Decarbonisation of Single Use Beverage Packaging

Investigating 1.5ºC aligned carbon budgets for aluminum, PET and glass beverage containers in the EU

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eunomia

ZERO WASTE EUROPE

Report For

ZERO WASTE EUROPE

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Executive Summary

This study builds upon Eunomia's previous investigation into materials decarbonisation pathways in the report *"Is Net Zero Enough for the Material Production Sector?"*[1]. Focussing on the four materials with the greatest emissions globally, the study found that each will have great difficulty in reducing GHG emissions in line with a 1.5°C future by 2050, particularly if mass consumption continues and increases. Whilst studying the global material picture provides valuable insights; policymakers may find it more useful to have the same approach applied at the product level. Therefore, this study delves into the Net Zero pathways of aluminium, PET, and glass when utilised in beverage packaging within the EU, evaluating their potential performance within a cumulative GHG emissions budget that aligns with the goal of limiting global warming to 1.5°C.

Approach

As the focus of this report shifts from raw materials to products, some simplifications have been necessary. It is important to note that the results presented should not be considered a comprehensive cradle-to-gate assessment. Instead, they provide an initial overview of the key material greenhouse gas (GHG) impacts during the critical 30-year period ahead.

Similar to the previous study, published net-zero strategies have been utilised whenever possible. Existing analyses for aluminium and PET (plastic) have been adapted to specifically address beverage containers. Regarding glass, the analysis is primarily based on a single published Net Zero strategy by British Glass with additional support from academic papers.

It is important to acknowledge that some key technological interventions, such as Carbon Capture, Utilization, and Storage (CCUS), as well as the deployment of green hydrogen as a fuel source, have not yet been proven at a commercially viable scale. Furthermore, there may be risks associated with costly interventions (e.g., electrification of glass furnaces). Therefore, a risk rating has been assigned to each technological intervention to account for the potential of not fully realising their intended benefits.

Results

Figure E- 1 illustrates the cumulative GHG emissions of each material compared to the 1.5°C aligned budget, including the combined budget for beverage packaging using these three materials. The projections indicate that, collectively, the materials are expected to surpass the allocated budget by +150% including risk adjustment, with glass and PET being significant contributors to this exceedance at +200% and +150% respectively. Aluminium's budget overshot is estimated to be around 50%.

The growth rate for the consumption of all materials by the beverage packaging sector is assumed to be zero (i.e. the same demand in 2050 as 2020). It is considered unlikely that overall container use can continue to grow indefinitely. Alongside this, the EU population is expected to be lower by 2050 than it is today, and we would expect container use to have a close relationship to population size. Nevertheless, the results show that even with no growth in material consumption, the beverage container industry is likely to significantly overshoot the proposed cumulative emissions budget aimed at staying within 1.5°C warming.

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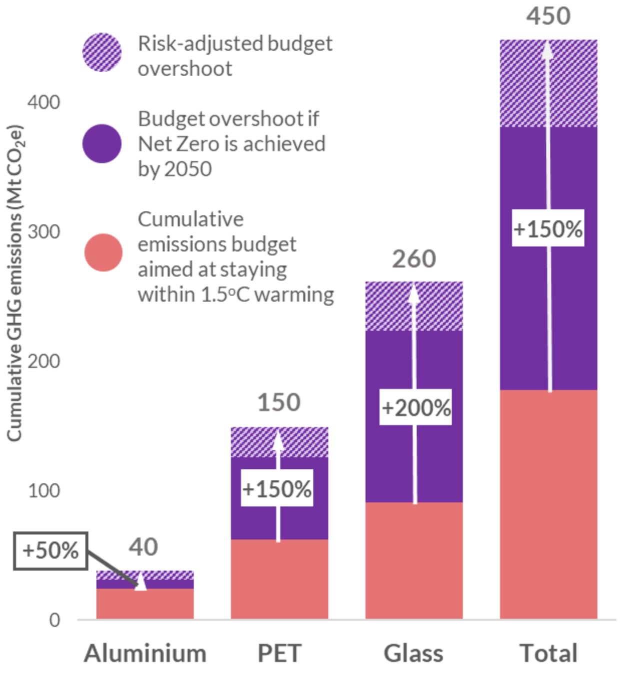
[1] https://zerowasteeurope.eu/wp-content/uploads/2022/11/Is-Net-Zero-Enough-for-the-Materials-Sector-Report-1.pdf

Figure E- 1: Cumulative EU Beverage Container GHG Emissions to 2050



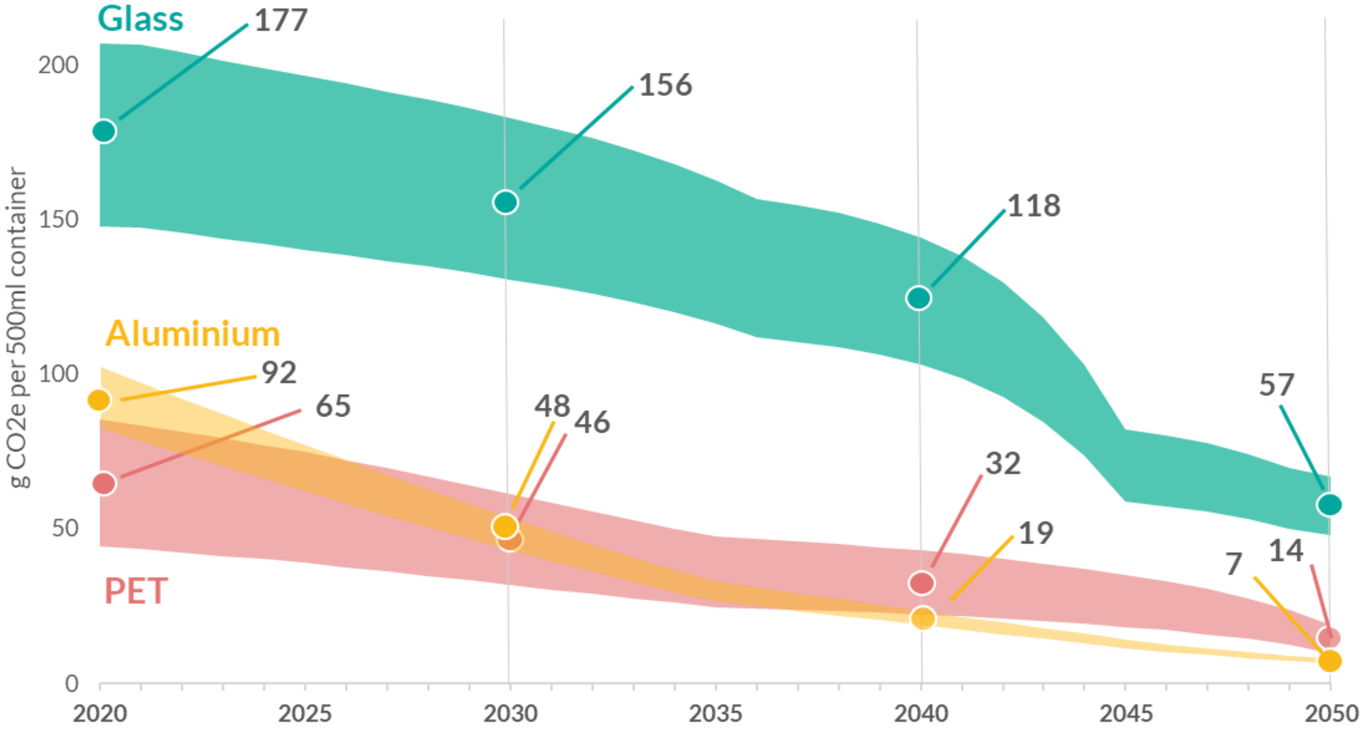
To provide further context regarding the differences between materials, results are shown in Figure E- 2 per container rather than as total industry emissions shown in the previous sections.

