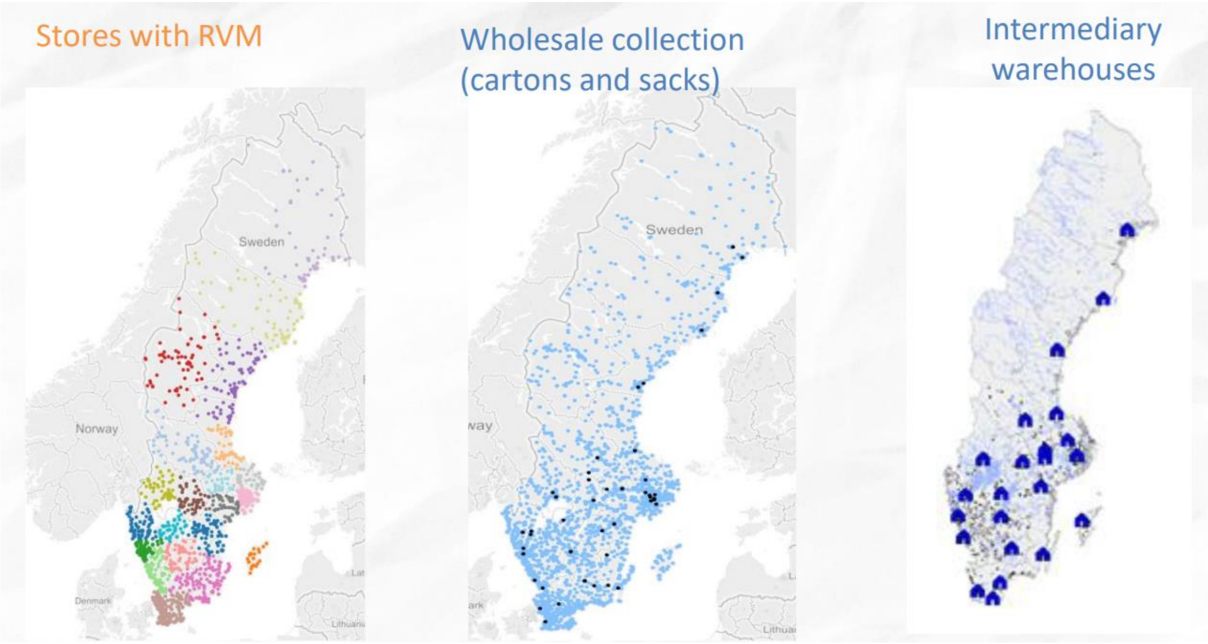

Figure 3: Swedish DRS collection infrastructure

Netherlands[6] –

- The reverse logistics of the dominant DRS (see next bullet) relies on the existing forward logistic supply chain (manufacturer to customers). Most collections (89%) are automated via RVMs while 11% are manually collected.
- Two DRS run in parallel. SRN (Stichting Retourverpakking Nederland), the Dutch Return Packaging Foundation is the DMO for the dominant return system. SRN system collects PET bottles over 0.75 L and refillable glass beer bottles (0.25 - 0.5 L) mostly via RVMs in supermarkets and some off-licenses (manual collections). About 5-10% of returns (from the catering industry) come through beverage wholesalers.

[6] CE Delft 2017, Costs and impacts of deposits on small bottles and cans (NL) https://bit.ly/3Gtmy4i

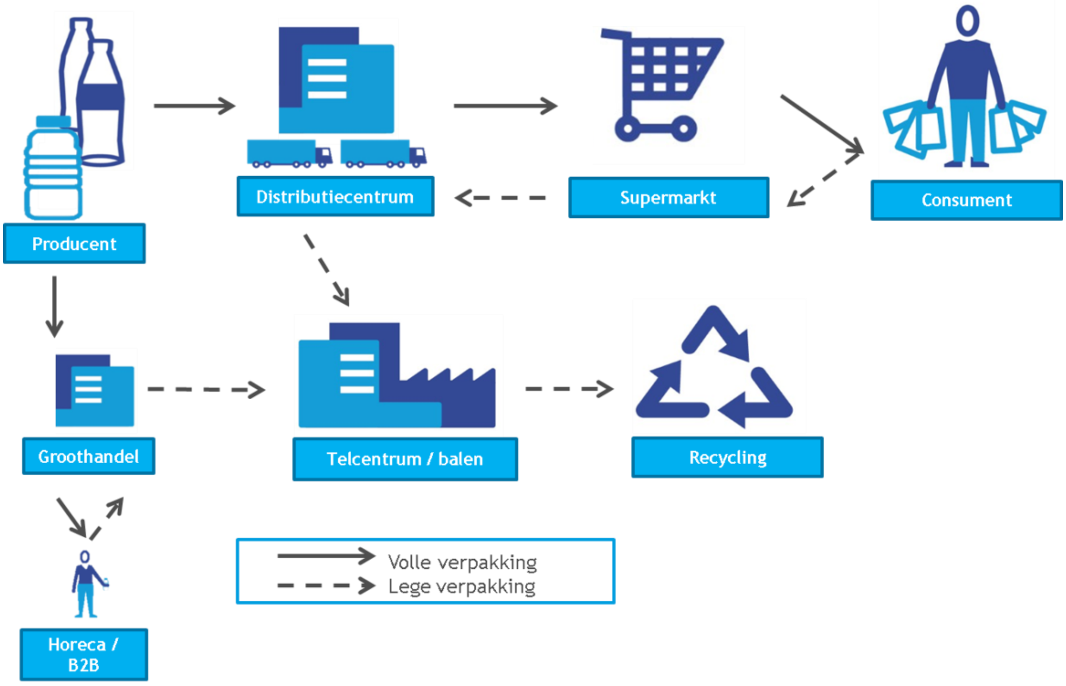

Figure 4: Dominant DRS in Netherland operated by SRN (see translation table below)

