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Life cycle assessment of the current recycling system and an alternative reuse system for bottles in Norway

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Summary

Packaging is one of the focus areas of EU's new circular economy action plan which is one of the main building blocks of the European green deal. As a result, packaging, including beverage packaging, has been targeted as one of the areas with the highest potential for circularity. In Norway, Infinitum, has for more than 20 years been running a highly successful national deposit return scheme for beverage packaging. In 1999, they started the single-use system consisting of single-use PET bottles and single-use aluminium cans. The cans and bottles are returned by the consumers through reverse vending machines and the collection rate for the Norwegian system is high: in 2021, the average collection rate for aluminium cans and PET bottles returned to retailer and collected for recycling was 91.6% and 93.3%.

The goal of this study is to compare Infinitum's deposit system for single-use PET bottles and aluminium cans with an alternative system for reusable PET and glass bottles to assess under what circumstances these systems become environmentally preferable relative to each other. The study is based on Life Cycle Assessment (LCA) methodology and the results are presented for four environmental impact categories.

A discussion group, consisting of Infinitum, NORSUS and other organizations with expertise in reuse and recycling systems for bottles and cans have been constructed to ensure credibility of the results. The aim of this group was to ensure the quality and representativeness of the systems being modelled and the data applied.

The functional unit is defined as: Production, collection and waste treatment of beverage containers and distribution packaging representing the market mix of containers used for distributing 1000 litres of beverage to Norwegian consumers.

The conclusion from the study is that the single-use system performs better than the reuse system for the three impact categories; climate change, cumulative energy demand (CED) and terrestrial acidification, while the reuse system performs best for the impact category mineral resource scarcity. PET bottles perform best in both systems. The reuse system has higher transport-related impacts than the single-use system for all impact categories analysed. The back-to-market return rate is crucial for calculating the average number of uses per bottle in the reuse system, and the study has documented the importance of considering realistic back-to-market rates by including all potential losses throughout the value chain.

Three different recycling modelling principles have been applied in order to address how these affect the results and conclusion: the Cut-off, the CFF (Circular Footprint Formula) and the System expansion_net scrap approaches. The ranking of the systems regarding environmental performance is not affected by the choice of modelling approach. Still, the choice of modelling approach affects the calculated performance for each system. For the single-use system, the System expansion_net scrap approach clearly gives the best result for all the assessed impact categories while the CFF approach gives lowest impact for the reuse system. The study clearly shows that the single-use system is more sensitive to the different modelling principles compared to the reuse system, which is logic because it has a bigger material throughput being affected by recycling.

Sensitivity analyses have been caried out for climate change. They show that the single-use system outperforms the reuse system (as analysed in the main analysis) until its recycled content decreases to 20%. Furthermore, the reuse system must reach a collection rate near 100% in order to be able to compete with the single-use system (as analysed in the main analysis with 93% collection rate).

The study has been designed to represent Norwegian conditions with relatively long transport distances. A potential reuse system with more local sited breweries and sorting/washing facilities would give shorter transport distances which affects the related transport burdens. It is therefore important that studies are designed with realistic assumptions, and the results in this specific study should not be interpreted as valid for reuse systems in general. A lot of effort has been put on obtaining representative data and assumptions for the systems, and sensitivity analyses have been performed. However, there are still issues and aspects which could have been analysed, such as changing to biofuel and/or electrified transport, reducing the bottle weights and increasing the amount of recycled content in the reuse system. It will always be difficult to predict the future, and more detailed data and additional sensitivity analyses could have given added value to the study.

Sammendrag

Emballasje er ett av fokusområdene i EUs nye handlingsplan for sirkulær økonomi, en viktig del av Europas grønne giv, og har blitt utpekt som ett av områdene med størst potensial for sirkularitet. I Norge har Infinitum i over 20 år drevet et nasjonalt pantesystem for drikkevareemballasje, som fra 1999 har bestått av et engangssystem med PET-flasker og aluminiumsbokser. Flaskene og boksene returneres av forbrukerne gjennom panteautomater, og innsamlingsgraden er høy: 91,6 % for aluminiumsbokser og 93,3 % for PET-flasker i 2021.

Målet med denne studien er å sammenligne miljømessig prestasjon fra Infinitums pantesystem med et alternativt ombrukssystem bestående av PET- og glassflasker. Studien er basert på LCA-metodikk (Life Cycle Assessment), og resultatene er presentert for fire miljøpåvirkningskategorier.

En diskusjonsgruppe bestående av Infinitum, NORSUS og andre organisasjoner med erfaring innen pantesystemer, ble etablert for å sikre kvalitet og representativitet til data og forutsetningene som inngår.

Funksjonell enhet er definert som: produksjon, innsamling og avfallshåndtering av drikkevare- og distribusjonsemballasje, representert ved dagens markedsmiks av drikkevareemballasje, for distribusjon av 1000 liter drikke til norske forbrukere.

Hovedkonklusjonene fra studien er at engangssystemet presterer bedre enn ombrukssystemet for de tre miljøpåvirkningskategoriene klimaendring, bruk av primære energikilder og forsuring, mens gjenbrukssystemet presterer best for kategorien sårbarhet av mineralressurser (mineral resource scarcity). PET-flasker har best miljøprestasjon i begge systemene. Ombrukssystemet gir vesentlig høyere transportbelastninger enn engangssystemet for alle miljøpåvirkningskategoriene. Andelen ombruksflasker som blir levert tilbake bryggeriene er vesentlig for beregning av antall ganger en ombruksflaske i gjennomsnitt blir brukt, og studien har dokumentert viktigheten av å beregne dette basert på potensielle tap gjennom verdikjeden.

Det er benyttet tre forskjellige prinsipper for modellering av resirkulering for å se hvordan disse påvirker resultatene og konklusjonen: Cut-off, CFF (Circular Footprint Formula) og System expansion_net scrap. Resultatene viser at rangeringen av systemene med hensyn til miljøprestasjon ikke påvirkes av valgt modelleringsprinsipp. Men valg av prinsipp påvirker beregnet miljøprestasjon for hvert system. For engangssystemet gir System expansion_net scrap klart best resultat for alle vurderte påvirkningskategorier, mens CFF gir lavest påvirkning for gjenbrukssystemet. Studien viser at engangssystemet er mer følsomt for de forskjellige modelleringsprinsippene sammenlignet med gjenbrukssystemet, noe som er logisk fordi det har en større materialstrøm som påvirkes av resirkulering.

Følsomhetsanalyser er utført for klimaendringer, og de viser at engangssystemet presterer bedre enn ombrukssystemet (som det er analysert i hovedanalysen) så lenge engangssystemet har et resirkulert innhold i flaskene/boksene på over 20%. Følsomhetsanalyser viser også at ombrukssystemet må opp i en innsamlingsgrad på tilnærmet 100 % for å kunne konkurrere med engangssystemet (som det er analysert i hovedanalysen med 93 % innsamlingsgrad).

Studien er designet for å representere norske forhold med relativt lange transportavstander. Et ombrukssystem som har flere lokale bryggerier og sorteringsanlegg vil medføre kortere transportavstander, noe som vil påvirke transportbelastningene. Det er derfor viktig at denne typen studier blir designet med realistiske forutsetninger, og resultatene i denne studien er ikke nødvendigvis gjeldende for ombrukssystemer generelt. Det er lagt ned mye innsats i å fremskaffe representative data og forutsetninger,

og det er gjennomført flere følsomhetsanalyser. Imidlertid er det fortsatt andre aspekter som kunne inngått i studien, som for eksempel overgang til biodrivstoff og/eller elektrifisert transport, reduksjon av vekten på flasker/bokser, samt økt andel resirkulert innhold i flaskene i ombrukssystemet. Det vil alltid være vanskelig å forutsi hvordan fremtiden vil bli, og mer detaljerte data og ytterligere følsomhetsanalyser ville følgelig kunne gi merverdi til studien.

Contents

1 Introduction

Packaging is one of the focus areas of EU's new circular economy action plan (EC, 2020) which is one of the main building blocks of the European green deal. As a result, packaging, including beverage packaging, has been targeted as one of the areas with the highest potential for circularity. The beverage industry has followed up by launching ambitious initiatives towards the goal of achieving full circularity by 2030 (UNESDA, 2021). In addition, for beverage plastic bottles specifically, the EU has also set a target for recycled content (30% by 2030) and collection rate (90% by 2029). Across the EU there has recently been a shift in policy priorities away from recycling and towards reuse models of plastic packaging (PWC, 2021).

In Norway, Infinitum, has for more than 20 years been running a highly successful national deposit return scheme for beverage packaging. In 1999 they started the single-use system system consisting of single-use PET bottles and single-use aluminium cans. The cans and bottles are returned by the consumers through reverse vending machines and the collection rate for the Norwegian system is high: in 2021, the average collection rate for aluminium cans and PET bottles returned to retailer and collected for recycling was 91.6% and 93.3%, respectively (Infinitum, 2021a). After collected through the reverse vending machines, the packaging is further sorted and recycled into new, secondary material (PET and aluminium).

NORSUS has previously conducted the study "LCA of beverage container production, collection and treatment systems", including an assessment of Infinitum's deposit system for PET bottles as well as aluminium cans (Raadal, Iversen, & Modahl, 2016). More recently, NORSUS has conducted a study including a literature review of life cycle assessment (LCA) studies on reuse systems for bottles as well as European reuse system actors (Furberg, Lye Moum, Nørsterud, & Lerche Raadal, 2021). Both studies were commissioned by Infinitum who now has requested a comparative LCA of Infinitum's current system for recycling of bottles/cans with an alternative reuse system for bottles in Norway.

The goal of this study is to compare Infinitum's deposit system for recycling single-use polyethylene terephthalate (PET) bottles and aluminium cans with an alternative Norwegian system for reusable PET and glass bottles to assess under what circumstances these systems become environmentally preferable relative to each other. This also involves the assessment of improvement potentials for these systems. Four different environmental impact categories have been considered to assess a broad scope of environmental effects. Life Cycle Assessment (LCA), based on standardised methodology (European Commission Joint Research Centre, 2010; ISO, 2006) has been performed to assess the potential environmental impact of the systems.

Key to the study is the discussion group that was established to assess the quality of the data applied and the comparability of the systems assessed. Extensive effort has been dedicated to collecting and selecting data to ensure the reuse system reflects a practically realistic option for the Norwegian market. The literature study by Furberg et al. (2021) served as a basis for the reuse system as it highlights important aspects, including methodological ones, to consider.

The study has provided valuable insight related to modelling principles in the assessed systems, as three different modelling approaches for recycling have been applied.

2 System and modelling description

2.1 Goal and scope of the study

Today, there exists a beverage packaging system for single-use bottles and cans in Norway. This system is operated by Infinitum who is responsible for the Norwegian deposit scheme for beverage containers. A system for reusable bottles does not exist in Norway today, however, the interest in such systems is increasing from the perspective of potentially reduced environmental impacts, waste generation and littering (Briedis et al., 2019; Coelho, Corona, & Worrel, 2020; UNEP, 2020).

The goal of this study is to compare Infinitum's current single-use deposit system for PET- bottles and aluminium cans with an alternative Norwegian system for reusable PET and glass bottles to assess under what circumstances these systems become environmentally preferable relative to each other. This also involves the assessment of improvement potentials for these systems.

The recycling system is here defined as a system where used bottles and cans are collected for recycling with a bottle-to-bottle and can-to-can quality. The reuse system is defined as a system where used bottles, after collection, are returned to the filler, washed, refilled, and then returned to the retailer to be sold again in a certain number of cycles until the bottles cannot be reused anymore. At that point, the reusable bottles are sent to relevant waste treatment.

The fulfilment of the study goal will increase knowledge regarding benefits and burdens of the assessed beverage distribution systems. The study will also address the effect of using different recycling modelling principles in LCA. The study and its results are intended to be applied to provide recommendations to beverage packaging system actors and public authorities under what circumstances the assessed recycling and reuse systems become environmentally preferable within a Norwegian context.

2.2 Discussion group

A discussion group, consisting of Infinitum, NORSUS and other organizations with expertise in reuse and recycling systems for bottles and cans have been constructed to ensure credibility of the results. The aim of this group was to ensure the quality and representativeness of the systems being modelled and the data applied. Thus, the group has contributed to the robustness of the study, e.g., by providing and reviewing the data applied, as well as discussing and interpreting the study results. The members of the group are presented in Table 1.

Table 1. Discussion group members.

Name	Organisation	Country
Kaupo Karba	Eesti Pandipakend	Estonia
Tobias Bielenstein	Genossenschaft Deutscher Brunnen (GDB)	Germany
Ole Faye	Infinitum	Norway
Kjell Olav Maldum	Infinitum	Norway
Sten Nerland	Infinitum	Norway
Jan Audun Larsen	Lerum Fabrikker	Norway
Arve Gøperød	Prime Cargo	Norway

Pasi Nurminen	Palpa	Finland
Emma Bjørke	Ringnes	Norway
Anna Furberg	NORSUS (until December 2022)	Norway
Hanne Lerche Raadal	NORSUS	Norway
Ingunn Saur Modahl and Simon A. Saxegård	NORSUS (from January 2023)	Norway

Six digital discussion group meetings took place throughout the project with the following meeting themes:

- Goal and scope of the study, i.e., the foundations for the study, data quality, methodological choices, etc. (6th of April 2022)
- Data to be applied and scenarios constructed for the analysis (19th of May 2022)
- Further discussions on data to be applied and scenarios constructed for the analysis (27th of September 2022)
- Agreement on systems, assumptions and data to be modelled (25th of January 2023)
- Digital input to report draft sent out April the 28th 2023)
- Discussion on final report draft November the 2nd 2023

The discussion group members have participated in meeting discussions, and they have had the opportunity to comment on relevant documents sent out beforehand by NORSUS and to comment on minutes from the meetings sent out after the meetings by NORSUS. The discussion group members have jointly defined the goal and scope, and they have decided upon the type of data to be applied, including scenarios to be constructed, and discussed the study results and their interpretation.

2.3 Functional unit

In LCA, a functional unit is defined to quantitatively express the function of products or services (Baumann & Tillman, 2004). This unit should be selected to represent the function that the products or systems deliver in a way that is relevant and enables fair comparisons.

The functional unit in this study is defined as: Production, collection and waste treatment of beverage containers and distribution packaging representing the market mix of containers used for distributing 1000 litres of beverage to Norwegian consumers.

The market mixes of bottles and cans for the respective single-use and reuse system for 2021 are presented in Figure 1 and described more detailed in Appendix 1.

As described in section 2.1, the current single-use beverage packaging system and an alternative reuse system (not existing in Norway today) have been assessed. The reuse system is constructed by converting the single-use PET bottles volume into reuse PET bottles and the single-use aluminium cans volume into glass bottles, see Figure 1 for a simplified illustration. Both the single-use and reuse systems are considered to use a deposit collection system with reverse vending machines in grocery stores, which is the case for the current recycling system for bottles and cans in Norway.

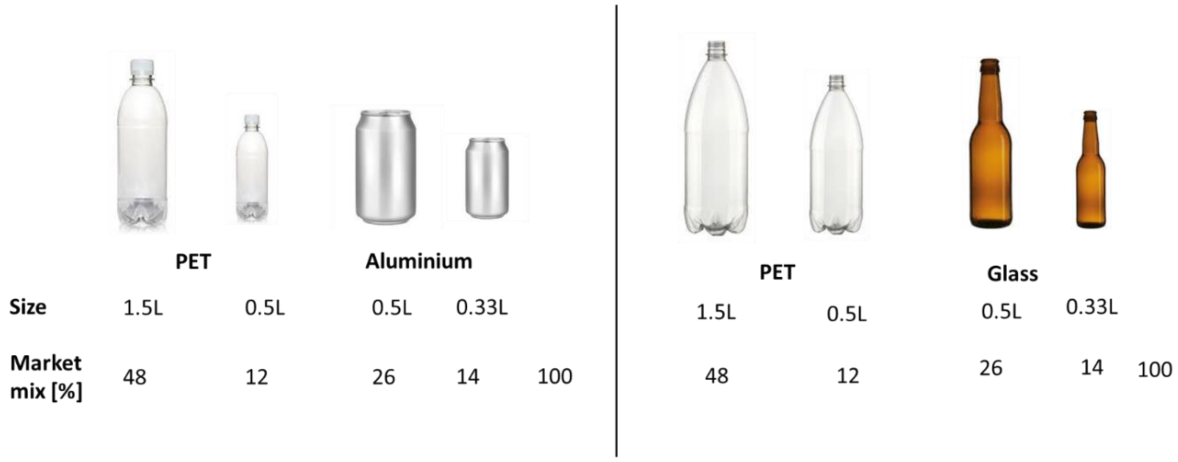


Figure 1 Illustration of the simplified mix of bottles and cans for the respective single-use and reuse system, based on the market mix in 2021 (Appendix 1).

It should be emphasised that the figure above shows a simplified illustration of the mix of bottles and cans in the two systems, as the actual variety of models is much higher in both systems. The average bottle and can sizes and types in the single-use system represents around 200 different models while the reuse system is based on 20 different models: 12 PET bottles, of which 4 standard and 8 brand models and 8 glass bottles of which 6 standard and 2 brand models. The variety in reuse models are reflected in the LCA-model by taking different transport distances into account for the share of standard and brand bottles, respectively. The variety of models are mainly related to appearance, while the volumes are predominantly as specified in the illustration. The specific single-use bottles and cans and reusable bottles assessed in this study are described in the next sections.

2.4 Single-use beverage packaging systems

Infinitum´s deposit system manages a large diversity of single-use beverage packaging that vary in terms of size, material (aluminium and PET), shape, and colour (Infinitum, 2022b). However, a limited selection of PET bottles and aluminium cans, in terms of size and material, typically dominate this market. For PET bottles, the 0.5L and 1.5L sizes were alone accounting for about 83% of the total PET single-use bottle units sold in 2021, corresponding to about 88% of the total volume of sold PET bottles volume. For aluminium cans, the 0.33L and 0.5L sizes dominated the market for aluminium cans in 2021 with about 90% of total can units sold, corresponding to about 92% of the total sold can volume. The container sizes 0.5 L and 1.5 L, and 0.33 L and 0.5 L represent the average weights of PET bottles and alu-cans, respectively (see

Table 2).

A market mix for the total beverage volume distributed by PET bottles and aluminium cans was calculated based on sales figures in 2021 (

Table 2). For more details on the data behind the selection of specific single-use bottles and cans and the calculation of the market mix, see Appendix 1.

Table 2. Single-use bottles and cans assessed for Infinitum's existing recycling system and the corresponding market mix representing 2021. For more information, see Appendix 1 and Appendix 2.

Characteristics	**Single-use PET bottle system**		**Single-use aluminium can system**		**Reference**
	1.5 L	**0.5 L**	**0.5 L**	**0.33 L**	
Weight [g]	46.3	26.9	15	12.5	Infinitum (2022b)
Recycled content [weight-%]	65	65	55	55	Infinitum (2022b)
Market mix [% of sold beverage volume]	48	12	26	14	Calculated based on data from Infinitum (2022b)

A simplified flowchart for the single-use beverage packaging systems is shown in Figure 2. All transport (Tx) and production (Px) activities are further described in Appendix 2.

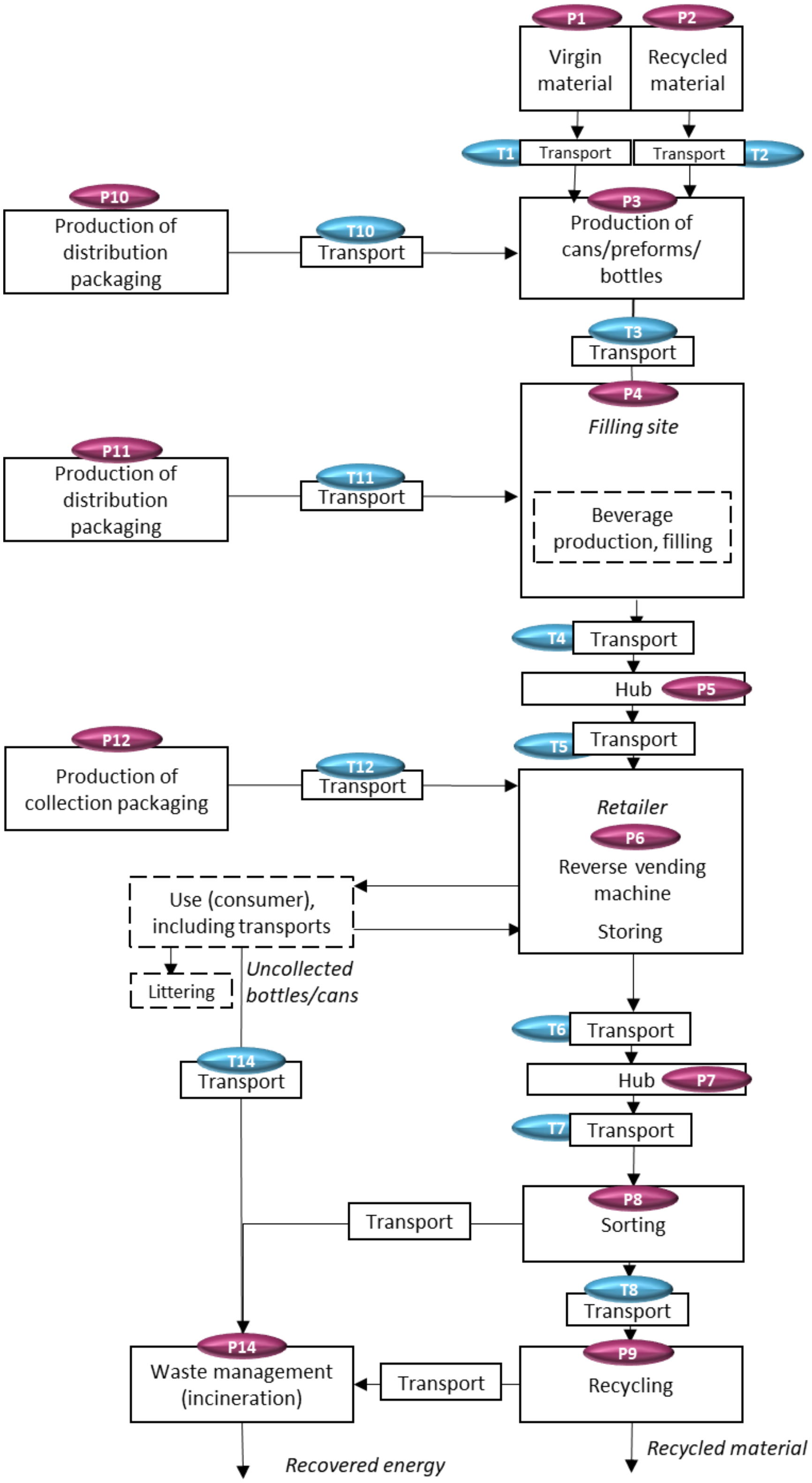


Figure 2 Simplified flowchart for the current single-use recycling system of PET bottles and aluminium cans in Norway. All transport (Tx) and production (Px) activities are further described in Appendix 2. Activities shown with dashed lines are excluded from the system boundaries.

Single-use bottles are produced from PET preforms consisting of both virgin and recycled materials. The preforms are sent to the beverage company for moulding/blowing and subsequent bottling of the beverage. In the case of aluminium cans, the manufactured cans (with a separate lid) are transported to the beverage company where the beverage is tapped, and the lid is mounted. According to data representative for 2021, 9% of the filled PET bottles and 34% of the aluminium cans (based on sales numbers) were imported (Infinitum, 2022b). Thus, imported bottles and cans which have been filled outside Norway and then transported to be sold on the Norwegian beverage market, have been included in the study. After filling, the bottles/cans are transported according to the transport descriptions shown in Figure 2. A detailed description of the transport modelling is additionally provided in Appendix 4. Distribution and transport packaging for the bottles/cans are also included in the analyses, see Appendix 2 for details. The two hubs (P5 and P7) represent locations for storing and reloading of goods and do not contribute to any environmental burden in the analyses.

After use, a certain share of the bottles/cans is returned to the store and deposited by the consumer using a reverse vending machine (RVM). A small portion (approx. 4-5%), of the volume is returned through smaller outlets that do not have an RVM, termed "manual returns" (Infinitum, 2022b). Bottles and cans from these manual returns are counted by reverse vending machines at the sorting centres. These containers returned by the consumers represent the collection rate in the deposit return system (DRS). The containers that are not being returned by the consumers represent the deposit loss and are assumed to be collected as municipal waste and thereby sent to incineration.

The reverse vending machine compresses the cans and bottles together in one common compactor before being further transported to the wholesaler distribution centre and to Infinitum’s sorting plants. As of 2022, Infinitum’s sorting plants are located at Heia (Lillestrøm, near Oslo), Bjerkvik (Narvik in northern Norway), and Heimdal (Trondheim, middle Norway) (Infinitum, 2022a). In the sorting plants, the PET bottles and aluminum cans are separated and compressed. The PET bottles are transported to recycling at a recycling facility at Heia, Lillestrøm (owned by Veolia PET Norge) (infinitum, 2022c). This facility was taken into use during 2021. It is in direct vicinity to Infinitum’s sorting facility at Heia and the recycled material is used in new bottles. In 2021, Infinitum entered an agreement with Novelis, UK (Infinitum, 2021b) to recycle all the aluminium cans collected in Norway by Infinitum (Infinitum, 2021c), in the UK and Germany, to be used for the production of new beverage cans (“canstock” aluminium sheets). The bottles/cans that are not collected via reverse vending machines are assumed to be collected with municipal waste and sent to incineration.

The system boundaries applied for the single-use bottles and cans in this study are also shown in Figure 2.

Primary data, e.g., from Infinitum, have been collected to the extent possible for the foreground system while secondary data, from e.g., databases and literature, have been applied for the background system. Some processes have been excluded from the modelling, such as beverage production, filling, storing at the retailer and the use phase of the bottle as well as the transport between the consumer and the store/reverse vending machine. The reasons for this are that the process of beverage production will be the same for all alternatives assessed (single-use bottles and cans and reusable bottles). It should, however, be noted that beverage losses from the filling process might differ between the beverage packaging, but this is excluded from the system boundaries. The use phase is also considered to be similar for the alternatives assessed, while the burdens of transport between the consumer and the store/reverse vending machine are allocated to grocery shopping and not to the beverage packaging, specifically, in this study. Capital goods in the foreground system, i.e., the infrastructure needed for the different processes such as for the sorting and recycling facilities, reverse vending machines, are excluded from the analysis. Capital goods are included in the background system. All processes that are needed to be able to compare different beverage packaging systems are included in line with the study goal. The system boundaries related to the end-of-life modelling are described in Section 2.7.

2.5 Reusable beverage packaging system

As presented in Figure 1, the alternative reuse system for glass and PET bottles is based on the same market mix as the single-use system. More details are given in Table 3. As reusable PET bottles used for still or carbonated water (about 14% of the single-use PET bottles system in 2021) need to be handled in a system separated from soft drinks, this has been included by considering specific transportation needs for this share of the PET bottles, see details in Appendix 2. Additionally, the reusable PET bottles are separated into brand (56%) and standard (44%) bottles based on whether they are used for specific beverage brands. For glass bottles the split between brand and standard bottles is 19% and 81%, respectively. The impact of this is described in chapter 2.6. For more information on the selection of specific reusable bottles and the calculation of the market mix, see Appendix 1.

Table 3. Reusable glass and PET bottles assessed for an alternative reuse system and a market mix representing 2021. PET=polyethylene terephthalate. For more information, see Appendix 1 and Appendix 2.

Characteristics	**Reusable PET bottle**		**Reusable glass bottle**		**Reference**
	1.5 L, transparent	**0.5 L, transparent**	**0.5 L, brown**	**0.33 L, transparent**	
Weight [g]	70	43	370	265	Eesti Pandipakend (2022), GDB (2022)
Recycled content [weight-%]	30	30	61	61	Discussion group
Market mix [% of sold beverage volume]	48	12	26	14	Calculated based on data from Infinitum (2022b) and assuming that reusable glass and PET has similar market shares as single-use aluminium cans and PET bottles, respectively.

A simplified flowchart for the alternative reuse system in Norway is presented in Figure 3. All transport (Tx) and production (Px) activities are further described in Appendix 2.

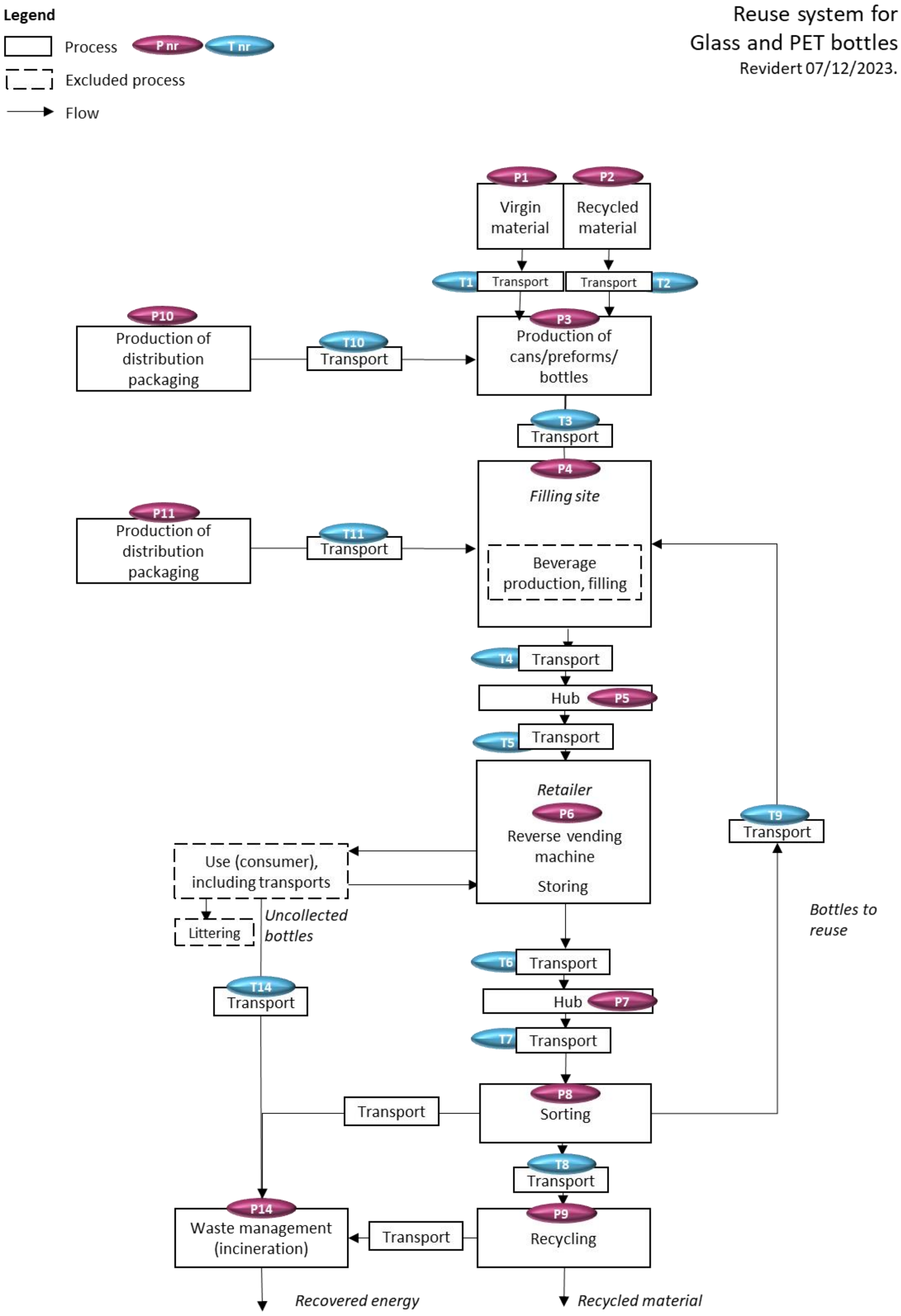


Figure 3 Simplified flowchart for an alternative reuse system in Norway. All transport (Tx) and production (Px) activities are further described in Appendix 2. Activities shown with dashed lines are excluded from the system boundaries.

Reusable PET and glass bottles can be produced from a mix of virgin and recycled materials. The bottles are sent to the beverage company for subsequent filling of beverage. It is assumed that imported bottles constitute a lower share of the beverage packaging market in the reuse system compared to the single-use system. The reason for this is that import of bottles to a Norwegian reuse system would probably require either that the reuse systems in different countries are compatible or that the reuse system is complemented by a recycling system for the imported beverage volume. The study has assumed an import share in the reuse system of 12.5% from the neighbouring countries of Sweden (10%) and Denmark (2.5%). This import share is lower than the import share of specific bottles/cans in today's single-use system in Norway, being 9% for PET bottles and 34% for aluminium cans, based on sales numbers in 2021. After filling, bottles are transported according to the transport descriptions shown in Figure 3. A detailed description of the transport modelling is additionally provided in Appendix 4. Distribution and transport packaging for the bottles, typically crates, are also included in the analyses.

After use, a certain share of the bottles is returned to the store by the consumer using a reverse vending machine (RVM). The amount not being returned by the consumers, the deposit loss, is assumed to be collected with the municipal waste and thereby sent to incineration (same as for single-use system). Besides deposit loss, there are two more loss processes for the bottles before reuse: pollution loss and scuffing loss. Pollution loss is represented by the bottles that are taken out from further circulation because they are damaged or polluted, a mechanism which act randomly among the bottles. The scuffing loss occurs as the bottles have a final technical lifetime (set as 30 number of uses) before being defined as too worn. An inspection is made among deposited bottles that have passed the damage control, and units that bear significant signs of abrasion are rejected from further circulation. Finally, from time-to-time, bottles are subject to redesign, causing the full stock of bottles and its remaining serving capacity to be discarded. Hence, a model replacement of the full stock of bottles is needed. The effect of the different losses on the total back-to-market rate has been investigated by the Norwegian Computing Center (Norsk Regnesentral) by Haug and Løland (2023) and is further described in chapter 2.6.

After being collected through the reverse vending machine and stacked in crates, the bottles are further transported to a sorting facility (note that the reusable bottles are not compressed before they are sent to the sorting facility, which is the case for single-use PET and aluminium bottles). Reusable bottles are sent further to a quality control and a washing process at the refilling site before being refilled and distributed to the grocery store to be used once more. Bottles that do not pass the quality control, either due to pollution, breakage or scuffing, are sent to subsequent waste treatment.

An important difference between single-use bottles/cans and reusable bottles are the transportation of the bottles/cans after use. While collected single-use bottles and cans are transported to sorting and further recycling, collected reusable bottles are transported to sorting and then to washing/re-filling across the country. Hence, the reusable bottles are transported to different breweries at various locations in Norway dependent on the varying demand for different bottles. Extra logistics are thus required to receive the specific bottles needed at a specific time. A simplified model has been constructed to represent the logistics of reusable bottles based on average data on re-transport and sorting of bottles, such as additional transport needed for reusable bottles (see Appendix 2).

Capital goods are included in the background system. All processes that are needed to be able to compare different beverage packaging systems are included in line with the study goal. The system boundaries related to the end-of-life modelling are described in Section 2.7.

2.6 Number of bottles and cans needed per functional unit

The amount of times a reusable bottle is used has a large influence on the LCA results for reuse systems (Furberg et al., 2021). It quantifies the average number of servings delivered for each unit produced in the system and depends on the total back-to-market rate, which is dependent on the losses throughout the systems as introduced in chapter 2.5. The different losses are given in the schematic setup for the reuse system in Figure 4.