This figure considers the projected GHG emissions for each year, ***including the risk factor***, divided by the weight of material used in a hypothetical 500ml container. Different typical weight ranges for containers of each material are considered, particularly for PET, where packaging weight limitations are often more technical than commercial. Aluminium exhibits a narrower weight range per container due to the need for pressurisation in all cans, resulting in greater standardisation across brands. In contrast, glass containers have a wider weight range as they can vary significantly between brands and drink types with limited standardisation.

These results indicate that the GHG emissions per unit of packaging material are consistently three to four times higher for glass bottles compared to aluminium and PET throughout the decarbonisation pathway. Even when accounting for uncertainties in each material's pathway, it seems unlikely that this performance gap can be bridged, especially considering that glass's projected endpoint by 2050 is similar to or higher than the emissions of aluminium and PET by 2030. Such a significant difference in magnitude would pose a considerable challenge to overcome.

Both aluminium and PET exhibit similar trends along the pathway, and the speed and effectiveness of decarbonisation interventions could lead to one outperforming the other, particularly from 2030 onwards. However, both materials need to prioritize the development of credible pathways towards net-zero emissions since they are expected to exceed their respective budgets.

Figure E- 2: EU Beverage Container Decarbonisation Projections – per Typical 500ml Container Range



Key Findings

The following summarises the key findings of this report:

- All three materials face significant challenges in decarbonization, posing a risk to achieving net-zero emissions by 2050. The most pressing challenges are as follows:
    - ***Aluminium* – ** Transitioning the entire smelting capacity to run on green energy will necessitate substantial investments due to its high energy requirement (~15MWh/tonne).
    - ***PET* –** A fundamental shift in the value chain to bio-based feedstock is necessary, but technical hurdles currently exist and may conflict with the fossil-focused nature of the industry.
    - ***Glass* –** electrifying gas furnaces will require either a costly and complete infrastructure upgrade or a gradual replacement of legacy systems. Despite efforts, glass manufacturing will continue to have high energy consumption (~2MWh/tonne).
- All three materials are projected to surpass their allocated carbon budget, with glass exhibiting the highest proportional exceedance. The beverage packaging sector in the EU as a whole is expected to exceed its total carbon budget. It is evident that sustaining or increasing current demand for beverage packaging materials is incongruent with achieving a future of less than 1.5°C global warming.
- The inferior performance of glass becomes more pronounced when comparing the specific unit weights of glass containers to those made of aluminium and PET. The findings consistently demonstrate that the production of glass bottles results in three to four times higher greenhouse gas (GHG) emissions compared to aluminium and PET throughout their respective decarbonisation pathways.
- Enhancing recycling and circularity practices appears to be of utmost importance for aluminium and PET, but it holds significantly less significance for glass. This disparity arises from the fact that producing aluminium from recycled content has a significantly lower impact than using virgin materials, whereas PET that is not recycled is often incinerated. In contrast, glass lacks these drivers, and substantial energy consumption persists even with high levels of recycled content.
- Recycled glass still requires 75% of the energy needed for virgin glass production, whereas aluminium only requires approximately 10%. Consequently, both materials require approximately 1.5MWh/tonne for recycling. However, it's important to note that aluminium cans fulfil the same container function as glass while requiring significantly less mass. These characteristics are inherent to the properties of the materials and are unlikely to change over time.

Recommendations

The challenge lies in the fact that all the materials in this study require significant technological investment to transition towards Net Zero. However, it is evident that reducing material demand should be a top priority. Under current business models in a market-driven economy, these two ideas are conflicting. Hence, it is crucial to separate the amount of material sold from the value derived from it. Developing reuse systems for beverage containers appears to be the most promising approach to achieve this goal. Nonetheless, it is important to ensure that reduced material demand does not result in a transfer of emissions burdens elsewhere, including sectors outside of material production.

Furthermore, it is evident that both PET and aluminium offer more compelling options compared to glass in single use applications. From a purely climate change perspective, switching to these materials may be preferable. However, reducing demand for glass presents challenges, as weight reduction can only go so far. Given that glass is highly suitable for reuse, adopting a system that promotes reuse is likely to significantly decrease glass demand in terms of mass (but maintaining unit use). Therefore, it would be informative to examine decarbonisation pathways for beverage container materials while accounting for reuse. It is important to expand the system boundaries to encompass the entire lifecycle, as the impacts of reuse systems extend beyond material use.

Moreover, it is essential to conduct comparative studies that consider the decarbonisation pathways rather than focusing on a single point in time, typically the present day. Such studies will provide a more comprehensive understanding, particularly when the burdens shift from material to energy in reuse systems (e.g. reducing materials, but increasing transport). This aspect warrants further investigation, along with broader efforts to optimise reuse systems.