Dutch	English
Producent	Producer
Distributiecentrum	Distribution centre
Supermarkt	Supermarket
Consument	Consumer
Groothandel	Wholesale
Telcentrum / balen	Counting centre / bales
Recycling	Recycling
Horeca / B2B	Catering industry / B2B
Volle verpakking Lege verpakking	Full packaging Empty packaging

- From RVMs, collected bottles are bagged in large transparent bags, sealed and shipped to counting centres via distribution centres. Based on the volume of the container and size of the bags, there is a limit on the number of bottles per bag. For instance, the catering industry uses small bags (approx. 70 bottles)
    - At the counting centres, bottles are counted in large deposit machines or industrial RVMs using a scan of their barcodes and the number of each brand is recorded by supermarket or wholesaler. Bottles are sorted by colour and then baled.
    - The collected deposit money is paid by SRN to participating producers based on the counts at the counting centres. Deposit receipts lost by the consumers are a gain for producers since retailers pass on deposit money paid to producers on to the consumers at the time of purchase.
- A secondary closed system is operated via Aldi and Lidl for their own brand bottles not returnable to competitors. Aldi partially reimburses its own bottles deposited elsewhere (outside Aldi stores). It also accepts an A-brand 1.75 L bottle (which is also returned via the dominant DRS).

- This system does not involve counting centres. At Aldi, bottles are immediately baled by the RVMs. The settlement between various branches happens through the cash register. At Lidl, bottles are directly deposited into large transparent bags using a lift.

Norway

The Producers finance the entire DRS system and have collaborated with retailers to set up Infinitum, the DMO[7]. The approval process of in-scope containers includes a review of labels (including the glue used to affix them). Containers can have standard barcodes allowing bottles to be sold outside the country and generate costs for the producer or importer (intended to cover risk of fraud). Additionally, they can have a Norway-specific barcode, which lowers the costs to the producer since it prevents consumers from redeeming deposits for containers bought outside Norway. Bottles are bagged and sealed with integrated closing tape to prevent any tampering of the contents. Each bag is then tagged with a unique RFID chip to facilitate electronic tracking to prevent fraud or container escape from the system post collection.

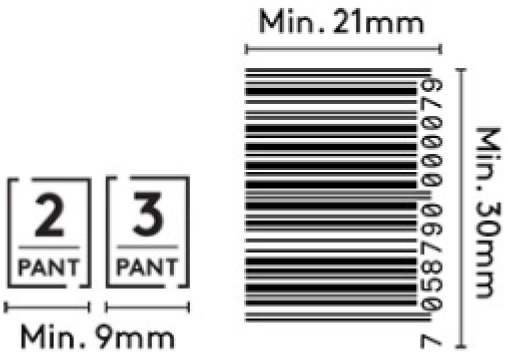

Figure 5: DRS logo and barcode specification (Source: Infinitum)

California

The DRS material verification in California, USA is based on container weights. California Refund Value (CRV) is a deposit paid to consumers after the containers are weighed (5 cents for <24oz; 10 cents >= 24oz) and the value is calculated using a state-supplied formula. Weight-based systems require regular updates to the conversion factor (average weight) due to the pace of change and variety in bottle sizes and weights.

2.2 Possible verification measures in a DDRS

In order to understand how verification measures could be built into a DDRS, the following section provides a detailed description of the current kerbside recycling collection flows and verification procedures. This includes a review of the scope and capabilities of the existing material and data verification processes and the potential technological, legislative and other changes that will become important considerations when incorporating a DDRS into kerbside collections.

[7] Innowo 2020, How do effective deposit refund systems work? https://bit.ly/3uxRy0H

1.1.6 Current flow and tracking of material post-collection at the kerbside in the UK

Recyclables presented in comingled, twin and multi -stream collections at the kerbside are often partially or fully compacted in collection vehicles, except when collected with glass. If glass has been separately collected, then the remaining materials may undergo compaction.

In most cases, kerbside collections are first taken to an interim stop for bulking (co-located with depots or at Waste Transfer Stations (WTSs)) before being forward hauled to Material Recovery Facilities (MRFs). The various co-collected streams within twin and multi-stream collections are hauled and stored separately throughout the transportation and storage stages. Some kerbside collections might be direct hauled to the nearest MRFs.

Some authorities undertake some level of pre-sorting at their own WTS. Such WTSs are usually equipped with basic sorting capabilities and are called mini-MRFs. This is often the case with councils who collect highly contaminated kerbside recyclables and therefore, need to ensure their collections do not exceed acceptable levels of contamination at their MRFs, or those who operate a multi-stream collection service like Bristol City Council. Bristol's co-collected plastic and cans are pre-sorted at their WTS before being sent directly to reprocessors. This helps the Council maximise the value of the aluminium in the collections and bypass the MRF as a result.

Co-collected streams from twin and multi stream collections might undergo sorting in specialised recycling facilities that are equipped to sort plastics into different polymers or types. These are called container MRFs (multiple sorting lines including a 'container line' for plastics and cans) or Plastic Recycling Facilities (PRFs). These facilities also receive partially sorted materials from MRFs for secondary sorting.