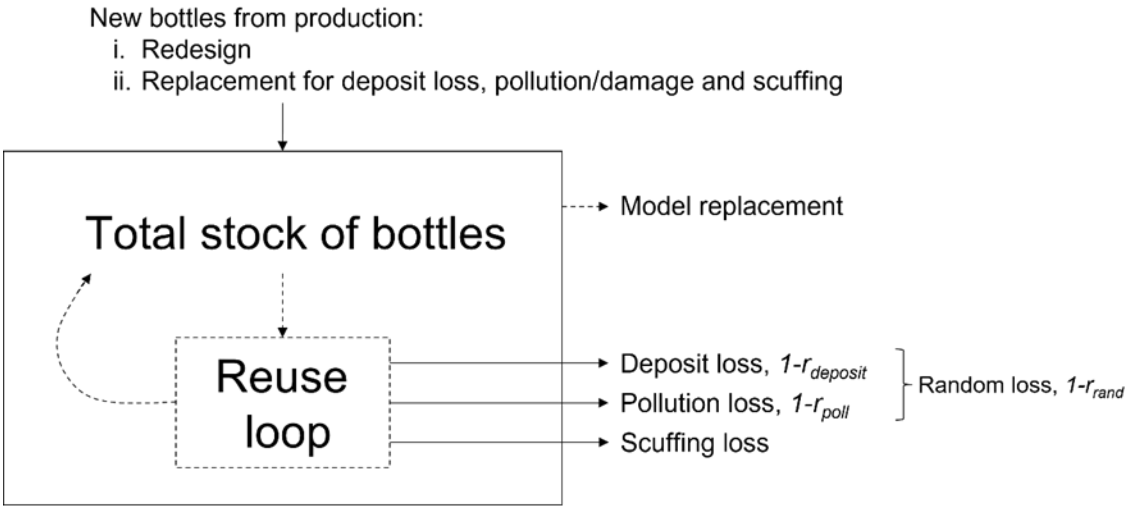


Figure 4 Schematic setup for the reuse system (Figure 1 in the report "A reuse system for bottles – trip rate calculations under model replacement" by Haug and Løland (2023)).

The back-to-market return rate is calculated based on the deposit, the damage and pollution, and the scuffing losses, as given in Figure 4. Additionally, bottles are also subject to redesign, causing the full stock of bottles and its remaining serving capacity to be discarded ("model replacement"). After redesign, a full replacement of the stock of bottles is needed.

Generally, the number of uses (m) for an average bottle is calculated according to Equation 1:

$$\text{Number of uses } (m) = 1/(1-r)$$

Equation 1 Calculation of number of uses (m) based on the back-to-market rate throughout the value chain.

Where r represents the back-to market return rate throughout the assessed system.

Based on data from Infinitum regarding losses throughout the system, as well as number of years between redesign of a standard and a brand pool, respectively, NR has calculated analogous number of reuse (m') and back-to-market return rates (r' = 1 – 1/m') for each of the systems. The overall assumptions and results are given in Table 4 below. For calculations and explanations, the reader is referred to Haug and Løland (2023).

Table 4 Assumptions and results for calculations of number of reuse (m') and back-to-market return rates (r').

	PET system				Glass system			
Assumptions	**Brand**	**Standard**	**Brand**	**Standard**	**Brand**	**Standard**	**Brand**	**Standard**
Bottle size [litres]	1,50		0,5		0,5		0,33	
Overall share of brand/standard bottles of total volume [%]	56 %	44 %	56 %	44 %	19 %	81 %	19 %	81 %
$r_{deposit}$ [deposit return rate]	94,3 %	94,3 %	89,1 %	89,1 %	92,1 %	92,1 %	90,7 %	90,7 %
t_{design} [number of cycles between design change]	18	54	18	54	18	54	18	54
Number of cycles per year for a bottle pool	3,1							
Number of years between design change	6,0	17,5	6,0	17,5	6,0	17,5	6,0	17,5
C_{ratio}, average of 0.40 and 0.65 [%]	0,525							
$C_{wornout}$	0,03							
t_{max}, technical lifetime per bottle [number of uses]	30							
Results	**Brand**	**Standard**	**Brand**	**Standard**	**Brand**	**Standard**	**Brand**	**Standard**
m` [number of uses]	5,5	8,2	4,2	5,8	4,9	7,1	4,5	6,3
r` [back-to-market return rate]	81,9 %	87,7 %	76,2 %	82,6 %	79,5 %	85,9 %	77,9 %	84,2 %

The terms "Brand" and "Standard" in Table 4 represent bottle types used for specific brands (e.g., specific bottles for Coke) and standard bottles, respectively. For the PET reuse system, the share of brand and standard bottles are 56% and 44%, respectively, while similar figures for glass bottles are 19% and 81% (data provided by Infinitum).

Table 5 summarizes the parameters applied for the single-use and reusable systems to calculate the number of units and the weight of single-use and reusable beverage packaging required to fulfil the functional unit. Be aware that the numbers for m' in Table 5 represent weighted average values for brand and standard bottles based on the data provided in Table 4.

Table 5. The number of units and the weight of single-use and reusable beverage packaging required to fulfil the functional unit (delivery of 1 000 litres of beverage to the Norwegian consumer), considering that each bottle should individually deliver this function (i.e., no market mix is considered at this stage).

Parameter	**Single-use beverage packaging**				**Reusable beverage packaging**			
	PET		**Aluminium**		**PET**		**Glass**	
Functional unit [L]	1000	1000	1000	1000	1000	1000	1000	1000
Size per unit [L]	1.5	0.5	0.5	0.33	1.5	0.5	0.5	0.33
Weight per unit [g]	46.3	26.9	15	12.5	70	43	370	265
Collection rate from consumers to reverse vending machines, including manually collected bottles/cans [%]*	94.3 %	89.1 %	92.1 %	90.7 %	94.3 %	89.1 %	92.1 %	90.7 %
Recycling rate [%]	91.4 %	86.4 %	90.4 %	89.0 %				
Back-to-market return rate (r`) [%]					84.5 %	79.0 %	84.7 %	83.0 %
Number of uses during lifetime (m`) [-]	1	1	1	1	6.7	4.9	6.7	6.0
Number of "unique" units needed per functional unit [-]	667	2 000	2 000	3 030	99.7	407.8	299.3	508.6
Weight of "unique" units needed per functional unit [kg]	30.9	53.8	30.0	37.9	7.0	17.5	110.7	134.8

* Assumed the same collection rates for reusable PET and glass as for single-use PET and aluminium cans, respectively.

2.7 Modelling approaches for recycling

A material recycling process represents a waste management process for the product being recycled but is also a material production process of the product using the recycled material. According to Tomas. Ekvall et al. (2020) there are currently 12 different recycling modelling approaches in LCA for allocation burdens and credits of recycling between different stages of product cascade systems, but there is no consensus which method to apply (Allacker, Mathieux, Pennington, & Pant, 2017; Tomas Ekvall, 2020). The choice of recycling modelling approach can influence the environmental impact results significantly (de Sadeleer & Lyng, 2022). In order to evaluate how the choice of end-of-life modelling approach might lead to different conclusions, the following three different approaches have been applied: Cut-off, System expansion (also called End of life) and the Circular Footprint Formula (CFF) approach (Tomas. Ekvall et al., 2020). The Cut-off and System expansion approaches are the two most commonly applied approaches in LCA, while CFF is a relatively new method developed within the product environmental footprint (PEF) methodology (Zampori & Pant, 2019). The different approaches require different system boundaries and are described in more detail below (see chapters 2.7.1 2.7.2 and 2.7.3). It should be emphasised that results cannot be compared across modelling approaches as they require different system boundaries.

In previous LCAs of recycling and reuse systems, credits are typically given for avoided burdens from the recycling of these materials (Furberg et al., 2021). This is in line with the system expansion and CFF approaches which both credits avoided burdens from recycling, however, they do so in somewhat different ways as impacts are allocated differently between processes and further between life cycles.

It is worth mentioning that (Allacker et al., 2017) proposed a new approach, referred to as the "linearly degressive approach", which uses the 50:50 approach for the allocation of the recycling impact. The impact of the virgin production is allocated in a linearly degressive way to all products in the product cascade system, allocating the highest share of impact to the first product. The impact due to final disposal is also allocated in a linearly degressive way to all products in the overall system but allocating the highest share of impact to the last product. This formula takes into account the number of recycling cycles of a material and was identified as preferred to reach physical realism and to allocate burdens and benefits of repeatedly recycling of a material over the different products in a product cascade system. However, as the data on the number of recycling cycles was insufficiently available (for the time being), it has not been included into any standards yet. Instead, a formula based on the 50:50 approach—allocating shared end-of-life processes equally between the previous and subsequent product—was selected for the PEF methods and referred to as the Circular footprint formula (CFF).

It should also be mentioned that there is an ongoing project (Environmental impact of different types of circularity), financed by Handelens Miljøfond in Norway of which the aim is to understand where recycled plastic should be used. The project will analyse the environmental impact from using recycled plastics in product applications with different lifetimes. For example, how beneficial is it to recycle packaging material (short lifetime) into furniture products (longer lifetime)? Which type of products should be recycled in closed loops rather than open loops? When are reuse solutions preferred?

This study has used three different recycling modelling principles which are further described in the chapters below.

2.7.1 Cut-off approach

In the Cut-off approach, also called “recycled content” and “100:0”, recycling activities are allocated to the product using recycled material. Hence, the recycling process is defined as a production process and a system boundary (cut-off) is placed between the first and second product system. The Cut-off approach (or simple cut-off) is probably the easiest approach to modelling end of life (Tomas. Ekvall et al., 2020). In this approach, each product is assigned the environmental burdens of processes in that product´s life cycle. There is only a need for a definition of the boundary between the life cycles. This “cut-off point” is often defined at the place in the life cycle where the material has its lowest value, usually before the waste has been collected for material recycling. The Cut-off approach provides incentives to use recycled materials if recycling has lower impacts than virgin material production. When using this approach, recycled materials only bear the burden from recycling activities and not from the virgin material production.

A simplified flowchart for the system boundaries for the Cut-off approach is presented in Figure 5 and Figure 6 for the single-use and reuse systems, respectively.

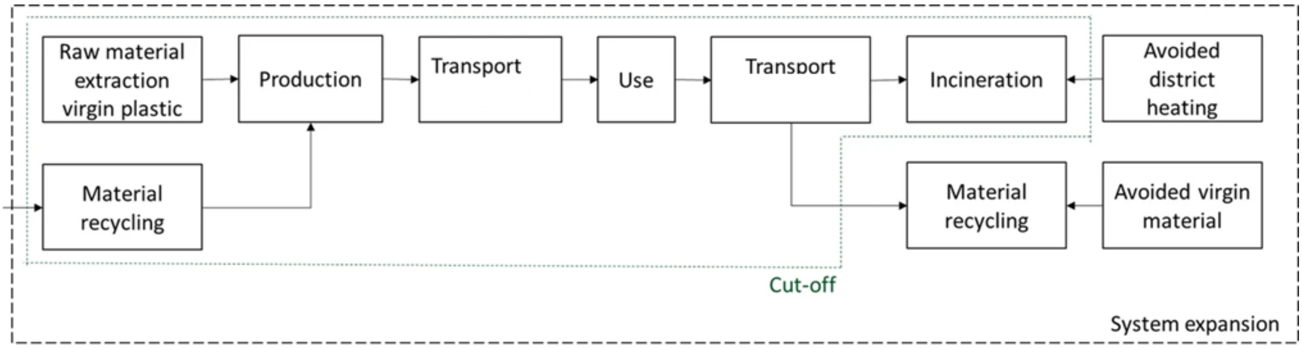


Figure 5 Flowchart of single-use system with system boundaries for Cut-off (green dotted lines) and System expansion (grey dotted lines). Figure from de Sadeleer and Lyng (2022).

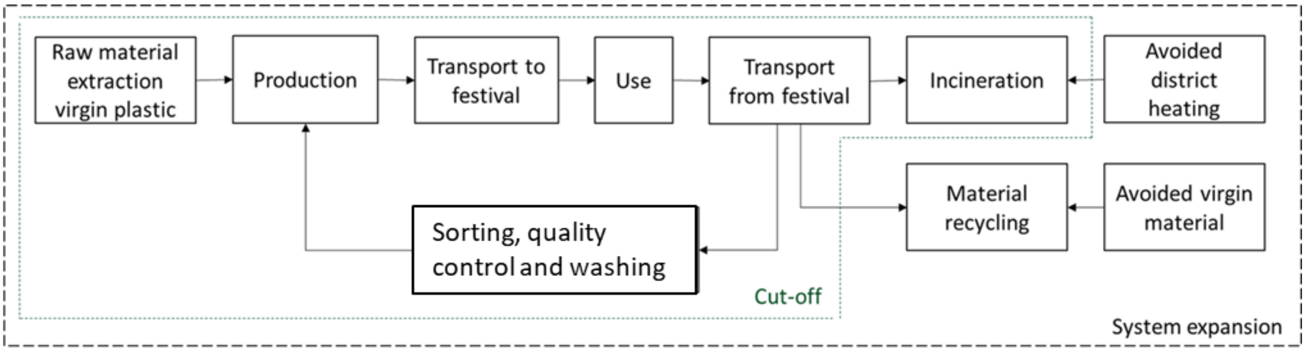


Figure 6 Flowchart of reuse system with system boundaries for Cut-off (green dotted lines) and System expansion (grey dotted lines). Recycled content as input to production is handled the same ways as shown in Figure 5 for the single-us system. Figure from de Sadeleer and Lyng (2022).

2.7.2 System expansion, net scrap approach

The System expansion (0:100), net scrap approach, includes all environmental impacts from the recycling process as well as the environmental benefits of substituting virgin material. The term “net scrap” means that only the net virgin share of the recycled material is allowed to substitute virgin material in order to avoid double-counting of the recycling benefits. If the recycled content is 50% and the recycling rate is 80%, only the “net virgin share being recycled” (80%-50% = 30%) will substitute virgin plastic as the remaining part (50%) has been counted for as recycled content.

A simplified flowchart for the system boundaries for the Cut-off approach is presented in Figure 5 and Figure 6 for the single-use and reuse systems, respectively.

2.7.3 Circular footprint formula (CFF)

The CFF has been developed within the PEF methodology and provides an approach to model material recycling and energy recovery at a product´s end of life (Tomas. Ekvall et al., 2020; Zampori & Pant, 2019). This approach typically provides incentives to use recycled materials, to recycle products after use and that the quality of materials should be safeguarded (Tomas. Ekvall et al., 2020). The emphasis that is put on these various incentives depends on the selected values for various factors in the CFF. This formula is rather complex and considers several factors, such as the share of recycled material in the product and the ratio of end-of-life material recycling but also the market supply and demand for recycled materials and the quality of materials that enter and leave the product´s life cycle. Thus, the allocation of environmental burdens between life cycles when using the CFF is dependent on many factors. The full CFF formula and a detailed description of all its factors are provided in Zampori and Pant (2019).

The impacts from recycled content and end of life are modelled by applying the CFF equation which consists of three different layers: the material, energy and disposal layer (Zampori & Pant, 2019), as shown in Equation 2.

Material

$$(1-R_1)E_V + R_1 \times \left(AE_{recycled} + (1-A)E_V \times \frac{Q_{Sin}}{Q_p}\right) + (1-A)R_2 \times \left(E_{recyclingEoL} - E_V^{*} \times \frac{Q_{Sout}}{Q_P}\right)$$

Energy

$$(1-B)R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec})$$

Disposal

$$(1-R_2-R_3) \times E_D$$

Equation 2 The Circular footprint Formula (CFF)

The different parameters of the CFF are described below.

- A: allocation factor of burdens and credits between supplier and user of recycled materials.
- B: allocation factor of energy recovery processes. It applies both to burdens and credits.
- Qs_{in}: quality of the ingoing secondary material, i.e. the quality of the recycled material at the point of substitution.
- Qs_{out}: quality of the outgoing secondary material, i.e. the quality of the recyclable material at the point of substitution.
- Q_p: quality of the primary material, i.e. quality of the virgin material.
- R_1: it is the proportion of material in the input to the production that has been recycled from a previous system.

- R_2: it is the proportion of the material in the product that will be recycled (or reused) in a subsequent system. R_2 shall therefore take into account the inefficiencies in the collection and recycling (or reuse) processes. R_2 shall be measured at the output of the recycling plant.
- R_3: it is the proportion of the material in the product that is used for energy recovery at EoL.
- $E_{recycled}$ (E_{rec}): specific emissions and resources consumed (per functional unit) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process.
- $E_{recyclingEo}$L (E_{recEoL}): specific emissions and resources consumed (per functional unit) arising from the recycling process at EoL, including collection, sorting and transportation process.
- Ev: specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material.
- E*v: specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials.
- E_{ER}: specific emissions and resources consumed (per functional unit) arising from the energy recovery process (e.g. incineration with energy recovery, landfill with energy recovery, etc.).
- $E_{SE,heat}$ and $_{ESE,elec}$: specific emissions and resources consumed (per functional unit) that would have arisen from the specific substituted energy source, heat and electricity respectively.
- ED: specific emissions and resources consumed (per functional unit) arising from disposal of waste material at the EoL of the analysed product, without energy recovery.
- $X_{ER,heat}$ and $X_{ER,elec}$: the efficiency of the energy recovery process for both heat and electricity.
- LHV: lower heating value of the material in the product that is used for energy recovery.

In this study, the parameter A is 0.5 and B is zero, according to Zampori and Pant (2019).

3 Life cycle impact assessment

The potential environmental impacts of the beverage packaging systems has been assessed applying the life cycle impact assessment (LCIA) method of ReCiPe midpoint (H) version 2016 (M. A. J. Huijbregts et al., 2017) for the impact categories climate change, cumulative energy demand, terrestrial acidification and mineral resource scarcity (Table 6). These impact categories are commonly applied in LCA studies and were furthermore applied in some recently published LCA studies on recycling and/or reuse systems for bottles (Furberg et al., 2021). The LCA software tool SimaPro, version 9.4.0.2 (Pré, 2021) and the ecoinvent LCA database, version 3.9.1 (Wernet et al., 2016) have been used.

Littering of single-use plastic bottles is commonly highlighted as a critical issue and one important reason why reusable bottles are receiving increased interest due to their potentially reduced littering effect compared to single-use beverage packaging (Briedis et al., 2019; Coelho et al., 2020; UNEP, 2020). Methodologies to consider littering in LCA are under development, as exemplified by Stefanini, Borghesi, Ronzano, and Vignali (2021) who assessed environmental impacts, including littering, of single-use and reusable bottles and developed a marine littering indicator for this purpose. So far, however, littering of plastic bottles has only been assessed to a very limited extent, probably due to the fact that standardised assessment methods for littering of marine and terrestrial ecosystems are currently lacking (UNEP, 2020). Plastic littering has not been part of this study.

Table 6. Description of the impact categories assessed *(M. Huijbregts et al., 2016; M. A. J. Huijbregts et al., 2017)*.

Impact category	Characterization factor unit	Environmental relevance	LCIA method
Climate change	kg CO_2-eqv.	Increased atmospheric concentration of greenhouse gases, caused by emissions of such gases, in turn lead to increased radiative forcing and a rise in the mean global temperature and more extreme weather conditions. This ultimately leads to damage to human health and ecosystems.	ReCiPe midpoint version 2016 with the hierarchist perspective
Terrestrial acidification	kg SO_2-eqv.	The atmospheric deposition of emitted acidic substances, such as sulphates, causes alterations in the acidity of soil and water bodies. When the acidity level deviates from its optimum, plants and animals become negatively affected.	
Mineral resource scarcity	kg Cu-eqv.	As mineral resources become extracted, overall ore grades decrease. This leads to a larger ore amount needed to be mined per kg mineral resource extracted. Mineral and metal extraction leads to resource depletion.	
Cumulative energy demand (CED)	MJ HHV	Use of primary energy: CED is short for Cumulative Energy Demand and is a resource indicator for the use of primary energy. It includes not only fossil primary energy, but all forms of primary energy being used throughout the system. This indicator counts primary energy carriers used for energy purposes only (not used as feedstock). Separate into four sub-categories: fossil and renewable primary energy, primary energy used for nuclear power production and unspecified primary energy. Developed by NORSUS, based on own experience, EPD-guidelines from Environdec 2015 (PCR 2007:08, CPC 171 v.4.2, 2007-10-31, revised 2021-06-24: Electricity, Steam, and Hot/Cold Water Generation and Distribution) and Norwegian regulations.	Developed by NORSUS

4 Material Flow Analysis (MFA)

A Material Flow Analysis (MFA) model was developed for the studied systems, based on data given in Appendix 2. The results from this MFA model serves as foreground input data (LCI: Life Cycle Inventory) for the respective systems to a parameterised model in the LCA software Simapro where the LCAs have been carried out.

The MFA model is output driven from the point of the use phase (1000 l beverage delivered to consumers) and input driven downstream the use phase. The LCA functional unit is 1000L beverage being delivered to consumers. The MFA model is based on the respective masses of beverage packaging material (given as grams bottles/can material) that flow through each activity to satisfy the functional unit.

The detailed flow charts results from the MFA for each of the 4 specific single-use and 8 specific reuse systems as presented in Figure 2, Figure 3 and Table 7 are shown in Appendix 3. The reuse system is shown for 8 separate sub systems due to the share of brand and standard bottles (see Table 4).

Table 7. Main characteristics for the bottle and can types and sizes for the assessed single-use and reuse systems.

Parameter	Single-use beverage packaging				Reusable beverage packaging			
	PET		Aluminium		PET		Glass	
Functional unit [L]	1000	1000	1000	1000	1000	1000	1000	1000
Size per unit [L]	1.5	0.5	0.5	0.33	1.5	0.5	0.5	0.33
Weight per unit [g]	46.3	26.9	15	12.5	70	43	370	265
Market mix [% of sold beverage volume]	48	12	26	14	48	12	26	14

5 Results Life Cycle Assessment (LCA)

In the following chapters, the analysed environmental impact categories (as described in chapter 3) are presented for the compared single-use and reuse systems.

5.1 Climate change

Chapter 5.1.1 presents climate change results for the overall single-use and reuse systems, represented by the market mix of bottles and cans, as shown in Table 7. The results are presented for the three different modelling approaches Cut-off, Circular footprint formula (CFF) and System expansion_net scrap, as described in chapter 2.7. Additionally, climate change results for the respective single-use and reuse bottle/can systems are presented in chapter 5.1.2 . As these serves as input for the overall figures, potential important differences in the climate change results between the bottle/can sizes and types can be discovered here.

5.1.1 Results for the overall single-use and reuse systems

This chapter presents net climate change burdens as kilograms CO_2-eq per functional unit for the overall single-use (blue bars) and reuse systems (grey bars), represented by the market mix of bottles and cans shown in Table 7.

The net climate change results are presented in Figure 7 while in Figure 8 these results are separated into the major life cycle activities for each of the systems.

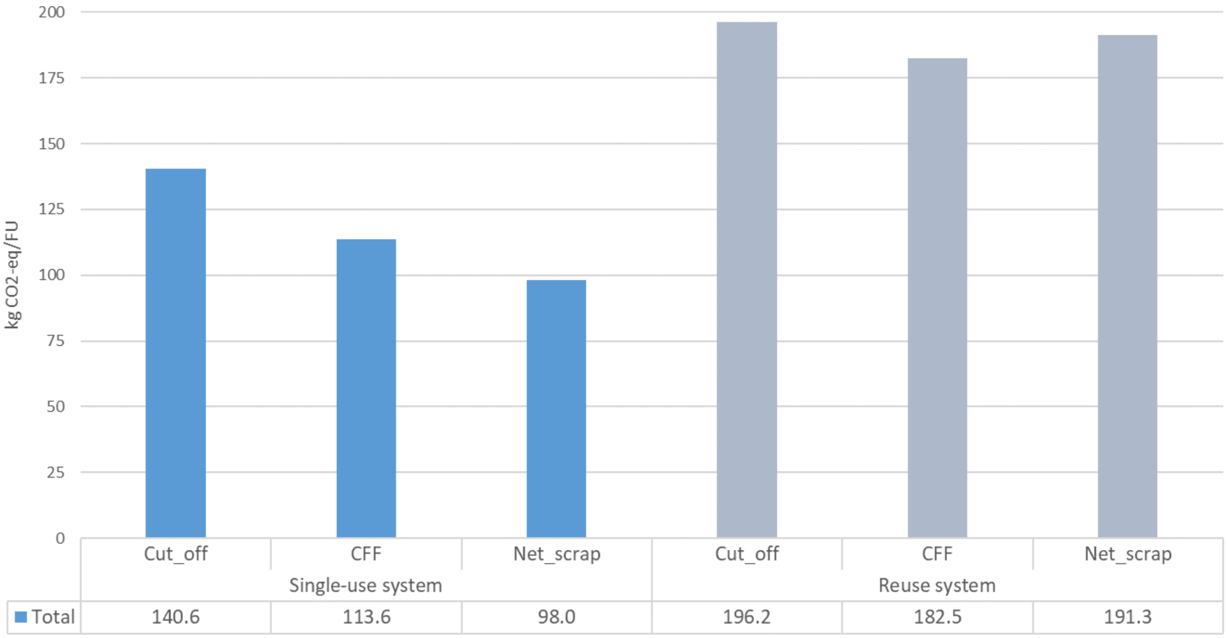
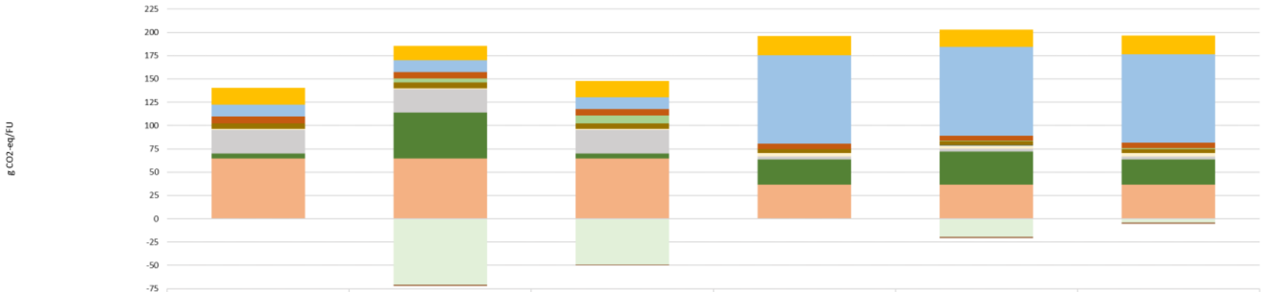


Figure 7 Net climate change [kg CO_2-eq per functional unit] for the overall single-use and reuse systems, presented for the three different modelling approaches.

Figure 7 shows that the single-use system performs better in terms of climate change compared to the corresponding reuse system for all the recycling modelling approaches. The single-use system constitutes 72%, 62% and 51% of the impact from the reuse system for the respective recycling modelling approaches Cut-off, CFF and System expansion_net scrap.

The System expansion_net scrap approach gives the lowest impact for the single-use system. The major reason for this is that this approach favours high recycling rates after use, which is the case for the single-use system as this share is even higher than the recycled content (65%). Hence, the "net virgin share being recycled" is positive and contributes to avoided emissions in the system. Generally, the Cut-off approach favours a high proportion of recycled content in the packaging while the System expansion_net scrap approach favours a high recycling rate after use. The CFF approach lies somewhere between the Cut-off and Net_scrap regarding this, dependent on the A-factor in the formula (see Equation 2). As seen from the figure, the results for the Cut-off and Net_scrap approaches are approximately the same for the reuse system. This is further explained in chapter 5.1.2

The reason for the differences between the systems can be further described in Figure 8 which presents the climate change results separated into the major life cycle activities for each of the systems.



	Cut_off	CFF Single use	Net_scrap	Cut_off	CFF Reuse	Net_scrap
■ P14 Avoided impacts from incineration	0.0	-0.9	-0.9	0.0	-1.0	-1.0
■ P9 Avoided impacts from recycling	0.0	-70.9	-49.1	0.0	-19.7	-4.2
■ Distribution packaging	18.4	15.4	17.5	20.7	18.9	20.1
■ Transport	12.8	12.8	12.8	95.1	95.1	95.1
■ P14 Incineration	7.0	7.0	7.0	5.5	5.5	5.5
■ P9 Recycling	0.0	4.1	8.2	0.0	0.5	1.0
■ P8 Sorting	6.1	6.1	6.1	4.6	4.6	4.6
■ P6 Retailer	0.1	0.1	0.1	0.1	0.1	0.1
■ P4 Filling (and washing)	0.9	0.9	0.9	3.4	3.4	3.4
■ P3 Manufacturing	25.2	25.2	25.2	3.1	3.1	3.1
■ P2 Recycled material	5.4	49.1	5.4	27.3	35.6	27.3
■ P1 Virgin material	64.7	64.7	64.7	36.4	36.4	36.4

Figure 8 Climate change separated into the major life cycle activities [kg CO_2-eq per functional unit] for the single-use and reuse systems, presented for the three different modelling approaches.

Figure 8 shows the climate change results separated into the major life cycle activities for each of the systems. First, it clearly shows the difference in the system boundaries of the recycling modelling approaches: where the Cut-off system is not credited any avoided impacts, while both the CFF and System expansion_net scrap systems are. This is in line with the description of the modelling approaches provided in chapter 2.7. Furthermore, avoided impacts from the reuse systems are considerably lower than for the single-use systems. This is logical since the reuse system uses less material per functional unit (as the largest share of the bottle material is reused, see also the MFA flow charts in Appendix 3).

The largest impact in the single-use system is the production and manufacturing of the packaging material, which, to different degrees, is compensated for by avoided impact in the CFF and System expansion_net scrap approach. The avoided burden from these activities represents 63% and 51 % of the overall net climate change impact for the CFF and System expansion approaches, respectively. Despite larger packaging unit weights, the production and manufacturing impact from the reuse systems is significantly less as it constitutes about 70% and 55% of the impact from the same activities in the single-use systems for the Cut-off/System expansion_net scrap and CFF approaches, respectively. Since each bottle is used several times, the production impact per functional unit is divided by this number of uses (m’). The larger the number of uses, the lower impact from the production and manufacturing stage. The recycled material in the reuse system (green part of the bar) comes mainly from production of recycled glass (recycled content 60%).

The reuse system has, however, larger burdens related to transport. Here, transport contributes about 50% of the overall net impact. The total transport burdens in the reuse system represent about 7.4 times the transport burdens in the single-use system.

5.1.2 Results per bottle/can type and size

This chapter presents net climate change results for the respective single-use (blue bars) and reuse (grey bars) bottle/can systems which serve as input to the overall results for the single-use and reuse systems presented in chapter 5.1.1 above. This might help discovering potential important differences between the bottle/can sizes and types.

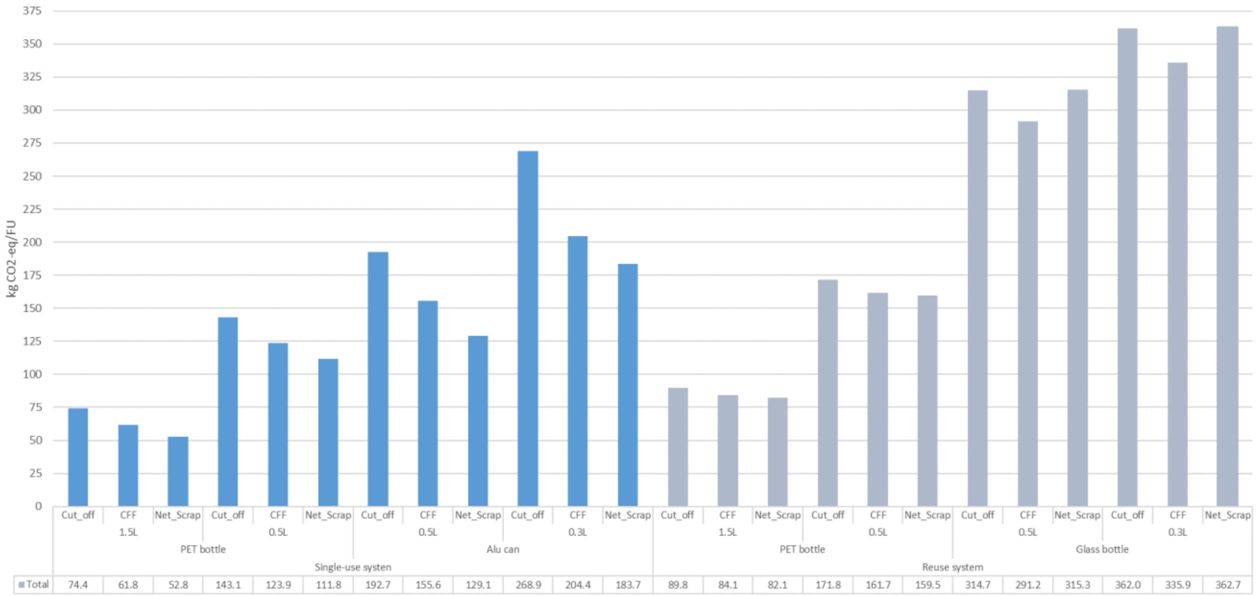
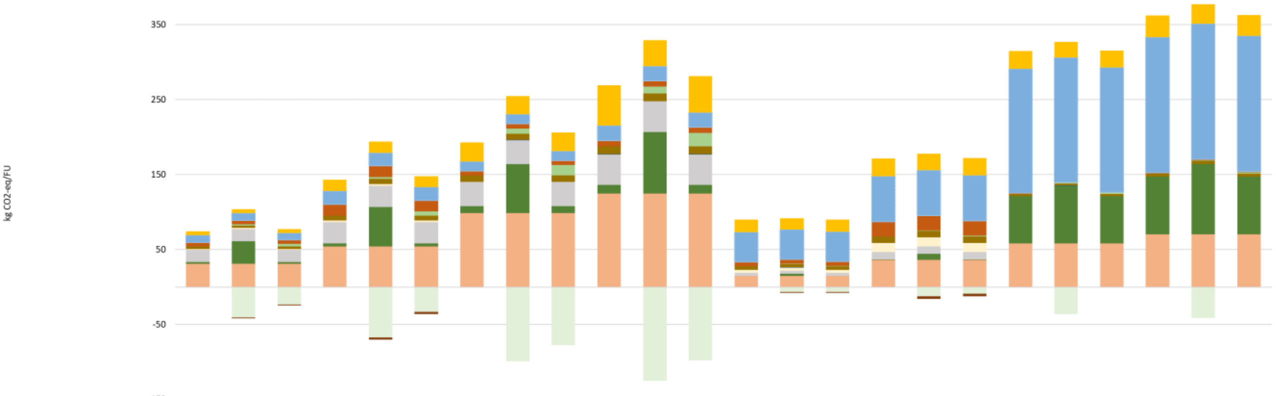


Figure 9 Net climate change [kg CO_2-eq per 1000 l beverage distributed] for the specific bottles/cans in respective single-use and reuse systems, presented for the three different modelling approaches.

An obvious result from Figure 9 is that larger packaging sizes perform better than smaller. This is not surprising, as smaller sizes require more packaging material per functional unit (distribution of 1000 litres beverage). The figure also confirms the general trend that the Cut-off approach performs worst of the three recycling modelling approaches, with largest differences for the single-use systems. However, for the glass system, the results for Cut-off and Net_scrap approaches are approximately the same. This is explained by the high recycled content (60%) in the glass bottles which leads to a “net negative virgin share to recycling” (see the MFA balances in appendix 3) and therefore no benefit from avoided virgin glass production is included in the Net_scrap approach. Hence, the Cut-off and Net_scrap approaches perform almost equal. The figure also clearly shows that the single-use systems are more sensitive than the reuse systems with regard to the different modelling principles, which is logic because they have a bigger material throughput being affected by recycling.

Furthermore, Figure 9 shows that PET bottles perform best in both systems. When comparing 0.5L bottles and cans, the single-use aluminium can system and the reuse PET system almost performs equal, depending on the modelling approach.

More details between the systems are provided in Figure 10 which presents the climate change results separated into the major life cycle activities.