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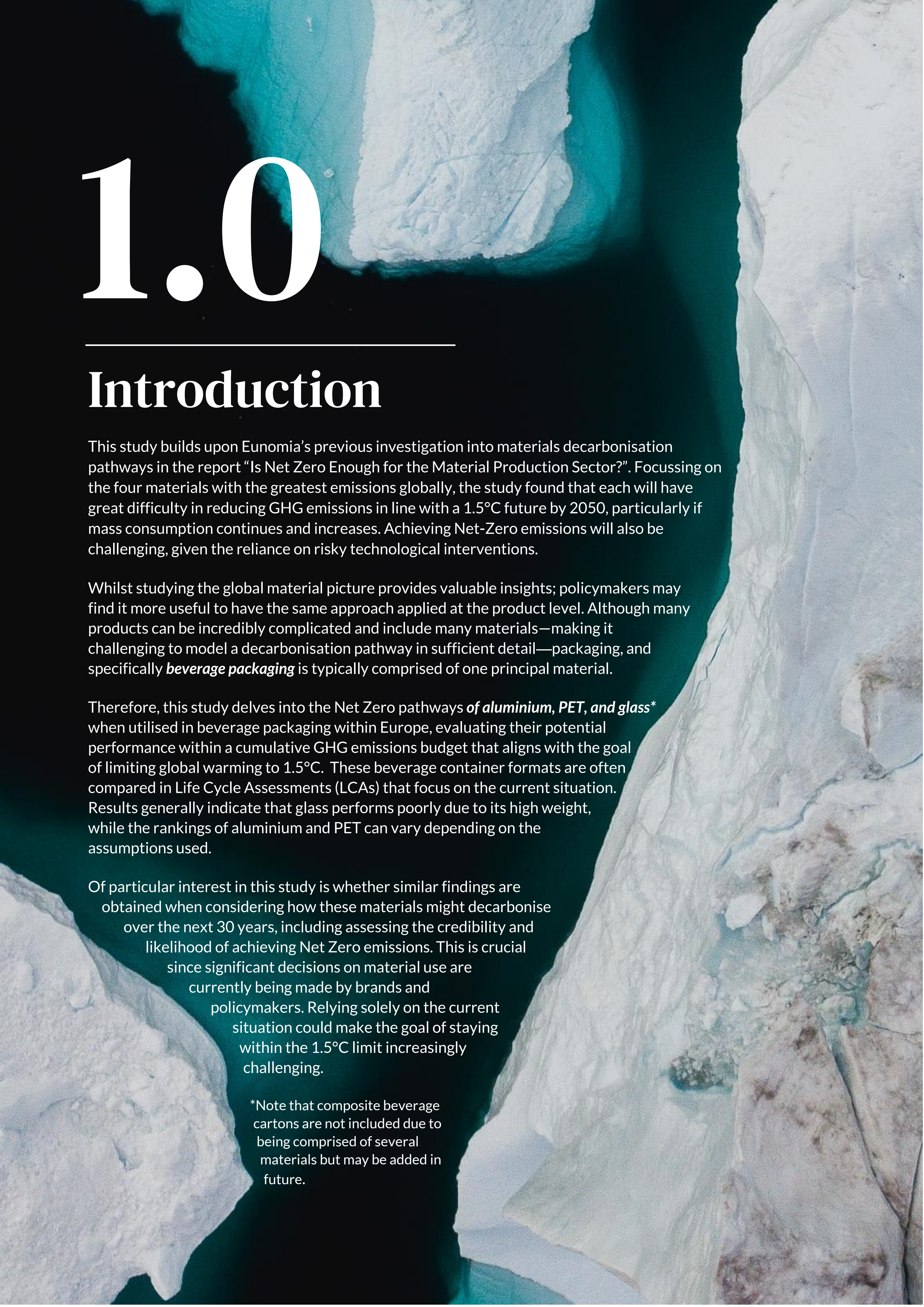


1.0

Introduction

This study builds upon Eunomia's previous investigation into materials decarbonisation pathways in the report "Is Net Zero Enough for the Material Production Sector?". Focussing on the four materials with the greatest emissions globally, the study found that each will have great difficulty in reducing GHG emissions in line with a 1.5°C future by 2050, particularly if mass consumption continues and increases. Achieving Net-Zero emissions will also be challenging, given the reliance on risky technological interventions.

Whilst studying the global material picture provides valuable insights; policymakers may find it more useful to have the same approach applied at the product level. Although many products can be incredibly complicated and include many materials—making it challenging to model a decarbonisation pathway in sufficient detail—packaging, and specifically ***beverage packaging*** is typically comprised of one principal material.

Therefore, this study delves into the Net Zero pathways ***of aluminium, PET, and glass**** when utilised in beverage packaging within Europe, evaluating their potential performance within a cumulative GHG emissions budget that aligns with the goal of limiting global warming to 1.5°C. These beverage container formats are often compared in Life Cycle Assessments (LCAs) that focus on the current situation. Results generally indicate that glass performs poorly due to its high weight, while the rankings of aluminium and PET can vary depending on the assumptions used.

Of particular interest in this study is whether similar findings are obtained when considering how these materials might decarbonise over the next 30 years, including assessing the credibility and likelihood of achieving Net Zero emissions. This is crucial since significant decisions on material use are currently being made by brands and policymakers. Relying solely on the current situation could make the goal of staying within the 1.5°C limit increasingly challenging.

*Note that composite beverage cartons are not included due to being comprised of several materials but may be added in future.

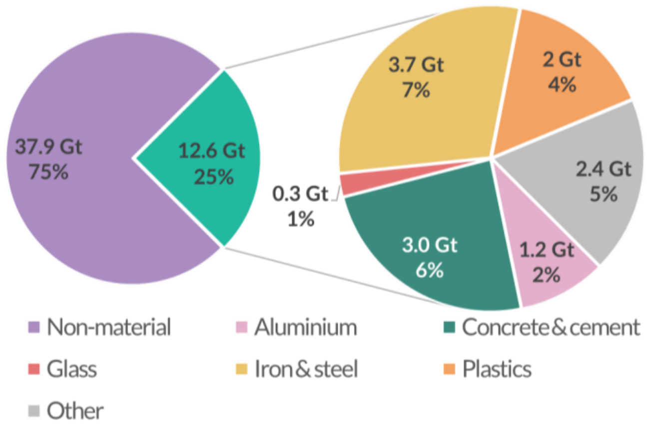
2.0

Methodology

2.1 GHG Emissions Budgeting

GHG emissions budgeting for key materials was introduced in Eunomia's previous report *"Is Net Zero Enough for the Materials Sector?"*[2] This report proposed possible <1.5°C aligned cumulative emissions budgets for steel, aluminium, concrete and plastics. The findings suggested that likely Net Zero trajectories were insufficient to stay within these budgets. The current report adopts the same approach but focuses on key materials used ***in single use beverage containers within the EU27*** - and which includes the addition of glass into the analysis. The focus for the plastics industry is PET as the material responsible for around 98% of EU beverage bottles.[3] Aluminium in the form of the can is the third and final container type. Beverage cartons are excluded from the study because they utilise multiple materials, which significantly complicates the materials value chain and, consequently, the decarbonisation pathway.

Figure 2-1: Global GHG Emissions from Material Production in 2020[4]



As shown in Figure 2-1, all glass material contributes only 1% to global GHG emissions; however, when annual EU emissions for beverage containers are considered, glass has the largest share currently (Figure 2-2). The cumulative emissions budgets are set by taking the current share of *global* emissions for each material and creating a decarbonisation pathway that is consistent with reaching <1.5°C. To apportion part of the global cumulative emissions to each material used in beverage containers in the EU, it is assumed the current proportional share of GHG emissions stays consistent throughout the pathway. For example, EU glass beverage containers account for 0.09% of global GHGs and therefore are assigned 0.09% of the global budget.

This is a simplification which assumes that budgets set for the EU are maintained relative to the rest of the world. The overall budget for the EU could, however, be much smaller if the population growth and economic development of developing countries is also accounted for in the analysis. As such, the budgets set in this report should be considered as generous.