1.1.7 Typical MRF process flow

It is likely that DDRS materials collected with other kerbside recyclables will need to undergo some form of quantity verification at MRFs. It is, therefore, important to understand the current verification capabilities and process flows in MRFs to understand how verification under a DDRS system would work. A detailed overview of processes and monitoring systems currently undertaken at MRFs and the technology that enables them is discussed below.

An initial quality check of the mixed recyclables brought to site in collection vehicles is carried out by visual inspection [8,9]. Materials are then transferred on to a conveyor belt and pre-sorted manually to remove obvious non-recyclables.

The pre-sorted materials first go through an Old Corrugated Cardboard (OCC) screen (series of rotating discs) to separate out cardboard, where it drops down into storage bays. Glass falls through into a glass breaker and proceeds for further separation. From the remaining mixed recyclables, metals are sorted out by magnetic and eddy current separation. The remaining mixed, predominantly plastic fraction undergoes different sorting processes depending on the technical capability of the MRF. MRFs without advanced sorting technology generate mixed plastic outputs. These may go through secondary sorting at PRFs. Some MRFs (e.g., Biffa, Casepack) use different optical sorters to sort plastic into different polymer types and colours using near infrared scanners. For instance, Biffa's facilities have five optical sorters while Casepack facilities have only three. Precision air injectors are used in combination with the scanners to accurately

[8] Biffa MRF video, https://bit.ly/3uzbUGY
[9] Casepack MRF process, https://bit.ly/3sp5tnd

sort out the plastic into different polymers. After a final quality assurance, the different output fractions are bailed and forward hauled to reprocessors. For example, at Biffa, the HDPE and PP mixed fraction are bailed and transferred to their polymer plant at Redcar. Currently, in most recovery facilities, HDPE (opaque) and clear PET are prioritised for separation over other polymer categories. Pots, tubs and trays (PTT) may or may not be sorted from the PET mixture (PET bottles separately collected have the highest value).

1.1.8 Validation of waste flows

Most WTSs, MRFs and PRFs have a weighbridge to weigh and record information regarding incoming and outgoing loads. Weighbridge tickets generated during the entry and exit of vehicles transporting waste contain high-level details about the material being transported (general waste stream / category, timestamp, vehicle registration and weight) and are used by these facilities and local authorities to track material flows. In this manner, each load can be traced back to the waste generator local authority. MRFs and PRFs also generate reports with information about the materials they process. These reports are tailored to local authorities that send their waste to the facility and include details such as the output weights, material categories, levels of contamination and any other data requested by the authorities. These details allow local authorities to report their data to the Environment Agency (EA) via the Waste Data Flow (WDF) platform. MRFs also report information regarding the quality of input and output waste materials via the EA and Natural Resources Wales (NRW) (previously via the Materials Facility or MF portal).

According to Natural Resources Wales (NRW), validation processes mainly involve verifying recycling targets for authorities[10]. The data review processes are based on trends and identification of outliers against previous audits. A high-level manual review of waste data submitted by local authorities usually identifies outlier authorities that are underperforming or demonstrate unusual trends, using specific tolerance levels for errors (previously based percentages but now based on tonnages). The outlier local authorities or waste stream datasets that look out of place are then queried to understand the cause of any abnormality. The focus of the manual review is to ensure that recyclable materials are appropriately treated and can be traced onwards as processing and export flows. Once the material is identified as being sent to a reprocessor, there are no further verification processes, as it is assumed that they are sent for recycling.

Materials from different local authorities collected as part of the kerbside systems are often combined before reaching the MRFs. This is to achieve efficiencies in scale and costs through compacting and bulking materials from different sources. Integrating DRS into kerbside collection in the current system will result in in-scope materials being co-collected and mixed with out-of-scope materials. The existing verification system and sorting infrastructure could potentially struggle to distinguish the two groups of materials. Verification considerations for a future DRS system also include the use of counts versus weight. While DRS are traditionally based on counts, the current waste industry uses weights as part of its verification processes. There is no current centralised record of losses occurring between collection and reprocessing of materials either, making the tracking of in-scope materials that may be collected by are not received for recycling or reprocessing difficult. This can result in challenges in the verification of DDRS materials.

MRF regulations require facility operators to conduct periodic testing of samples at input and output stages. These generate an average contamination level for MRFs, which is not granular to the level of

[10] Based on a call with NRW

batches or loads. As a result, any contamination level (e.g. residual liquid in PET bottles) are averages rather than batch specific. MRFs also report reject rates[11] through Waste Data Flow. However, there is no testing regime to determine how much of these rejects include non-target materials, contaminants or indeed target materials that gets dragged out with non-targets (process losses).

1.1.9 Currently available sorting and verification technology

The existing sorting technology in MRFs or PRFs is largely dependent on optical sorters (see section **Error! Reference source not found.**). The more advanced facilities are incorporating artificial intelligence and robotics to achieve better quality in sorting and data generation. For example, MAX-AI Robots[12,13] typically comprise of AI scanners (eyes), a machine learning element (brain) and robots (arms)[14]. This enables them to mirror the functionality of manual sorting albeit with a greater speeds and levels of accuracy. Currently, robots are used at QC stages in MRFs. Their material characterisation capabilities help them to recognise increasing levels of details such as material types (e.g., OCC, metals, plastic), recognition confidence, surface area, mass of individual container (crucial link to the sampling regime) and bale quality information.

Pros

AI is capable of recognising brands, logos, bottles shapes quickly and accurately if adequately 'trained' through machine learning. There are also significant benefits from a data collection point of view, with respect to the data generation on counts and types and weights when AI is used for sampling as well as sorting.