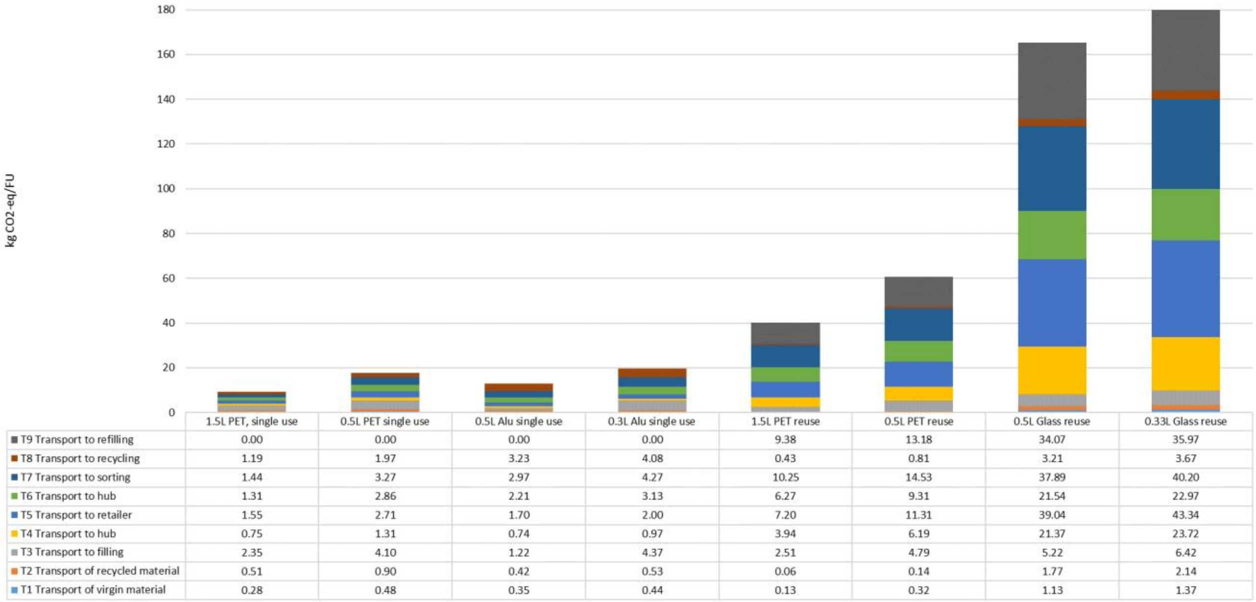
	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap
	1.5L			0.5L			0.5L			0.3L			1.5L			0.5L			0.5L			0.3L		
	PET bottle						Alu can						PET bottle						Glass bottle					
	Single- use system												Reuse system											
■ P14 Avoided impacts from incineration	0.0	-1.1	-1.1	0.0	-3.0	-3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.1	-1.1	0.0	-3.9	-3.9	0.0	0.0	0.0	0.0	0.0	0.0
■ P9 Avoided impacts from recycling	0.0	-40.7	-23.5	0.0	-67.1	-33.2	0.0	-99.1	-77.4	0.0	-125.2	-97.7	0.0	-6.4	-6.6	0.0	-12.1	-8.5	0.0	-36.0	-0.1	0.0	-41.2	0.0
■ Distribution packaging	5.3	5.1	5.1	15.0	14.6	14.7	25.1	24.2	24.9	53.8	34.9	48.6	16.2	14.8	15.7	23.9	21.8	23.1	23.4	21.3	22.6	28.5	25.8	27.5
■ Transport	9.4	9.4	9.4	17.7	17.7	17.7	12.9	12.9	12.9	19.8	19.8	19.8	40.2	40.2	40.2	60.7	60.7	60.7	166.1	166.1	166.1	180.9	180.9	180.9
■ P14 Incineration	5.4	5.4	5.4	14.9	14.9	14.9	6.0	6.0	6.0	7.5	7.5	7.5	5.7	5.7	5.7	19.6	19.6	19.6	0.9	0.9	0.9	1.1	1.1	1.1
■ P9 Recycling	0.0	1.6	3.2	0.0	2.6	5.2	0.0	7.0	13.9	0.0	8.8	17.6	0.00	0.25	0.5	0.0	0.5	0.9	0.0	0.7	1.5	0.0	0.8	1.7
■ P8 Sorting	3.3	3.3	3.3	6.6	6.6	6.6	8.4	8.4	8.4	10.7	10.7	10.7	4.5	4.5	4.5	8.9	8.9	8.9	2.8	2.8	2.8	4.2	4.2	4.2
■ P6 Retailer	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
■ P4 Filling (and washing)	1.3	1.3	1.3	2.3	2.3	2.3	0.0	0.0	0.0	0.0	0.0	0.0	4.2	4.2	4.2	11.7	11.7	11.7	0.0	0.0	0.0	0.0	0.0	0.0
■ P3 Manufacturing	16.2	16.2	16.2	28.2	28.2	28.2	32.1	32.1	32.1	40.6	40.6	40.6	4.0	4.0	4.0	10.0	10.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0
■ P2 Recycled material	2.2	30.1	2.2	3.8	52.4	3.8	9.0	65.0	9.0	11.4	82.0	11.4	0.2	3.3	0.2	0.6	8.1	0.6	63.1	77.0	63.1	76.5	93.4	76.5
■ P1 Virgin material	31.2	31.2	31.2	54.4	54.4	54.4	98.9	98.9	98.9	124.9	124.9	124.9	14.7	14.7	14.7	36.4	36.4	36.4	58.2	58.2	58.2	70.5	70.5	70.5

Figure 10 Climate change [kg CO_2-eq per functional unit] separated into the major life cycle activities for the respective single-use and reuse bottle/can systems, presented for the three different modelling approaches.

The results provided in Figure 10 serve as input for the overall figures given in Figure 8 and can be further elaborated for discussing and explaining the differences in the overall single-use and reuse results. As an example, the figure shows that the burdens from transporting large and small glass bottles in the reuse system is between 3 and 4 times the impact from transporting corresponding sizes of PET bottles in the same system. The figure also shows the lack of benefit from avoided virgin glass material production in the net_scrap approach, as explained above. The figure also shows that the contribution from recycled material production in the CFF approach is higher compared to the Cut-off and Net_scrap approaches. The reason is that CFF is modelled with some contribution also from virgin material in order to allocate the environmental burdens between life cycles (more details in Equation 2).

5.1.3 Results for transport activities

As outlined in chapter 5.1.1 the total reuse transport burdens represent about 7.4 times the transport burdens in the single-use system. This is further elaborated in Figure 11 by presenting the climate change results for the transport burden (blue part in Figure 10) separated into the different transport activities for each of the single-use and reuse systems. As the calculation of transport burdens are not affected by the recycling modelling approach, the results are presented independent of this.



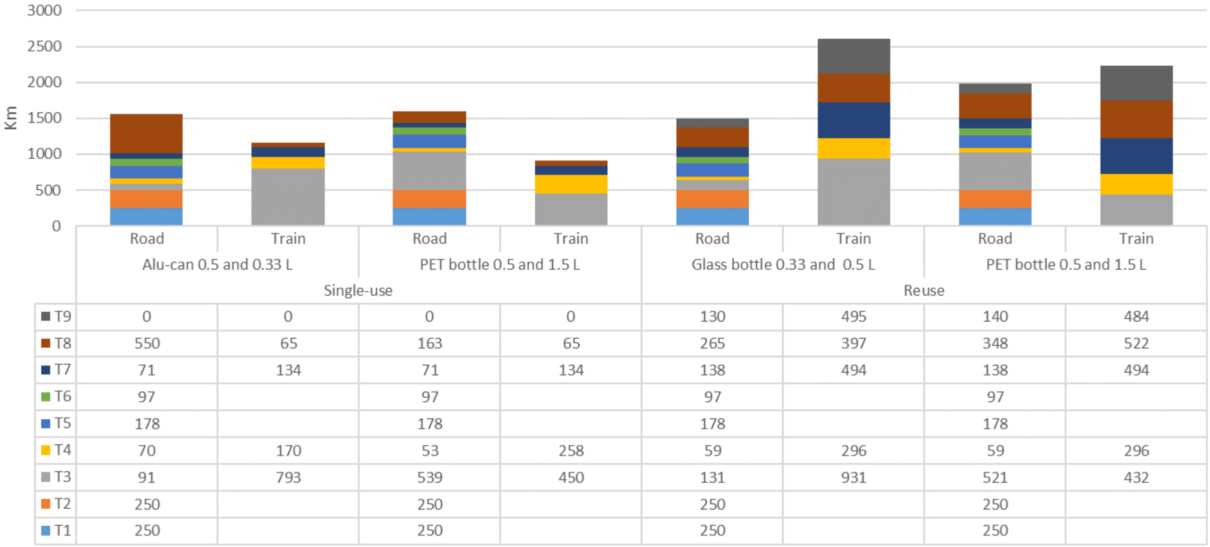
	1.5L PET, single use	0.5L PET single use	0.5L Alu single use	0.3L Alu single use	1.5L PET reuse	0.5L PET reuse	0.5L Glass reuse	0.33L Glass reuse
■ T9 Transport to refilling	0.00	0.00	0.00	0.00	9.38	13.18	34.07	35.97
■ T8 Transport to recycling	1.19	1.97	3.23	4.08	0.43	0.81	3.21	3.67
■ T7 Transport to sorting	1.44	3.27	2.97	4.27	10.25	14.53	37.89	40.20
■ T6 Transport to hub	1.31	2.86	2.21	3.13	6.27	9.31	21.54	22.97
■ T5 Transport to retailer	1.55	2.71	1.70	2.00	7.20	11.31	39.04	43.34
■ T4 Transport to hub	0.75	1.31	0.74	0.97	3.94	6.19	21.37	23.72
■ T3 Transport to filling	2.35	4.10	1.22	4.37	2.51	4.79	5.22	6.42
■ T2 Transport of recycled material	0.51	0.90	0.42	0.53	0.06	0.14	1.77	2.14
■ T1 Transport of virgin material	0.28	0.48	0.35	0.44	0.13	0.32	1.13	1.37

Figure 11 Total climate change [kg CO_2-eq per functional unit] from transport only, separated into the different transport activities for each of the single-use and reuse bottle/can systems.

As seen in Figure 11, the difference in climate change transport burdens between the single-use and reuse systems are large. The glass reuse system provides by far the biggest total transport burden, as mentioned above. This is not surprising as glass bottles have the highest weight, and therefore require more fuel to be transported. The overall reuse system (glass and PET bottles according to market mix) needs to transport about 10 times the weight of the overall single-use system per functional unit (1000 litres distributed beverage).

Additionally, the figure shows that transporting empty bottles from retailer to filling (T6, T7 and T9) represent large contributions to the total climate change transport burden in the reuse system, due to ineffective transport because the empty bottles require large volumes as they cannot be compressed. It should be emphasized that the transport distances T3, T6, T7 and T9 have been calculated by modifying the ecoinvent transport data (see Appendix 4).

An overview of the major transport modes (road or train) with corresponding weighted distances (km) used as input in the environmental analyses is given in Figure 12 below. This represents a brief summary of the detailed transport data given in Appendix 2.



	Road	Train	Road	Train	Road	Train	Road	Train
	Alu-can 0.5 and 0.33 L		PET bottle 0.5 and 1.5 L		Glass bottle 0.33 and 0.5 L		PET bottle 0.5 and 1.5 L	
	Single-use				Reuse			
■ T9	0	0	0	0	130	495	140	484
■ T8	550	65	163	65	265	397	348	522
■ T7	71	134	71	134	138	494	138	494
■ T6	97		97		97		97	
■ T5	178		178		178		178	
■ T4	70	170	53	258	59	296	59	296
■ T3	91	793	539	450	131	931	521	432
■ T2	250		250		250		250	
■ T1	250		250		250		250	

Figure 12 Transport overview for the analysed systems. Weighted distances for road and train transport.

It should be noted that load factors, as well as the weight of transported goods are important factors in addition to the distance when calculating the overall transport burden. Hence, the distances given here must be seen in connection with load factors and weights to explain the environmental results for transport.

5.2 Cumulative energy demand (CED)

This chapter presents cumulative energy demand (CED) as MJ per functional unit for the overall single-use (blue bars) and reuse (grey bars) systems, represented by the market mix of bottles and cans shown in Table 7. The results are presented for the three different modelling approaches Cut-off, Circular footprint formula (CFF) and System expansion_net scrap approach, as described in chapter 2.7.

The net CED results are presented in Figure 13 while in Figure 14 these results are separated into the major life cycle activities for each of the systems.

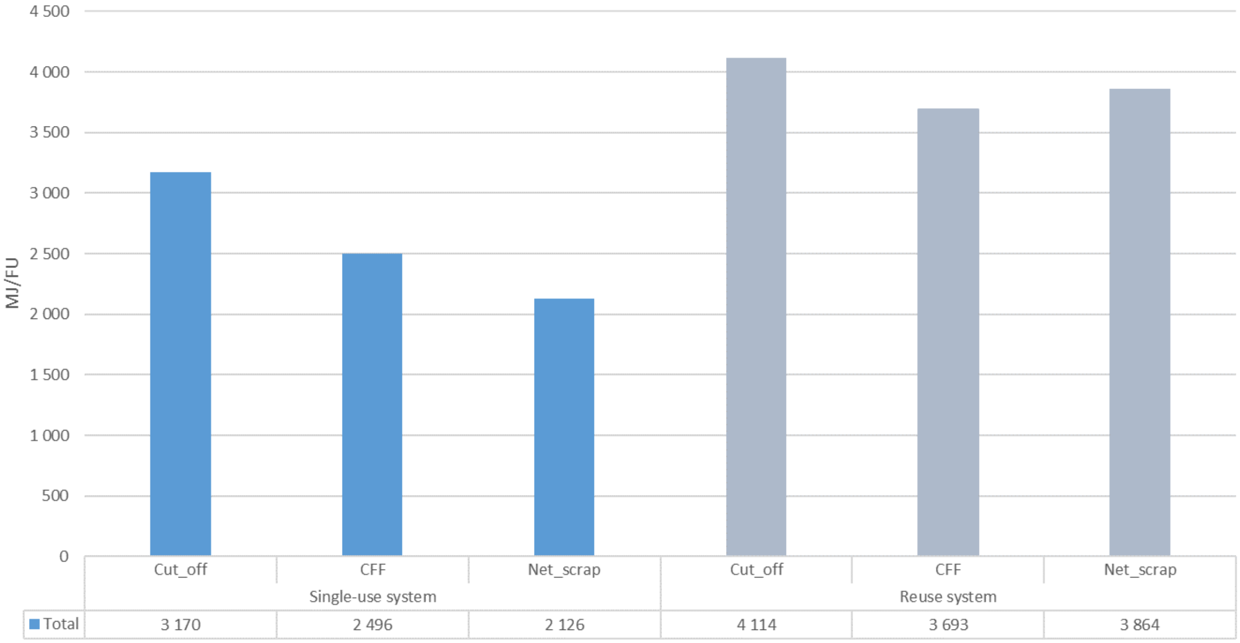
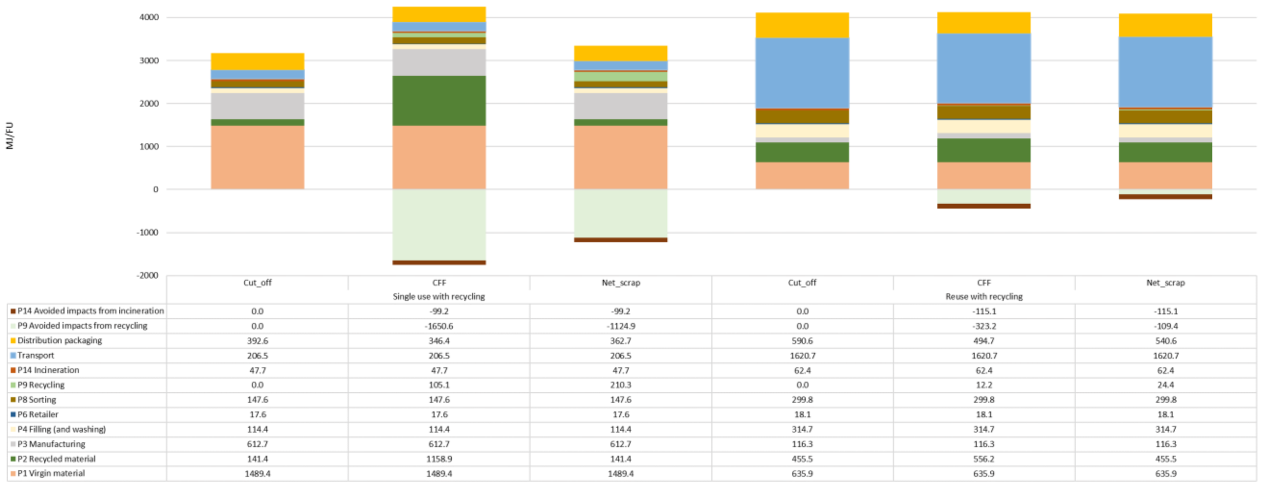


Figure 13 CED [MJ per functional unit] for the overall single-use and reuse systems, presented for the three different modelling approaches.

Figure 13 shows the same trend as for the Climate Change results: The single-use system performs better than the reuse system and the difference is largest for the System expansion_net scrap modelling approach. The single-use system constitutes 77%, 68% and 55% of the impact from the reuse system for the respective recycling modelling approaches Cut-off, CFF and System expansion_net scrap.

The CED can be further elaborated in Figure 14 which presents the results separated into the major life cycle activities.



	Cut_off	CFF	Net_scrap	Cut_off	CFF	Net_scrap
		Single use with recycling			Reuse with recycling	
■ P14 Avoided impacts from incineration	0.0	-99.2	-99.2	0.0	-115.1	-115.1
■ P9 Avoided impacts from recycling	0.0	-1650.6	-1124.9	0.0	-323.2	-109.4
■ Distribution packaging	392.6	346.4	362.7	590.6	494.7	540.6
■ Transport	206.5	206.5	206.5	1620.7	1620.7	1620.7
■ P14 Incineration	47.7	47.7	47.7	62.4	62.4	62.4
■ P9 Recycling	0.0	105.1	210.3	0.0	12.2	24.4
■ P8 Sorting	147.6	147.6	147.6	299.8	299.8	299.8
■ P6 Retailer	17.6	17.6	17.6	18.1	18.1	18.1
■ P4 Filling (and washing)	114.4	114.4	114.4	314.7	314.7	314.7
■ P3 Manufacturing	612.7	612.7	612.7	116.3	116.3	116.3
■ P2 Recycled material	141.4	1158.9	141.4	455.5	556.2	455.5
■ P1 Virgin material	1489.4	1489.4	1489.4	635.9	635.9	635.9

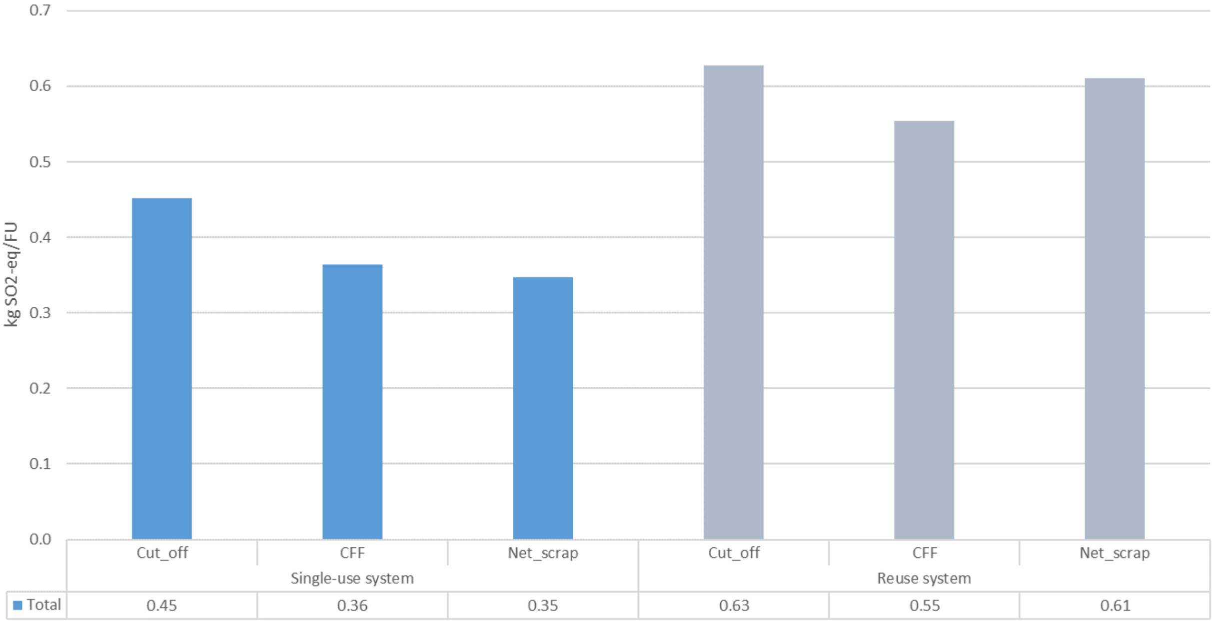
Figure 14 CED [MJ per functional unit] separated into the major life cycle activities for the single-use and reuse systems, presented for the three different modelling approaches.

The CED results per bottle/can type are shown in Appendix 5 and reflects the results for Climate change as shown in Figure 10.

5.3 Terrestrial acidification

This chapter presents terrestrial acidification as kilograms SO2-eq per functional unit for the overall single-use (blue bars) and reuse (grey bars) systems, represented by the market mix of bottles and cans shown in Table 7. The results are presented for the three different modelling approaches Cut-off, Circular footprint formula (CFF) and System expansion_net scrap approach, as described in chapter 2.7.

The net results are presented in Figure 15 while Figure 16 presents the same results separated into the major life cycle activities.

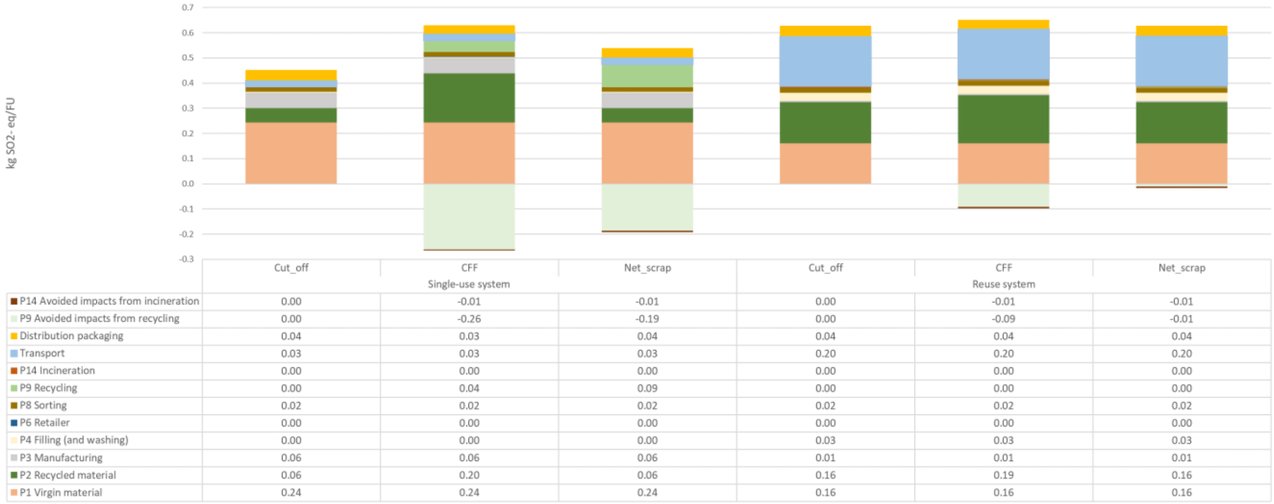


	Cut_off	CFF	Net_scrap	Cut_off	CFF	Net_scrap
		Single-use system			Reuse system	
■ Total	0.45	0.36	0.35	0.63	0.55	0.61

Figure 15 Net terrestrial acidification [kg SO2-eq per functional unit] for the single-use and reuse systems, presented for the three different modelling approaches.

Figure 15 shows the same general trend as for climate change and CED. The single-use system performs best, especially for the System expansion_net scrap approach. The single-use system constitutes 72%, 66% and 57% of the impact from reuse system for the respective recycling modelling approaches Cut-off, CFF and System expansion_net scrap.

The results can be further elaborated in Figure 16 which presents the results separated into the major life cycle activities.



	Cut_off	CFF	Net_scrap	Cut_off	CFF	Net_scrap
		Single-use system			Reuse system	
■ P14 Avoided impacts from incineration	0.00	-0.01	-0.01	0.00	-0.01	-0.01
■ P9 Avoided impacts from recycling	0.00	-0.26	-0.19	0.00	-0.09	-0.01
■ Distribution packaging	0.04	0.03	0.04	0.04	0.04	0.04
■ Transport	0.03	0.03	0.03	0.20	0.20	0.20
■ P14 Incineration	0.00	0.00	0.00	0.00	0.00	0.00
■ P9 Recycling	0.00	0.04	0.09	0.00	0.00	0.00
■ P8 Sorting	0.02	0.02	0.02	0.02	0.02	0.02
■ P6 Retailer	0.00	0.00	0.00	0.00	0.00	0.00
■ P4 Filling (and washing)	0.00	0.00	0.00	0.03	0.03	0.03
■ P3 Manufacturing	0.06	0.06	0.06	0.01	0.01	0.01
■ P2 Recycled material	0.06	0.20	0.06	0.16	0.19	0.16
■ P1 Virgin material	0.24	0.24	0.24	0.16	0.16	0.16

Figure 16 Terrestrial acidification [kg SO2-eq per functional unit] separated into the major life cycle activities for the single-use and reuse systems, presented for the three different modelling approaches.

The acidification results per bottle/can type are shown in Appendix 5 and reflects the results for Climate change (Figure 10).

5.4 Mineral resource scarcity

This chapter presents mineral resource scarcity as kilograms Cu-eq per functional unit for the overall single-use (blue bars) and reuse (grey bars) systems, represented by the market mix of bottles and cans shown in Table 7. The results are presented for the three different modelling approaches Cut-off, Circular footprint formula (CFF) and System expansion_net scrap approach, as described in chapter 2.7.

The net results are presented in Figure 17 while Figure 18 presents the same results separated into the major life cycle activities.

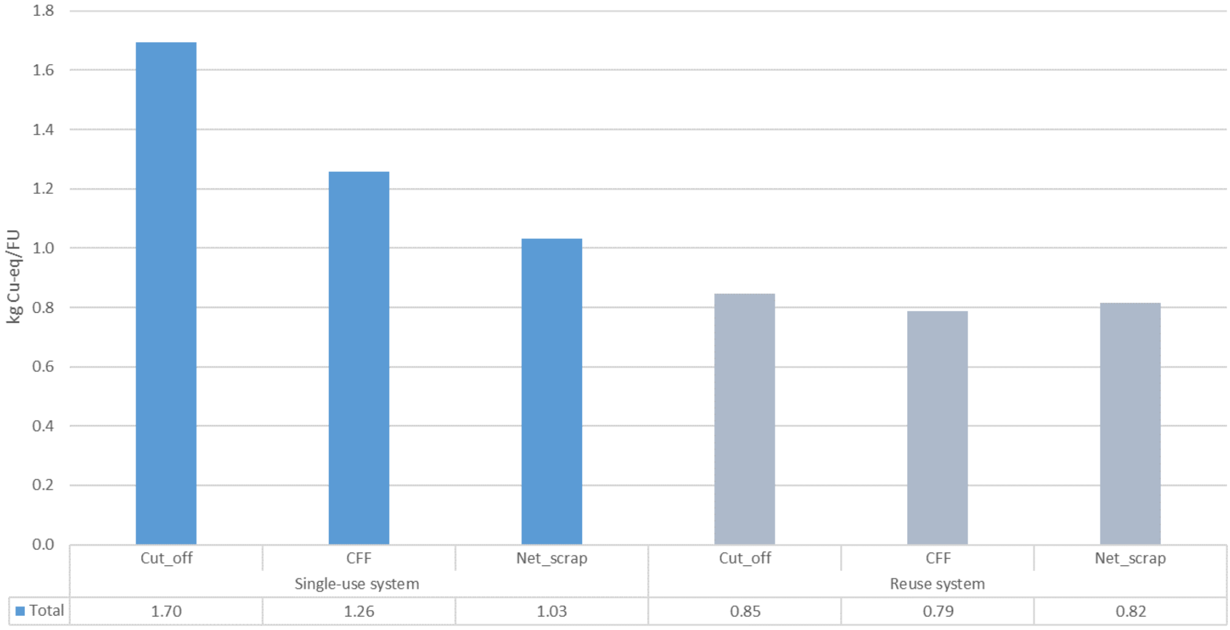
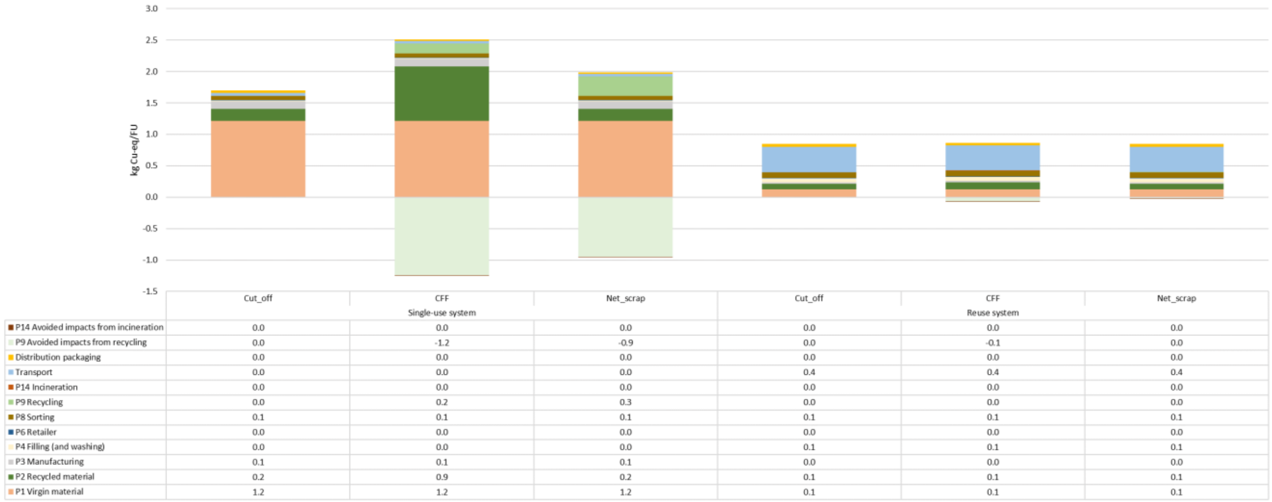


Figure 17 Net mineral resource scarcity [kg Cu-eq per functional unit] for the single-use and reuse systems, presented for the three different modelling approaches.

Figure 17 shows opposite results compared to climate change, CED and terrestrial acidification as the single-use system performs clearly worse compared to the reuse system. Still, the System expansion_net scrap modelling approach gives the best single-use system result also for this impact category. The single-use system results are respectively 2.7, 1.6 and 1.3 times larger than the impact from reuse system for the Cut-off, CFF and System expansion_net scrap modelling approaches.

The results can be further elaborated in Figure 18 which presents the results separated into the major life cycle activities.



	Cut_off	CFF	Net_scrap	Cut_off	CFF	Net_scrap
		Single-use system			Reuse system	
P14 Avoided impacts from incineration	0.0	0.0	0.0	0.0	0.0	0.0
P9 Avoided impacts from recycling	0.0	-1.2	-0.9	0.0	-0.1	0.0
Distribution packaging	0.0	0.0	0.0	0.0	0.0	0.0
Transport	0.0	0.0	0.0	0.4	0.4	0.4
P14 Incineration	0.0	0.0	0.0	0.0	0.0	0.0
P9 Recycling	0.0	0.2	0.3	0.0	0.0	0.0
P8 Sorting	0.1	0.1	0.1	0.1	0.1	0.1
P6 Retailer	0.0	0.0	0.0	0.0	0.0	0.0
P4 Filling (and washing)	0.0	0.0	0.0	0.1	0.1	0.1
P3 Manufacturing	0.1	0.1	0.1	0.0	0.0	0.0
P2 Recycled material	0.2	0.9	0.2	0.1	0.1	0.1
P1 Virgin material	1.2	1.2	1.2	0.1	0.1	0.1

Figure 18 Mineral resource scarcity [kg Cu-eq per functional unit] separated into the major life cycle activities for the single-use and reuse systems, presented for the three different modelling approaches.

As seen from Figure 18, the major impact from the single-use system comes from the packaging material production. When diving deeper into the results per packaging type (see Appendix 5), the contribution from aluminium cans represents approximately 80% of the overall single-use result even though it only covers 40% of the distributed volume. Hence, aluminium is responsible for the major impact from mineral resource scarcity. Extraction of bauxite related to aluminium production is the major contributor to this impact category. Silica, the major feedstock resource for glass, is not included in mineral resource scarcity, which explains why the production glass only contributes to a small degree to this impact category.

6 Sensitivity analyses

Chapters 6.1 and **Feil! Fant ikke referansekilden.** present sensitivity analyses for recycled content in the single-use system and collection rate in the reuse system to assess how these parameters impact the results for climate change. Chapter 6.3 presents how the of the length of a design period in the reuse system impact the climate change results. A design period is defined as the period (e.g., years) in which a bottle design remains the same.

6.1 Change in recycled content for the single-use system

The sensitivity analyses for varying recycled content are presented for climate change for the recycling modelling approach Cut-off. The results for the other recycling modelling approaches are shown in Appendix 6.

Figure 19 shows how climate change, expressed as kg CO_2-eq/FU, varies according to varying recycled content in the single-use system. The result from the main analysis (chapter 5.1) is highlighted by a larger bullet, representing an average recycled content of 61% (based on the market mix and respective recycled content values for PET-bottles (65%) and alu-cans (55%)). All other assumptions, such as collection and recycling rates are fixed and equal the values in the main analysis (see Table 5). In addition, the result for the reuse system from the main analysis is market with a grey bullet.

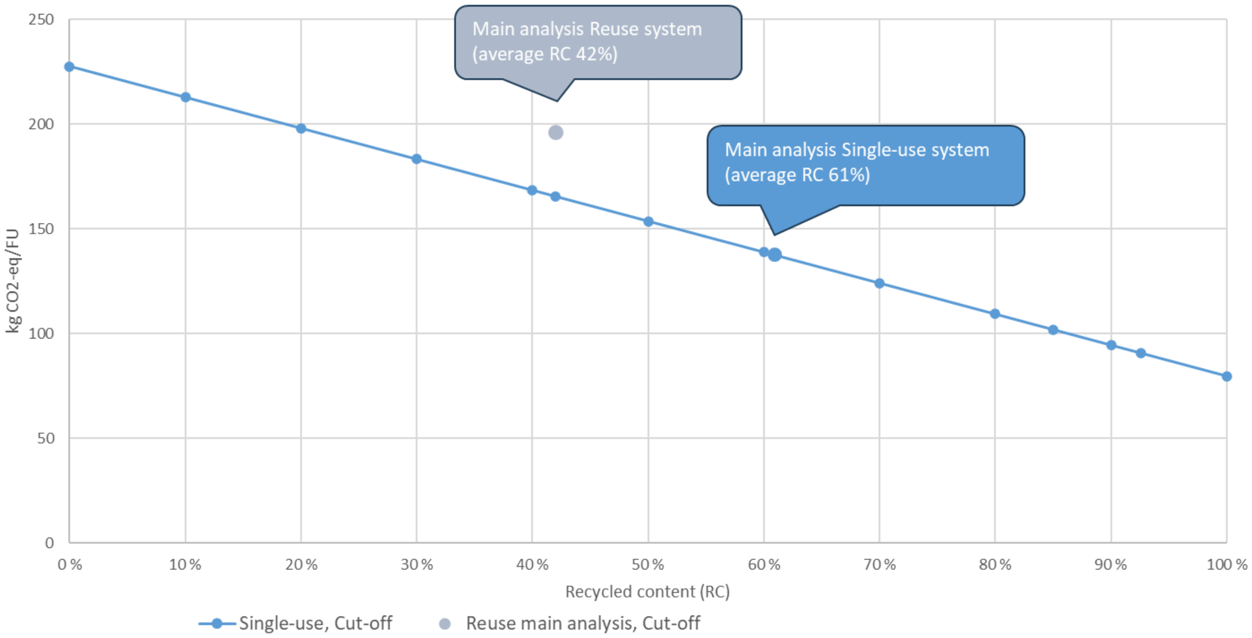


Figure 19 Climate change (kg CO_2-eq/FU) for varying recycled content in the single-use system, presented for the Cut-off modelling approach.