Figure 2-2: EU Single Use Beverage Container GHG Emissions

2.2 Scope

The scope of this report has been refined to focus on products rather than raw materials, resulting in the need for some simplification. Consequently, the findings should not be regarded as a comprehensive cradle to grave assessment but rather as an initial exploration of the primary GHG impacts associated with materials within the crucial 30-year timeframe ahead. It is important to note that this study does not aim to provide a direct comparison of products for making individual decisions, but rather presents an analysis of the overall system dynamics over time, taking into account the following limitations:

- ***Ancillaries to the containers such as lids, caps, labels and coatings*** – this is likely to be somewhat neutral in its relative impacts as all container types have some extra parts or coatings.
- ***Secondary/tertiary packaging*** – packaging used in transport or for displays is not included.
- ***The logistics of transporting the containers*** – likely to impact glass negatively as each container is typically 10-20 time heavier than alternatives.
- ***Open -loop recycling*** – only fully circular material is included, but for each material, some recycling takes place outside of these closed loops. Its benefit is not included.
- ***Reuse*** – this report does not include the impact of any transition to reusable packaging systems.

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[2] Zero Waste Europe (2022), Is net zero enough for the materials sector?

[3] EU Commission (2022), Study to develop options for rules on recycled plastic content for the implementing act related to single-use plastic bottles under Directive (EU) 2019/904

[4] Adapted from Hertwich, 2021 and Climate Watch Historical GHG Emissions from 2018 projected forward to 2020.

2.3 Sector Net Zero Strategies

As with the previous study, published Net Zero strategies have been drawn upon where possible and the existing analysis for aluminium and plastic (PET) is drawn upon and adapted to focus on beverage containers. Details of the background to aluminium and plastic can be found in the *"Is Net Zero Enough for the Materials Sector?"*[5] report.

Similar to the previous study, published net-zero strategies have been utilized whenever possible. Existing analyses for aluminium and PET (plastic) have been adapted to specifically address beverage containers. Regarding glass, the analysis is primarily based on a single published Net Zero strategy by British Glass. Additional support for the approach can be found in academic papers examining glass industries in other countries such as Germany[6] A detailed description of the approach to modelling of glass decarbonisation can be found in Appendix A 1.0.

A key element of the British strategy is a significant shift towards electrification. Glass furnaces use a significant amount of energy for melting the cullet (in Europe, this is currently mostly gas). Smaller furnaces are assumed to be fuelled 100% by electricity by 2050, with larger ones mixing electrification with other zero carbon fuels (predominantly hydrogen). The British strategy assumes a further increase in recycling takes place, although the literature notes there are currently limits in the use of recycled cullet where furnaces are fuelled 100% by electricity.

A significant contribution to glass production emissions is made from the use of inputs to the process such as soda ash, which in itself relies on relatively carbon intensive inputs such as ammonia. Glass production also results in emissions from combusting some of these inputs such as calcium carbonate. Additional activity is required to mitigate these impacts, and this is reflected in the British Glass strategy where carbon capture, utilisation and storage (CCUS) is anticipated to be required to tackle process emissions directly from glass manufacture from combusting carbonate fuels. Although not clearly set out in the strategy, further shifts towards electrification and alternative fuels also appear to be assumed to tackle the energy demands of the inputs such as soda ash. Further CCUS use is also assumed to be necessary to tackle emissions from some of these inputs. Increases in recycling will help to mitigate against these impacts to a certain extent.

2.4 Accounting for Risk

It is important to acknowledge that some key technological interventions, such as Carbon Capture, Utilization, and Storage (CCUS), as well as the deployment of green hydrogen as a fuel source, have not yet been proven at a commercially viable scale. Furthermore, there may be financial risks associated with costly interventions (e.g., electrification of glass furnaces), and their economic feasibility may be uncertain. Therefore, a risk rating has been assigned to each technological intervention to account for the potential of not fully realising their intended benefits.

A risk rating is assigned to each technological intervention to account for the risk of its potential not being fully realised; each intervention is assigned a 'low', 'medium' or 'high' risk rating, which translates to a risk factor of 5%, 25% and 50% respectively. A technology that is considered 'high' risk would therefore see its effectiveness reduced by 50% when risk is accounted for in the modelling. Two values for cumulative emissions between 2020 and 2050 were calculated for each sector: one assumes that 100% of its potential will be realised (and Net Zero is achieved), and another that accounts for the risk assigned to each intervention. Details of how the risk factors are assigned to each intervention can be found in Appendix A 1.0.

Risk Rating	Effectiveness Reduction
Low	5%
Medium	25%
High	50%

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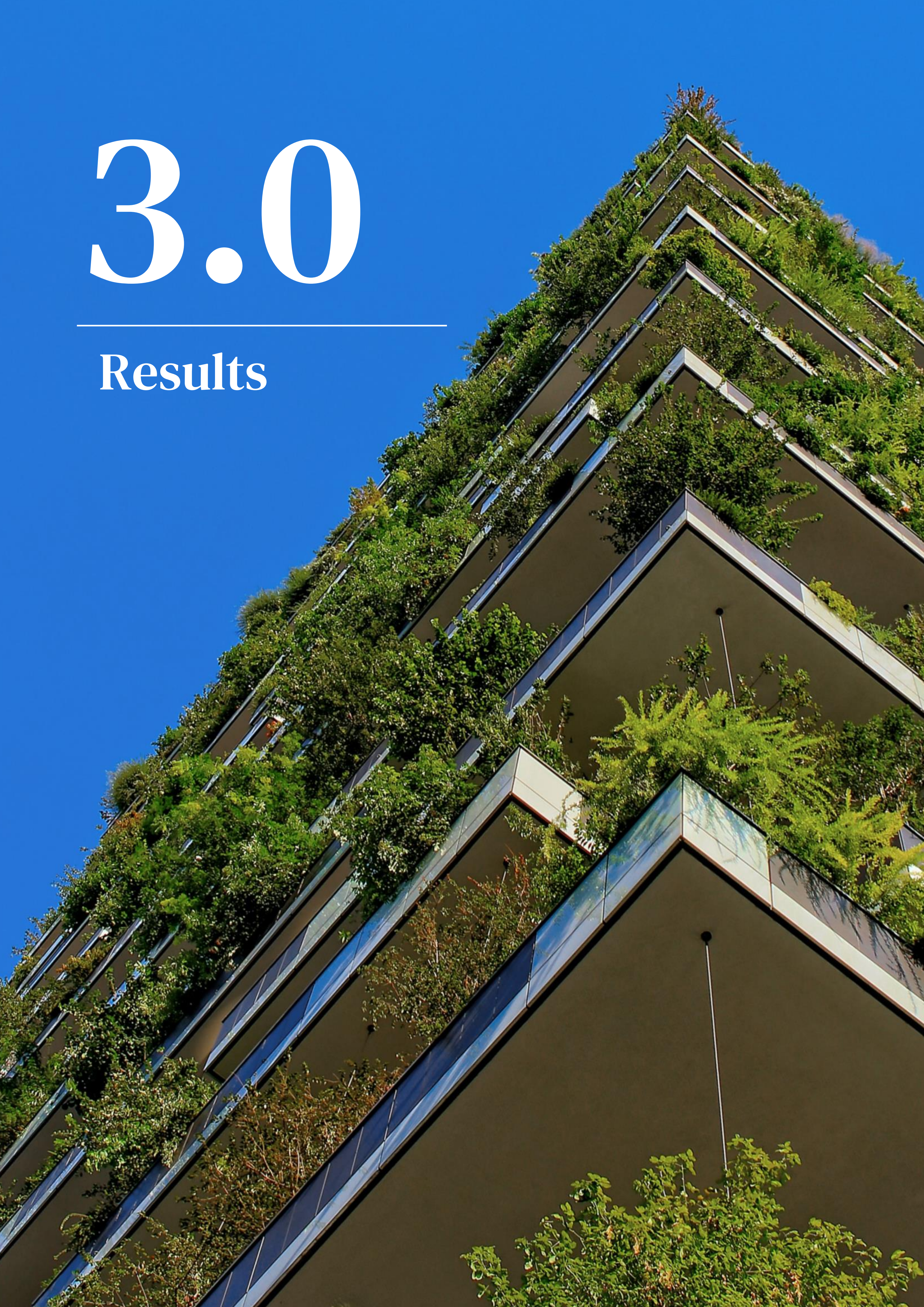
[5] Zero Waste Europe (2022), Is net zero enough for the materials sector?