Cons

Current AI-robot technology is expensive. These and AI vision technologies will need to match pace with the quantities and speed of materials being processed at the facilities to make sure all target (in-scope) materials are captured. Machine learning requires extensive human input, during the early stages, to help identify the sheer variety of packaging types collected at the kerbside.

1.1.10 Future MRF technology outlook

Greater sorting capabilities will be expected of MRFs in order to meet the requirements of future legislation changes such as Extended Producer Responsibility and DRS. This will include the need to go beyond identification of polymers and the potential use of AI and machine learning to sort products by material type and design. Product identifiers could range from product shapes, brand logos, RFID chips to QR codes[15]. EPR, DRS and requirements for consistency in local authority kerbside collections will drive up quality standards and there is likely to be a shift towards source separated material collections at the kerbside. MRFs will still be needed for sorting partly mixed streams such as mixed plastics, plastics and cans, glass and OCC etc. Geographical and other constraints will also mean that some comingled collections will continue.

Some examples of technology relevant to kerbside/digital DRS[16]

[11] Rejects include contamination and non-target materials.
[12] https://www.letsrecycle.com/news/first-max-robot-uk-recycling/
[13] https://www.mrw.co.uk/news/sorting-robots-come-to-mrf-26-01-2021/
[14] Based on RWM webinar - https://bit.ly/3wngx7U
[15] Suez 2020, https://bit.ly/3uwMytt
[16] Resource 2019, https://bit.ly/3snLc1m

- TOMRA has developed new technology via SHARP EYE, which uses higher light intensity to sort PET bottles versus food trays[17].
- One technology provider uses a unique PAC code on branded packaging to ‘trace’ and sort material to be reprocessed to identical grades and colours of plastic[18]. This technology was trialled in a recent DDRS trial[19]. The code could be scanned using a mobile app and dropped off at a designated collection site. The materials were then taken to a dedicated MRF.

3 Quantifying and comparing the value of consumers’ time

This section provides technical detail and context to support the summary provided in the Phase 2 report (page 27). The aim of conducting this research was to estimate the time requirements for individuals to engage with different DRS systems and placing a monetary value on this time. In doing this it is not only possible to see the ‘true cost’ of new systems that may be implemented, but we are also able to assess which of the DRS options are most convenient for the user.

In order to address these questions, the steps of returning empty containers were investigated to understand how the time required to engage with this service could vary. Existing data around service engagement for different DRS options was drawn together, where data wasn’t available reasonable assumptions were made based on current understanding. Different ways in which individuals time, for non-work tasks, is valued were assessed and compared. By drawing these streams of information together a model was built to estimate the national UK value of people’s time in using different DRS systems.

This Technical Appendix first outlines the process flow for each type of DRS (RVM, manual and kerbside based digital) to illustrate where time is spent. Value of time was firstly calculated at a household level before being scaled up to be representative of the UK nationally for a largely RVM-based model and a largely DDRS model (the calculations are based on a blend of engagement with both systems. Tables are provided which outline the figures used to calculate value of time for a UK household, with variability being captured through a low, medium, and high scenario.

Finally, wider context and discussion is included around the important themes of:

- monetary value of consumer’s time
- travel time and additional car journeys
- different RVM models

3.1 Value of consumers’ time required to return drinks containers to RVMs or manual take-back points

RVM based returns

The key steps for the consumer in for RVM based returns are shown in Figure 6.

[17] https://bit.ly/3NaXrIk
[18] https://bit.ly/3JCnvcW
[19] Greasby DDRS pilot 2019, https://www.polytag.co.uk/greasby-digital-drs-pilot/

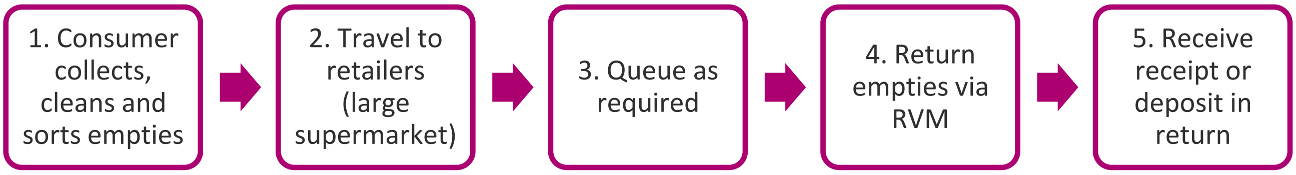

Figure 6 RVM DRS process flow

There are three key stages for which time has been quantified for RVM. Travel time (step 2), service engagement at home (step 1), and service engagement at RVM (step 3, 4 and 5). Times assigned to each aspect have been taken from research conducted into DRS or discussions/specifications from RVM manufacturers. The low, central, and high scenario aim to capture the variability in values found. Table 1 summarises values used to calculate value of time at a household level for RVM based returns.

Table 1: Summary of scenario assumptions for RVM returns based on the return of 15 containers per week

Variable	Low	Central	High
Additional journeys per week (average)	0	0.25	0.5
Value of time (travel)	A carer is provided with £67.60 per week, for 35 hours a week of work - £1.93/hr [20]	National living wage in UK as of April 2022, £9.50/hr[21]	£11.24/hour value of travel time – direct value from ONS value of unpaid work evaluation [22]

[20] Government, U. (2021, April). Carers Allowance. Retrieved from GOV.UK: https://www.gov.uk/carers-allowance
[21] Government, U. (2022, April). National minimum wage rates. Retrieved from GOV.UK: https://www.gov.uk/national-minimum-wage-rates
[22] Statistics, O. f. (2016, November). Women shoulder the responsibility of unpaid work. Retrieved from Office for National Statistics: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/articles/womenshouldertheresponsibilityofunpaidwork/2016-11-10

Variable	Low	Central	High
Value of time (service engagement)	A carer is provided with £67.60 per week, for 35 hours a week of work - £1.93/hr [23]	National living wage in UK as of April 2022, £9.50/hr[24]	£8.58 / hour value of time for cleaning, sorting, and returning items assumed to fall under 'housework'. Direct value from ONS value of unpaid work evaluation[25]. Note: this ONS source was used to correspond with the high-scenario value for travel time.