The figure shows clearly that the recycled content has a large impact on the results. The more recycled content in the beverage containers, the lower becomes the climate change impact. It can be seen from the figure that the climate change impact from the single-use system reaches the level of the reuse system (200 kg CO_2-eq per 1000 l distributed beverage) when the recycled content is 20% in the single-use system. If the recycled content in the single-use system decreases below this, the reuse system (with the fixed level of 42% recycled content from the main analysis) will be preferable.

The single-use system, where the packaging material is of major importance, is largely affected by the recycle content for the Cut-off modelling approach. For the System expansion_net scrap approach, however, this is of minor importance as the benefit of the increased recycled content is equalized by less avoided impact from recycling due to the system's high recycling rate. The CFF approach will be affected somewhere between the Cut-off and System expansion approach. The sensitivity analyses for the CFF and System expansion approaches are shown in Appendix 6. They both show that for climate change, the single-use system will outperform the reuse system even for zero percent recycled content in the single-use system.

6.2 Change in collection rate for the reuse system

Figure 20 shows how climate change, expressed as kg CO_2-eq/FU, varies according to varying collection rate in the reuse system. It should be emphasised that the sensitivity analysis is calculated for a simplified reuse system, including only the standard system which represents 44% and 81% of the PET and glass bottle volume, respectively. In addition, the analysis excludes any impact of potential design changes. Hence, this sensitivity analysis represents a slightly more efficient reuse system than in the main analysis. This can be seen in Figure 20 were the result from the main analysis (chapter 5.1) is highlighted by a grey triangle for the average collection rate of 92.6% (based on the market mix and respective collection rate for small and large PET- and glass bottles, see Table 4). All other assumptions, e.g., other losses throughout the system, are fixed and equal the values in the main analysis. Additionally, the result for the Single-use system from the main analysis is market with a blue bullet.

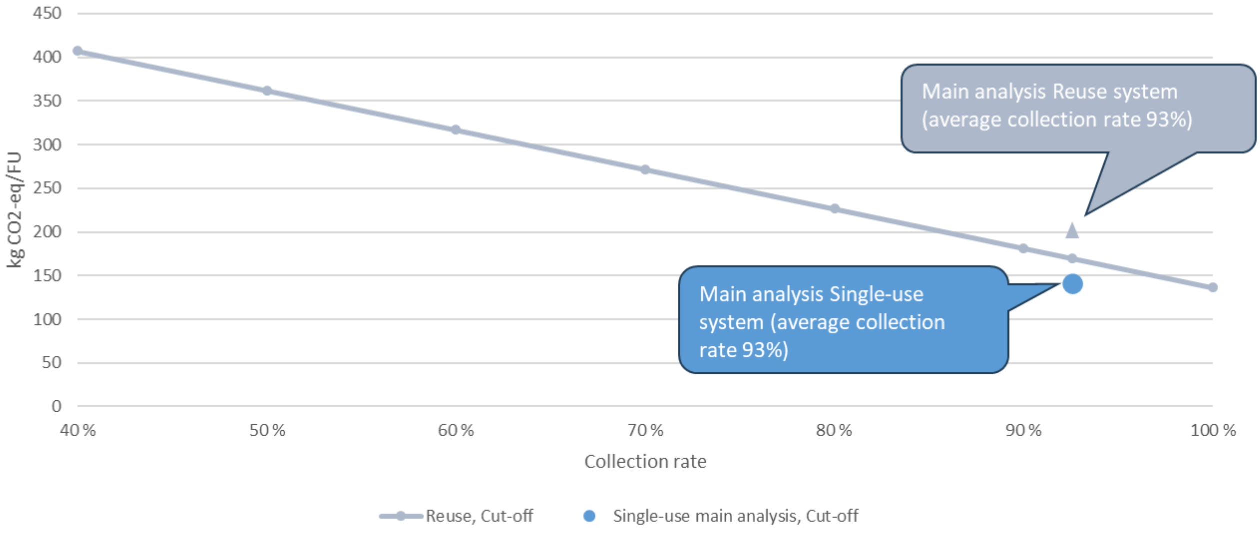


Figure 20 Climate change (kg CO_2-eq/FU) for different collection rates in the simplified reuse system, presented for the Cut-off modelling approach.

The figure clearly shows that the collection rate has a large impact on the climate change results. The higher collection rate, the lower becomes the climate change impact. The figure also shows that the simplified reuse system must reach a 100% collection rate to compete with the single-use system (having a collection rate of 93%).

The sensitivity analyses for the CFF and System expansion_net scrap approach show that for climate change, the single-use system from the main analyses will still perform best compared to the reuse system even for a collection rate of 100% (see Appendix 6).

6.3 Change in design period for the reuse system

As described in chapter 5.1.1 an important factor for the reuse system is the back-to-market rate, which directly affects the average number of uses (m’) of each bottle. In the current analysis, these are calculated based on the provided losses throughout the reuse systems and the average estimated time period for changes in bottle design, as described in chapter 2.6.

Figure 21 shows how the climate change, expressed as kg CO_2-eq/FU, varies according to different design periods for a bottle pool consisting of 1.5 L PET bottles, in the reuse system. How often the bottle design is changed (t_design = number of cycles between design changes) in the main analyses (18 and 54 for brand and standard bottles, respectively) are also presented in the figure. The results are presented for the three different modelling approaches.

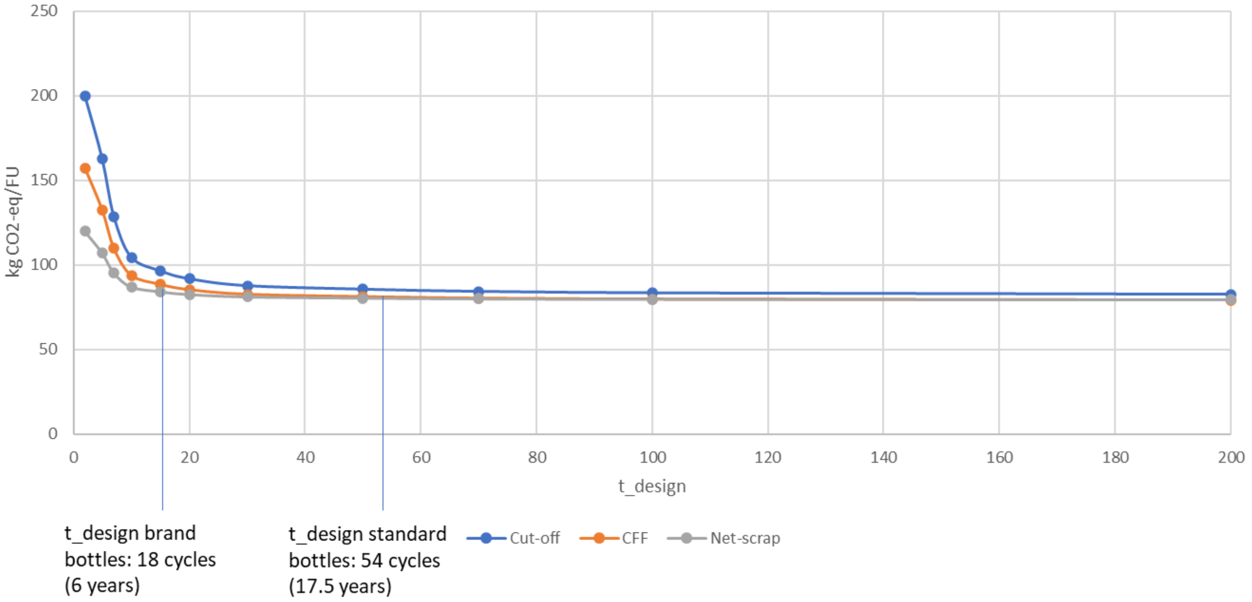


Figure 21 Climate change (kg CO_2-eq/FU) for different design periods or number of cycles (t_design) for a bottle pool consisting of 1.5 L PET bottles.

The figure clearly shows that the more often a design change happens, the larger is the climate change impact of the bottles system. Hence, the shorter design periods, the larger climate change. This is logic as a design change means that the entire bottle pool must be replaced, which decreases the average number of uses per bottle (m’) and, hence, increase the production burden per number of uses of a bottle. The design period (t_design) used in the main analyses are 18 and 54 cycles for brand and standard bottles, respectively, which represent a change of bottle design every 6th and 17.5th year. Associated climate change values for t_design = 18 (brand bottles) are 94, 86 and 83 kg CO_2-eq/FU for Cut-off, CFF and Net_scrap, respectively, while similar values for t_design = 54 (standard bottles) are 86, 81 and 80 kg CO_2-eq/FU. As seen in Figure 21, the curve is steeper for values below 20 cycles, and significantly steeper for values below 10 cycles, which means that a change in bottle design (t_design) in this area increases the climate change impact significantly. Increasing the bottle design period above 20 cycles will only affect the results to a small degree.

The results for the weighted average for brand and standard 1.5 L PET bottles from the main analysis (see Figure 9) are 89.8, 84.1 and 82.1 kg CO_2-eq/FU for Cut-off, CFF and Net_scrap, respectively.

Increasing the bottle design period to t_design = 200 would reduce the climate change impact of 1.5 litre PET bottles to about 80 kg CO_2-eq per functional unit for all modelling approaches. This would still represent a significant higher climate burden than the comparable values of the single-use 1.5 litre PET-bottles (these vary from 52.8 to 74.4 kg CO_2-eq per functional unit for the three modelling approaches, see Figure 9).

This sensitivity analysis shows that a frequent change in bottle pool design affect the climate change impact of reuse systems to a large degree, especially if changes happen more frequently than every 3rd year (t_design =10). It should, however, be emphasised that such a change is driven by the beverage industry themselves as they are the key decision makers for changes in bottle design. A key message to the decision makers of reuse systems is hence that design changes should be avoided to the greatest extent possible to reduce the systems' climate impact.

7 Discussion and conclusions

This study shows that the single-use system performs better than the reuse system for the three impact categories; climate change, cumulative energy demand (CED) and terrestrial acidification, while the reuse system performs best for the impact category mineral resource scarcity. PET bottles perform best in both systems.

Three different recycling modelling approaches, Cut-off, Circular Footprint Formula (CFF) and System expansion_net scrap, have been analysed to address how these affect the results and conclusions. The ranking of the systems regarding environmental performance is not affected by the choice of modelling approach. Still, the choice of modelling approach affects the calculated performance for each system. For the single-use system, the System expansion_net scrap approach clearly gives the best results for all the assessed impact categories while the Cut-off approach results in highest environmental impact. The major reason for this is that the System expansion_net scrap approach favours systems with recycling rates higher than recycled content, as this results in avoided emissions credited to the system. For the reuse system, the CFF approach results in the lowest impacts while the System expansion_net scrap and the Cut-off approaches give approximately equal results. This is explained by the high recycled content (60%) in the glass bottles which leads to a net negative virgin share to recycling and therefore no benefit from avoided virgin glass production is credited the System expansion_net scrap approach. The study also clearly shows that the single-use system is more sensitive to the different modelling principles compared to the reuse system, which is logic because it has a bigger material throughput being affected by recycling.

The relative comparison for the assessed impact categories is summarised in Figure 22.

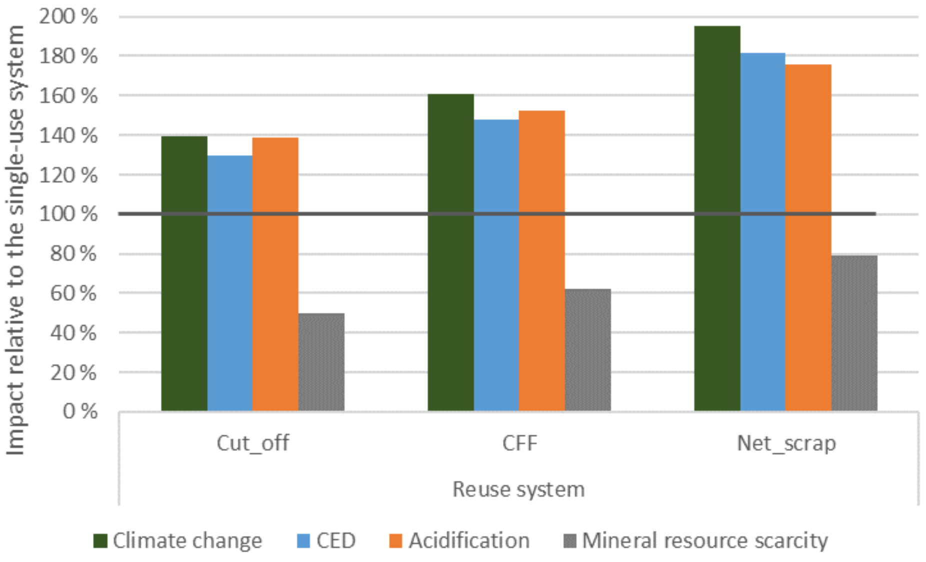


Figure 22 Impacts for the reuse system relative to the single-use system (defined to be 100%) for climate change, CED, acidification and mineral resource scarcity.

For climate change, the reuse system gives 1.4, 1.6 and 1.95 times the impact from the single-use system for the respective recycling modelling approaches Cut-off, CFF and System expansion_net scrap. Corresponding numbers for CED and terrestrial acidification are 1.3, 1.5 and 1.8, and 1.4, 1.5 and 1.75, respectively. For mineral resource scarcity, the ranking between the two main systems is the opposite, with the reuse system performing best, resulting in 37%, 63%, and 79% of the impact from the single-use system for the Cut-off, CFF and System expansion_net scrap modelling approaches, respectively. The reuse system has higher transport-related impacts than the single-use system for all impact categories analysed.

The back-to-market return rate is crucial for calculating the average number of uses per bottle in the reuse system, and the study has documented the importance of considering realistic back-to-market rates by including all potential losses throughout the value chain.

The recycled content in the bottles/cans has a large impact on the results, especially when using the Cut-off and CFF approaches. Sensitivity analyses show that the single-use system outperforms the reuse system (as analysed in the main analysis) for climate change until the recycled content decreases to 20% in the single-use system. Sensitivity analyses also show that the reuse system must reach a collection rate near 100% in order to be able to compete with the single-use system for climate change.

The study has been designed to represent Norwegian conditions with relatively long transport distances. A potential reuse system with more local sited breweries and sorting/washing facilities would give shorter transport distances which strongly affect the related transport burdens. It is therefore important that studies are designed with realistic assumptions, and the results in this specific study should not be interpreted as valid for reuse systems in general.

A lot of effort has been put on obtaining representative data and assumptions for the systems, and sensitivity analyses have been performed. However, there are still issues and aspects which could have been analysed, such as changing to biofuel and/or electrified transport, reducing the bottle weights and increasing the amount of recycled content in the reuse system. It will always be difficult to predict the future, and more detailed data and additional sensitivity analyses could have given added value to the study.

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Appendix 1 Selection of specific bottles and cans

Specific single-use bottles and cans assessed

Infinitum´s deposit system manages a large diversity of single-use bottle and can beverage packaging, which vary in terms of size (volume), material, shape, and colour (Infinitum, 2022b). In total in 2021, the system comprised as much as 31 different sizes of PET bottles and 15 different sizes of aluminium cans, and within each size there may be additional differences in terms of shape and colour, resulting in a complex market mix for single-use bottles and cans. Note that this study will focus on differences in size and weight of beverage packaging alternatives while the diversity in terms of different bottle and can shapes and colours will not be considered. An exception is that the proportion of coloured PET bottles in Infinitum's system will be considered in relation to the PET recycling process since transparent PET bottles are currently recycled into new PET bottles while coloured PET bottles are not (Infinitum, 2022b). According to Infinitum (2022b), the separation of coloured PET bottles and its subsequent recycling into new coloured PET bottles is possible but currently not done in Norway. Thus, the share of coloured PET has an influence on the share of recycled PET that is recycled into new PET bottles and how much that is recycled into other types of products. However, as the share of coloured PET bottles is low (appr 4% of the total PET volume, Infinitum at Disussion group meeting #3), this has been neglected in the study, hence all PET bottles have been assumed to be recycled into new bottles.

Although a large variety of single-use bottles and cans exist on the Norwegian market, a limited selection of bottles and cans, in terms of volume and material, dominated this market in 2021, see Table 8. This market dominance of a limited number of single-use bottles and cans has been the case for several years in Norway according to data representative for 2015 to 2021 (Infinitum, 2022b).

Table 8. Shares of single-use bottles and cans of various sizes in Infinitum's deposit system in Norway in terms of total units sold and total sold volume of beverage in 2021. In total, 672 338 276 PET bottles and 1 036 167 085 aluminium cans were sold in 2021. The table is based on data from Infinitum (2022b). Note that these values are assumed to also be representative for imported bottles (the market mix for imported bottles, i.e., filled outside Norway, and for bottles filled in Norway were assumed to be the same in this study). Values are presented with two significant numbers in the table.

Single-use PET bottle		
Size (volume)	**Share of total units sold [%]**	**Share of total sold volume of beverage [%]**
0.5L	36	18
1.5L	47	70
Other sizes	17	12
Sum	100	100
Single-use aluminium can		
Size (volume)	**Share of total units sold**	**Share of total sold volume of beverage**
0.33L	40	31
0.5L	50	60
Other sizes	10	9
Sum	100	100

Table 8 shows that the 0.5L and 1.5L PET single-use bottle sizes were alone accounting for about 83% of the total PET single-use bottle units sold in 2021. The third most sold PET bottle in terms of share of total units sold in 2021 were the 1L bottle at about 3.8% while all other sizes each constituted less than about 2.4% of the total number of bottle units sold. If considering the share of total volume of sold beverage instead, the 0.5L and the 1.5L PET bottle together accounted to as much as about 88% in 2021. Thus, both when considering the number of bottles sold and the market share based on the volume of beverage sold, the 0.5 L and 1.5 L PET bottles clearly dominated the type of bottles used in Infinitum´s deposit system in 2021. Furthermore, the weights of the 0.5L and 1.5L PET bottles, being 26.9g and 46.3g respectively, are in line with the average weight of the entire PET bottle population at 38 g. More specifically, the average weight for small bottles (0.2-0.5L) was about 26g and about 45g for large bottles (0.55-2L) based on sales figures in 2021 (Infinitum, 2022b). Based on this, the 0.5L and 1.5L PET bottles are selected to be assessed in this study (Table 9).

Table 8 also shows that a limited selection of aluminium cans dominated the market for aluminium cans in 2021 in Infinitum´s deposit system. The 0.33L and 0.5L aluminium can sizes dominated the market for aluminium cans in 2021 with about 90%. The third most sold aluminium can in terms of share of total units sold in 2021 were the 0.25L can at about 5.7% while all other sizes each constituted less than about 1.8% of the total number of can units sold. The same conclusion can be drawn if instead considering the share of the volume of sold beverage, the 0.33 L and the 0.5 L aluminium cans together accounted for about 92% in 2021. Thus, both when considering number of bottles sold and the market share based on the volume of beverage sold, the 0.33 L and 0.5 L aluminium cans dominated the type of cans used in Infinitum´s deposit system in 2021. Furthermore, the weights of the 0.33L and 0.5L aluminium cans at 12.5g and 15g, respectively, are in line with the average weight of the entire can population at 14g. The average weight for small cans (0.15-0.49L) was about 12g and about 15g for large cans (0.5-0.95L) based on sales figures in 2021 (Infinitum, 2022b). Based on this, the 0.33L and 0.5L aluminium cans were selected to be assessed in this study (Table 9).

A single-use system market mix were then constructed based on these selected PET bottles (0.5L and 1.5L) and aluminium cans (0.33L and 0.5L) and knowledge on the total number of bottle and can units sold in 2021 and the volume of the bottles and cans, see Table 9. More specifically, the market mix of PET bottles and aluminium cans were calculated as the share of the total volume of beverage sold by these specific bottles and cans in 2021. In this way, the market mix was calculated to about 12% 0.5L PET bottles, 48% 1.5L PET bottles, 14% 0.33L aluminium cans and 26% 0.5L aluminium cans, see Table 9. In number of total units sold, 83% and 90% of the total units sold for PET bottles and aluminium cans, respectively, in 2021 are represented in this study.

Table 9. Single-use bottles and cans assessed in this study for Infinitum's existing recycling system. The data are representative for 2021. PET=polyethylene terephthalate.

	PET bottle 0.5L	PET bottle 1.5L	Reference	Comment
Weight [g]	26.9	46.3	Infinitum (2022b)	
Number of units sold by members of the Infinitum deposit system [-]	241 063 975	319 020 609	Infinitum (2022b)	This value also includes imported bottles. The market mix for imported bottles and for bottles filled nationally were assumed to be the same.
Beverage volume sold by members of the Infinitum deposit system [L]	120 000 000	480 000 000	Calculated based on data from Infinitum (2022b)	Calculated based on data on number of units sold and the volume of the bottles. Values presented with two significant figures.
Market mix [% of sold beverage volume]	12	48		Share of total volume of 995 mill litres in 2021
	Aluminium can 0.33L	**Aluminium can 0.5L**	**Reference**	**Comment**
Weight [g]	12.5	15.0	Infinitum (2022b)	
Number of units sold by members of the Infinitum deposit system [-]	411 113 672	520 665 225	Infinitum (2022b)	This value also includes imported bottles. The market mix for imported bottles and for bottles filled nationally were assumed to be the same.
Beverage volume sold by members of the Infinitum deposit system [L]	140 000 000	260 000 000	Calculated based on data from Infinitum (2022b)	Calculated based on data on number of units sold and the volume of the cans. Values presented with two significant figures.
Market mix [% of sold beverage volume]	14	26		Share of total volume of 995 mill litres in 2021

Specific reusable bottles assessed

Estonia, Germany and Finland are three examples of European countries with reuse systems for PET and/or glass bottles in place today (Eesti Pandipakend, 2022; GDB, 2022; Palpa, 2022). Different types of reusable bottles (sizes and designs) are used in these systems. Note that this study will focus on differences in size and weight of PET beverage packaging alternatives and differences in size, weight, and colour of glass beverage packaging alternatives. The more detailed diversity in terms of different bottle shapes will not be considered.

In Germany, reusable bottles constitute a significant share of the annual beverage volume handled by the GDB (GDB, 2022). For example, about 41% of the annual sold volume of mineral water were delivered by reusable PET and glass bottles in 2021 (GDB, 2022). Several reusable PET bottles are applied, ranging from 0.5L, weighing 43 gram, to 1.5L, weighing 70 gram (GDB, 2022). Based on this information, and the fact that the current recycling system in Norway is dominated by bottles of similar sizes, the 0.5L and 1.5L PET reusable bottles were selected for this study.

Many different reusable glass bottles are also used in Germany, including but not limited to, 0.33L (220-310 gram), 0.5L (365-410 gram) and 1L, at 650 gram (GDB, 2022). In Estonia and Finland, reusable glass bottles are applied to various extents (Eesti Pandipakend, 2022; Palpa, 2022). According to Eesti Pandipakend (2022), their annual beverage volume sales is about 386 million litre and about 9.8% of this is delivered by reusable glass bottles. Seven different reusable bottles, which vary in size (0.33L or 0.5L) and colour (transparent, green, or brown), are being used. The top three reusable glass bottles in terms of size and colour given in percentage of the annual beverage volume sales with reusable bottles are in decreasing order; 0.5L brown (55.3%), 0.33L transparent (38%) and 0.33L green (4.9%) (Eesti Pandipakend, 2022). Thus, the Estonian market is dominated by the brown 0.5L and the transparent 0.33L bottles at 93.3% of the annual beverage volume sales with reusable bottles. In Finland, the use of reusable bottles has declined significantly over the recent years and today only one reusable alternative is applied on the Finnish market, namely the 0.33L brown beer glass bottle (Palpa, 2022). Based on this information, the average size of 0.33L and the 0.5L glass bottles were selected to be assessed in this study. As described in chapter 2.3, the variety in reuse models (12 PET bottles, of which 4 standard and 8 brand models and 8 glass bottles of which 6 standard and 2 brand models) are reflected in the LCA-model by taking different transport distances into account for the share of standard and brand bottles, respectively. Potential environmental effects of different colours in the glass bottles have not been possible to analyse.

The selected reusable glass and PET bottle sizes correspond well with the sizes of the selected single-use aluminium cans and PET bottles, respectively, that are used in the Infinitum deposit system, see Table 9. Based on this, a similar market mix was assumed for the reusable glass and PET bottles as for the single-use aluminium cans and PET bottles, respectively, see

Table 2 and Table 3. That is, the market mix for reusable glass bottles was assumed to be similar as the market mix for single-use aluminium cans (e.g. both glass bottles and aluminium cans can be used to serve beer) and the market mix for reusable PET bottles was assumed to be similar as the market mix for single-use PET bottles in Infinitum´s deposit system in Norway in 2021.

Table 10. Alternative reusable bottles assessed in this study.

	PET bottle 0.5L	PET bottle 1.5L	Reference	Comment
Weight [g]	43	70	GDB (2022)	
	Glass bottle 0.33L, transparent	**Glass bottle 0.5L, brown**	**Reference**	**Comment**
Weight [g]	265	370	Eesti Pandipakend (2022), GDB (2022)	According to Eesti Pandipakend (2022), 0.33L transparent and 0.5L brown glass bottles weigh about 252-259 g and 330 g. According to GDB (2022), 0.33L and 0.5L glass bottles weigh about 220-310 g and 365-410 g. The glass bottle weights were selected as average values based on these value ranges.

Appendix 2 Major data input to the analyses

Single-use system: Aluminium cans

Table 11. Major system data for the single-use system with 0.33L and 0.5L aluminium cans.

No	Parameter [unit]	Value	Source	Comment
P1	**Production of virgin aluminium**			
	Aluminium production process data.	-	ecoinvent	
T1	**Transport of virgin aluminium to aluminium can production**			
	Distance by truck [km]	250	ecoinvent	Assumed
P2	**Production of recycled aluminium**			
	Aluminium can production process data.		ecoinvent	
T2	**Transport of recycled aluminium to aluminium can production**			
	Distance by truck [km]	250	ecoinvent	Assumed
P3	**Production of aluminium cans (located in Sweden)**			
	Aluminium can production process data.		ecoinvent	
	Average weight of 0.33 L can [g]	12.5	Infinitum (2022b)	
	Average weight of 0.5 L can [g]	15		
	Recycled content, aluminium [weight-%]	55	Ringnes (2022a)	The post-consumer recycled content for Ringnes largest can supplier in Western Europe was 59.9% in 2021. The same value for their second largest can supplier was, depending on their supply location in Western Europe, 35%, 51%, 54%, or 81%. Based on this, a recycled content at 55% is applied as the baseline.
T3	**Transport of cans (and distribution packaging/crates) from production site to filling site**			
	Distance from can production plant in Sweden to Oslo by train [km]	570	Infinitum (2022b)	Approximate distance between production in Sweden to Oslo, Norway.
	Average distance from Oslo to filling sites in Norway [km]	Train: 494 Truck: 138	NORSUS	Assume the same distance as T9 for the reuse systems (distance for standard bottles from central sorting plant in Oslo to Norwegian filling sites)
	Distance from plant in Sweden to filling site in Sweden by train [km]	190	NORSUS	Assume 1/3 of the distance (570 km) from the can production plant (Sweden) to Norway
	Distance from plant in Sweden to filling site in Denmark by train [km]	570	NORSUS	Assume same distance (570 km) from the can production plant (Sweden) to Norway
	50cl std: 5474 stk/pall, 33cl std: 8211stk/pall		Ringnes	
P4	**Filling site**			
	Filling sites in Norway (16 sites): share of total number of single-use aluminium cans sold by Infinitum members in 2021 [%]	66	Infinitum (2022b)	
	Share of total number of single-use aluminium imported from Sweden [%]	27	Infinitum	Share of import of PET bottles and aluminium cans from • Sweden: 80% • Denmark: 20%
	Share of total number of single-use aluminium	7		

	imported from Denmark [%]			
T4	**Transport from filling site to hub before retailer**			
	Average distance from filling site in Norway to retailer [km]	Truck: 53 Train: 233 Ship: 161	Bø, Hammervoll, and Tvedt (2013)	
	Average distance from filling sites in Sweden to transportation hub, imported PET bottles and aluminium cans [km]	Truck: 50 Train: 450	Infinitum	• Suggest using the same import distances from filling sites to transportation hubs for the recycling system as for the reuse system. • 20 pallets per truck to/from rail terminal • EUR container size truck, assume 28.9t (acc. to ecoinvent 3.2).
	Average distance from filling sites in Denmark to transportation hub, imported PET bottles and aluminium cans [km]	Truck: 50 Train: 700		
P5	**Hub before retailer**			
	No data included			
T5	**Transport from hub to retailer**			
	Share of total number of collected bottles that are collected per region in 2021 [-]	North: 10% Mid: 14% West: 14% South: 14% East: 48%	Infinitum	
	Transport distance from retailer to collection hub per region by truck [km]	North: 460 Mid: 230 West: 287 South: 287 East: 57	Infinitum	Based on the calculated transport distances (T6) calculated per region from retailer to hub, these distances have been changed according to half the number of hubs (20 vs 40 and hence assumed double transport distances) and 15% increased efficiency gains due to longer distances.
	Average weighted distance from hub to retailer Norway [km]	178	Infinitum	Average transport based on the above date for share of total volume per region and respective distances. Distribution trucks will typically be of 5 - 10 ton capacity and hold 10 - 18 pallets.
P6	**Retailer: reverse vending machine and storing**			
	Collection rate aluminium can, 0.33l, via reverse vending machines and manually collected [weight-%]	90.7	Infinitum (2022b)	Cans (≤ 0.4L) collected via reverse vending machines, including manually collected bottles (90.7%). The remainder (9.3%) is assumed to be collected with residual waste and sent to incineration. The recycling of a certain share of aluminium from incineration ashes will be considered in the background system modelling.
	Collection rate aluminium can, 0.5l, via reverse vending machines and manually collected [weight-%]	92.1		Cans (> 0.4L) collected via reverse vending machines, including manually collected bottles (92.1%). The remainder (7.9%) is assumed to be collected with residual waste and sent to incineration. The recycling of a certain share of aluminium from incineration ashes will be considered in the background system modelling.
	Electricity consumption per bottle or can collected via a reverse vending machine [kWh/bottle or can]	0.0015	Raadal et al. (2016)	Data representative for 2016. According to Raadal et al. (2016), the annual electricity consumption of a reverse vending machine, with an annual collection of 350 000 bottles/cans, was 525 kWh in 2016. Based on this, the electricity consumption per bottle or can collected via a reverse vending machine has been calculated by dividing the annual electricity consumption by the annual number of bottles/cans collected.
	Storage time [days]	Single-use: 1.5 pallet	Infinitum	Assumptions storage time:

		stored for 4,3 days before pick-up		Re-use system requires 2-3 more storage space in shop, and also a 3-fold increase in number of pick-ups per store. The single-use system has 1.5 pallets in the shop for storage until pick-up, the re-use system has 4 pallets. Single use system: 1.5 pallets stored per shop, on average 84 pick-ups per year. Average time between pick-ups: (365 days/year)/(84 pick-ups/year) = 4.3 days storage time/pick-up.
	Energy use for storing, single-use aluminium can units stored	$1.1e^{-3}$ kWh/can	Calculated based on data from Infinitum and (Enova, 2017)	Units per pallet: • Single-use aluminium cans (compressed): 3500 Flooring needed for storing of one pallet with goods, assuming dimensions 1200 mm and 800 mm: 1.2 m x 0.8 m = 0.96 m^2/pallet. Data for use of energy given by the ENOVA statistics from 2017. The value 219 kWh/m^2 for commercial buildings, not including grocery stores, is used. This is the annual value. Per day the value is (219 kWh/m^2)/365 days = 0.6 kWh/m^{2}day. Single use system, use of flooring: 1.5 pallets stored for 4.3 days -> 1.5 pallets x 0.96 m^2/pallet x 4.3 days = 6.19 m^2*days. Energy use: 6.19 m^2*days x 0.6 kWh/m^{2}day = 3.72 kWh. Per unit: • Single-use aluminium cans: 3.72 kWh/3500 cans = $1.1e^{-3}$ kWh/can
T6	**Transport from retailer to hub before sorting**			
	Share of total number of collected bottles that are collected per region in 2021 [-]	North: 10% Mid: 14% West: 14% South: 14% East: 48%	Infinitum	
	Transport distance from retailer to collection hub per region by truck [km]	North: 249 Mid: 124 West: 155 South: 124 East: 31	Infinitum	Transport distances per region is calculated based on average distance per retailer in each region and average number of retailers per distribution route.
	Average weighted distance from hub to retailer Norway by truck [km]	97	Infinitum	Average transport based on the above date for share of total volume per region and respective distances. Distribution trucks will typically be of 5 - 10 ton capacity and hold 10 - 18 pallets.
	Number of units (compressed) per pallet, single-use aluminium can and PET bottles [-]	3 500	Infinitum/ TrioWorld	1/1 pallet size bag (bag weight at 1 020 g, recycled content at 30 weight-%): Contain about **1 400 units** (cans and PET-bottles) after compaction of the units in the reverse vending machine.
P7	**Hub before sorting**			
	No data included			
T7	**Transport from hub to sorting**			
	Average distance for aluminium cans from collection site to sorting plant (Heia, Bjerkvik or Heimdal) [km]	Truck: 71 Train: 135	Raadal et al. (2016), Infinitum (2022b)	Data from 2016 but still valid for 2021 according to Infinitum (2022b). Average transport distance for aluminium cans by truck and train from wholesaler distribution centres to Infinitum's sorting plants. Truck with average load at 1.6 ton and capacity utilisation at 46% (Infinitum, 2022b).
P8	**Sorting of aluminium cans at Heia, Berkvik and Heimdal**			

	Electricity use [kWh/ aluminium can]	0.00165	Raadal et al. (2016), Infinitum (2022b)	Data representative for 2016, calculated based on an annual electricity consumption for Infinitum´s sorting facilities (Heia, Bjerkvik or Heimdal) at 2 274 000 kWh/year and that in total 950 645 460 units (PET bottles and aluminium cans) were sorted in 2016 indicate an electricity use at 0.0024 kWh/aluminium can (Raadal et al., 2016). According to Infinitum (2022b), the electricity use is currently 0.0015 kWh/unit at Heia and it is slightly higher in Heimdal and Bjerkvik at about 0.0018 kWh/unit since more units are sorted while the annual electricity consumption can be assumed to be the same as in 2016. Based on this, 0.00165 kWh/unit is applied in this study.
	Loss of aluminium in sorting process [weight-%]	0.1	Infinitum (2022b)	According to Infinitum (2022b), this aluminium follows the PET and cap stream that is returned to Infinitum, very small net loss. This is assumed to be waste from this process.
T8	**Transport from sorting to recycling**			
	Weighted average distance for aluminium cans with truck from sorting plant in Norway to recycling in the UK [km]	320	Infinitum (2022b)	The average distances were calculated based on the following data from Infinitum: Infinitum has three sorting plants (located in Heia, Bjerkvik and Heimdal). Bales of sorted aluminium cans are transported directly on the truck/trailer, why no transport packaging is needed for this process. • 80 weight-% of aluminium cans are sorted at Heia and are then sent to Brevik by truck (about 200 km), from there to Hull by ship (about 800 km) and from there to the recycling plant in Latchford, UK by truck (about 200 km). • 6.5 weight-% of aluminium cans are sorted at Bjerkvik in Narvik and sent to Heia by train (1 000 km) and are then further transported from there in the same way as the cans sorted at Heia. • 13.5 weight-% of aluminium cans are sorted at Heimdal in Trondheim and are then sent directly to Novelis recycling plant in Germany by truck (about 1 700 km).
	Weighted average distance for aluminium cans with ship from sorting plant in Norway to recycling in the UK [km]	690		
	Weighted average distance for aluminium cans with train from sorting plant in Norway to recycling in the UK [km]	65		
	Weighted average distance for alu cans with truck from sorting plants in Norway to recycling in Germany [km]	230		
P9	**Recycling**			
	Aluminium recycling process.	-	ecoinvent	
T9	**Not in use in this system**			
P10	**Production and waste management of distribution packaging**			
	Reusable wood pallets with carton spacer plates in between and plastic straps. 50cl std: 5474 stk/pall, 33cl std: 8211stk/pall		Ringnes	
	Recycling and incineration		ecoinvent	
T10	**Transport of distribution packaging to aluminium can production**			
	Data not included			
P11	**Production and waste management of distribution packaging**			
	0,33L: 10-pack carton 85,3 g, 3 carton spacer		Møller et al. (2014)	

	plates in between 128,3 g per half pallet, 900 cans per half pallet. 0,5L: Six-pack with shrink (plastic) 8,34 g, 4 carton spacer plates in between 159,7 g per half pallet, 756 cans per half pallet.			
	Recycling and incineration		ecoinvent	
T11	**Transport of distribution packaging to filling site**			
	No data included			
P12	**Production and waste management of collection packaging**			
	Average use of PP plastic bags [g/unit collected]	0.78	Infinitum (2022b), TrioWorld by data via Infinitum (2022b)	Polypropylene (PP) plastic bags are used for the transportation of cans from the collection process to the sorting process. The PP bags are used to transport a mix of single-use aluminium cans and PET bottles. 96% of the bottle/can volume is collected by reverse vending machines (60% of reverse vending machine bags used are ½ pallet while the remaining 40% are 1/1 pallet) while the remaining 4% is collected manually. The average use of PP bags was calculated based on this and the following data describing the different bags being used: • 1/1 pallet size bag (bag weight at 1 020 g, recycled content at 30 weight-%): Contain about 1 400 units (cans and PET-bottles) after compaction of the units in the reverse vending machine. • ½ pallet size bag (bag weight at 580 g, recycled content at 70%): Contain about 700 units (cans and PET-bottles) after compaction of the units in the reverse vending machine. • Manual size bag (bag weight at 335 g, recycled content at 70%): Contain about 200 units which are uncompressed. This gives an average PP bag weight at 739g, an average number of units collected in an average PP bag at 949 units (i.e. 0.78 g PP bag per unit).
	Recycled content [%]	55	TrioWorld via Infinitum (2022b).	
	Transport from sorting to recycling by truck [km]	310	Infinitum	All PP bags are sorted out by Infinitum and sold to recyclers after use. The PP bags are assumed to be transported from the sorting plant Heia to recycling in Folldal.
	Recycling and incineration		ecoinvent	
T12	**Transport of collection packaging to retailer**			
	No data included			
T14	**Transport of uncollected aluminium cans from consumer to waste management**			
	Transport with residual waste from consumer's home to incineration plant, by truck [km]	73	Raadal et al. (2016)	
P14	**Waste management of uncollected aluminium cans from consumer and sorting residues from P8 and P9**			
	Incineration of uncollected cans and sorting residues		Raadal et al. (2016), ecoinvent	

Single-use system: PET bottles

Table 12. Major system data for the single-use system with 0.5L and 1.5L PET bottles. Note that some data are confidential, hence the specific values are not given in this table.