[6] Zier M, Stenzel P, Kotzur L, Stolten D (2021) A Review of Decarbonization Options for the Glass Industry, Energy conversion and management X 100083

3.0

Results



3.1 Aluminium Cans

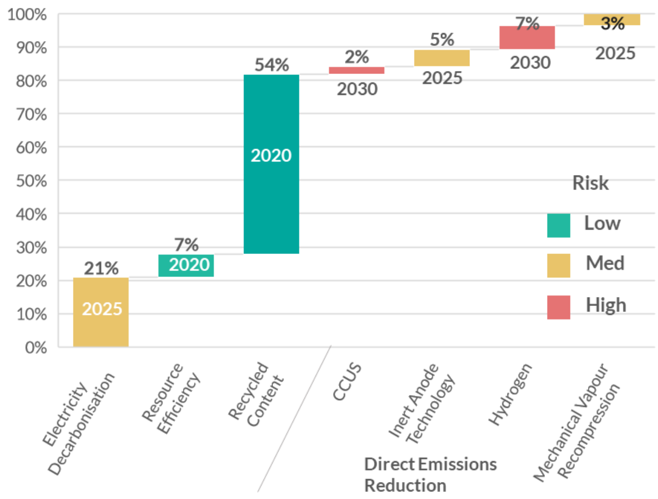
The potential Net Zero trajectory for the aluminium can in Europe is based upon The International Aluminium Institute (IAI) document entitled Aluminium Sector Greenhouse Gas Pathways to 2050.[7] The same interventions required at a global level will also be needed for aluminium cans. However, given the European focus, the origin of the raw materials used in production is different to the global average, as is the amount of recycled content.

Aluminium used in Europe for the can sector is generally of a lower carbon intensity than the global average. This is because the smelting (electrolysis) process for aluminium used in European can making—which is the most energy intensive part of virgin aluminium production with 74% of the production GHG emissions—takes place predominantly in Europe (54%) and in other countries which use more renewables (14%). A much smaller amount of the aluminium (32%) is imported from countries relying more on coal.[8] This is in contrast with the global average which is dominated by aluminium produced in China using electricity generated from coal (China produces just under 60% of the world's primary aluminium[9]). Despite this, China also has the most energy efficient smelting globally due to its newer infrastructure – although this does not make up for the use of coal.

To improve upon the European average, the beverage can sector may, of course, procure aluminium from the most advanced smelting plants in Europe (typically with a carbon intensity less than half the European and a quarter of the global average[10]), but this moves the issue to other parts of the aluminium sector. It is therefore important that the European aluminium sector as a whole becomes decarbonised to make Net Zero for the can achievable and credible.

Figure 3-1 shows the projected contributions of the key interventions to Net Zero and the estimated years that each would begin to be implemented. The risk is also shown for each intervention.

Figure 3-1: Aluminium Net Zero Contributions



The largest contributor to Net Zero is the shown to be the integration of more recycled content. Whilst aluminium is eminently recyclable, the recycled material does not always end up back in cans. Therefore, the current recycled content is estimated to be around 44%[11] with the potential for this to increase to a theoretical maximum of 90%.[12] It is possible to increase this, but at the expense of greater material usage. Currently, two different grade alloys are used for the body and the ends. When the two are mixed in recycling,

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[7] International Aluminium Institute (2021) Aluminium Sector Greenhouse Gas Pathways to 2050.

[8] Analysis by Eunomia for the IAI - https://international-aluminium.org/resource/european-aluminium-can-cycle/

[9] https://international-aluminium.org/statistics/primary-aluminium-production/

[10] https://www.hydro.com/en/aluminium/products/low-carbon-and-recycled-aluminium/low-carbon-aluminium/

[11] Analysis by Eunomia for the IAI - https://international-aluminium.org/resource/aluminium-beverage-can-study/

[12] Metabolic (2019), Assessing the Circular Potential of Beverage Containers in the United States

virgin alloys need to be added to maintain the correct strength properties. The alternative is to make the can out of a single alloy, which would require more material to strengthen it and increase the weight of the can.

With no technical barriers to reaching 90% and a strong EU policy direction towards higher recycling rates, this is deemed to be a low-risk intervention.

The other key contributor to the pathway is the decarbonisation of electricity in the smelting process which needs to be from fully renewable sources to achieve Net Zero. For most smelting plants this is typically a hydro-plant located nearby – very little electricity is produced using other renewables due to the large amounts of energy needed, with plants relying on self-generation rather than purchases from the local grid. Decarbonising the smelting process is deemed to be a medium-risk due to the requirement for large infrastructure investment not only in Europe but also in other countries where EU policy has little influence.

For the direct emission (mostly from the chemical reactions in the smelting process) reductions the risk is medium to high due to the level of investment and the current state of their technological development. In particular, CCUS, whilst providing a low contribution is a technology with significant challenges to overcome and is therefore considered high risk (as it also is for the other materials considered here).