[23] Government, U. (2021, April). Carers Allowance. Retrieved from GOV.UK: https://www.gov.uk/carers-allowance
[24] Government, U. (2022, April). National minimum wage rates. Retrieved from GOV.UK: https://www.gov.uk/national-minimum-wage-rates
[25] Statistics, O. f. (2016, November). Women shoulder the responsibility of unpaid work. Retrieved from Office for National Statistics: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/articles/womenshouldertheresponsibilityofunpaidwork/2016-11-10

Variable	Low	Central	High
Service Engagement at RVM	2 minutes 3 seconds service engagement at RVM – 1 minute queue time (assumed) + 1-minute lowest time required to use RVM based on per minute processing times[26] + 3 seconds additional time for processing of receipt or choice of how to receive refund[27].	4 minutes 3 seconds service engagement at RVM – 1 minute queue time (assumed) + 3 minutes mean average of time required to use RVM based on per minute processing times[28] + 3 seconds additional time for processing of receipt or choice of how to receive refund[29].	6 minutes 3 seconds service engagement at RVM – 1 minute queue time (assumed) + 5 minutes highest time required to use RVM based on per minute processing times[30] + 3 seconds additional time for processing of receipt or choice of how to receive refund[31].

[26] Reverse Vending Systems. (n.d.). Retrieved from TOMRA: https://www.tomra.com/en-gb/collection/reverse-vending/reverse-vending-systems
[27] Woods, O. (2019). Improving the Capture Rate of Single Use Beverage Containers in Ireland. Eunomia.
[28] Reverse Vending Systems. (n.d.). Retrieved from TOMRA: https://www.tomra.com/en-gb/collection/reverse-vending/reverse-vending-systems
[29] Woods, O. (2019). Improving the Capture Rate of Single Use Beverage Containers in Ireland. Eunomia.
[30] Reverse Vending Systems. (n.d.). Retrieved from TOMRA: https://www.tomra.com/en-gb/collection/reverse-vending/reverse-vending-systems
[31] Woods, O. (2019). Improving the Capture Rate of Single Use Beverage Containers in Ireland. Eunomia.

Variable	Low	Central	High
Service Engagement at home	4 minutes 12 seconds collecting and sorting DRS materials at home per week. A Norwegian study found that an average household spent a total time of 14 minutes handling recycling in the home[32]. A recent Bristol waste composition analysis found that 30% of all recycling could be impacted by the current all-in DRS proposal. These two figures were multiplied in order to assume the time required to handle DRS material in the home.		
Travel time	15 minutes travel time return trip – based on Department for Transport data of average travel time to supermarkets in Urban areas [33]		
Results (£/hhld/year)	**£10.45**	**£98.80**	**£149.28**
Results (hrs/hhld/year)	**5h 25m**	**10h 24m**	**15h 23m**

Manual takeback

The process for RVM based and manual takebacks are very similar. The key steps in for manual take backs are shown in Figure 7.

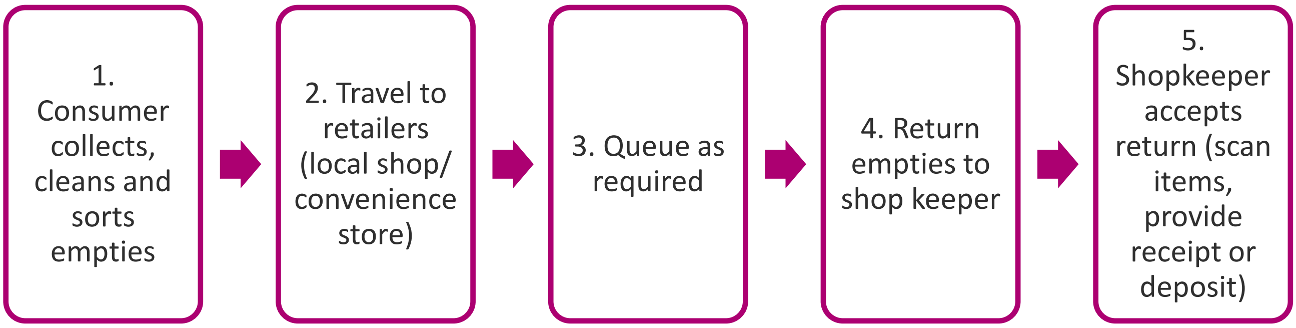

Figure 7 Manual takeback DRS process flow

[32] Annegrete Bruvoll a, *. B. (2002). Households' recycling efforts. Resources, Conservation and Recycling, 337–354.
[33] Survey, N. T. (2015). Why people travel shopping. Department for Transport.

There are three key stages for which time has been quantified for manual take back points. Travel time (step 2), service engagement at home (step 1), and service engagement at return point (step 3, 4 and 5). Times assigned to each aspect have been taken from research conducted into DRS or discussions/specifications from RVM manufacturers. The low, central, and high scenario aim to capture the variability in values found. Table 2 summarises values used to calculate value of time at a household level for manual takebacks.