No.	Parameter [unit]	Value	Source	Comment
P1	**Production of virgin PET**			
	Production of virgin PET		ecoinvent	
T1	**Transport of virgin PET to PET preform production**			
	Distance by truck [km]	250	ecoinvent	Assumed
P2	**Production of recycled PET**			
	Production of recycled PET			Recycling of PET bottles at Veolia in Norway and the Netherlands, see P9
T2	**Transport of recycled PET to PET preform production**			
	Distance by truck [km]	250	ecoinvent	Assumed
P3	**Production of PET preform**			
	Average weight of 0.5 L PET bottle (and preform) [g]	26.9	Infinitum (2022b), Ringnes (2022b)	Data on bottle weights from Infinitum (2022b). Caps and labels (with an average weight at 2.1 g and 0.5 g, respectively, on the Norwegian market according to Infinitum (2022b)) are excluded from this study since they only constitute about 4-7% and 1-2% of the total weight (bottle, cap, and label), respectively. According to Ringnes (2022b), there are no losses during blowing of preforms why the weight of the preform is the same as for the bottle after the blowing process.
	Average weight of 1.5 L PET bottle (and preform) [g]	46.3		
	Recycled content, PET [weight-%]	65	Infinitum (2022b)	Estimated by Infinitum based on data on the recycled content in Norwegian beverage producers' packaging and the producers market shares in Norway.
	Electricity use, injection moulding [kWh/kg PET preform produced]	Confidential	PET preform production company 1	Assumed to be valid also for PET preform production company 2.
	Share of PET preforms on Norwegian market produced by PET production company 1 [weight-%]	Confidential	Assumption by the authors based on data from Infinitum (2022b)	
	Share of PET preforms on Norwegian market produced PET production company 2 [weight-%]	Confidential		
T3	**Transport of PET preforms (and distribution packaging) from preform production site to filling site**			
	Steel cages per truckload [-]	Confidential	PET production company 1	Assumed to be valid also for PET production company 2.
	Distance from PET preform production company 1 to Oslo by truck [km]	Confidential	PET production company 1	
	Distance from PET preform production company 2 to Oslo [km]	Truck: 670 Ship: 330	Infinitum (2022b)	
	Average distance from Oslo to filling sites in Norway [km]	Train: 494 Truck: 138	NORSUS	Assume the same distance as T9 for the reuse systems (distance for standard bottles from central sorting plant in Oslo to Norwegian filling sites)
	Distance from PET preform production to filling sites in Sweden by [km]	Truck: 100	NORSUS	Assumptions based on the share and locations of the PET preform production companies

	Distance from PET preform production to filling sites in Denmark [km]	Ship: 250	NORSUS	
P4	**Filling site: blowing of PET preforms**			
	Filling sites in Norway (16 sites): share of total number of single-use PET bottles sold by Infinitum members in 2021 [%]	91	Infinitum (2022b)	Personal communication
	Share of total number of single-use PET bottles imported from Sweden [%]	7	Infinitum	Share of import of PET bottles and aluminium cans from - Sweden: 80% - Denmark: 20%
	Share of total number of single-use PET bottles imported from Denmark [%]	2		
	Electricity use, stretch blow moulding [kWh/kg PET bottle produced]	Confidential	PET production company 1	Assumed to be valid also for PET production company 2.
	Loss of PET in the blowing process [weight-%]	0	Ringnes (2022b)	The weight of the PET preform equals the weight of the produced bottle.
T4	**Transport from filling site to hub before retailer**			
	Average distance from filling site in Norway to retailer [km]	Truck: 53 Train: 233 Ship: 161	Bø et al. (2013)	
	Average distance from filling sites in Sweden to transportation hub, imported PET bottles and aluminium cans [km]	Truck: 50 Train: 450	Infinitum	- Suggest using the same import distances from filling sites to transportation hubs for the recycling system as for the reuse system. - 20 pallets per truck to/from rail terminal - EUR container size truck, assume 28.9 t (acc. to ecoinvent 3.2).
	Average distance from filling sites in Denmark to transportation hub, imported PET bottles and aluminium cans [km]	Truck: 50 Train: 700		
P5	**Hub before retailer**			
	No data included			
T5	**Transport from hub to retailer**			
	Pallets per truckload [-]	Confidential	PET production company 1	Assumed to be valid also for PET production company 2.
	Transport distance from retailer to collection hub per region by truck [km]	North: 460 Mid: 230 West: 287 South: 287 East: 57	Infinitum	Based on the calculated transport distances (T6) calculated per region from retailer to hub, these distances have been changed according to half the number of hubs (20 vs 40 and hence assumed double transport distances) and 15% increased efficiency gains due to longer distances.
	Average weighted distance from hub to retailer Norway [km]	178	Infinitum	Average transport based on the above date for share of total volume per region and respective distances. Distribution trucks will typically be of 5 - 10 ton capacity and hold 10 - 18 pallets.
P6	**Retailer: reverse vending machine and storing**			
	Collection rate PET bottle, 0.5l, via reverse vending	89.1	Infinitum (2022b)	Bottles (≤ 0.5L) collected via reverse vending machines, including manually collected bottles (89.1%). The

	machines any manually collected [weight-%]			remainder (10.9 %) was assumed to become collected with residual waste and sent to incineration.
	Collection rate PET bottle, 1.5l, via reverse vending machines any manually collected [weight-%]	94.3		Bottles (> 0.5L) collected via reverse vending machines, including manually collected bottles (94.3%). The remainder (5.7 %) was assumed to become collected with residual waste and sent to incineration.
	Electricity consumption per bottle or can collected via a reverse vending machine [kWh/bottle or can]	0.0015	Raadal et al. (2016)	Data representative for 2016. According to Raadal et al. (2016), the annual electricity consumption of a reverse vending machine, with an annual collection of 350 000 bottles/cans, was 525 kWh in 2016. Based on this, the electricity consumption per bottle or can collected via a reverse vending machine can be calculated by dividing the annual electricity consumption by the annual number of bottles/cans collected.
	Storage time [days]	Single-use: 1.5 pallet stored for 4,3 days before pick-up	Infinitum	Assumptions on storage time: Re-use system requires 2-3 more storage space in shop, and also a 3-fold increase in number of pic-ups per store. The single-use system has 1.5 pallets in the shop for storage until pick-up, the re-use system has 4 pallets. Single use system: 1.5 pallets stored per shop, on average 84 pick-ups per year. Average time between pick-ups: (365 days/year)/(84 pick-ups/year) = 4.3 days storage time/pick-up.
	Energy use for storing, single-use PET bottle units stored	$1.1e^{-3}$ kWh/PET bottle	Calculated based on data from Infinitum and (Enova, 2017)	Units per pallet: • Single-use PET 0.5/1.5l bottles (compressed): 3500 Flooring needed for storing of one pallet with goods, assuming dimensions 1200 mm and 800 mm: 1.2 m x 0.8 m = 0.96 m^2/pallet. Data for use of energy given by the ENOVA statistics from 2017. The value 219 kWh/m^2 for commercial buildings, not including grocery stores, is used. This is the annual value. Per day the value is (219 kWh/m^2)/365 days = 0.6 kWh/m^2day. Single use system, use of flooring: 1.5 pallets stored for 4.3 days -> 1.5 pallets x 0.96 m^2/pallet x 4.3 days = 6.19 m^2*days. Energy use: 6.19 m^2*days x 0.6 kWh/m^2day = 3.72 kWh. Per unit: • Single-use 0.5/1.5l PET bottles: 3.72 kWh/3500 bottles = $1.1e^{-3}$ kWh/bottle
T6	**Transport from retailer to hub before sorting**			
	Share of total number of collected bottles that are collected per region in 2021 [-]	North: 10% Mid: 14% West: 14% South: 14% East: 48%	Infinitum	
	Transport distance from retailer to collection hub per region by truck [km]	North: 249 Mid: 124 West: 155 South: 124 East: 31	Infinitum	Transport distances per region is calculated based on average distance per retailer in each region and average number of retailers per distribution route.
	Average weighted distance from hub to retailer Norway by truck [km]	97	Infinitum	Average transport based on the above date for share of total volume per region and respective distances. Distribution trucks will typically be of 5 - 10 ton capacity and hold 10 - 18 pallets.

	Number of units (compressed) per pallet, single-use aluminium can and PET bottles [-]	3 500	Infinitum/ TrioWorld	1/1 pallet size bag (bag weight at 1 020 g, recycled content at 30 weight-%): Contain about **1 400 units** (cans and PET-bottles) after compaction of the units in the reverse vending machine.
P7	**Hub before sorting**			
	No data included			
T7	**Transport from hub to sorting**			
	Average distance for PET bottles from collection site to sorting plant (Heia, Bjerkvik or Heimdal) [km]	Truck: 71 Train: 134	Raadal et al. (2016), Infinitum (2022b)	Data from 2016 but still valid for 2021 according to Infinitum (2022b). Average transport distance for PET bottles by truck and train from wholesaler distribution centres to Infinitum's sorting plants. Truck with average load at 1.6 ton and capacity utilisation at 46% (Infinitum, 2022b).
P8	**Sorting at Heia, Berkvik and Heimdal**			
	Electricity use [kWh/ PET bottle]	0.00165	Raadal et al. (2016), Infinitum (2022b)	Data representative for 2016, calculated based on an annual electricity consumption for Infinitum´s sorting facilities (Heia, Bjerkvik or Heimdal) at 2 274 000 kWh/year and that in total 950 645 460 units (PET bottles and aluminium cans) were sorted in 2016 indicate an electricity use at 0.0024 kWh/aluminium can (Raadal et al., 2016). According to Infinitum (2022b), the electricity use is currently 0.0015 kWh/unit at Heia and it is slightly higher in Heimdal and Bjerkvik at about 0.0018 kWh/unit since more units are sorted while the annual electricity consumption can be assumed to be the same as in 2016. Based on this, an electricity use at 0.00165 kWh/unit is applied in this study.
	Loss of PET in sorting process [weight-%]	1.5	Infinitum (2022b)	PET sorted with aluminium, is assumed to be incinerated.
T8	**Transport from sorting to recycling**			
	Weighted average distance for PET bottles with forklift (diesel-driven) from sorting plant in Norway to recycling in Norway [km]	0.08	Infinitum (2022b)	The average distances were calculated based on the following data from Infinitum: Infinitum has three sorting plants (located in Heia, Bjerkvik and Heimdal). Bales of sorted PET bottles are transported directly on the truck/trailer, why no transport packaging is needed for this process. • 80 weight-% of collected PET bottles are sorted at Heia and are then sent to Veolia at Heia via trolleys pulled by a diesel-driven forklift (100 m). • 6.5 weight-% of collected PET bottles are sorted at Bjerkvik in Narvik, sent to Heia by train (1 000 km) and then further transported from Heia to Veolia by a diesel-driven forklift (100 m). • 13.5 weight-% of collected PET bottles are sorted at Heimdal in Trondheim and are then sent directly to Spijk, Netherlands by truck (1 250 km) to the Wellmann recycling company.
	Weighted average distance for PET bottles with train from sorting plant in Norway to recycling in Norway [km] by train	65		
	Weighted average distance for PET bottles with truck from sorting plant in Norway to recycling in the Netherlands [km] by truck	163		
P9	**Recycling of PET bottles at Veolia in Norway and the Netherlands**			
	Electricity use at Veolia [kWh/kg food-grade PET pellets produced]	1.03	Veolia via Infinitum (2022b), assumption by the authors	Assumed to also be representative for recycling in the Netherlands.
	Losses of PET in the recycling process at Veolia [weight-%]	2		Assumed to also be representative for recycling in the Netherlands. The loss for the total recycling process is 1.6% for non-food and food grade while the loss is 2.0 % for food-grade only. The latter value was used here since the bottles are used for beverage.

	Input of caustic soda, 50%, at Veolia [kg/ton food-grade PET pellets produced]	2.97		Assumed to also be representative for recycling in the Netherlands.
	Input of natrium chloride at Veolia [kg/ton food-grade PET pellets produced]	3.94		Assumed to also be representative for recycling in the Netherlands.
	Input of citric acid, 50%, at Veolia [kg/ton food-grade PET pellets produced]	0.92		Assumed to also be representative for recycling in the Netherlands.
	Input of Anti-foam Struktol at Veolia [kg/ton food-grade PET pellets produced]	0.42		Assumed to also be representative for recycling in the Netherlands.
	Input of Tubiwash SKP at Veolia [kg/ton food-grade PET pellets produced]	0.27		Assumed to also be representative for recycling in the Netherlands.
T9	**Not in use in this system**			
P10	**Production and waste management of distribution packaging**			
	Distribution packaging – steel cage [kg/kg preform]	Confidential	PET production company 1, assumption by the authors	Assumed to be valid also for PET production company 2. The steel cage was assumed by the authors to be reused 50 times and then sent to recycling.
	Distribution packaging plastic bag [kg/kg preform]	Confidential	PET production company 1, assumption by the authors	Assumed to be valid also for PET production company 2. It was assumed by the authors that the plastic bag is made of high-density polyethylene (HDPE).
	Recycling and incineration		ecoinvent	
T10	**Transport of distribution packaging to PET preform production**			
	No data included			
P11	**Production and waste management of distribution packaging**			
	Distribution packaging – wooden pallet [kg/kg PET bottle]	Confidential	PET production company 1, assumption by the authors based on Zampori and Pant (2019)	Assumed to be valid also for PET production company 2. The wooden pallet was assumed by the authors to be reused 25 times, based on Zampori and Pant (2019), and then sent to recycling.
	Distribution packaging – cardboard [kg/kg PET bottle]	Confidential	PET production company 1	Assumed to be valid also for PET production company 2.
	Distribution packaging – stretch plastic [kg/kg PET bottle]	Confidential	PET production company 1, assumption by the authors	Assumed to be valid also for PET production company 2. It was assumed by the authors that the stretch plastic is made of linear low-density polyethylene (LLDPE).
	Recycling and incineration		ecoinvent	
T11	**Transport of distribution packaging to filling site**			
	No data included			
P12	**Production and waste management of collection packaging**			
	Average use of PP plastic bags [g/unit collected]	0.78	Infinitum (2022b), TrioWorld via Infinitum (2022b)	Polypropylene (PP) plastic bags are used for the transportation of cans from the collection process to the sorting process. The PP bags are used to transport a mix of single-use aluminium cans and PET bottles. 96% of the bottle/can volume is collected by reverse vending

				machines (60% of reverse vending machine bags used are ½ pallet while the remaining 40% are 1/1 pallet) while the remaining 4% is collected manually. The average use of PP bags was calculated based on this and the following data describing the different bags being used: • 1/1 pallet size bag (bag weight at 1 020 g, recycled content at 30 weight-%): Contain about 1 400 units (cans and PET-bottles) after compaction of the units in the reverse vending machine. • ½ pallet size bag (bag weight at 580 g, recycled content at 70%): Contain about 700 units (cans and PET-bottles) after compaction of the units in the reverse vending machine. • Manual size bag (bag weight at 335 g, recycled content at 70%): Contain about 200 units which are uncompressed. This gives an average PP bag weight at 739g, an average number of units collected in an average PP bag at 949 units (i.e. 0.78 g PP bag per unit)
	Recycled content [%]	55	TrioWorld via Infinitum (2022b).	
	Transport from sorting to recycling by truck [km]	310	Infinitum	All PP bags are sorted out by Infinitum and sold to recyclers after use. The PP bags are assumed to be transported from the sorting plant Heia to recycling in Folldal.
	Recycling and incineration		ecoinvent	
T12	**Transport of collection packaging to retailer**			
	No data included			
T14	**Transport of uncollected PET bottles from consumer to waste management**			
	Transport with residual waste from consumer's home to incineration plant, by truck [km]	73	Raadal et al. (2016)	
P14	**Waste management of uncollected PET bottles from consumer and sorting residues from P8 and P9**			
	Incineration of uncollected bottles		Raadal et al. (2016), ecoinvent	

Reuse system: Glass bottles

Table 13. Major system data for the reuse system with 0.33L and 0.5L glass bottles.

No	Parameter [unit]	Value	Source	Comment
P1	**Production of virgin glass**			
	Glass production process data	-	ecoinvent	
T1	**Transport of virgin glass to glass bottle production**			
	Distance by truck [km]	250	ecoinvent	Assumed
P2	**Production of recycled glass**			
	Recycled glass production data		ecoinvent	
T2	**Transport of recycled glass to glass bottle production**			
	Distance by truck [km]	250	ecoinvent	Assumed
P3	**Production of glass bottles**			
	Average weight of 0.33 L transparent glass bottle [g]	265	Eesti Pandipakend (2022), GDB (2022), Infinitum (2022b)	Data representative for 2021. According to Eesti Pandipakend (2022), 0.33L transparent glass bottles weigh about 252-259 g. According to GDB (2022), 0.33L glass bottles weigh about 220-310 g. The glass bottle weight was selected as average value based on these value ranges. Note that caps and labels (with an average weight at 2.1 g and 0.5 g, respectively, on the Norwegian market according to Infinitum (2022b)) were excluded from this study since they only constitute about 0.8% and 0.2% of the total weight (bottle, cap, and label), respectively.
	Average weight of 0.5 L brown glass bottle [g]	370	Eesti Pandipakend (2022), GDB (2022), Infinitum (2022b)	Data representative for 2021. According to Eesti Pandipakend (2022), 0.5L brown glass bottles weigh about 330 g. According to GDB (2022), 0.5L glass bottles weigh about 365-410 g. The glass bottle weight was selected as average value based on these value ranges. Note that caps and labels (with an average weight at 2.1 g and 0.5 g, respectively, on the Norwegian market according to Infinitum (2022b)) were excluded from this study since they only constitute about 0.6% and 0.1% of the total weight (bottle, cap, and label), respectively.
	Recycled content, glass [weight-%]	61	Furberg et al. (2021)	The recycled content of reusable glass bottles ranged from 35% to 87% in the LCA studies reviewed by the reference. The value 61% was selected since it lies in the middle of this range.
T3	**Transport of glass bottles (and distribution packaging/crates) from production site to filling site**			
	Distance from glass bottle producer to Oslo, transport by train [km]	570	Ringnes (2022a), assumption by authors	According to Ringnes (2022a), new reusable glass bottles to be used in Norway are typically produced in Sweden (the production of reusable bottles otherwise typically take place in the country where they are going to be used. Something that is true for countries such as Denmark, Sweden, Poland, and Germany). Based on this, an approximate distance between Sweden and Oslo at 570 km by train was assumed by the authors.
	Average distance from Oslo to filling sites in Norway [km]	Train: 494 Truck: 138	NORSUS	Assume the same distance as T9 for the reuse system (distance for standard bottles from central sorting plant in Oslo to Norwegian filling sites)
	Distance from glass bottle producer to filling sites in Sweden, by truck [km]	100	NORSUS	Assumptions made based on location of glass bottle producer
	Distance from glass bottle producer to filling sites in Denmark, by ship [km]	250	NORSUS	Assumptions made based on location of glass bottle producer
P4	**Filling site: washing of glass bottles**			

	Filling sites in Norway (20 sites): assumed market share of glass bottles [%]	87.5	Discussion group	Minutes from meeting in Discussion group Sept 27th:
	Assumed share of total glass bottles imported from Sweden [%]	10	Infinitum	Share of import of glass bottles (12.5 %) from • Sweden: 80% • Denmark: 20%
	Share of total glass bottles imported from Denmark [%]	2.5		
	Water for washing [L/glass bottle unit]	0.67	Tua, Grosso, and Rigamonti (2020)	Inputs/outputs required for the reconditioning of one reusable glass bottle based on data from the reference, who assessed reusable glass bottles in Italy. The reference applied primary data obtained from Italian mineral water companies using reusable glass bottles. The data were obtained from questionnaires and field visits. It is assumed that this data also can be representative for the bottles assessed in this study.
	Heating of water [kJ/glass bottle unit]	459		
	Detergent, caustic soda [g/glass bottle unit]	0.24		
	Disinfectant, peracetic acid [g/glass bottle unit]	1.15		
	Sulfuric acid (treatment of wastewater) [g/glass bottle unit]	2.5		
	Process sludge (treatment of wastewater) [g/glass bottle unit]	0.36		
T4	**Transport from filling site to hub before retailer**			
	Average distance from filling site in Norway to retailer [km]	Truck: 53 Train: 233 Ship: 161	Bø et al. (2013)	
	Reduced transport efficiency due to imbalance of bottles/crates delivery and pick-up		Infinitum	Some empty crates must be included in the transport due to imbalance of bottles/crates delivery. This has been adjusted for by lower transport efficiency.
	Average distance from filling sites in Sweden to transportation hub, imported PET bottles and aluminium cans [km]	Train: 450 Truck: 50	Infinitum	Infinitum: • Assumed same distance from filling to transportation hub as sorting to filling. One sorting plant in Oslo. • 20 pallets per truck to/from rail terminal • EUR container size truck
	Average distance from filling sites in Denmark to transportation hub, imported PET bottles and aluminium cans [km]	Train: 700 Truck: 50		
P5	**Hub before retailer (20 hubs)**			
	No data included			
T5	**Transport from hub to retailer**			
	Transport distance from retailer to collection hub per region by truck [km]	North: 460 Mid: 230 West: 287 South: 287 East: 57	Infinitum	Based on the calculated transport distances (T6) calculated per region from retailer to hub, these distances have been changed according to half the number of hubs (20 vs 40 and hence assumed double transport distances) and 15% increased efficiency gains due to longer distances.
	Average weighted distance from hub to retailer Norway [km]	178	Infinitum	Average transport based on the above date for share of total volume per region and respective distances. Distribution trucks will typically be of 5 - 10 ton capacity and hold 10 - 18 pallets.

	Reduced transport efficiency due to imbalance of bottles/crates delivery and pick-up		Infinitum	Some empty crates must be included in the transport due to imbalance of bottles/crates delivery. This has been adjusted for by lower transport efficiency.
P6	**Retailer: reverse vending machine and storing**			
	Collection rate glass bottle, 0.33l, via reverse vending machines and manually collected [weight-%]	90.7	Infinitum (2022b)	Assumed to be the same as the collection rate for <0.4L can.
	Collection rate glass bottle, 0.5l, via reverse vending machines and manually collected [weight-%]	92.1		Assumed to be the same as the collection rate for >0.4L can.
	Electricity consumption per bottle/can collected via a reverse vending machine [kWh/unit]	0.0015	Raadal et al. (2016)	Data representative for 2016. According to Raadal et al. (2016), the annual electricity consumption of a reverse vending machine, with an annual collection of 350 000 bottles/cans, was 525 kWh in 2016. Based on this, the electricity consumption per bottle or can collected via a reverse vending machine can be calculated by dividing the annual electricity consumption by the annual number of bottles/cans collected.
	Number of units per crate for reusable bottles [-]	0.33L glass: 24 0.5L glass: 20	Infinitum	
	Number of crates per pallet for reusable bottles [-]	0.33L glass: 40 0.5L glass: 32	Infinitum	
	Degree of crate utilization [%]	90	Infinitum	Assumed some empty spaces in the crates.
	Area required in store for one pallet [m^2]	0.96	Infinitum	Pallet length: 1.2m and pallet width: 0.8m.
	Storage time [days]	Reuse: 4 pallets stored 1.5 days before pick-up	Infinitum	Assumptions on storage time: Re-use system requires 2-3 more storage space in shop, and also a 3-fold increase in number of pic-ups per store. The single-use system has 1.5 pallets in the shop for storage until pick-up, the re-use system has 4 pallets. Re-use system: 4 pallets stored per shop. Pick-up is 3 times more often than single use (252 times per year) i.e. 1.4 days storage time before pick-up (and then picking up 4 pallets instead of 1.5).
	Energy use for storing, reusable glass 0.33L bottle	3.7e^{-3} kWh/glass bottle	Calculated based on data from Infinitum and (Enova, 2017)	Units per pallet: • Reusable glass 0.33l bottles: 864 • Reusable glass 0.5l bottles: 576 Flooring needed for storing of one pallet with goods, assuming dimensions 1200 mm and 800 mm: 1.2 m x 0.8 m = 0.96 m^2/pallet. Data for use of energy given by the ENOVA's building statistics from 2017. The value 219 kWh/m^2 for commercial buildings, not including grocery stores, is used. This is the annual value. Per day the value is (219 kWh/m^2)/365 days = 0.6 kWh/m^{2}day.
	Energy use for storing, reusable glass 0.5L bottle	5.6e^{-3} kWh/glass bottle		

				Re-use system, use of flooring: 4.0 pallets stored for 1.4 days -> 4.0 pallets x 0.96 m^2/pallet x 1.4 days = 5.38 m^2*days. Energy use: 5.38 m^2*days x 0.6 kWh/day = 3.23 kWh. Per unit: • Reusable glass 0.33l bottles: 3.23 kWh/864 bottles = $3.7e^{-3}$ kWh/bottle • Reusable glass 0.5l bottles: 3.23 kWh/576 bottles = $5.6e^{-3}$ kWh/bottle
T6	**Transport from retailer to hub before sorting**			
	Share of total number of collected bottles that are collected per region in 2021 [-]	North: 10% Mid: 14% West: 14% South: 14% East: 48%	Infinitum	
	Transport distance from retailer to collection hub per region by truck [km]	North: 249 Mid: 124 West: 155 South: 124 East: 31	Infinitum	Transport distances per region is calculated based on average distance per retailer in each region and average number of retailers per distribution route.
	Average weighted distance from hub to retailer Norway [km]	97	Infinitum	Average transport based on the above date for share of total volume per region and respective distances. Distribution trucks will typically be of 5 - 10 ton capacity and hold 10 - 18 pallets.
	Reduced transport efficiency due to imbalance of bottles/crates delivery and pick-up		Infinitum	Some empty crates must be included in the transport due to imbalance of bottles/crates delivery. This has been adjusted for by lower transport efficiency.
	Pallets per truck [-]	18	Infinitum	
	Weight wood pallet [kg]	25	Infinitum	This is an approximation.
	Weight HDPE plastic pallet [kg]	15	Infinitum	Infinitum: Plastic NLP pool-pallet (commonly used inside Norway)
	Share of the number of pallets used that are plastic (rest is wood) [%]	70	Infinitum	Infinitum: Assume 70% NLP pallet in domestic transports.
P7	**Hub before sorting**			
	No data included			
T7	**Transport from hub to sorting**			
	Share of total number of collected bottles that are collected per region in 2021 [-]	North: 10% Mid: 14% West: 14% South: 14% East: 48%	Infinitum	
	Transport distance by train per region [km]	North: 1544 km Mid: 480 km West: 520 km South: 430 km East: 290 km	Infinitum	Infinitum: One sorting plant in Oslo is assumed. Infinitum: Trucks will typically be of 10 ton capacity, and hold 18 pallets, for such long-haul. If on rail, capacity per rail (shipping) container is typically 20 pallets. To/from rail terminal (if close enough) is typically with container-truck i.e. also 20 pallet.
	Transport distance by truck per region [km]	North: 240 km Mid: 109 km West: 353 km South: 67 km East: 82 km	Infinitum	
	Average distance from collection hub to sorting in Oslo by train [km]	494 km	Calculated based on data from Infinitum	Average transport distance from collection hubs (assuming 40 hubs in Norway as in Infinitum's single-use system of today) to sorting (one plant in Oslo).

	Average distance from collection hub to sorting in Oslo by truck [km]	138 km		Calculated based on data for the number of bottles collected per five regions (north, mid, west, south, east) in Norway in 2021, the transport distance (average) from collection hub to sorting by train for each region and the transport distance (average) from collection hub to sorting by truck and train for each region.
	Reduced transport efficiency due to imbalance of bottles/crates delivery and pick-up		Infinitum	Some empty crates must be included in the transport due to imbalance of bottles/crates delivery. This has been adjusted for by lower transport efficiency.
P8	**Sorting**			
	Electricity use [kWh/glass bottle unit]	0.044	Tua et al. (2020)	Inputs/outputs required for the reconditioning of one reusable glass bottle based on data from the reference, who assessed reusable glass bottles in Italy. The reference applied primary data obtained from Italian mineral water companies using reusable glass bottles. The data were obtained from questionnaires and field visits. It was assumed that this data also can be representative for the bottles assessed in this study.
T8	**Transport from sorting to recycling**			
	Average distance for glass bottles from sorting plant to recycling site (transport by train) [km]	397	Infinitum (2022b), SSB (2022), assumption by NORSUS	Reusable glass bottles which cannot be reused anymore (i.e. which are damaged, too worn or too contaminated) are discarded and sent to recycling (Sirkel) in Fredrikstad, Norway (Infinitum, 2022b). It can be assumed that 60 weight-% of the glass bottles are transported by train and the remainder (40 weight-%) by truck and the following distances can be applied (Infinitum, 2022b): • Distance between Narvik and Fredrikstad: 1500 km • Distance between Oslo and Fredrikstad: 100 km • Distance between Trondheim and Fredrikstad: 580 km The share of collected bottles that are sorted at each of the sorting centres (assumed to be in Oslo, Trondheim and Narvik) were estimated based on the number of persons living in different regions in Norway in 2022 under the assumption that the different sorting centres will be responsible to sort bottles from different regions: • Sorting centre Narvik: Regions - Troms og Finnmark and Nordland. Population: 481 926 in 2022, about 9% of total population in Norway (SSB, 2022). • Sorting centre Trondheim: Regions - Trøndelag and Møre og Romsdal. Population: 739 979 in 2022, about 14% of total population in Norway (SSB, 2022). • Sorting centre Oslo: Regions - Vestland, Rogaland, Agder, Vestfold og Telemark, Innlandet and Oslo. Population: 4 203 365 in 2022, about 77% of total population in Norway (SSB, 2022). It was assumed that the share of the population considered to be connected to each sorting plant can be used as a proxy for the weight-% of bottles that are sorted at these facilities.
	Average distance for glass bottles from sorting plant to recycling site (transport by truck) [km]	265		
P9	**Recycling**			
	Glass recycling process	-	ecoinvent	

T9	**Transport of glass bottles and crates from sorting to filing site**			
	Standard reusable bottles, share of number of total collected bottles, [%]	0.33L/0.5L glass: 81%	Calculated based on data from Infinitum	NORSUS: Assume the same shares for large/small bottles. Glass: 100-19 (brand glass) = 81%
	Brand reusable bottles, share of number of total collected bottles, [%]	0.33L/0.5L glass: 19%	Calculated based on data from Infinitum	Infinitum: 19% of total aluminium cans (different sizes), here translated into 19% of total number of reusable glass bottles (different sizes). Separate number of reuse should ideally have been considered for the brand bottles as the pool is smaller and must take into account seasonal variations, buffer capacity, change of standard type, etc. Due to too much complexity in the LCA model, this has not been possible. Instead, this has been analysed by a sensitivity analysis of reduced number of uses of the entire system.
	Share of total number of collected bottles that are collected per region [-]	North: 10% Mid: 14% West: 14% South: 14% East: 48%	Infinitum	NORSUS: These data include standard, brand, and water bottles. Assume this can be representative for standard bottles, specifically, In 2021.
	Transport distance by train per region, non-imported standard bottles (excluding glass brand bottles) [km]	North: 1544 km Mid: 480 km West: 520 km South: 430 km East: 290 km	Infinitum	Infinitum: One sorting plant in Oslo is assumed. It is furthermore assumed that the same transport distances and types for sorting to filling site (refilling) can be applied as from collection hubs to central sorting.
	Transport distance by truck per region, non-imported standard bottles (excluding glass brand bottles) [km]	North: 240 km Mid: 109 km West: 353 km South: 67 km East: 82 km	Infinitum	
	Average distance for **non-imported standard bottles**, [km]	494 by train 138 by truck	Calculated based on data from Infinitum	**Non-imported standard bottles** The distances are calculated based on data for the number of bottles collected per five regions (north, mid, west, south, east) in Norway in 2021. The distances take int account the average share of the bottles of the total volume. Can be calculated directly as the "Norwegian distances".
	Transport distance, **non-imported brand bottles** [km]	494 by train 158 by truck	Calculated based on data from Infinitum	**Non-imported brand bottles** The distances are calculated based on data on distances (and transport types) for the brand bottles producers (filling sites) provided from infinitum. The distances take int account the average share of the bottles of the total volume. Can be calculated directly as the "Norwegian distances".
	Reduced transport efficiency due to imbalance of bottles/crates delivery and pick-up		Infinitum	Some empty crates must be included in the transport due to imbalance of bottles/crates delivery. This has been adjusted for by lower transport efficiency.
	Import from Sweden of total collected bottles [%]	10%	Infinitum	
	Import from Denmark of total collected bottles [%]	2.5%	Infinitum	
	Transport distance, imported bottles, Sweden [km]	Train: 450 km Truck: 50 km	Infinitum	Same distance as T4

	Transport distance, imported bottles, Denmark [km]	Train: 700 km Truck: 50 km	Infinitum	
	Pallets per truck [-]	18	Infinitum	Trucks will typically be of 10 ton capacity, and hold 18 pallets, for such long-haul. If on rail, capacity per container is typically 20 pallets. To/from rail terminal (if close enough) is typically with container-truck i.e. also 20 pallets.
P10	**Production of distribution packaging (crates)**			
	Crate production (PP) [kg/crate]	1.450	Email from Pasi Nurminen (16.11.22)	For 24x0,33L crate
	Weight of crates [kg/kg carrying capacity]	0.12	Tua, Biganzoli, Grosso, and Rigamonti (2019), assumption by the authors	Data on reusable crates used for food were applied as a proxy for reusable crates for reusable bottles. The reusable polypropylene (PP) crates studied by Tua et al. (2019) weighted 1.49 kg and had a carrying capacity at 12 kg. New crates are assumed by the authors to be produced in the country where the bottle production takes place (i.e. in Sweden for glass bottles) with an average distance to the production site at 500 km by truck. The reconditioning of crates (background system) were modelled in line with Tua et al. (2019). The recycled content of the crates was assumed to be 0 weight-%. These crates are used between the production site via the filling site to retailer, from collection site (at retailer) to sorting and back to filling site / washing and then back to the production site.
	Number of uses for crates [-]	40	Zampori and Pant (2019), UNESDA (2022)	According to Zampori and Pant (2019), crates can be reused about 30 times based on a technical approximation for plastic crates made by the reference based on technical specifications (guaranteed lifetime of 10 years) and a return of three times per year. According to UNESDA (2022) (representing the European soft drinks industry), crates can be reused up to about 50 times. The value in the middle of this range (30-50) was applied for this study.
T10	**Transport of distribution packaging (crates) to glass bottle production**			
	No data included			
P11	**Production of distribution packaging**			
	See P10			
T11	**Transport of distribution packaging to filling site**			
	No data included			
P14	**Waste management of uncollected glass bottles from consumer**			
	Incineration of uncollected bottles and crates		ecoinvent	
T14	**Transport of uncollected glass bottles from consumer to waste management**			
	Transport with residual waste from consumer's home to incineration plant, by truck [km]	73	Raadal et al. (2016)	

Reuse system: PET bottles

Table 14. Major system data for the reuse system with 0.5L and 1.5L PET bottles.