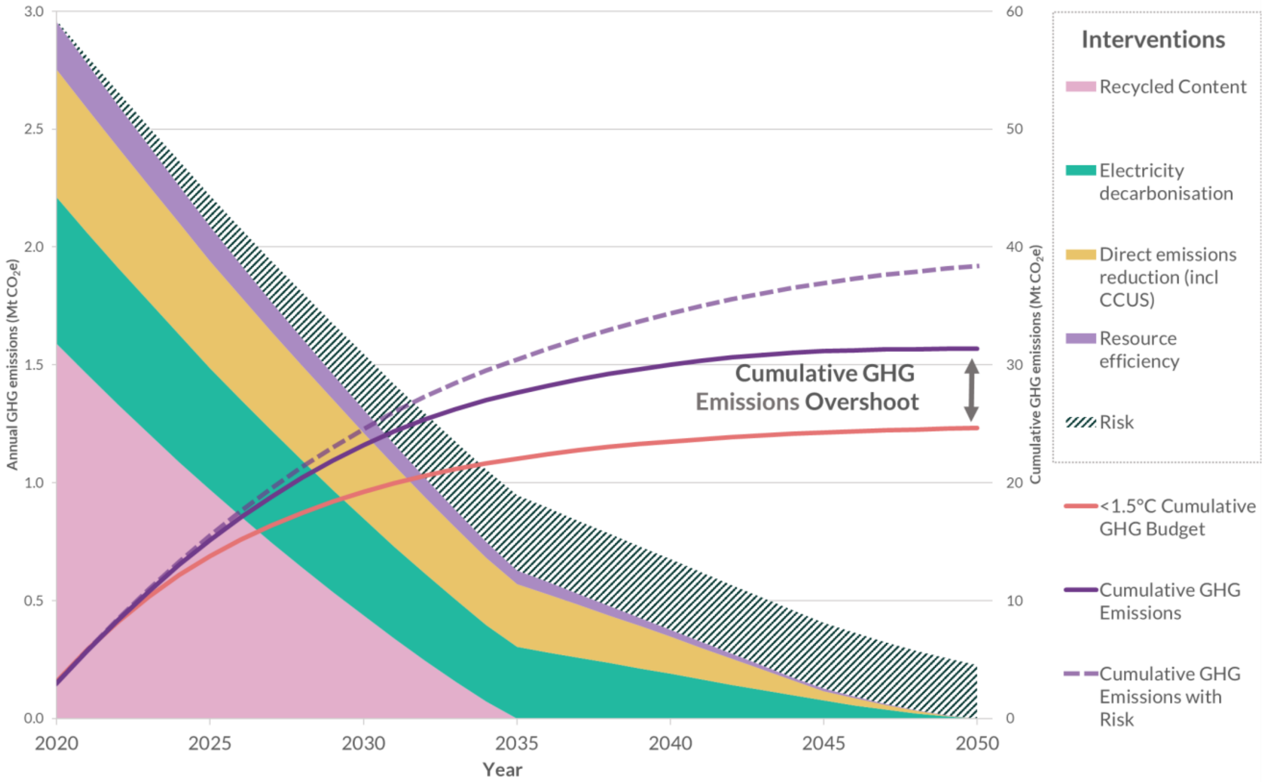
Finally, resource efficiency focuses on improving the production process in areas such as internal scrap remelt which has a small impact overall as much of this has already been achieved. Small incremental improvements are still possible and therefore this is given a low risk.

Figure 3-2 shows the cumulative emissions trajectory when calculated based upon these interventions, their timing and implementation speed. The coloured sections (using the left axis) show the interventions and their annual contribution on a trajectory to Net Zero. The lines (using the right axis) show the cumulative emissions over the time period.

Recycled content is notably the highest contributor to the pathway, and the credibility of it relies on an immediate and concerted effort to improve this (efforts are assumed to peak in 2035). The high contribution is due to recycled aluminium requiring only around 10% of the energy that is needed for virgin aluminium production (~1.5MWh/tonne vs 15MWh/tonne) along with no mining or refining needed (noting that both of these steps also causing other land-based environmental issues).

With the other interventions starting later and being implemented slower there is still a budget overshoot of 50% when accounting for risk. Early and concerted investment in decarbonising the smelting process will be key to reducing that potential overshoot and meeting Net Zero.

Figure 3-2: Modelling Potential Net Zero Trajectory for Beverage Aluminium



3.2 PET Bottles

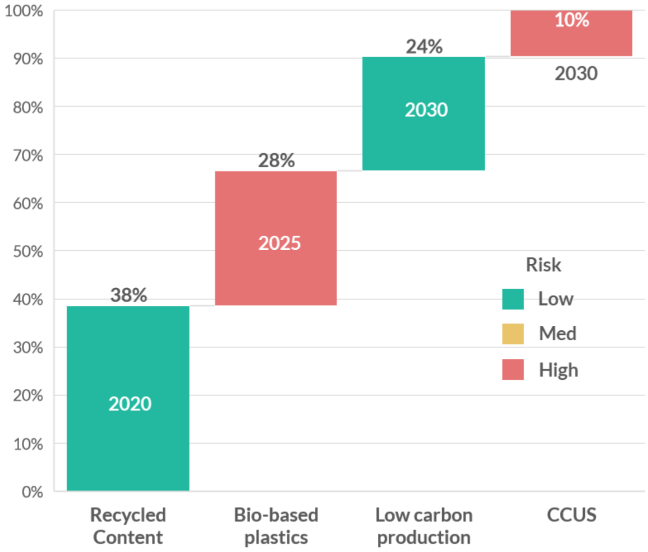
The plastics industry does not have a unified Net Zero pathway that it is committed, either for plastics as a whole or for PET specifically. In part of this is because there are several different options available to different value chain actors (linked to investment in current infrastructure) – complicating the picture compared to the other materials. The work set out here builds on analysis undertaken by Zheng et al[13] which identified some key pathways for the global plastics industry as a whole. These have been adapted to focus on PET in the EU.

PET beverage bottles have been subject to increasing attention from EU law makers; as such, a significant increase in recycled content is likely to take place over the next decade. The technology for recycling PET is well established, with the main barrier of accessing the material through efficient collection being addressed through minimum collection targets. The current average recycled content in PET bottles is 17% but is thought to reach a technical ceiling of around 75% when mechanically recycled - this takes into account polymer degradation and contamination that prevents a system where 100% recycled content is possible (noting that 100% recycled content is possible on an individual item, but not as a credible average across the sector).[14] Chemical (depolymerisation) recycling could increase this limit, but it is unclear how this would be integrated at this time, therefore a conservative 2050 recycled content of 80% is suggested. Given these drivers, an increase in recycled content is assigned a low risk as shown in Figure 3-3.

Alongside the likely technical ceiling to recycling/recycled content, it is also necessary to make the switch to bio-based content. This is essential to remove the reliance on fossil fuels in the production of virgin polymers. The exact pathway to decarbonisation for bio-based is unclear — and many current day analyses show bio-based plastics to have a similar or worse carbon footprint. Zhang suggested that by 2050 PET produced from sugarcane (or more likely sugar beet in Europe) will be a net carbon sink (i.e. absorbing more CO_2 than is released) by 2050. This assumption is used in the present study but is highly uncertain.

The uncertainty around the future impacts of bio-based production combined with the current technical difficulty in producing 100% bio-based PET—the constituent monomer TPA which makes up 70% of PET is not commercially available— means this intervention is given a high-risk rating at this time.

Figure 3-3: PET Net Zero Contributions



Low carbon production represents the decarbonisation of the conversion process (i.e. blow moulding). As this is mostly electricity use, it is expected that this reduction will take place as national electrical grids decarbonise. It is therefore given a low-risk rating.

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[13] Zheng, J., and Suh, S. (2019) Strategies to reduce the global carbon footprint of plastics, Nature Climate Change, Vol.9, pp.374–378.

[14] Zero Waste Europe (2022), How Circular is PET?

However, decarbonising the grid also has the effect of reducing the credits received from the energy produced during plastic waste incineration (to the point where burning this in an incinerator would lead to similar emissions to that of burning fossil fuels). This means that whilst low carbon production can significantly contribute to decarbonising PET, any material that is not recycled will have a much higher impact during the transition from fossil to bio-based plastic. The result is that recycling becomes increasingly important as it not only removes the need for virgin production but reduces the impact of incineration.