Table 2: Summary of scenario assumptions for manual returns based on the return of 15 containers per week

Variable	Low	Central	High
Additional Journeys per week	0	0.5	1
Value of time (travel)	A carer is provided with £67.60 per week, for 35 hours a week of work - £1.93/hr [34]	National living wage in UK as of April 2022, £9.50/hr[35]	£11.24/hour value of travel time – direct value from ONS value of unpaid work evaluation [36]
Value of time (service engagement)	A carer is provided with £67.60 per week, for 35 hours a week of work - £1.93/hr [37]	National living wage in UK as of April 2022, £9.50/hr[38]	£8.58 / hour value of time for queuing and returning items – direct value for 'housework' from ONS value of unpaid work evaluation [39]. Note: this ONS source was used to correspond with the high-scenario value for travel time.
Service Engagement at counter	3 minutes 22 seconds service engagement at Manual return point 2-minute queue time (assumed) + 1 minutes 12 seconds service engagement (scaled up from findings for return of 48 seconds to return 10 containers from[40]+ 10 seconds additional time to process receipt.		

[34] Government, U. (2021, April). Carers Allowance. Retrieved from GOV.UK: https://www.gov.uk/carers-allowance
[35] Government, U. (2022, April). National minimum wage rates. Retrieved from GOV.UK: https://www.gov.uk/national-minimum-wage-rates
[36] Statistics, O. f. (2016, November). Women shoulder the responsibility of unpaid work. Retrieved from Office for National Statistics: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/articles/womenshouldertheresponsibilityofunpaidwork/2016-11-10
[37] Government, U. (2021, April). Carers Allowance. Retrieved from GOV.UK: https://www.gov.uk/carers-allowance
[38] Government, U. (2022, April). National minimum wage rates. Retrieved from GOV.UK: https://www.gov.uk/national-minimum-wage-rates
[39] Statistics, O. f. (2016, November). Women shoulder the responsibility of unpaid work. Retrieved from Office for National Statistics: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/articles/womenshouldertheresponsibilityofunpaidwork/2016-11-10
[40] Woods, O. (2019). Improving the Capture Rate of Single Use Beverage Containers in Ireland. Eunomia.

Variable	Low	Central	High
Service Engagement at home	4 minutes 12 seconds collecting and sorting DRS materials at home per week. Norwegian study found that an average household spent a total time of 14 minutes handling recycling in the home[41]. A recent Bristol waste composition analysis found that 30% of all recycling could be impacted by the current all in DRS proposal. These two figures were multiplied in order to assume the time required to handle DRS material in the home.		
Travel time	5 minutes return trip. Based on the minimum travel distance assumed in SLR study of 2km one way, assuming a speed of 30 mph, this is between 2 mins 30 seconds[42].		
Results (£/hhld/year)	**£12.66**	**£82.91**	**£105.00**
Results (hrs/hhld/year)	**6h 34m**	**8h 44m**	**10h 54m**

3.2 Value of consumers' time required to scan and redeem drinks containers at the kerbside

Digital kerbside returns remove the need to consider users' travel time. For kerbside returns, service engagement is the key driver of time, both in the home sorting empty containers and at the kerbside scanning and depositing returns.

DDRS is a newer concept than RVM or manual returns, so less research is available. Research to date on DDRS systems is mainly qualitative including interviews/surveys with trial participants. With less quantitative research available findings in this section are less robust, with more basis in assumption or inference.

The UK differs from continental Europe in the long-term establishment and normalcy of kerbside collections for all material streams. Therefore, convenience of kerbside DRS and perceived inconvenience of RVM or manual takeback point should be considered as a potential barrier. Research conducted on behalf of DEFRA found that users are unwilling to spend more than an additional 20 minutes per week on this task. Regardless of what these calculations show, people do not want to have to engage with any services in addition to the kerbside collected waste. [43] The key steps in for kerbside digital returns are shown in Figure 8.

[41] Annegrete Bruvoll a, *. B. (2002). Households' recycling efforts. Resources, Conservation and Recycling, 337–354.
[42] SLR. (2021). HIGH LEVEL STUDY TO ASSESS THE CARBON IMPACTS OF SMART DRS Briefing Note. Irish Waste Management.
[43] DEFRA. (2019). Defra: Consumer research to inform the design of an effective deposit return scheme. Kantar.

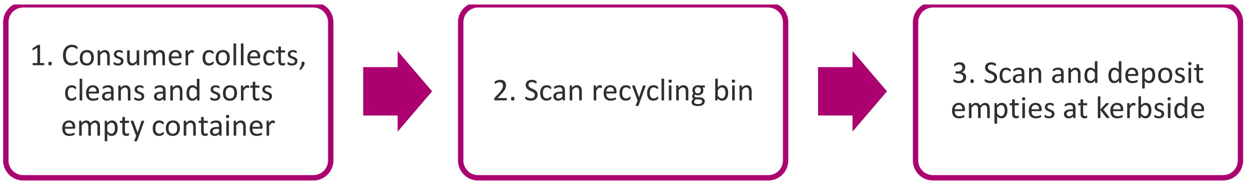

Figure 8 DDRS returns process flow

Table 3 summarises values used to calculate value of time at a household level for DDRS returns.