No	Parameter [unit]	Value	Source	Comment
P1	**Production of virgin PET**			
	Production of virgin PET		ecoinvent	
T1	**Transport of virgin PET to PET preform production**			
	No data included			
P2	**Production of recycled PET**			
	Production of recycled PET			Recycling of PET bottles at Veolia in Norway and the Netherlands, see P9
T2	**Transport of recycled PET to PET preform production**			
	No data included			
P3	**Production of PET preform and blowing**			
	Average weight of 0.5 L PET bottle [g]	43	GDB (2022), Infinitum (2022b)	Bottle weight data from GDB (2022). Note that caps and labels (with an average weight at 2.1 g and 0.5 g, respectively, on the Norwegian market according to Infinitum (2022b)) were excluded from this study since they only constitute about 5% and 1% of the total weight (bottle, cap, and label), respectively.
	Average weight of 1.5 L PET bottle [g]	70	GDB (2022), Infinitum (2022b)	Bottle weight data from GDB (2022). Note that caps and labels (with an average weight at 2.1 g and 0.5 g, respectively, on the Norwegian market according to Infinitum (2022b)) were excluded from this study since they only constitute about 3% and 0.7% of the total weight (bottle, cap, and label), respectively.
	Recycled content, PET [weight-%]	30	Petainer (2022)	According to the reference, reusable PET bottles can be produced with up to 30% recycled content.
	Electricity use, injection moulding [kWh/kg PET preform produced]	Confidential	PET production company 1	Same data as for single-use PET preform (per kg PET preform produced). Assumed to be valid also for PET production company 2.
	Electricity use, stretch blow moulding [kWh/kg PET bottle produced]	Confidential	PET production company 1	Blowing: The data for blowing of single-use PET bottles (injection moulding process) were assumed to also be representative for reusable PET bottles.
	Loss of PET in the blowing process [weight-%]	0	Ringnes (2022b)	Blowing: The weight of the PET preform equals the weight of the produced bottle for single use PET bottles. The data for blowing of single-use PET bottles were assumed to also be representative for reusable PET bottles.
	Share of PET bottles on Norwegian market produced by PET production company 1 [weight-%]	Confidential	Assumption by the authors based on data from Infinitum (2022b)	Data for single-use PET were assumed to also be representative for reusable PET bottles (only the weight of the preform was varied).
	Share of PET bottles on Norwegian market produced PET production company 2 [weight-%]	Confidential	Assumption by the authors based on data from Infinitum (2022b)	Data for single-use PET were assumed to also be representative for reusable PET bottles (only the weight of the preform was varied).
T3	**Transport of PET bottles (and distribution packaging/crates) from production site to filling site**			
	Distance from PET preform production company 1 to Oslo by truck [km]	Confidential	PET production company 1	
	Distance from PET preform production company 2 to Oslo [km]	Truck: 670 Ship: 330	Infinitum (2022b)	

	Average distance from Oslo to filling sites in Norway [km]	Train: 494 Truck: 138	NORSUS	Assume the same distance as T15 for the reuse systems (distance for standard bottles from central sorting plant in Oslo to Norwegian filling sites)
	Distance from PET bottle production to filling sites in Sweden by [km]	Truck: 100 km	NORSUS	Assumptions based on the share and locations of the PET preform production companies
	Distance from PET bottle production to filling sites in Denmark [km]	Ship: 250	NORSUS	
P4	**Filling site: washing of PET bottles**			
	Filling sites in Norway (20 sites): assumed share of PET bottles in the market [%]	87.5	Discussion group	Minutes from meeting in Discussion group Sept 27th
	Assumed share of total PET bottles imported from Sweden [%]	10	Infinitum	Share of import of glass bottles (12.5 %) from • Sweden: 80% • Denmark: 20%
	Share of total PET bottles imported from Denmark [%]	2.5		
	Water for washing [L/PET bottle unit]	0.67	Tua et al. (2020)	It was assumed that the sorting and washing of reusable PET bottles will be in line with these processes for reusable glass bottles (per bottle unit). Inputs/outputs required for the reconditioning of one reusable glass bottle based on data from the reference, who assessed reusable glass bottles in Italy. The reference applied primary data obtained from Italian mineral water companies using reusable glass bottles. The data were obtained from questionnaires and field visits. It was assumed that this data also can be representative for the bottles assessed in this study.
	Heating of water [kJ/PET bottle unit]	459		
	Detergent, caustic soda [g/PET bottle unit]	0.24		
	Disinfectant, peracetic acid [g/PET bottle unit]	1.15		
	Sulfuric acid (treatment of wastewater) [g/PET bottle unit]	2.5		
	Process sludge (treatment of wastewater) [g/PET bottle unit]	0.36		
T4	**Transport from filling site to hub before retailer**			
	Average distance from filling site in Norway to retailer [km]	Truck: 53 Train: 233 Ship: 161	Bø et al. (2013)	
	Reduced transport efficiency due to imbalance of bottles/crates delivery and pick-up		Infinitum	Some empty crates must be included in the transport due to imbalance of bottles/crates delivery. This has been adjusted for by lower transport efficiency.
	Average distance from filling sites in Sweden to transportation hub, imported PET bottles and aluminium cans [km]	Train: 450 Truck: 50	Infinitum	Infinitum: • Assumed same distance from filling to transportation hub as sorting to filling. One sorting plant in Oslo. • 20 pallets per truck to/from rail terminal • EUR container size truck
	Average distance from filling sites in Denmark to transportation hub, imported PET bottles and aluminium cans [km]	Train: 700 Truck: 50		
P5	**Hub before retailer**			
	No data included			
T5	**Transport from hub to retailer**			

	Transport distance from retailer to collection hub per region by truck [km]	North: 460 Mid: 230 West: 287 South: 287 East: 57	Infinitum	Based on the calculated transport distances (T6) calculated per region from retailer to hub, these distances have been changed according to half the number of hubs (20 vs 40 and hence assumed double transport distances) and 15% increased efficiency gains due to longer distances.
	Average weighted distance from hub to retailer Norway [km]	178	Infinitum	Average transport based on the above date for share of total volume per region and respective distances. Distribution trucks will typically be of 5 - 10 ton capacity and hold 10 - 18 pallets.
	Reduced transport efficiency due to imbalance of bottles/crates delivery and pick-up		Infinitum	Some empty crates must be included in the transport due to imbalance of bottles/crates delivery. This has been adjusted for by lower transport efficiency.
P6	**Retailer: reverse vending machine and storing**			
	Collection rate reusable PET bottle, 0.5l, via reverse vending machines and manually collected [weight-%]	89.1	Infinitum (2022b)	Assumed to be the same as the collection rate for 0.5 l single-use PET bottle.
	Collection rate reusable PET bottle, 0.5l, via reverse vending machines and manually collected [weight-%]	94.3		Assumed to be the same as the collection rate for 1.5 l single-use PET bottle.
	Electricity consumption per bottle/can collected via a reverse vending machine [kWh/unit]	0.0015	Raadal et al. (2016)	Data representative for 2016. According to Raadal et al. (2016), the annual electricity consumption of a reverse vending machine, with an annual collection of 350 000 bottles/cans, was 525 kWh in 2016. Based on this, the electricity consumption per bottle or can collected via a reverse vending machine can be calculated by dividing the annual electricity consumption by the annual number of bottles/cans collected.
	Number of units per crate for reusable bottles [-]	0.5L PET: 20 1.5L PET:10	Discussion group	
	Number of crates per pallet for reusable bottles [-]	0.5L PET: 32 1.5L PET: 24	Infinitum	
	Degree of crate utilization [%]	90	Infinitum	Assumed some empty spaces in the crates.
	Area required in store for one pallet [m^2]	0.96	Infinitum	Pallet length: 1.2m and pallet width: 0.8m.
	Storage time [days]	Reuse: 4 pallets stored 1.5 days before pick-up	Infinitum	Assumptions on storage time: Re-use system requires 2-3 more storage space in shop, and also a 3-fold increase in number of pic-ups per store. The single-use system has 1.5 pallets in the shop for storage until pick-up, the re-use system has 4 pallets. Re-use system: 4 pallets stored per shop ("bottle and crate size" enclosure). Pick-up is 3 times more often than single use (252 times per year) ie 1.4 days storage time before pick-up (and then picking up 4 pallets instead of 1.5).

	Energy use for storing, reusable PET 0.5L bottle units stored	$5.6e^{-3}$ kWh/PET bottle	Calculated based on data from Infinitum and (Enova, 2017)	Units per pallet: • Reusable PET 0.5l bottles: 576 • Reusable PET 1.5l bottles: 259 Flooring needed for storing of one pallet with goods, assuming dimensions 1200 mm and 800 mm: 1.2 m x 0.8 m = 0.96 m^2/pallet. Data for use of energy given by the ENOVA's building statistics from 2017- The value 219 kWh/m^2 for commercial buildings, not including grocery stores, is used. This is the annual value. Per day the value is (219 kWh/m^2)/365 days = 0.6 kWh/m^{2}day. Re-use system, use of flooring: 4.0 pallets stored for 1.4 days -> 4.0 pallets x 0.96 m^2/pallet x 1.4 days = 5.38 m^2*days. Energy use: 5.38 m^2*days x 0.6 kWh/day = 3.23 kWh. Per unit: • Reusable PET 0.5l bottles: 3.23 kWh/576 bottles = $5.6e^{-3}$ kWh/bottle • Reusable PET 1.5 bottles: 3.23 kWh/259 bottles = $12.5e^{-3}$ kWh/bottle
	Energy use for storing, reusable PET 1.5L bottle units stored	$12.5e^{-3}$ kWh/bottle		
T6	**Transport from retailer to hub before sorting**			
	Share of total number of collected bottles that are collected per region in 2021 [-]	North: 10% Mid: 14% West: 14% South: 14% East: 48%	Infinitum	
	Transport distance from retailer to collection hub per region by truck [km]	North: 249 Mid: 124 West: 155 South: 124 East: 31	Infinitum	Transport distances per region is calculated based on average distance per retailer in each region and average number of retailers per distribution route.
	Average weighted distance from hub to retailer Norway [km]	97	Infinitum	Average transport based on the above date for share of total volume per region and respective distances. Distribution trucks will typically be of 5 - 10 ton capacity and hold 10 - 18 pallets.
	Reduced transport efficiency due to imbalance of bottles/crates delivery and pick-up		Infinitum	The transport load must take into account that empty crates (volume based) must be included in the transport due to imbalance of bottles/crates delivery. It is assumed that 60% of the stores are of the smaller type and that these have a 20% lower volume of collection relative sales. Hence, 60% * 20% = 12% extra crates is assumed to be included in this transport.
	Pallets per truck [-]	18	Infinitum	
	Weight wood pallet [kg]	25	Infinitum	Infinitum: This is an approximation.
	Weight HDPE plastic pallet [kg]	15	Infinitum	Infinitum: Plastic NLP pool-pallet (commonly used inside Norway)
	Share of the number of pallets used that are plastic (rest is wood) [%]	70	Infinitum	Infinitum: Assume 70% NLP pallet in domestic transports.
P7	**Hub before sorting**			
	No data included			
T7	**Transport from hub to sorting**			
	Share of total number of collected bottles that are	North: 10% Mid: 14%	Infinitum	Infinitum: One sorting plant in Oslo is assumed.

	collected per region in 2021 [-]	West: 14% South: 14% East: 48%		Infinitum: Trucks will typically be of 10 ton capacity, and hold 18 pallets, for such long-haul. If on rail, capacity per rail (shipping) container is typically 20 pallets. To/from rail terminal (if close enough) is typically with container-truck i.e. also 20 pallets.
	Transport distance by train per region [km]	North: 1544 km Mid: 480 km West: 520 km South: 430 km East: 290 km		
	Transport distance by truck per region [km]	North: 240 km Mid: 109 km West: 353 km South: 67 km East: 82 km		
	Weighted average distance from collection hub to sorting in Oslo by train [km]	494 km	Calculated based on data from Infinitum	Average transport distance from collection hubs (assuming 40 hubs in Norway as in Infinitum's single-use system of today) to sorting (one plant in Oslo). Calculated based on data for the number of bottles collected per five regions (north, mid, west, south, east) in Norway in 2021, the transport distance (average) from collection hub to sorting by train for each region and the transport distance (average) from collection hub to sorting by truck and train for each region.
	Weighted average distance from collection hub to sorting in Oslo by truck [km]	138 km		
	Reduced transport efficiency due to imbalance of bottles/crates delivery and pick-up		Infinitum	The transport load must take into account that empty crates (volume based) must be included in the transport due to imbalance of bottles/crates delivery. It is assumed that 60% of the stores are of the smaller type and that these have a 20% lower volume of collection relative sales. Hence, 60% * 20% = 12% extra crates is assumed to be included in this transport.
P8	**Sorting**			
	Electricity use [kWh/PET bottle unit]	0.044	Tua et al. (2020)	It was assumed that the sorting and washing of reusable PET bottles will be in line with these processes for reusable glass bottles: Inputs/outputs required for the reconditioning of one reusable glass bottle based on data from the reference, who assessed reusable glass bottles in Italy. The reference applied primary data obtained from Italian mineral water companies using reusable glass bottles. The data were obtained from questionnaires and field visits. It was assumed that this data also can be representative for the bottles assessed in this study.
T8	**Transport from sorting to recycling**			
	Average distance for PET bottles from sorting plant to recycling site (transport by train) [km]	522	Infinitum (2022b), SSB (2022), assumption by NORSUS	Reusable PET bottles which cannot be reused anymore (i.e. which are damaged, too worn or too contaminated) are discarded and sent to recycling in Norrköping, Sweden (Infinitum, 2022b). According to Infinitum (2022b), reusable PET will probably be recycled in Norrköping in Sweden and not at Heia since the volume will be too low to maintain VPN at Heia. It can be assumed that 60 weight-% of the PET bottles are transported by train and the remainder (40 weight-%) by truck and the following distances can be applied (Infinitum, 2022b): • Distance between Narvik and Norrköping: 1600 km • Distance between Oslo and Norrköping: 500 km • Distance between Trondheim and Norrköping: 800 km

	Average distance for PET bottles from sorting plant to recycling site (transport by truck) [km]	348		The share of collected bottles that are sorted at each of the sorting centres (assumed to be in Oslo, Trondheim and Narvik) were estimated based on the number of persons living in different regions in Norway in 2022 under the assumption that the different sorting centres will be responsible to sort bottles from different regions: • Sorting centre Narvik: Regions - Troms og Finnmark and Nordland. Population: 481 926 in 2022, about 9% of total population in Norway (SSB, 2022). • Sorting centre Trondheim: Regions - Trøndelag and Møre og Romsdal. Population: 739 979 in 2022, about 14% of total population in Norway (SSB, 2022). • Sorting centre Oslo: Regions - Vestland, Rogaland, Agder, Vestfold og Telemark, Innlandet and Oslo. Population: 4 203 365 in 2022, about 77% of total population in Norway (SSB, 2022). It was assumed that the share of the population considered to be connected to each sorting plant can be used as a proxy for the weight-% of bottles that are sorted at these facilities.
P9	**Recycling**			
	Process for PET recycling			Assuming that the process data for single-use PET recycling (recycling at Veolia in Norway and the Netherlands) also can be applied for reusable PET recycling (only the weight of the bottle was varied). See lines below.
	Electricity use at Veolia [kWh/kg food-grade PET pellets produced]	1.03	Veolia via Infinitum (2022b), assumption by the authors	Assumed to also be representative for recycling in the Netherlands.
	Losses of PET in the recycling process at Veolia [weight-%]	2		Assumed to also be representative for recycling in the Netherlands. The loss for the total recycling process is 1.6% for non-food and food grade while the loss is 2.0 % for food-grade only. The latter value was used here since the bottles are used for beverage.
	Input of caustic soda, 50%, at Veolia [kg/ton food-grade PET pellets produced]	2.97		Assumed to also be representative for recycling in the Netherlands.
	Input of natrium chloride at Veolia [kg/ton food-grade PET pellets produced]	3.94		Assumed to also be representative for recycling in the Netherlands.
	Input of citric acid, 50%, at Veolia [kg/ton food-grade PET pellets produced]	0.92		Assumed to also be representative for recycling in the Netherlands.
	Input of Anti-foam Struktol at Veolia [kg/ton food-grade PET pellets produced]	0.42		Assumed to also be representative for recycling in the Netherlands.
	Input of Tubiwash SKP at Veolia [kg/ton food-grade PET pellets produced]	0.27		Assumed to also be representative for recycling in the Netherlands.
T9	**Transport of PET bottles and crates from sorting to filing site**			
	Standard reusable bottles, share of number of total collected bottles, [%]	0.5L/1.5L PET: 30%	Calculated based on confidential data from Infinitum	NORSUS: Assume the same shares for large/small bottles. PET: 100-56-14 = 30%.

	Brand reusable bottles, share of number of total collected bottles, [%]	0.5L/1.5L PET: 56%	Calculated based on confidential data from Infinitum	Infinitum: 56% of total single-use PET bottles (different sizes), here translated into 56% of total number of reusable PET bottles (different sizes). Separate number of reuse should ideally have been considered for the brand bottles as the pool is smaller and must take into account seasonal variations, buffer capacity, change of standard type, etc. Due to too much complexity in the LCA model, this has not been possible. Instead, this has been analysed by a sensitivity analysis of reduced number of uses of the entire system.
	Water (still and sparkling) reusable bottles, share of number of total collected bottles, [%]	0.5L/1.5L PET: 14%	Calculated based on confidential data from Infinitum	Separate number of reuse should ideally have been considered for the brand bottles as the pool is smaller and must take into account seasonal variations, buffer capacity, change of standard type, etc. Due to too much complexity in the LCA model, this has not been possible. Instead, this has been analysed by a sensitivity analysis of reduced number of uses of the entire system.
	Share of total number of collected bottles that are collected per region [-]	North: 10% Mid: 14% West: 14% South: 14% East: 48%	Infinitum	NORSUS: These data include standard, brand, and water bottles. Assume this can be representative for standard bottles, specifically, In 2021.
	Transport distance by train per region, non-imported standard bottles (excluding PET water and brand bottles) [km]	North: 1544 km Mid: 480 km West: 520 km South: 430 km East: 290 km	Infinitum	One sorting plant in Oslo is assumed. It is furthermore assumed that the same transport distances and types for sorting to filling site (refilling) can be applied as from collection hubs to central sorting.
	Transport distance by truck per region, non-imported standard bottles (excluding PET water and brand bottles) [km]	North: 240 km Mid: 109 km West: 353 km South: 67 km East: 82 km	Infinitum	
	Average distance, **non-imported standard bottles** [km]	494 by train 138 by truck	Infinitum	**Non-imported standard bottles** These distances are calculated based on data for the number of bottles collected per five regions (north, mid, west, south, east) in Norway in 2021. The distances are calculated based on data representing production sites for brand bottles producers. The distances take int account the average share of the bottles of the total volume. Can be calculated directly as the "Norwegian distances".
	Average distance **non-imported PET water bottles with water** [km]	545 by train 261 by truck	Infinitum	**Non-imported water bottles** The distances are calculated based on data on distances (and transport types) for the largest water producers (filling sites) provided from infinitum. The distances take int account the average share of the bottles of the total volume. Can be calculated directly as the "Norwegian distances".
	Average distance **non-imported brand PET bottles** [km]	507 km by train 156 by truck	Infinitum	**Non-imported brand bottles (PET)** The data are calculated based on data on distances (and transport types) for the largest brand bottles producers (filling sites) provided from infinitum**.** The distances take int account the average share of the bottles of the total volume. Can be calculated directly as the "Norwegian distances".

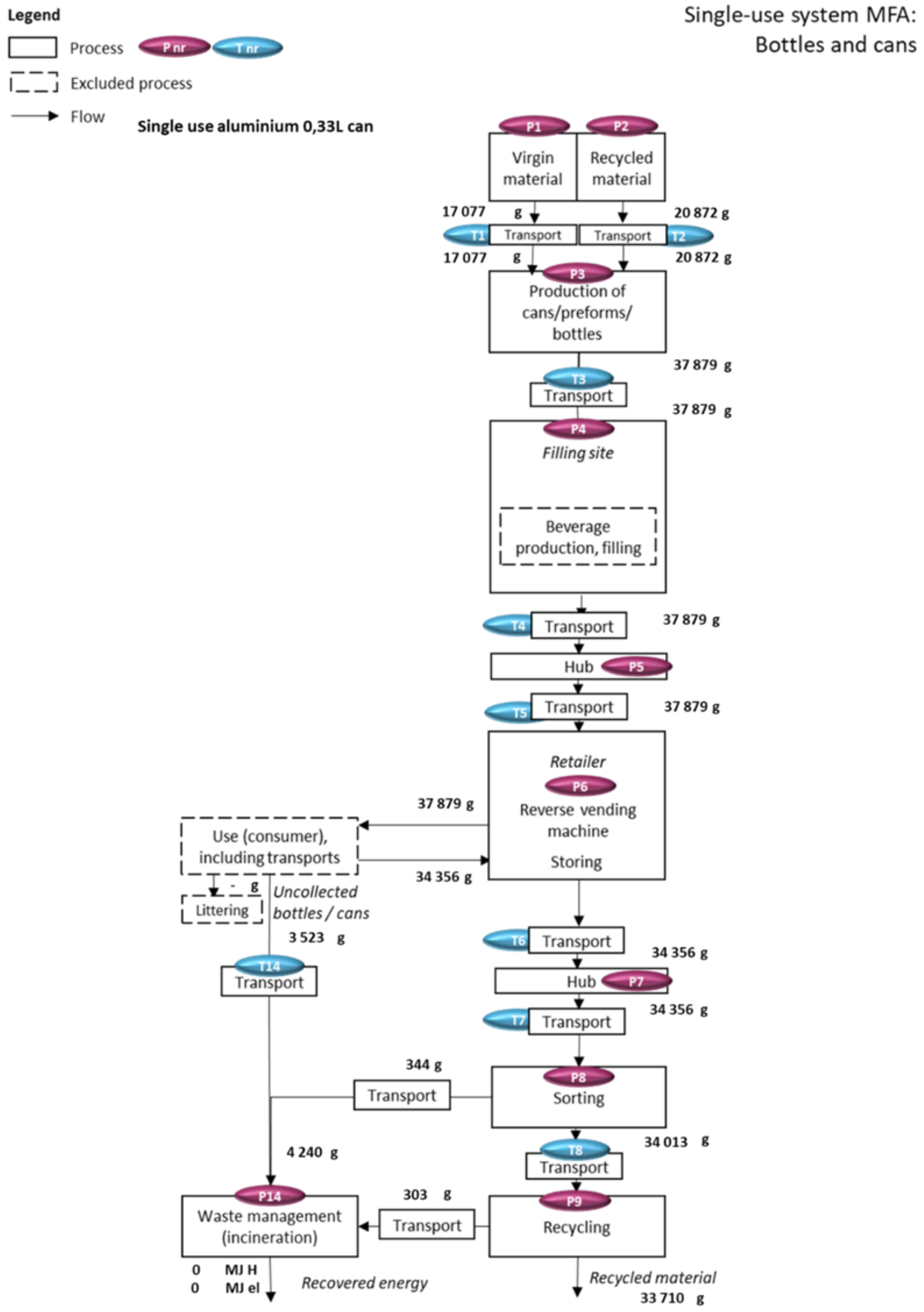
	Reduced transport efficiency due to imbalance of bottles/crates delivery and pick-up		Infinitum	The transport load must take into account that empty crates (volume based) must be included in the transport due to imbalance of bottles/crates delivery. It is assumed that 60% of the stores are of the smaller type and that these have a 20% lower volume of collection relative sales. Hence, 60% * 20% = 12% extra crates is assumed to be included in this transport. This has been adjusted for by lower transport efficiency.
	Import from Sweden of total collected bottles [%]	10	Infinitum	
	Import from Denmark of total collected bottles [%]	2.5%	Infinitum	
	Transport distance, imported bottles, Sweden [km]	Train: 450 Truck: 50	Infinitum	Same distance as T4.
	Transport distance, imported bottles, Denmark [km]	Train: 700 km Truck: 50 km	Infinitum	
	Pallets per truck [-]	18		Trucks will typically be of 10 ton capacity, and hold 18 pallets, for such long-haul. If on rail, capacity per container is typically 20 pallets. To/from rail terminal (if close enough) is typically with container-truck i.e. also 20 pallets.
P10	**Production of distribution packaging (crates)**			
	Crate production (PP) [kg/crate]	1.450	Email from Pasi Nurminen (16.11.22)	For 24x0,33l crate for glass bottles. Assume that all crates have the same weight (but the number of bottles depend on the bottle size)
	Weight of crates [kg/kg carrying capacity]	0.12	Tua et al. (2019), assumption by the authors	Data on reusable crates used for food were applied as a proxy for reusable crates for reusable bottles. The reusable polypropylene (PP) crates studied by Tua et al. (2019) weighted 1.49 kg and had a carrying capacity at 12 kg. New crates are assumed by the authors to be produced in the country where the bottle production takes place (i.e. in Sweden for glass bottles) with an average distance to the production site at 500 km by truck. The reconditioning of crates (background system) were modelled in line with Tua et al. (2019). The recycled content of the crates was assumed to be 0 weight-%. These crates are used between the production site via the filling site to retailer, from collection site (at retailer) to sorting and back to filling site / washing and then back to the production site.
	Number of uses for crates [-]	40	Zampori and Pant (2019), UNESDA (2022)	According to Zampori and Pant (2019), crates can be reused about 30 times based on a technical approximation for plastic crates made by the reference based on technical specifications (guaranteed lifetime of 10 years) and a return of three times per year. According to UNESDA (2022) (representing the European soft drinks industry), crates can be reused up to about 50 times. The value in the middle of this range (30-50) was applied for this study.
T10	**Transport of distribution packaging (crates) to PET bottle production**			
	No data included			
P11	**Production of distribution packaging**			
	See P10			
T11	**Transport of distribution packaging to filling site**			
	No data included			

P12	**Production of distribution packaging**			
	Not relevant			
T12	**Transport of distribution packaging to retailer**			
	Not relevant			
P14	**Waste management of uncollected PET bottles from consumer**			
	Incineration of uncollected bottles and crates		ecoinvent	
T14	**Transport of uncollected PET bottles from consumer to waste management**			
	Transport with residual waste from consumer's home to incineration plant, by truck [km]	73	Raadal et al. (2016)	

Appendix 3 MFA flow charts for bottles/cans (distribution and collection packaging excluded)

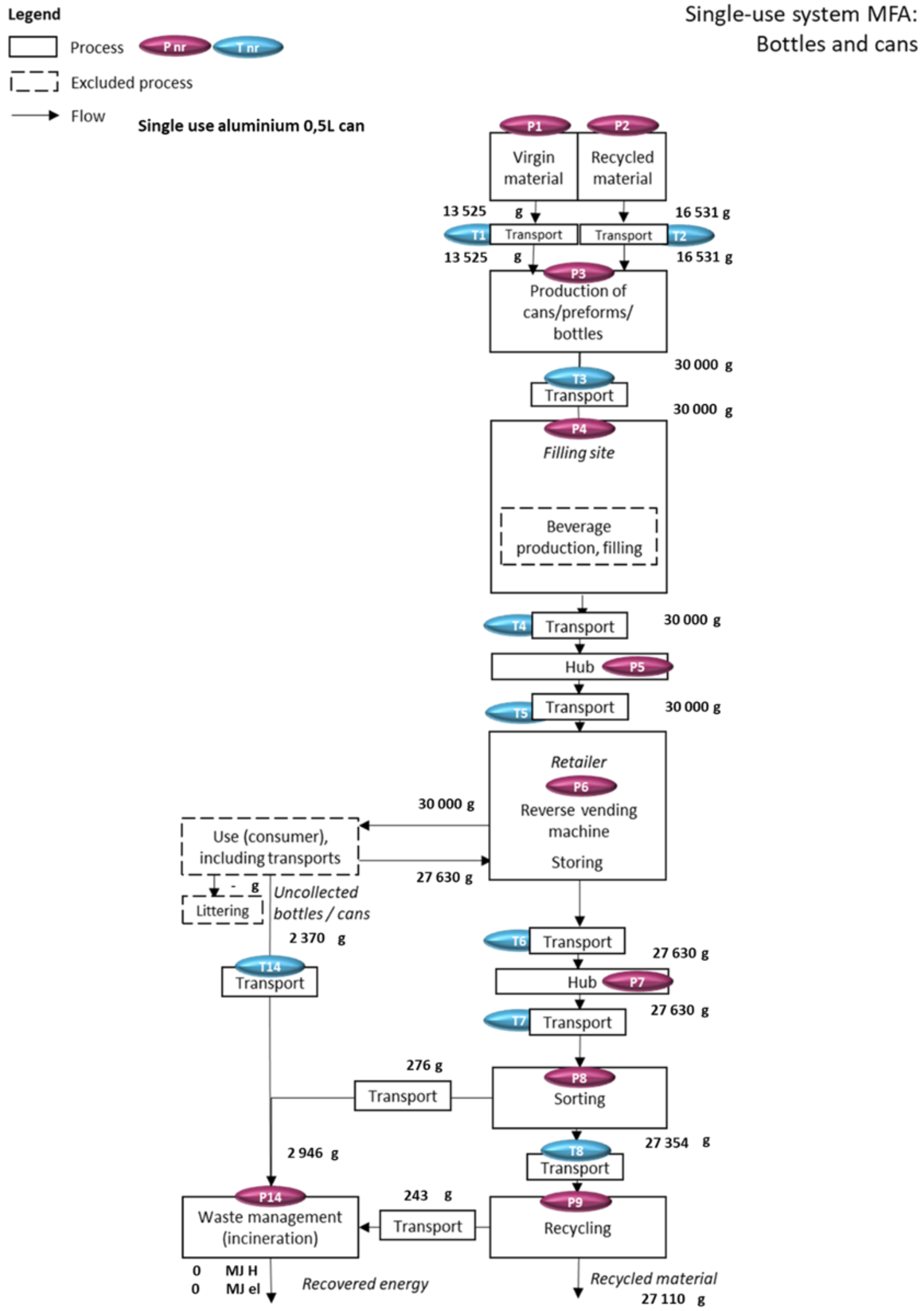
Single-use aluminium can: 0.33L

Flows of beverage material [g] throughout the value chain per FU (distributing 1000 litres of beverage to Norwegian consumers)



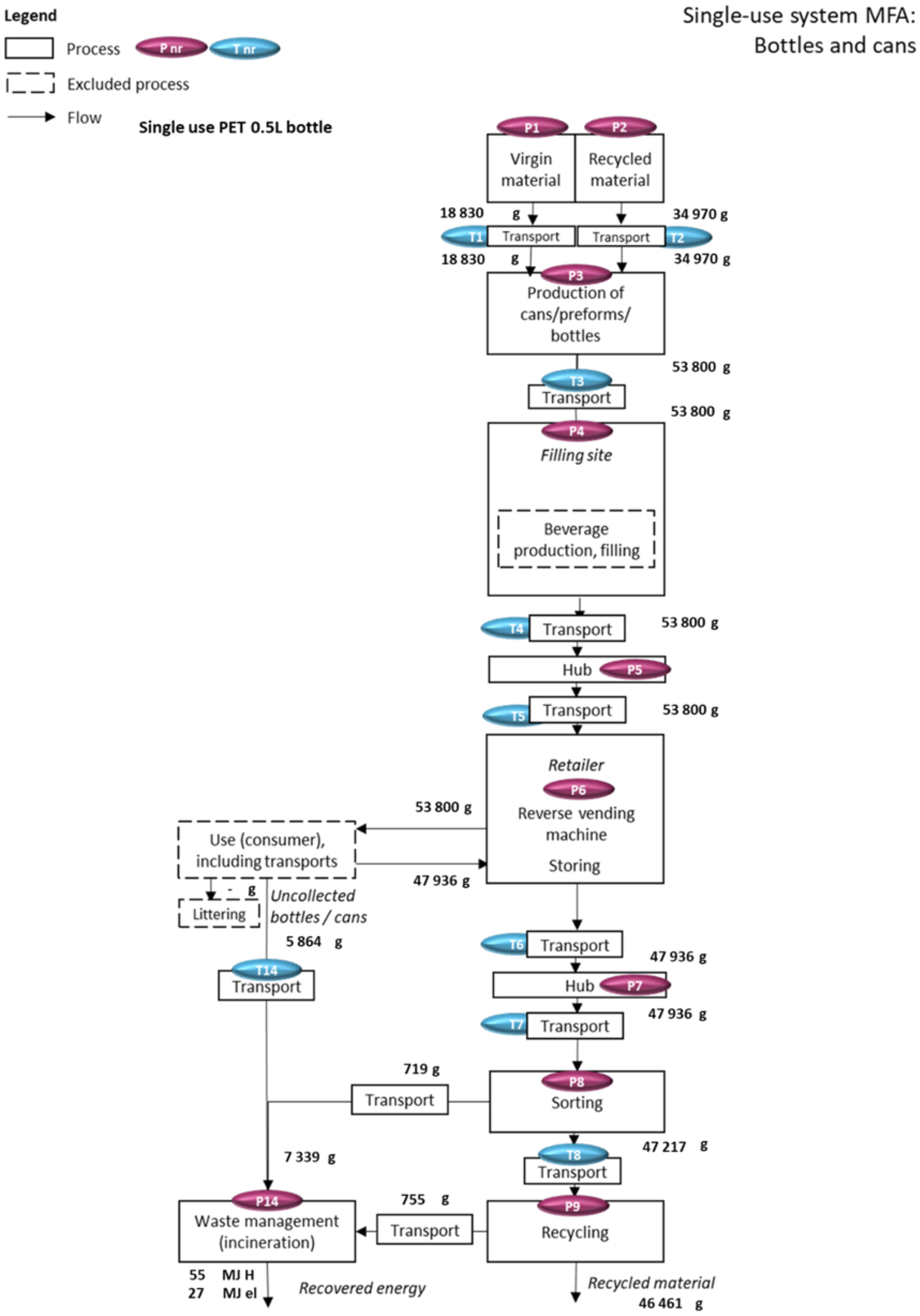
Single-use aluminium can: 0.5L

Flows of beverage material [g] throughout the value chain per FU (distributing 1000 litres of beverage to Norwegian consumers)