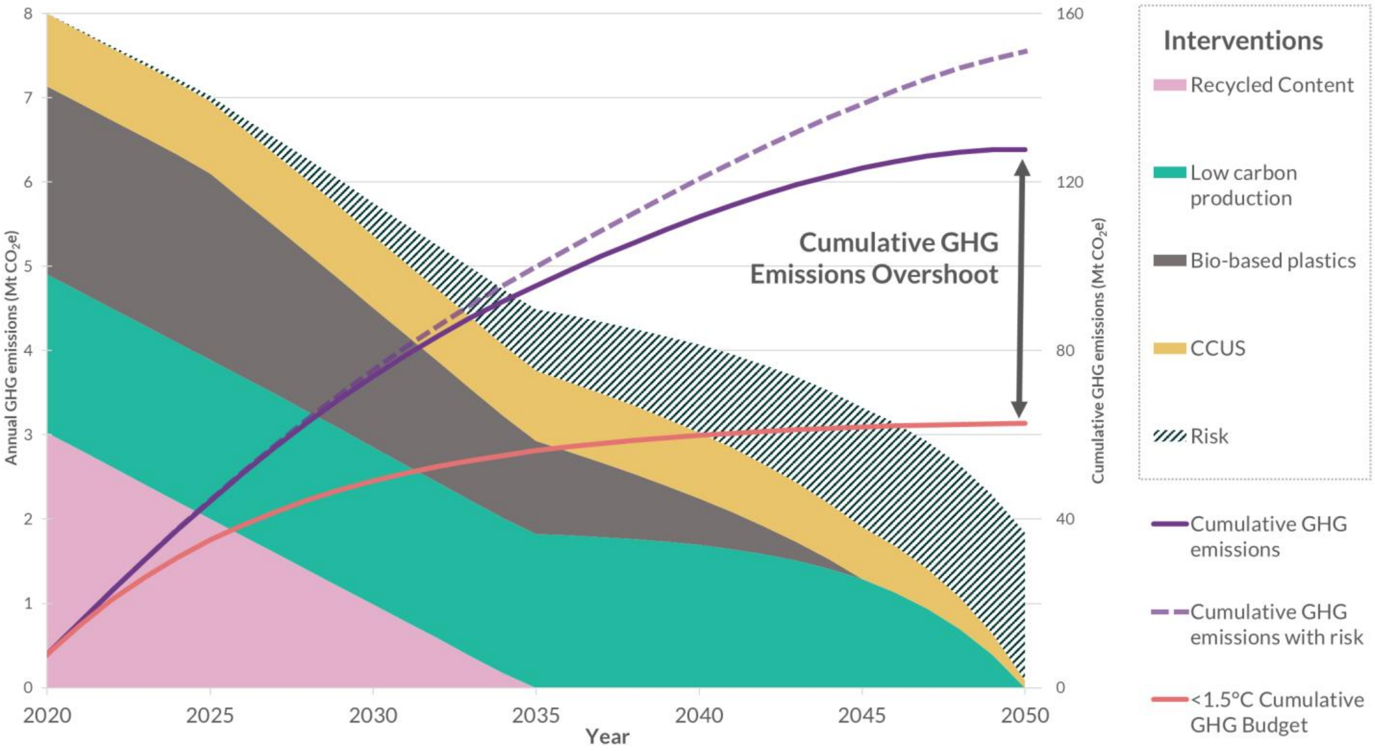
All remaining emissions (beyond those from energy use) are expected to be captured through CCUS. This is given a high-risk rating, not just due to the technological development, but owing to the uncertainty around where in the value chain these emissions will come from and how practical it will be to use CCUS (for example, SME's that cannot afford CCUS).

An aspect that has not been included within the trajectory is the potential for steam cracking—the process of producing monomers from hydrocarbons—to be run on hydrogen or electricity rather than fossil fuels. The adoption of either of these energy types for this process is highly uncertain and the plastics industry has not committed to a firm pathway at present. However, even with this intervention, the reliance will still be on feeding the steam crackers with fossil fuels in the short to medium term. Alternatives such as using chemically recycled or bio-based feedstocks (in place of fossil hydrocarbons) are not well developed and subject to questions around their credibility at present.

Steam cracking is used for the production of MEG (mono ethylene glycol), but not the second constitute monomer, TPA. Very little information is currently available on how TPA production will be decarbonised although it is likely to involve similar energy transitions and short-term reliance on fossil hydrocarbons.

Figure 3-4 shows the results of modelling the trajectory towards Net Zero with these interventions. The pathway demonstrates that there are considerable technical challenges in achieving Net Zero leading to a cumulative emissions overshoot of +150% when risk is accounted for. This uncertainty around particular solutions such as how to implement bio-based plastics is also problematic as is can lead to fragmented action, or even inaction in the short term. It is clear that a focus on circularity is needed and is likely to achieve significant improvement over the next decade particularly if novel chemical recycling technologies allow for recycled content across the industry to be pushed above 80%. However, the analysis shows that other interventions are as, if not more important over the long term.

Figure 3-4: Modelling Potential Net Zero Trajectory for Beverage PET



3.3 Glass Bottles

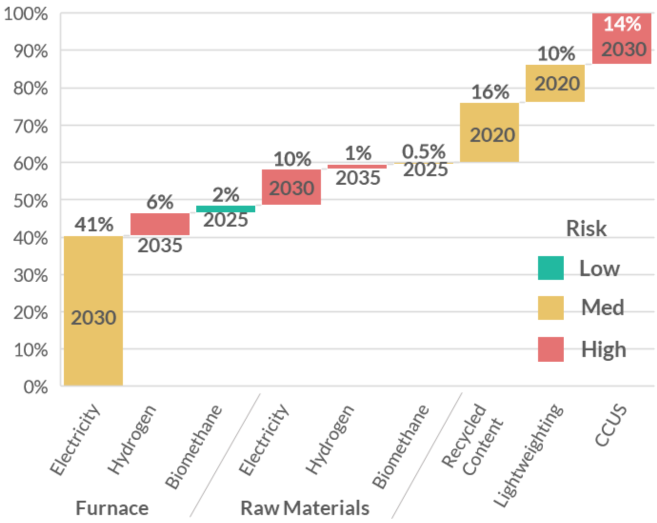
There is currently no published decarbonisation pathway for European container glass. This study therefore draws upon information presented in the British Glass Net Zero Strategy.[15] The strategy lacks in specific details therefore the carbon emissions of European glass container production were calculated on a bottom-up basis detailed in Appendix A 1.0.

The key interventions highlighted in the strategy revolve primarily around the switch to different fuels. A switch to electricity from natural gas is generally viewed as the main way to reduce these emissions. Figure 3-5 shows a significant contribution to decarbonisation from electrifying glass furnaces as well as in the electrification of energy supplies used in the production of inputs to the glass production process – in total around 50% of the decarbonisation effort comes from these two elements. The risk associated with the use of electricity for decarbonising the material inputs is considered to be higher than that associated with the use of electricity for the furnace; as yet there is no clear path for decarbonising the soda ash industry and of its constituent inputs such as ammonia. By contrast, some fully electric furnaces are already in operation for glass, and this is therefore given a medium risk rating, taking into account the financial viability issues with such a move.