Table 3: Summary of scenario assumptions for kerbside returns based on the return of 15 containers per week

Variable	Low	Central	High
Value of time (service engagement)	A carer is provided with £67.60 per week, for 35 hours a week of work - £1.93/hr [44]	National living wage in UK as of April 2022, £9.50/hr[45]	£8.58 / hour value of time for queuing and returning items – direct value for 'housework' from ONS value of unpaid work evaluation [46]. Note: this ONS value is used to maintain consistency with valuation methods for RVM based and manual returns.
Service Engagement at kerbside	55 seconds – based on the assumption that it takes 1 second to scan each data matrix code + 2 seconds to deposit each empty in recycling container+ 10 seconds to open app and scan bin.	1 minutes 34 seconds service engagement at kerbside - based on the assumption that it takes 3.5 seconds to scan each data matrix code + 2 seconds to deposit each empty in recycling container+ 10 seconds to open app and scan bin.	2 minutes 10 seconds service engagement at kerbside – based on the assumption that it takes 6 second to scan each data matrix code + 2 seconds to deposit each empty in recycling container+ 10 seconds to open app and scan bin.
Service Engagement at home	4 minutes 12 seconds collecting and sorting DRS materials at home per week – a Norwegian study found that an average household spent a total time of 14 minutes handling recycling in the home[47]. A recent Bristol waste composition analysis found that 30% of all recycling could be impacted by the current all in		

[44] Government, U. (2021, April). Carers Allowance. Retrieved from GOV.UK: https://www.gov.uk/carers-allowance
[45] Government, U. (2022, April). National minimum wage rates. Retrieved from GOV.UK: https://www.gov.uk/national-minimum-wage-rates
[46] Statistics, O. f. (2016, November). Women shoulder the responsibility of unpaid work. Retrieved from Office for National Statistics: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/articles/womenshouldertheresponsibilityofunpaidwork/2016-11-10
[47] Annegrete Bruvoll a, *. B. (2002). Households' recycling efforts. Resources, Conservation and Recycling, 337–354.

	DRS proposal. These two figures were multiplied in order to assume the time required to handle DRS material in the home.		
Results (£/hhld/year)	**£8.59**	**£47.75**	**£48.09**
Results (hrs/hhld/year)	**4h 27m**	**5h 18m**	**5h 36m**

3.3 Consideration of the monetary value of consumer's time

The principle that travel time and 'work' time require a different value has been used throughout this assessment, based on valuation methods in other studies. An overall value has been derived by combining £/hr for travel and £/hr for waste sorting and service engagement. The monetary value of this 'work' time could be derived in many different ways, the three different scenario models outlined in this report's attempt to cover this range of possibilities. From the government value of unpaid work, as defined through carers allowance (£1.93/hr)[48],the standard value of work as defined by the living wage, (£9.50/hr)[49] and the actual value of work as derived by the Office of National Statistics (£8.58/hr)[50].

There are multiple ways of estimating the value of individuals' time. Very rarely is unpaid work accounted for when attempting to quantify the financial impact of waste disposal methods, or other systems change, and even those that do are not regularly updated. Thought should be taken to consider whether or not the aim is to standardise methodology with current practice or do better.

The Office of National Statistics (ONS) has attempted to quantify the value of unpaid work in its analyses, primarily to understand the value that this adds to the national economy (GDP) and also to assess the gender pay gap[51]. The values calculated by ONS have been used as the basis of the high scenario model.

The transport sector also attempts to quantify individuals time in order to assess validity of new infrastructure. The UK uses these figures to value travel time that could be used to work[52].

It is harder to quantify the value of non-working time. Some economists use utility theory, which is a mathematical formulation that ranks the preferences of the individuals in terms of satisfaction that different "consumption bundles" provide[53]. The Department for Transport has quantified the value of non-working time under different activities, e.g., commuting £9.95/hour, with all other activities being valued at £4.54/hour market price[54]This is just one approach, a Norwegian study generated different formulas for the value of time based on the motivation of individuals to engage with recycling. This study did not conclusively determine values for individuals time, but derived formulas based on individuals' circumstances, including leisure time available, improvement to self-image and moral responsibility. This

[48] Government, U. (2021, April). Carers Allowance. Retrieved from GOV.UK: https://www.gov.uk/carers-allowance
[49] Government, U. (2022, April). National minimum wage rates. Retrieved from GOV.UK:
[50] Statistics, O. f. (2016, November). Women shoulder the responsibility of unpaid work. Retrieved from Office for National Statistics:
[51]Statistics, O. f. (2016, November). Women shoulder the responsibility of unpaid work. Retrieved from Office for National Statistics: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/articles/womenshouldertheresponsibilityofunpaidwork/2016-11-10
[52] Transport, D. o. (2021). TAG Data book. UK Government.
[53] https://saylordotorg.github.io/text_risk-management-for-enterprises-and-individuals/s07-01-utility-theory.html
[54] Transport, D. o. (2021). TAG Data book. UK Government.

would mean that the value of an individual's time who works 60 hours a week, would be considered higher than someone who works 5 hours, as it is more difficult for them to fit this extra unpaid time in. The study did make the statement that these models could only be used if there was also a willingness to pay for the service in absence of doing the work themselves[55].

3.4 Consideration of travel time and additional car journeys

Two key assumptions have been made in calculating travel time. These are detailed below:

- For RVM based returns, 15 minutes travel time for a return trip has been assumed. This is based on Department for Transport data of average travel time to supermarkets in urban areas[56]
- For manual returns 5 minutes travel time for a return trip has been assumed (2 * 2 minutes 30 second one-way journey). This is based on the assumptions made in the SLR study investigating carbon impact of DRS systems. In this model they used a range of values for travel time, this is the minimum time assumed[57].

These assumptions were drawn from a broader research basis, the key findings of which have been summarised. Most studies relate to RVM based returns and it is unclear if these assumptions hold true for manual returns as well.