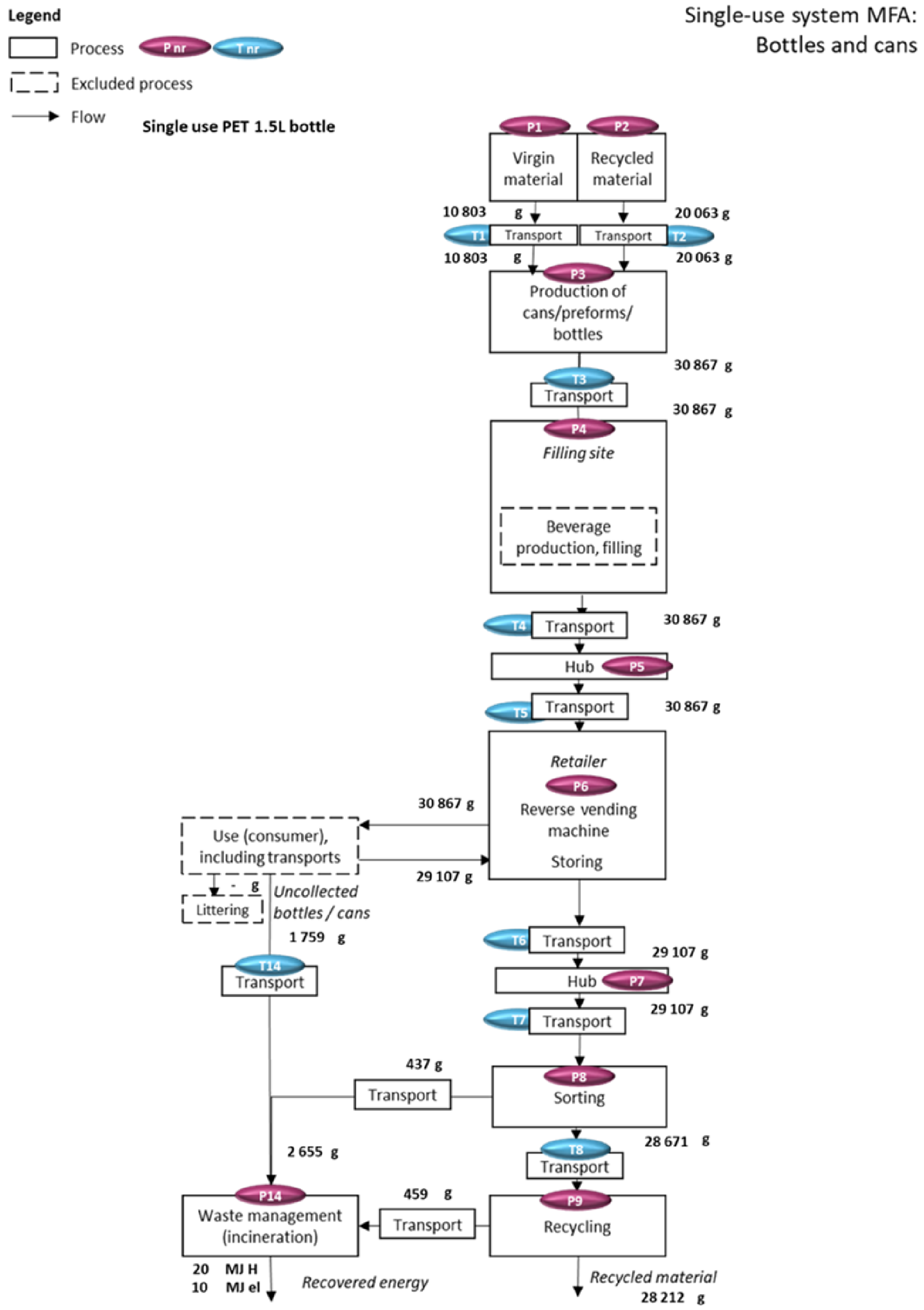
Single-use PET bottle: 0.5L

Flows of beverage material [g] throughout the value chain per FU (distributing 1000 litres of beverage to Norwegian consumers)



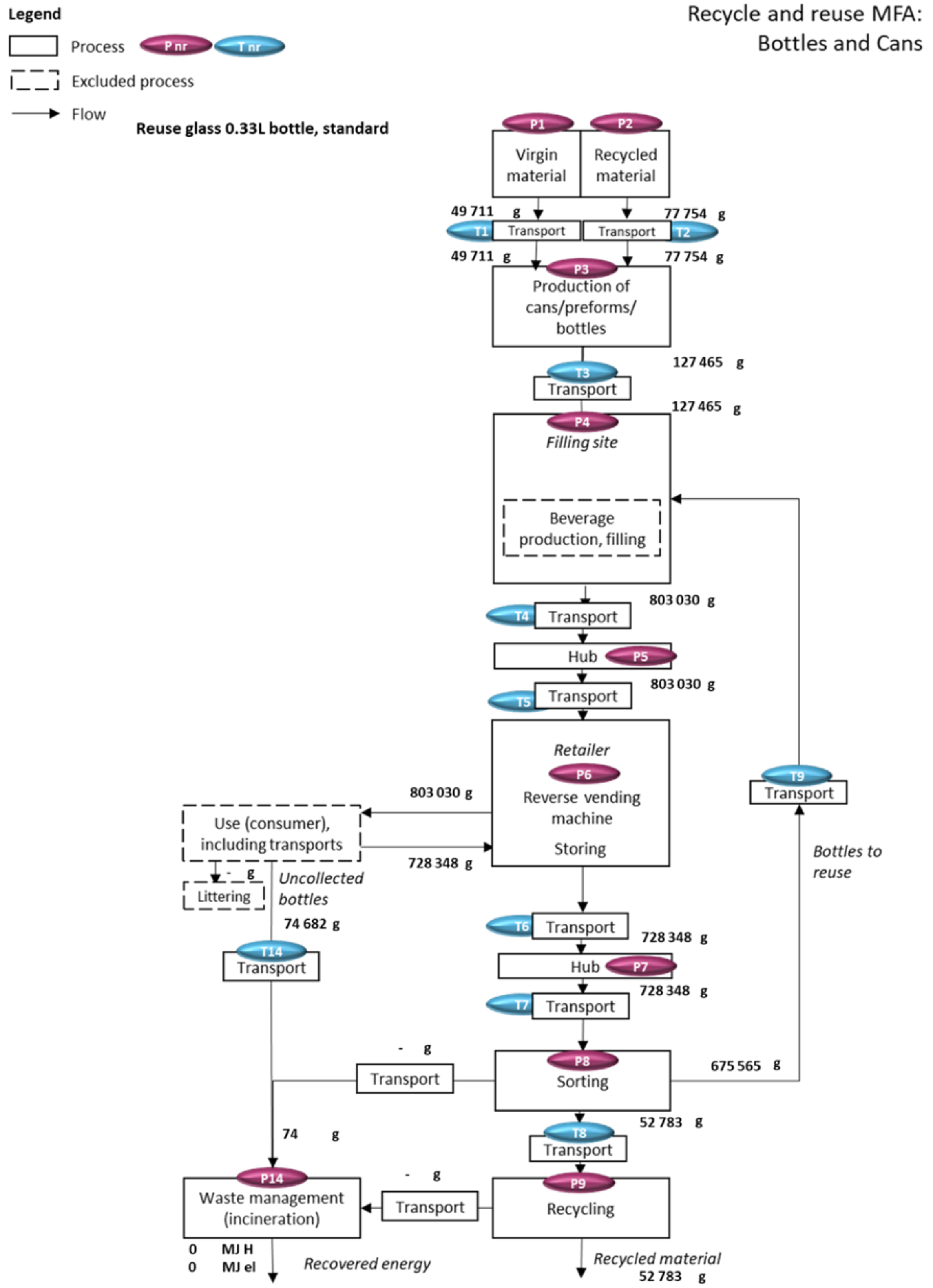
Single-use PET bottle: 1.5L

Flows of beverage material [g] throughout the value chain per FU (distributing 1000 litres of beverage to Norwegian consumers)



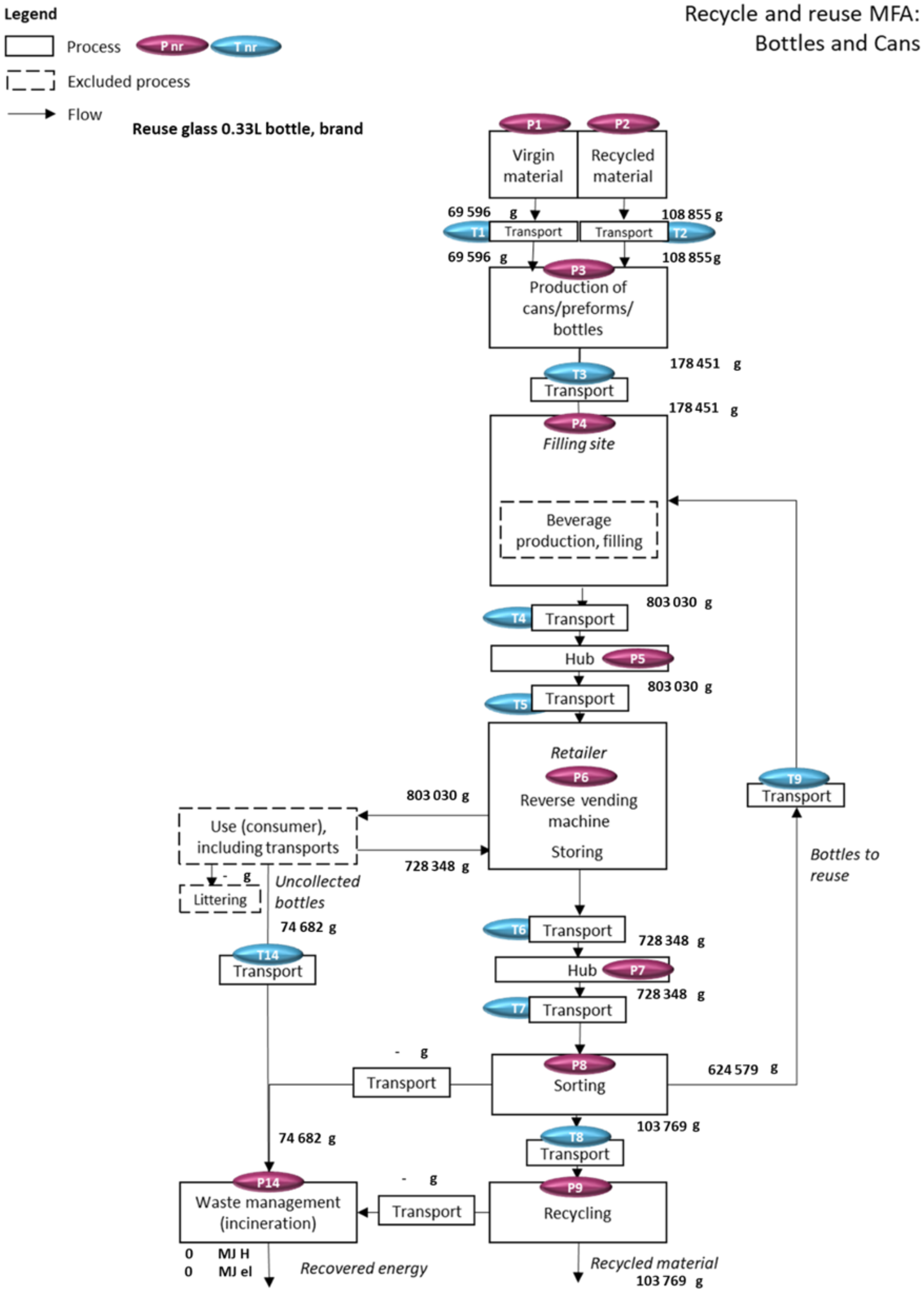
Reuse glass bottle: 0.33L standard

Flows of beverage material [g] throughout the value chain per FU (distributing 1000 litres of beverage to Norwegian consumers)



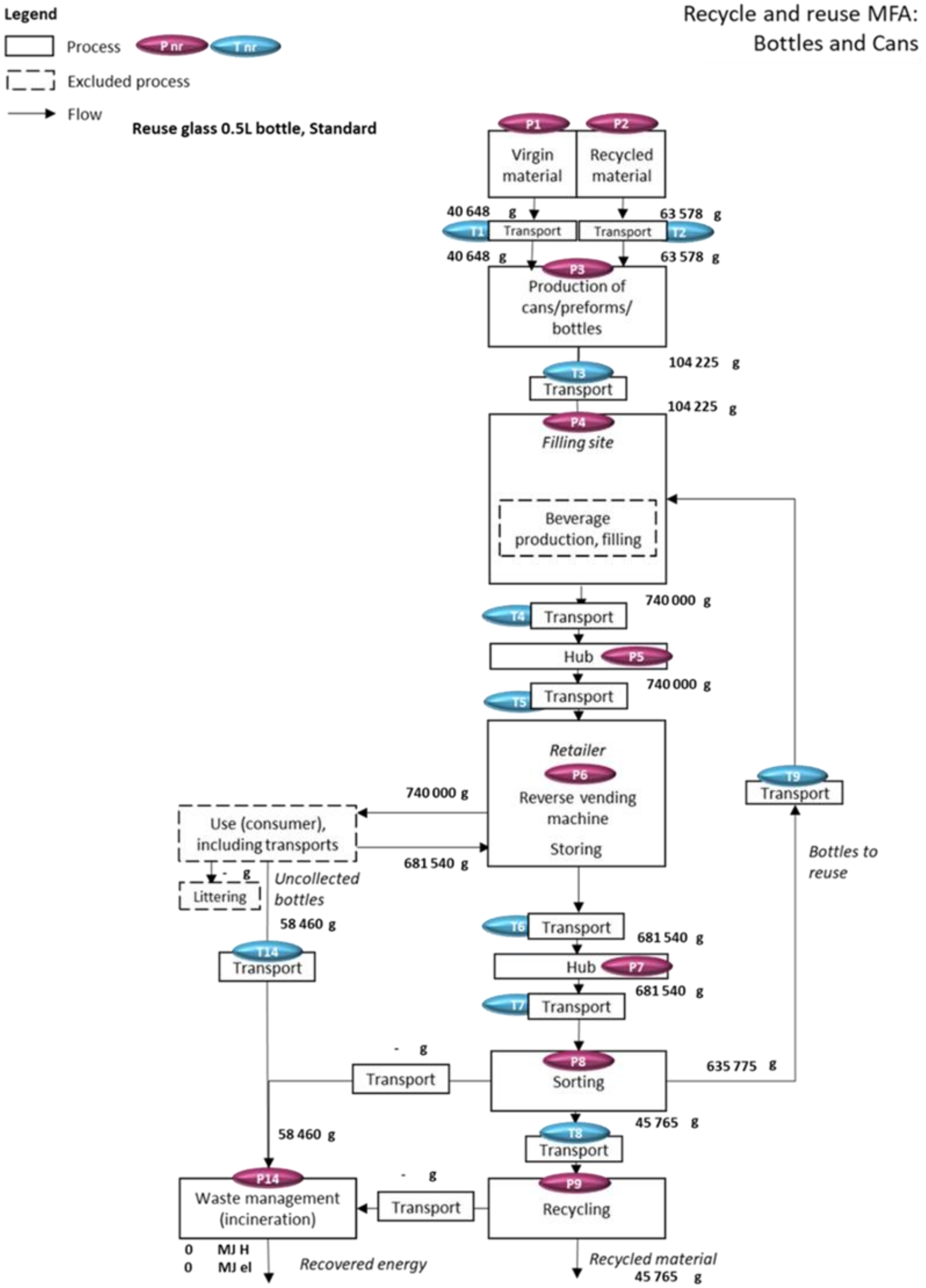
Reuse glass bottle: 0.33L brand

Flows of beverage material [g] throughout the value chain per FU (distributing 1000 litres of beverage to Norwegian consumers)



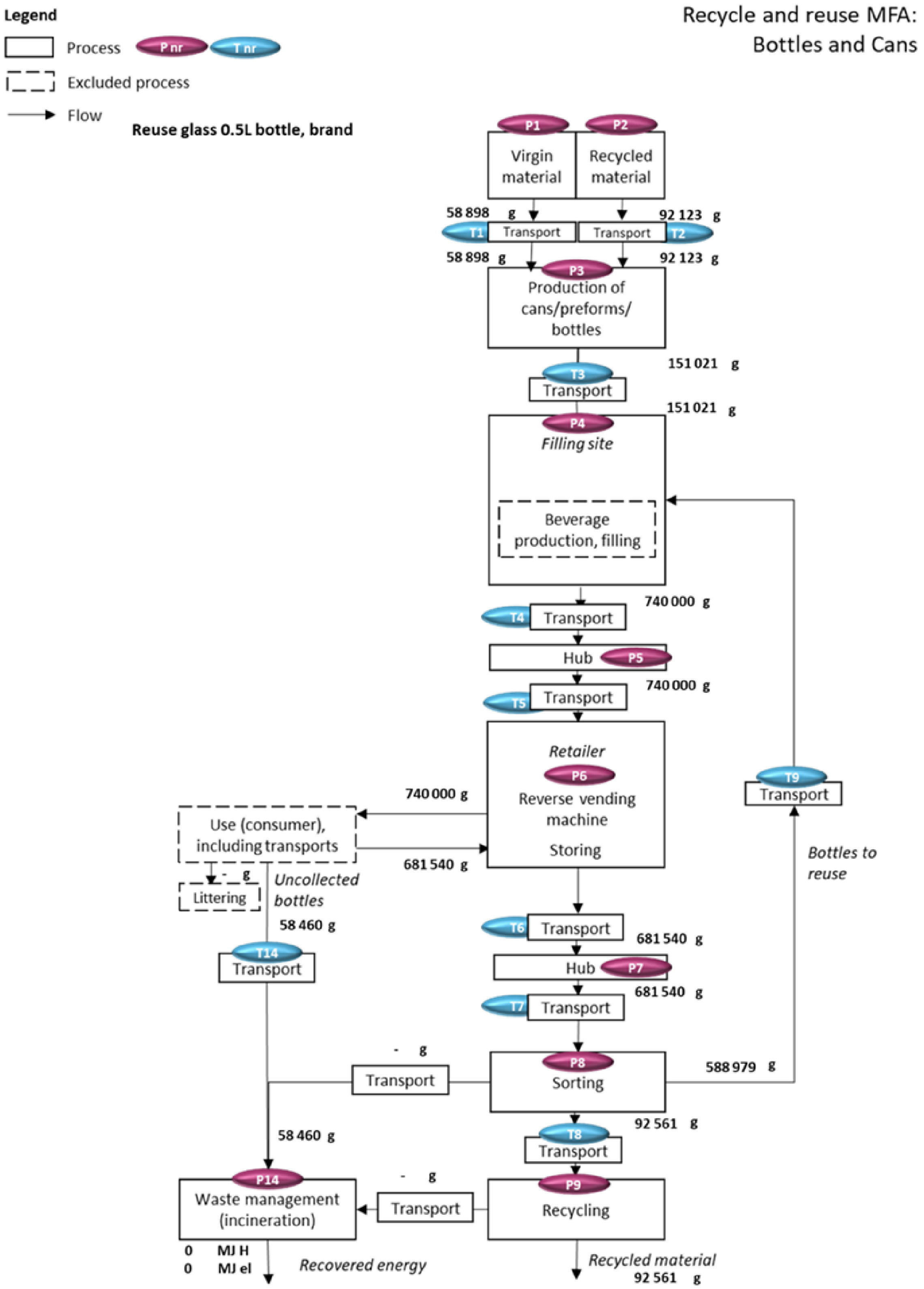
Reuse glass bottle: 0.5L standard

Flows of beverage material [g] throughout the value chain per FU (distributing 1000 litres of beverage to Norwegian consumers)



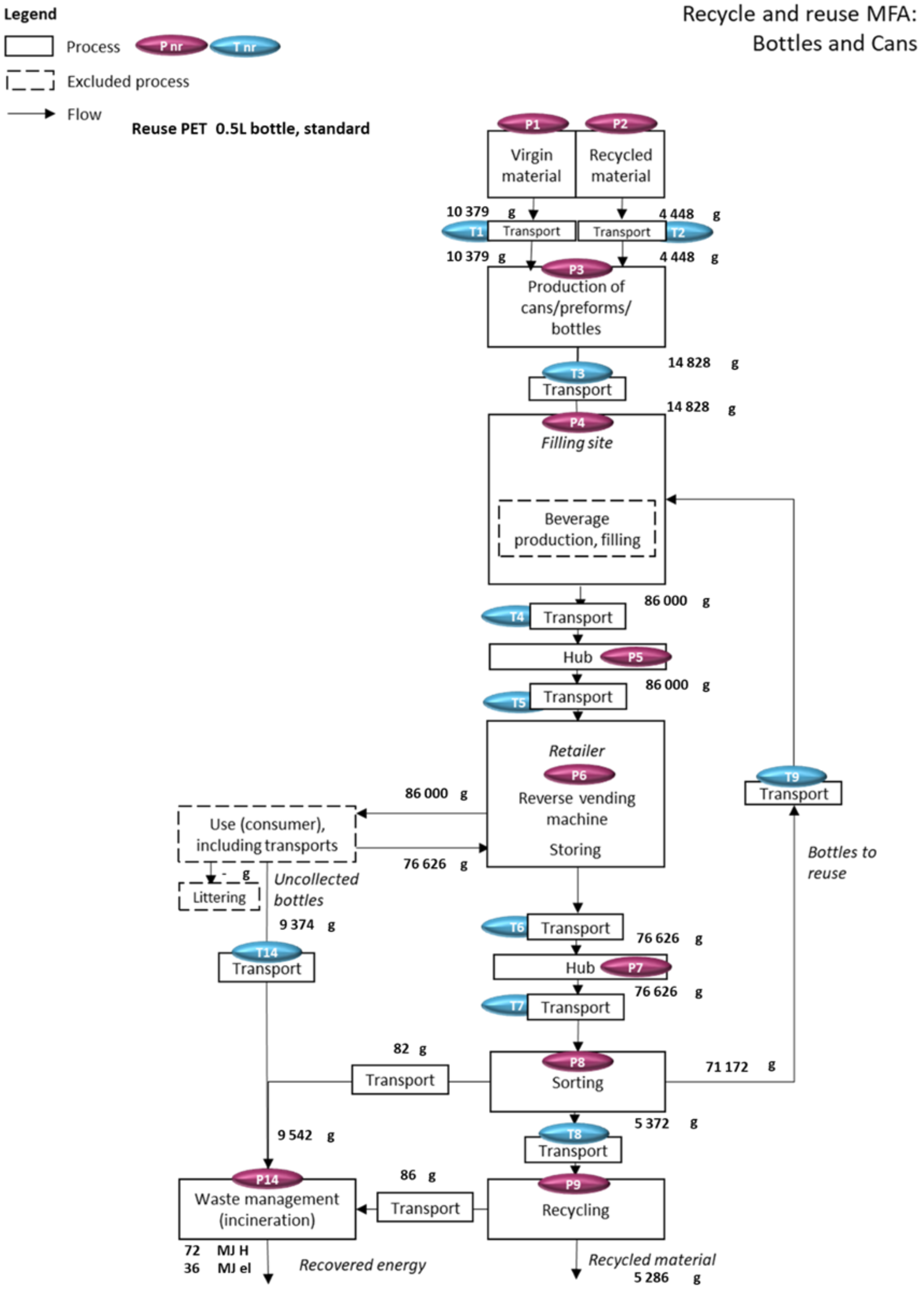
Reuse glass bottle: 0.5L brand

Flows of beverage material [g] throughout the value chain per FU (distributing 1000 litres of beverage to Norwegian consumers)



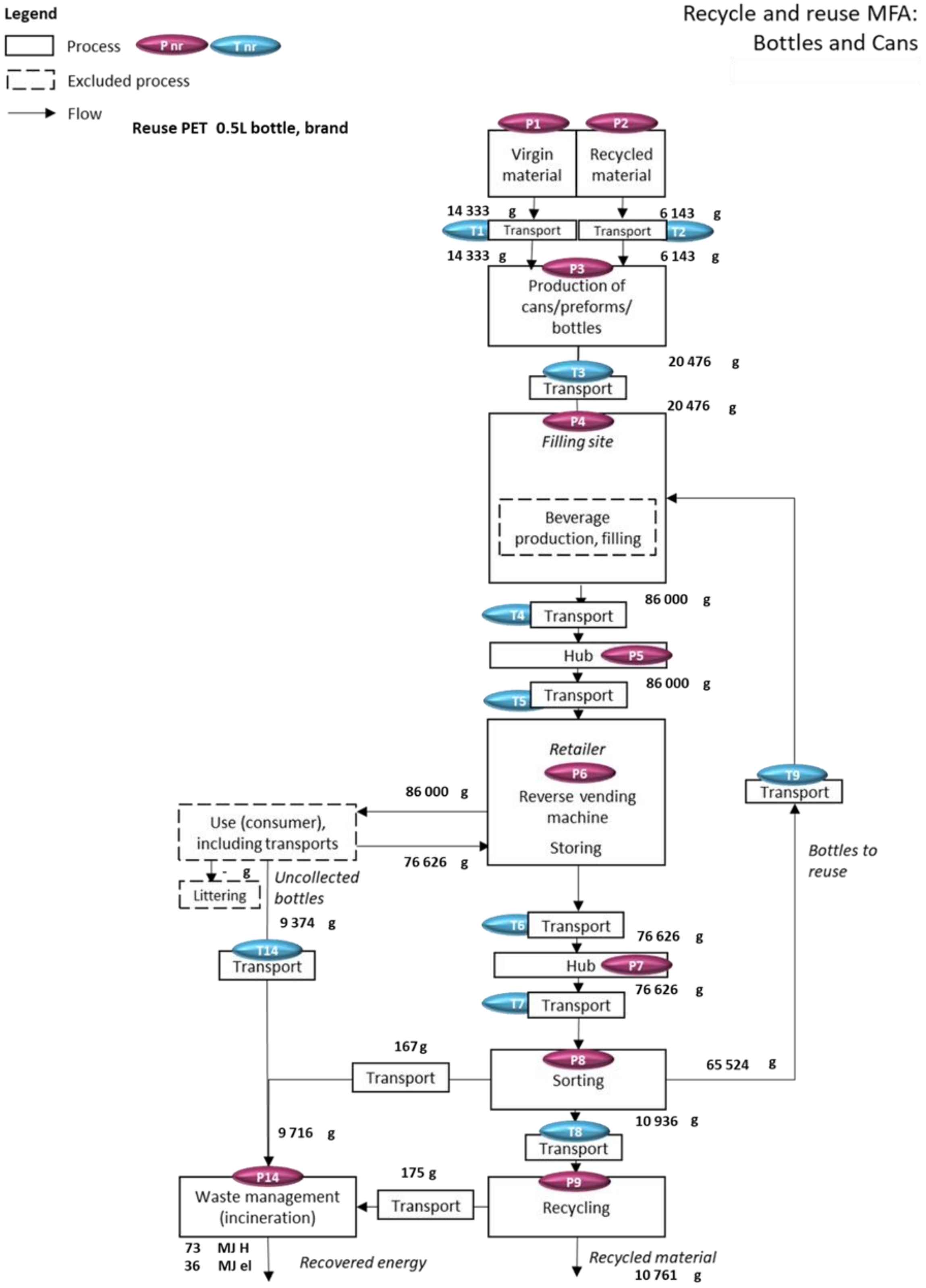
Reuse PET bottle: 0.5L standard

Flows of beverage material [g] throughout the value chain per FU (distributing 1000 litres of beverage to Norwegian consumers)



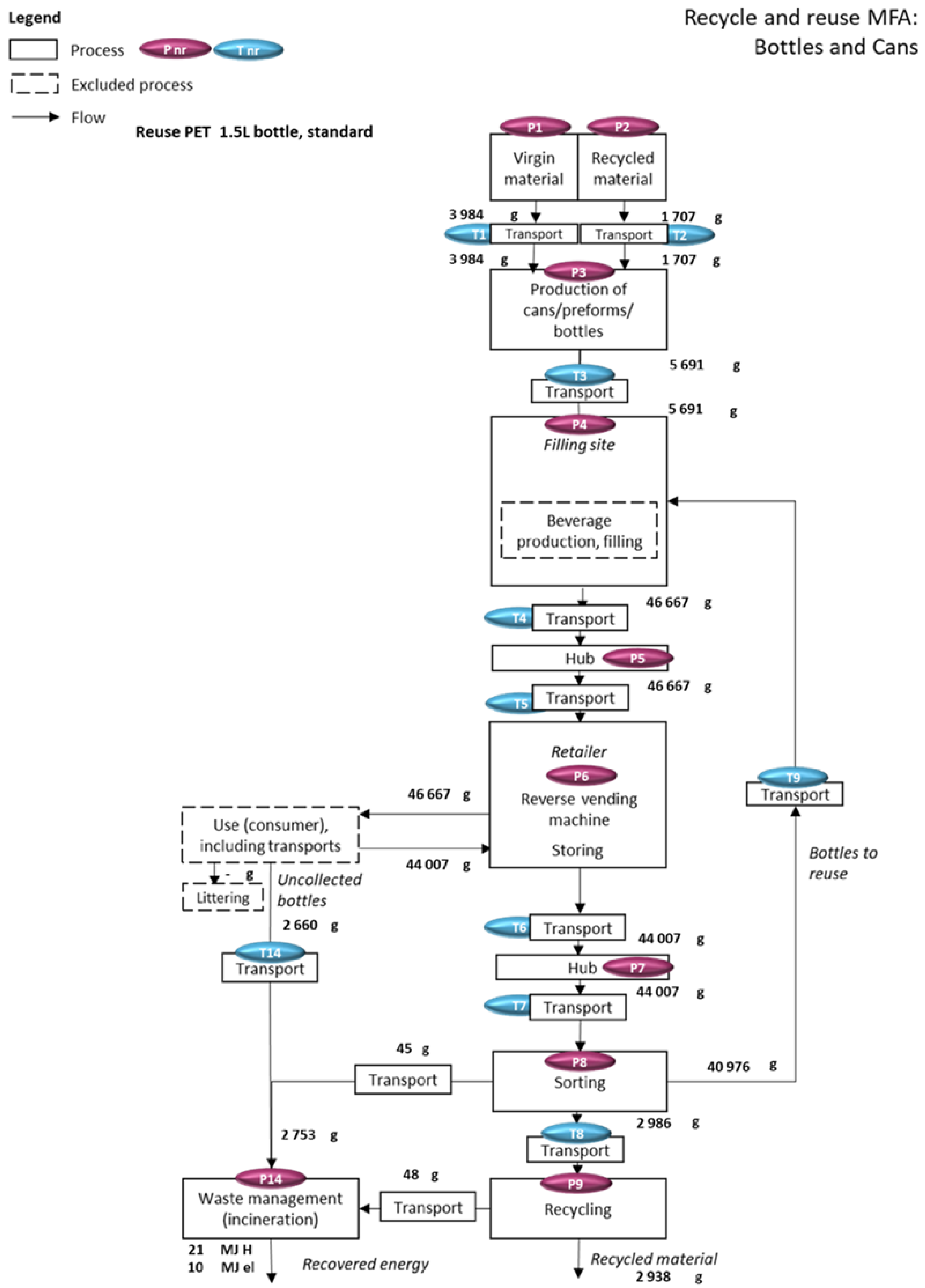
Reuse PET bottle: 0.5L brand

Flows of beverage material [g] throughout the value chain per FU (distributing 1000 litres of beverage to Norwegian consumers)



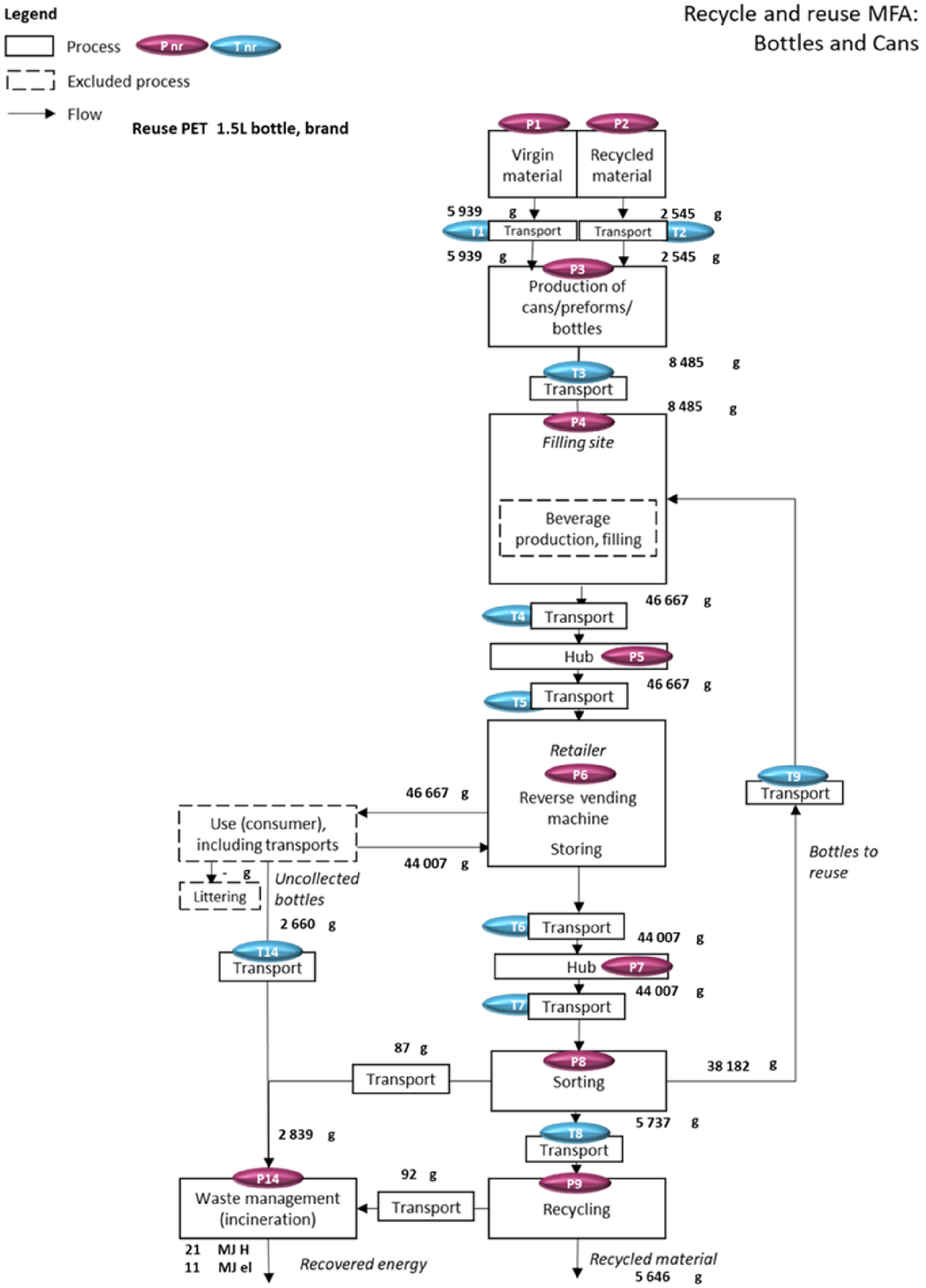
Reuse PET bottle: 1.5L standard

Flows of beverage material [g] throughout the value chain per FU (distributing 1000 litres of beverage to Norwegian consumers)



Reuse PET bottle: 1.5L brand

Flows of beverage material [g] throughout the value chain per FU (distributing 1000 litres of beverage to Norwegian consumers)



Appendix 4 Transport modelling

Transport and logistics are an integral part of reuse and recycling systems. The variation in transport, mainly vehicle size and capacity utilization, are therefore important activities for an LCA of reuse systems. Appendix 2 presents data on data on transport distances and means of transport. In addition, data was collected regarding vehicle capacities, loads per pallets and pallets per vehicle, as they have a significant impact on the emission profile of specific transport laps. In this study, the capacity utilization of the road transport laps T3, T6, T7 and T9 are modelled with specific vehicle sizes, vehicle capacities and a specific load for primary, secondary, and tertiary packaging. The definition of packaging follows the standard (CEN/TR 14182).