Most studies assume individuals will not make additional journeys and will only return empty containers during their regular food shop. The majority (61%) of UK residents undertake a food shop once or twice a week.[58] Consumer research was conducted for Welsh Government to inform the design of an effective Deposit Return Scheme (DRS). For many participants, large supermarkets were considered the most convenient location for returns points, allowing the bulk return of materials from home alongside a weekly big shop. However, both young unmarried individuals and the elderly who do not participate in the traditional weekly shop were resistant to changing their behaviours.[59]

Based on this finding this model has derived travel time from findings of Department for Transport via the National travel survey. This survey found that in urban areas of the UK the average travel time in one direction to a food store is 7 minutes 30 seconds, whilst in rural areas this increases to 9 minutes[60]. This assumption is supported by findings from a Norwegian study which concluded that residents spend on average 7 minutes transporting and depositing their empty containers[61].

A study conducted by SLR investigated the carbon impact of different DRS models used a range of values for additional car journeys required to return empty containers as no real-world data has been found. These calculations used a range of values, either 20, 30 or 40% of total shopping visits being additional car

[55] Bruvoll, A., & Nyborg, K. (2002). On the value of households' recycling efforts. Statistics Norway, Research Department, Oslo.
[56] Survey, N. T. (2015). Why people travel shopping. Department for Transport.
[57] SLR. (2021). HIGH LEVEL STUDY TO ASSESS THE CARBON IMPACTS OF SMART DRS Briefing Note. Irish Waste Management.
[58] Survey, N. T. (2015). Why people travel shopping. Department for Transport.
[59] KANTAR: Alice Fitzpatrick, A. M. (2019). Wales Report: Consumer research to inform the design of an effective of DRS. Welsh Government.
[60] Survey, N. T. (2015). Why people travel shopping. Department for Transport.
[61] Bruvoll, A., & Nyborg, K. (2002). On the value of households' recycling efforts. Statistics Norway, Research Department, Oslo.

journeys. This study stated that these assumptions were conservative estimate[62]. In the absence of quantitative data this same study again assumed a range of values for distance travelled to return empty containers. It was estimated most users would travel between 2 – 4km journey to reach a return point in one direction. Again, however it was noted that these estimates were considered to be conservative[63].

As previously discussed, the required travel distance to manual return points is influenced by the national DRS system, as some models would require more frequent return points, and some less. Many studies assume that a DDRS system would reduce the requirement for manual return points, and therefore increase the required travel distance. The SLR study, investigating carbon impact of DRS system assumed that travel distance could increase by 10km (one way) to manual take back points in a DDRS system[64].

3.5 Consideration of different RVM models

There are different models of RVMs, some require individual scanning (this will increase queuing time), whilst some allow bulk returning (reducing queuing time and likelihood of queue's developing). Queue time will depend on the time of day and type of business where the RVM is located. For example, there are likely to be multiple RVM units in a superstore, but potentially only one in a Sainsburys Local or Tesco Metro. In the UK, consumers are generally willing to queue up to about 6 minutes[65]. However, with use of RVMs, perceived time and actual time should be considered. For example, while self-service check outs are perceived to be quicker, research shows that it can often actually be longer. [66] As most consumers expect to return empty containers during their weekly shop, RVMs that allow quicker returns via bulk returns may be preferable to consumers.

As stated above there are different models of RVMs. Some require individual scanning or small bulk returns, meaning that the time users spend at the RVM will be higher. Whilst other models allow large bulk returning, allowing for quicker consumer returns and a decreased likelihood of queue's developing. The same RVM is unlikely to be used in all stores, dependent on size and footfall within different stores a different model of RVM can be selected based on cost and need. The consumer engagement time at an RVM will be variable on an individual basis and is likely be influenced by the consumers' level of confidence using the technology.

- Depending on RVM model return speed ranges from 15 per minutes for small bulk/single item return machines[67]
- RVM that requires each barcode to be individually scanned and bottle deposited, it is estimated 20 – 30 seconds to scan barcode and deposit empty into RVM[68]

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[62] SLR. (2021). HIGH LEVEL STUDY TO ASSESS THE CARBON IMPACTS OF SMART DRS Briefing Note. Irish Waste Management.
[63] SLR. (2021). HIGH LEVEL STUDY TO ASSESS THE CARBON IMPACTS OF SMART DRS Briefing Note. Irish Waste Management.
[64] SLR. (2021). HIGH LEVEL STUDY TO ASSESS THE CARBON IMPACTS OF SMART DRS Briefing Note. Irish Waste Management.
[65] https://qless.com/gone-in-6-minutes-average-queuing-time-uk-shoppers-are-willing-to-wait/
[66] https://www.irisys.net/blog/the-great-queue-method-debate-self-service-checkout-vs-staffed
[67] Reverse Vending Systems. (n.d.). Retrieved from TOMRA: https://www.tomra.com/en-gb/collection/reverse-vending/reverse-vending-systems
[68] Yin, C. C. (2019, May 29). Interview with operation manager of Sham Shui Po station. (W. K. Chung, Interviewer)

- RVM that allows bulk deposits of empties can handle up to 140 bottles per minute[69]

Depending on the RVM model and overall DRS system; users are likely to have a choice regarding between immediate receipt of deposit, electronic crediting of funds (potentially PayPal) or issue of receipt for redemption or use at a later date. This may influence total time taken to engage with the service.

Figure 9. TOMRA H10/H11 - small until individual/low volume

Figure 10. TOMRA R1 Multi feed RVM

[69] Reverse Vending Systems. (n.d.). Retrieved from TOMRA: https://www.tomra.com/en-gb/collection/reverse-vending/reverse-vending-systems

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