The life cycle inventory (LCI) modelling of capacity adjusted transport is done by defining the load capacity of a vehicle, the load of goods and the weight of returned goods. Three vehicle sizes are adapted from the ecoinvent 3.9.1 library:

- 3.5t lorry (T7 single use PET bottles and Aluminum cans)
- 10t lorry (T6, T7 and T9)
- 29t load capacity (T1, T2, T3, T4 and T5).

Capacity utilization is estimated by dividing the total mass load of the goods (both trip and return-trip), with the total capacity (equation 4.1).

Equation 4.1

$$CU_i = \frac{(M_{i,t} + M_{i,r})}{(C_{i,t} + C_{i,r})}$$

$CU_{,i}$ is the capacity utilization (CU) of vehicle type (i), $M_{i,t}$ is the Mass load in vehicle type (i) for the trip lap (t) whereas $M_{i,r}$ is the mass load in vehicle type (i) for the return-trip lap (r). $C_{i,t}$ is the Capacity in payload (C) for vehicle type i for the trip lap and $C_{i,r}$ is the capacity in payload (C) for vehicle type (i) return-trip (r).

The capacity utilization is used to estimate the total distance a vehicle has to drive to fulfill the freight of a 100% loaded vehicle. The total distance a vehicle drives to fulfill the freight of 100% load is labeled as vehicle kilometer (vkm), equation 4.2.

Equation 4.2

$$vkm_i = \frac{1}{(CU_i)}$$

$vkm_{,i}$ is vehicle kilometer as in the physical distance the vehicle drives for vehicle type (i) and $CU_{,i}$ is the capacity utilization (CU) of vehicle type (i).

The vkm is used to estimate the total fuel consumption per ton kilometer (tkm), which is the declared unit for transport. The tkm represent the total freighted tonnage and total distance driven for the goods in question. An example of this is presented in equation 4.3. All transport inventories (lorry production, road production, fossil and biofuel production, etc., are similarly estimated per vkm and multiplied with each's inventory individual CO_2-eq profile per a defined unit.

Equation 4.3: Direct emission profile estimation for CO_2 emissions from road transport.

$$E_{tkm,e,i} = \left(\frac{E_{f,e}}{L_f}\right) * L_{f,km,i} * \frac{vkm_i}{tkm_i}$$

$E_{tkm,e}$ is the emissions factor (E) associated to the transport of a mass of goods over a given distance (tkm) for impact category (e) in vehicle type (i). $E_{f,e}$ is the emission profile (E) of fuel type (f) for impact category (e). L_f is the quantity in liter (L) of fuel type (f). $L_{f,km,i}$ represent the fuel consumption (L) of fuel type (f), per distance driven (km) for vehicle type (i). $vkm_{,i}$ is vehicle kilometer as in the physical distance the vehicle drives for vehicle type (i). $tkm_{,I}$ is the the transport of a mass of goods over a given distance for vehicle type (i).

Equation 4.3 prerequisites that the fuel consumption per vkm is known. The fuel consumption can be estimated based on the empty vehicle fuel consumption, the full vehicle fuel consumption (in mass) and the load factor of the transport lap. See equation 4.4 which is derived from Ecotransit 2023, figure 13.

Equation 4.4 Estimating fuel consumption per km

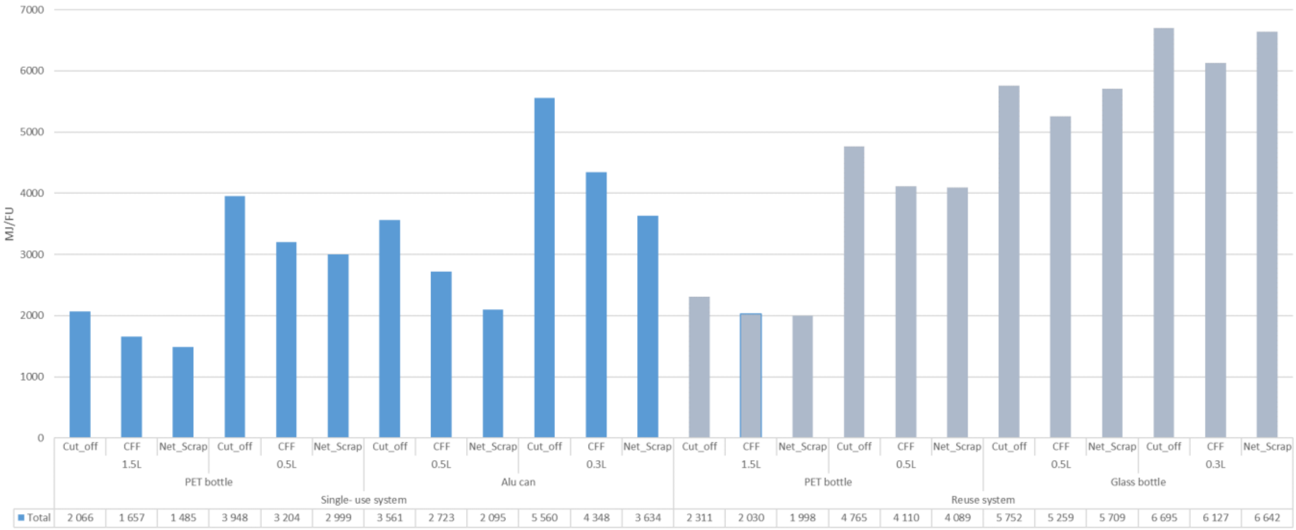
$$L_{f,km,i} = \left(L_{f,km,i,100\%} - L_{f,km,i,0\%}\right) * CU_i + L_{f,km,i,0\%}$$

Lf,km,i represent the fuel consumption (L) of fuel type (f), per distance driven (km) for vehicle type (i). Lf,km,i 100% represents the fuel consumption (L) of fuel type (f) when vehicle type (i) is fully loaded based on weight capacity. Lf,km,i 0%, represents the fuel consumption (L) of fuel type (f) when vehicle type (i) is driving with no load. CU,i is the capacity utilization (CU) of vehicle type (i).

For each transport lap and beverage type, the required data were assembled. A D-pak factor (secondary and tertiary packaging) has been estimated as a weight increase factor of the primary packaging when loaded in the lorry and multiplied with the weight of bottles or cans.

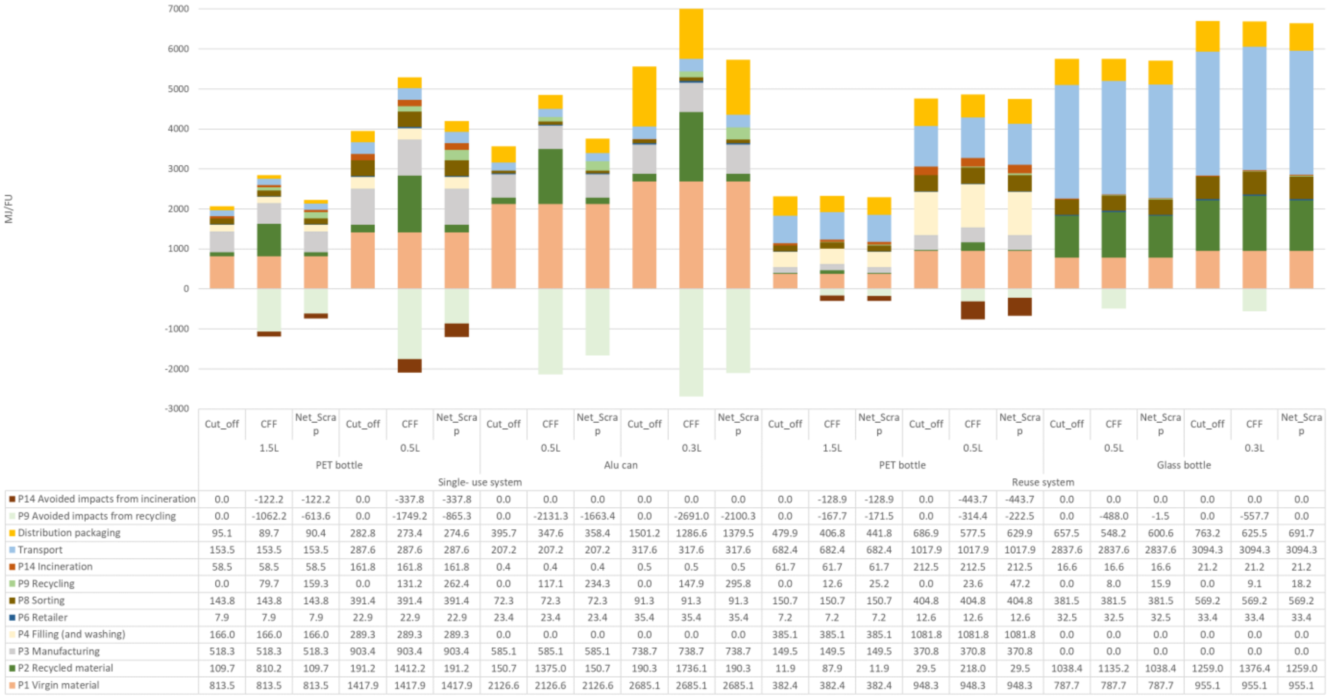
Appendix 5 Extra LCA results CED, acidification and mineral resource scarcity

CED (cumulative energy demand): results per bottle/can type and size



	Single- use system												Reuse system											
	PET bottle						Alu can						PET bottle						Glass bottle					
	1.5L			0.5L			0.5L			0.3L			1.5L			0.5L			0.5L			0.3L		
	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap
■ Total	2 066	1 657	1 485	3 948	3 204	2 999	3 561	2 723	2 095	5 560	4 348	3 634	2 311	2 030	1 998	4 765	4 110	4 089	5 752	5 259	5 709	6 695	6 127	6 642

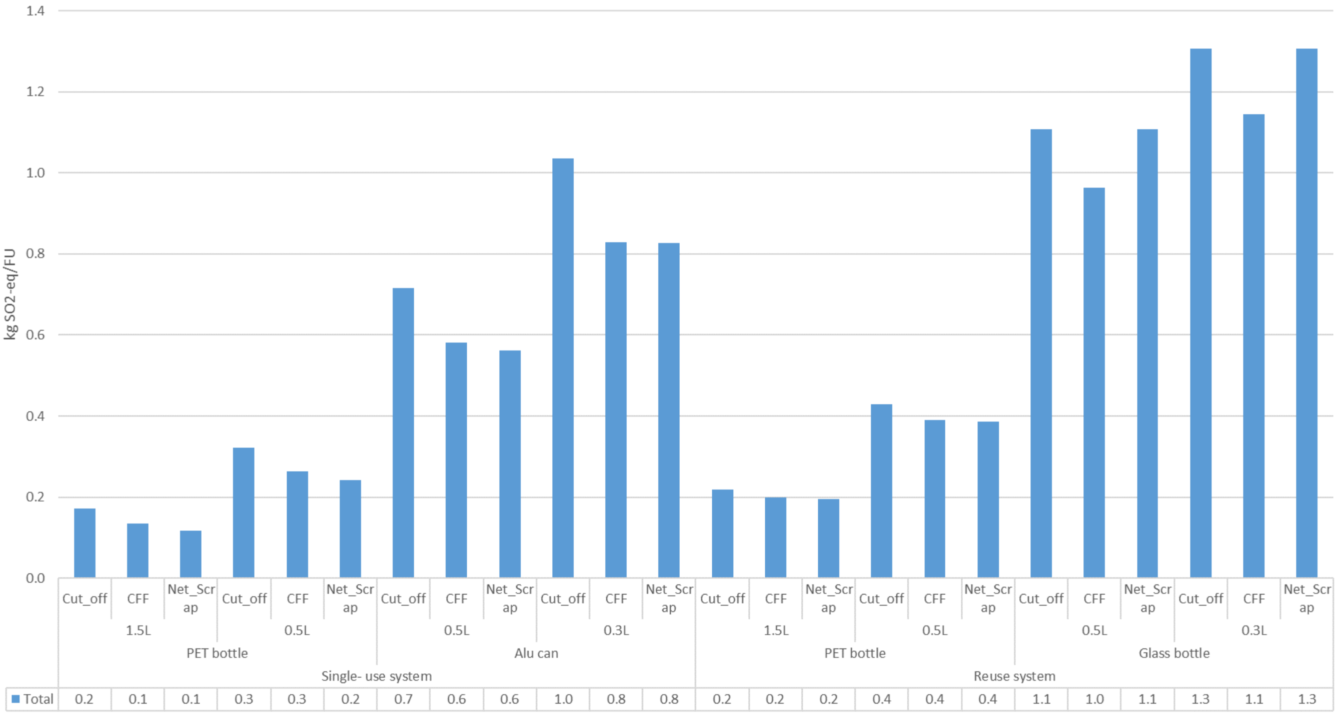
Figure A5.1 Net CED [MJ per 1000 l beverage distributed] for the specific bottles/cans in respective single-use and reuse systems, presented for the three different modelling approaches.



	Single- use system												Reuse system											
	PET bottle						Alu can						PET bottle						Glass bottle					
	1.5L			0.5L			0.5L			0.3L			1.5L			0.5L			0.5L			0.3L		
	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap
■ P14 Avoided impacts from incineration	0.0	-122.2	-122.2	0.0	-337.8	-337.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-128.9	-128.9	0.0	-443.7	-443.7	0.0	0.0	0.0	0.0	0.0	0.0
■ P9 Avoided impacts from recycling	0.0	-1062.2	-613.6	0.0	-1749.2	-865.3	0.0	-2131.3	-1663.4	0.0	-2691.0	-2100.3	0.0	-167.7	-171.5	0.0	-314.4	-222.5	0.0	-488.0	-1.5	0.0	-557.7	0.0
■ Distribution packaging	95.1	89.7	90.4	282.8	273.4	274.6	395.7	347.6	358.4	1501.2	1286.6	1379.5	479.9	406.8	441.8	686.9	577.5	629.9	657.5	548.2	600.6	763.2	625.5	691.7
■ Transport	153.5	153.5	153.5	287.6	287.6	287.6	207.2	207.2	207.2	317.6	317.6	317.6	682.4	682.4	682.4	1017.9	1017.9	1017.9	2837.6	2837.6	2837.6	3094.3	3094.3	3094.3
■ P14 Incineration	58.5	58.5	58.5	161.8	161.8	161.8	0.4	0.4	0.4	0.5	0.5	0.5	61.7	61.7	61.7	212.5	212.5	212.5	16.6	16.6	16.6	21.2	21.2	21.2
■ P9 Recycling	0.0	79.7	159.3	0.0	131.2	262.4	0.0	117.1	234.3	0.0	147.9	295.8	0.0	12.6	25.2	0.0	23.6	47.2	0.0	8.0	15.9	0.0	9.1	18.2
■ P8 Sorting	143.8	143.8	143.8	391.4	391.4	391.4	72.3	72.3	72.3	91.3	91.3	91.3	150.7	150.7	150.7	404.8	404.8	404.8	381.5	381.5	381.5	569.2	569.2	569.2
■ P6 Retailer	7.9	7.9	7.9	22.9	22.9	22.9	23.4	23.4	23.4	35.4	35.4	35.4	7.2	7.2	7.2	12.6	12.6	12.6	32.5	32.5	32.5	33.4	33.4	33.4
■ P4 Filling (and washing)	166.0	166.0	166.0	289.3	289.3	289.3	0.0	0.0	0.0	0.0	0.0	0.0	385.1	385.1	385.1	1081.8	1081.8	1081.8	0.0	0.0	0.0	0.0	0.0	0.0
■ P3 Manufacturing	518.3	518.3	518.3	903.4	903.4	903.4	585.1	585.1	585.1	738.7	738.7	738.7	149.5	149.5	149.5	370.8	370.8	370.8	0.0	0.0	0.0	0.0	0.0	0.0
■ P2 Recycled material	109.7	810.2	109.7	191.2	1412.2	191.2	150.7	1375.0	150.7	190.3	1736.1	190.3	11.9	87.9	11.9	29.5	218.0	29.5	1038.4	1135.2	1038.4	1259.0	1376.4	1259.0
■ P1 Virgin material	813.5	813.5	813.5	1417.9	1417.9	1417.9	2126.6	2126.6	2126.6	2685.1	2685.1	2685.1	382.4	382.4	382.4	948.3	948.3	948.3	787.7	787.7	787.7	955.1	955.1	955.1

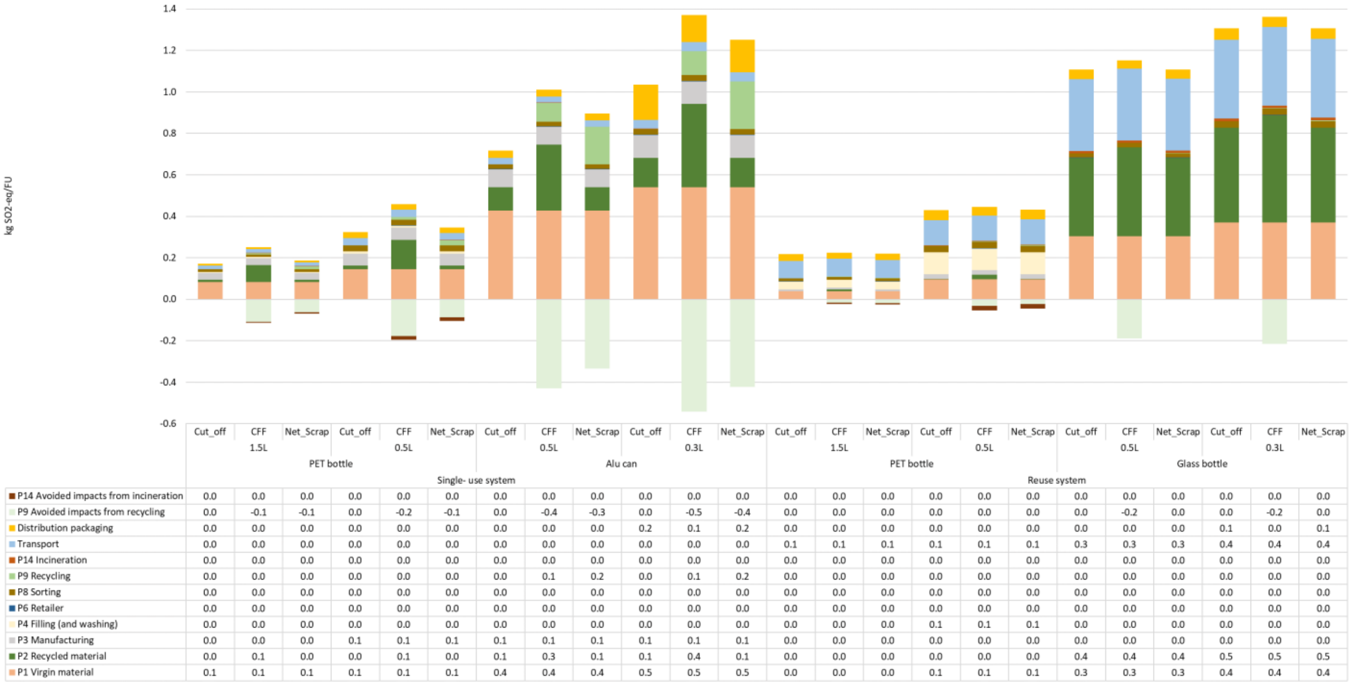
Figure A5.2 CED [MJ per 1000 l beverage distributed] separated into the major life cycle activities for the respective single-use and reuse bottle/can systems, presented for the three different modelling approaches.

Terrestrial acidification: results per bottle/can type and size



	Single- use system												Reuse system											
	PET bottle						Alu can						PET bottle						Glass bottle					
	1.5L			0.5L			0.5L			0.3L			1.5L			0.5L			0.5L			0.3L		
	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap
■ Total	0.2	0.1	0.1	0.3	0.3	0.2	0.7	0.6	0.6	1.0	0.8	0.8	0.2	0.2	0.2	0.4	0.4	0.4	1.1	1.0	1.1	1.3	1.1	1.3

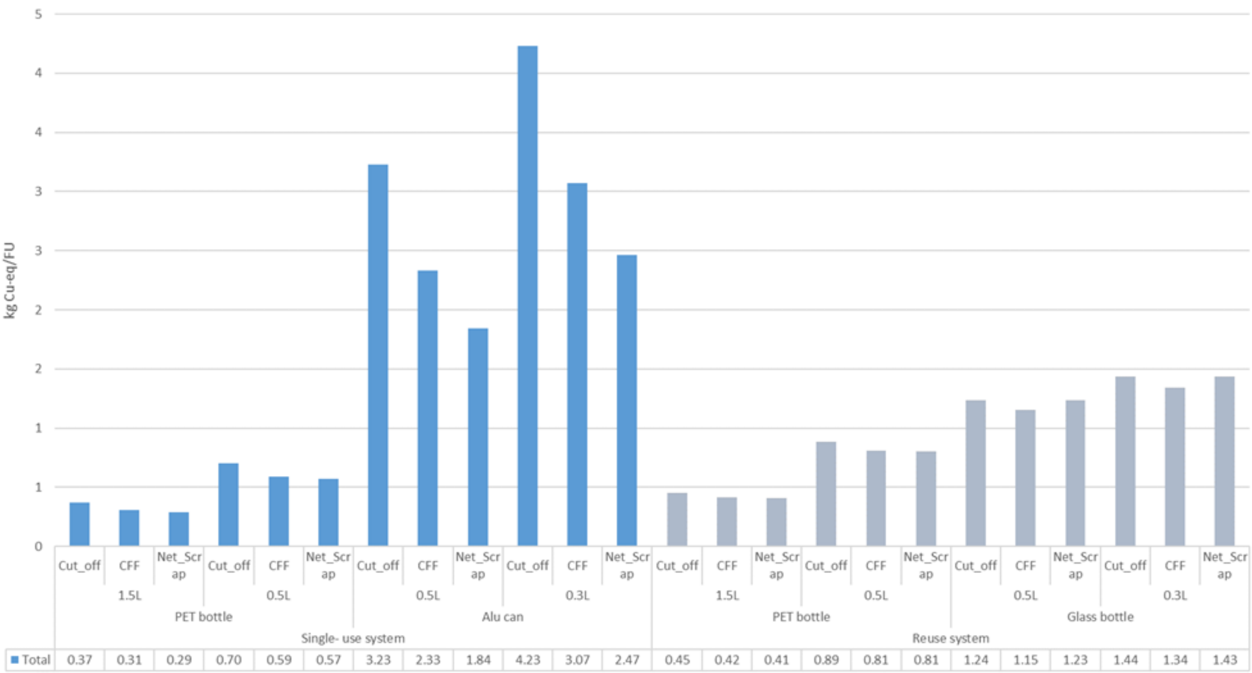
Figure A5.3 Net terrestrial acidification[kg SO2-eq per 1000 l beverage distributed] for the specific bottles/cans in respective single-use and reuse systems, presented for the three different modelling approaches.



	Single- use system												Reuse system											
	PET bottle						Alu can						PET bottle						Glass bottle					
	1.5L			0.5L			0.5L			0.3L			1.5L			0.5L			0.5L			0.3L		
	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap
■ P14 Avoided impacts from incineration	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
■ P9 Avoided impacts from recycling	0.0	-0.1	-0.1	0.0	-0.2	-0.1	0.0	-0.4	-0.3	0.0	-0.5	-0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.2	0.0	0.0	-0.2	0.0
■ Distribution packaging	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1
■ Transport	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.4	0.4	0.4
■ P14 Incineration	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
■ P9 Recycling	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
■ P8 Sorting	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
■ P6 Retailer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
■ P4 Filling (and washing)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
■ P3 Manufacturing	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
■ P2 Recycled material	0.0	0.1	0.0	0.0	0.1	0.0	0.1	0.3	0.1	0.1	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.4	0.5	0.5	0.5
■ P1 Virgin material	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.4	0.4	0.5	0.5	0.5	0.0	0.0	0.0	0.1	0.1	0.1	0.3	0.3	0.3	0.4	0.4	0.4

Figure A5.4 Terrestrial acidification [kg SO2-eq per 1000 l beverage distributed] separated into the major life cycle activities for the respective single-use and reuse bottle/can systems, presented for the three different modelling approaches.

Mineral resource scarcity: results per bottle/can type and size



	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap
	1.5L			0.5L			0.5L			0.3L			1.5L			0.5L			0.5L			0.3L		
	PET bottle						Alu can						PET bottle						Glass bottle					
	Single- use system												Reuse system											
■ Total	0.37	0.31	0.29	0.70	0.59	0.57	3.23	2.33	1.84	4.23	3.07	2.47	0.45	0.42	0.41	0.89	0.81	0.81	1.24	1.15	1.23	1.44	1.34	1.43

Figure A5.5 Net mineral resource scarcity [kg Cu-eq per 1000 l beverage distributed] for the specific bottles/cans in respective single-use and reuse systems, presented for the three different modelling approaches.

	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap	Cut_off	CFF	Net_Scrap
	1.5L			0.5L			0.5L			0.3L			1.5L			0.5L			0.5L			0.3L		
	PET bottle						Alu can						PET bottle						Glass bottle					
	Single- use system												Reuse system											
■ P14 Avoided impacts from incineration	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0
■ P9 Avoided impacts from recycling	0.0	-0.2	-0.1	0.0	-0.3	-0.1	0.0	-2.6	-2.0	0.0	-3.3	-2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	-0.1	0.0
■ Distribution packaging	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.1
■ Transport	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.7	0.7	0.7	0.8	0.8	0.8
■ P14 Incineration	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
■ P9 Recycling	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.6	0.0	0.4	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
■ P8 Sorting	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
■ P6 Retailer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
■ P4 Filling (and washing)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
■ P3 Manufacturing	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
■ P2 Recycled material	0.0	0.1	0.0	0.0	0.2	0.0	0.4	1.8	0.4	0.5	2.2	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.2	0.3	0.3	0.3
■ P1 Virgin material	0.1	0.1	0.1	0.2	0.2	0.2	2.6	2.6	2.6	3.3	3.3	3.3	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2

Figure A5.6 Mineral resource scarcity [kg Cu-eq per 1000 l beverage distributed] separated into the major life cycle activities for the respective single-use and reuse bottle/can systems, presented for the three different modelling approaches.

Appendix 6 Extra results sensitivity analyses

Additional results to chapters 6.1 and 6.2 for CFF and System expansion_Net scrap approach.

Change in recycled content for the single-use system.

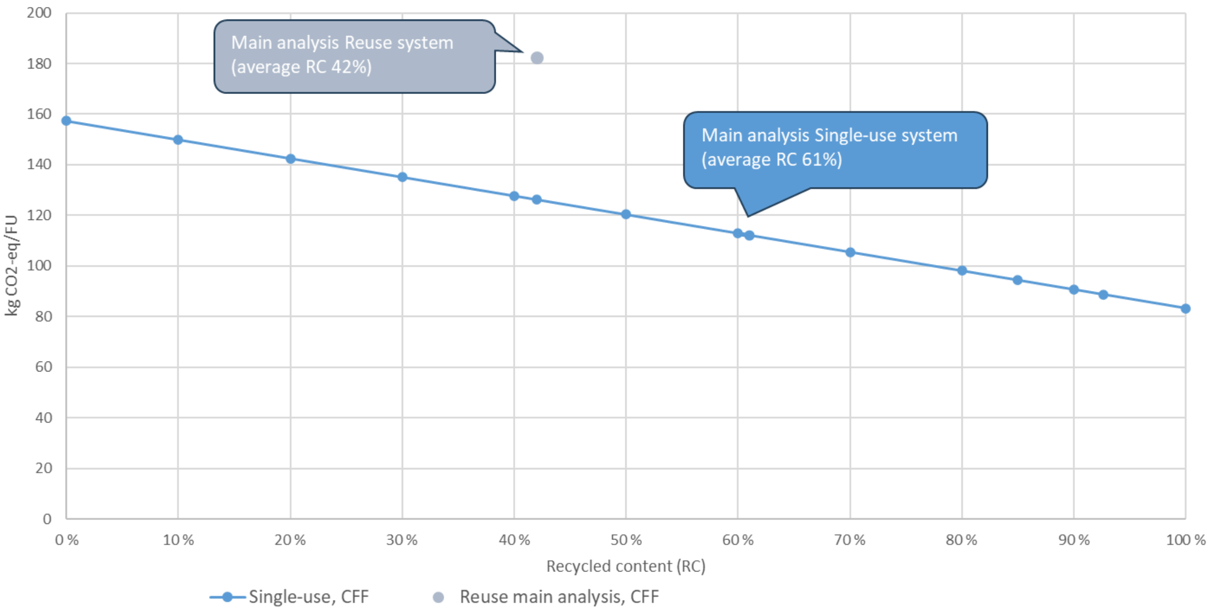


Figure A6.1 Climate change (kg CO_2-eq/FU) for varying recycled content for the single-use system, presented for the CFF modelling approach.

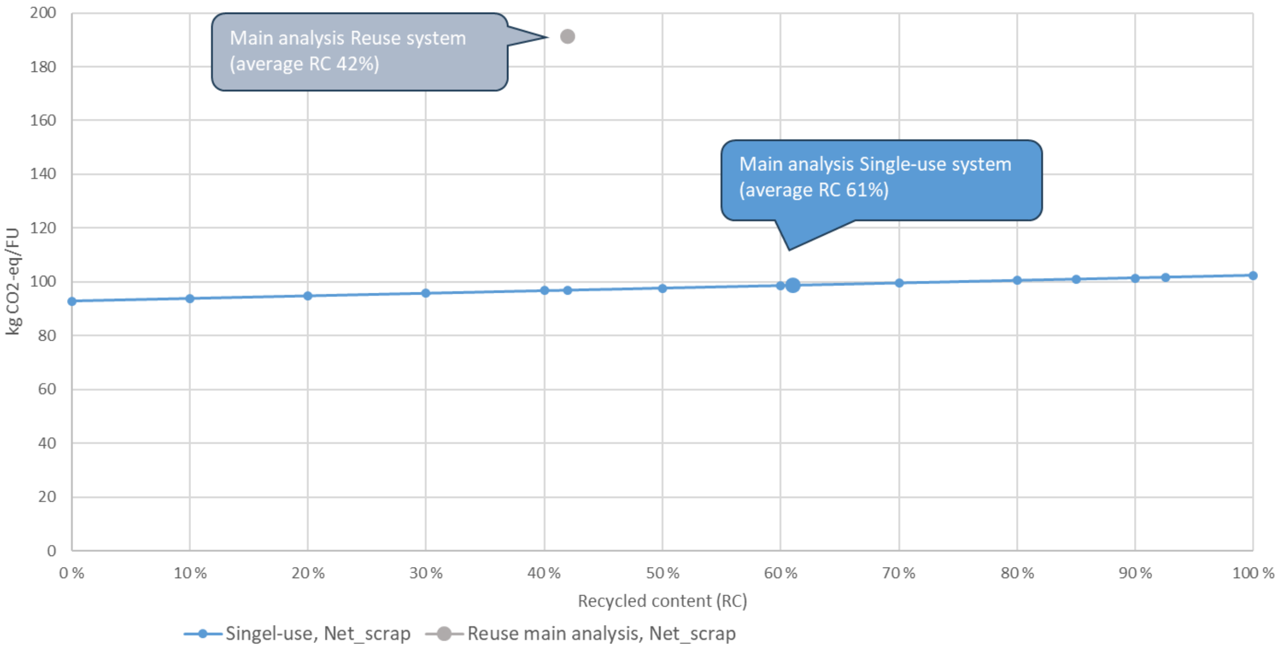


Figure A6.2 Climate change (kg CO_2-eq/FU) for varying recycled content for the single-use system, presented for the System expansion_net scrap modelling approach.

Change in collection rate for the reuse system.

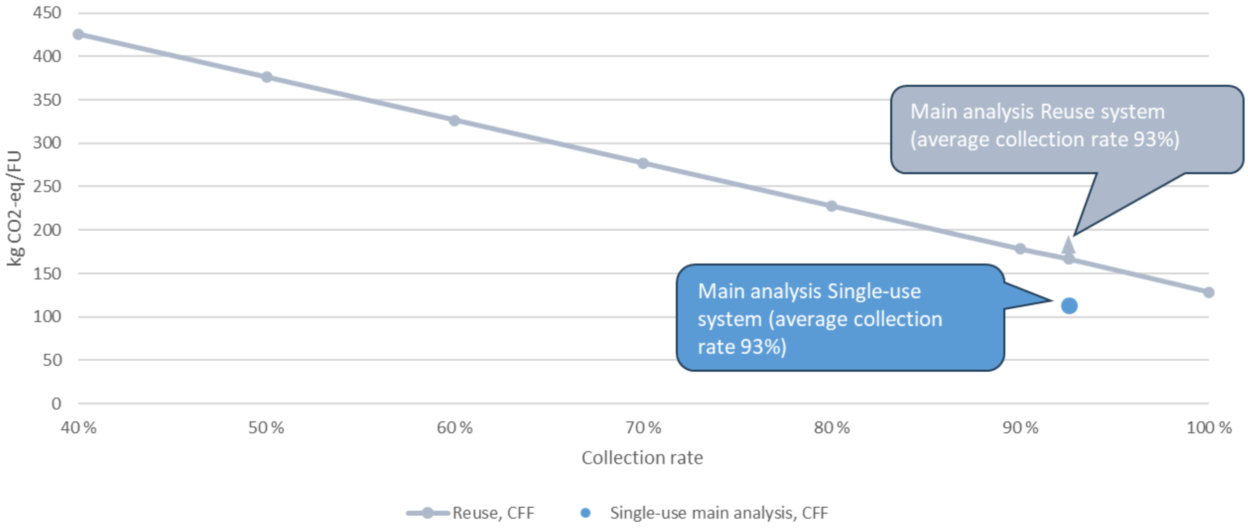


Figure A6.3 Climate change (kg CO_2-eq/FU) for different collection rates for the reuse system, presented for the CFF modelling approach.

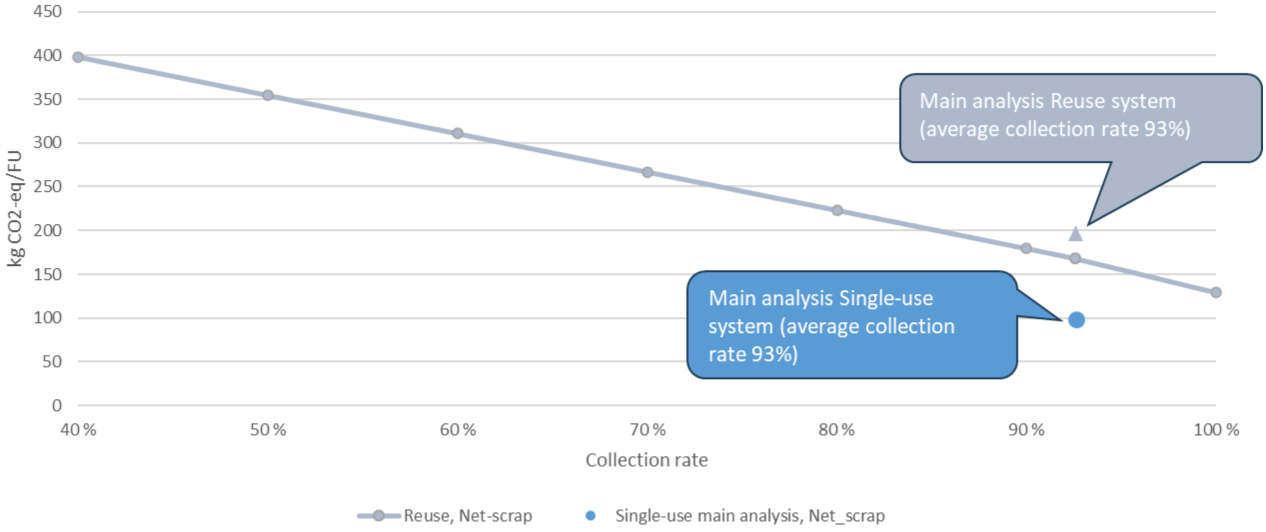


Figure A6.4 Climate change (kg CO_2-eq/FU) for different collection rates for the reuse system, presented for the System expansion_net scrap modelling approach.

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