Alongside a switch to electricity alternative fuels are also included such as hydrogen and biomethane. These are anticipated to be used as part of 'hybrid' furnaces; the modelled strategy assumes that, overall, 80% of the energy used in the furnaces comes from electricity with the remaining 20% from burning these alternative fuels. Biomethane is considered low risk as it is already in use in some industries although on site storage space is a hurdle to overcome. Hydrogen is high-risk as it is not yet commercially available, and it is expected there will be substantial competition for this fuel in the future.

CCUS similarly is used to tackle both emissions from the combustion of inputs in the furnace as well as process emissions arising from the production of inputs to the glass process. These direct emissions from the chemical reactions are not anticipated to be easy to abate under current technologies so may need to be directly captured.

Figure 3-5 – Glass Net Zero Contributions



An increase in recycled content will also play a part in reducing emissions, although furnace energy use is only reduced by 2.5% for every 10% recycled cullet.[16] It is also unclear what the average cullet use is throughout Europe as up to date figures are not available (published 'recycling rates' often include non-remelt applications). Recycled content could be as high as 65% in Germany, with France at around 42%[17] - the latter is therefore used as an optimistic starting point for Europe as a whole.

[15] British Glass (2021), Glass sector Net Zero strategy 2050

[16] JRC (2012), Best Available Techniques (BAT) Reference Document for Manufacture of Glass

[17] Zero Waste Europe (2022), How Circular is Glass?

There are various factors that affect the technical upper limit for recycled content, but this is mostly dictated by the collection and sorting systems, so will not reach 100%. Additionally, the movement of glass around Europe and the availability of particular types (colours) of cullet locally for remelt poses an additional challenge to reaching high recycled content. With improvements in these areas, it is thought that Germany could increase to 70% (with an 87% collection rate) under current conditions.[18]

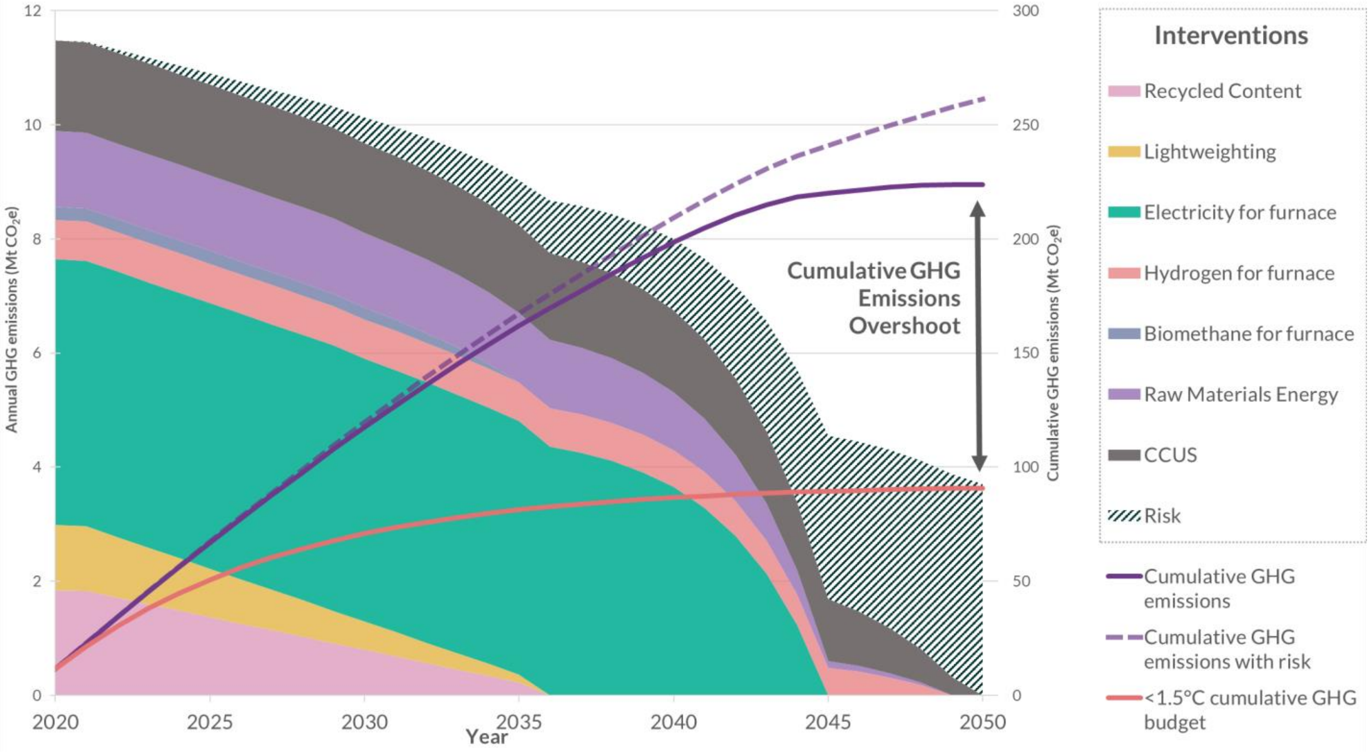
From a process perspective, there is a technical limitation of 55% cullet for electric only furnaces that has yet to be overcome – gas or hybrid furnaces don't have this limitation and therefore maximum cullet can be 60% (white glass) – 90% (green glass).[19]

Considering these factors an upper limit of 80% is used in this study to help understand whether focusing on improving the last few percentage points is worthwhile. However, due to highlighted uncertainties and technical barrier, increases in recycled content is given a medium risk.

Finally, a contribution from lightweighting is assumed to occur. This is not specifically identified by the glass industry as a key intervention, but it is being considered in both policy interventions and by end users of glass containers who recognise the high impact of their bottles relative to the contents (31% for wine).[20] Whilst the limit of this intervention is not known—some bottles are much heavier than others—a conservative 10% reduction is applied to show how this might impact the Net Zero pathway. A medium risk is applied as there are conflicting opinions around lightweighting with the European container glass body actively lobbying against policy intervention in this area.[21]Figure 3-6 shows the decarbonisation pathway modelled with the discussed interventions. It should be noted that much of the activity does not significantly get underway until 2030 or later. Only progress on recycled content and lightweighting is assumed to be starting from 2020. This, combined with the level of risk associated with the key technologies used in the interventions means that the annual GHG emissions by 2050 could still be well above zero; this leads to a cumulative performance that twice the budget when risk is included.

Importantly, whilst increasing circularity can contribute to the trajectory, the contribution is relatively small compared with impacts associated with decarbonising the production process. This is principally because a glass furnace still needs 75% of the energy to remelt cullet (~1.5MWh/tonne vs 2MWh/tonne).

Figure 3-6: Modelling Potential Net Zero Trajectory for Beverage Glass



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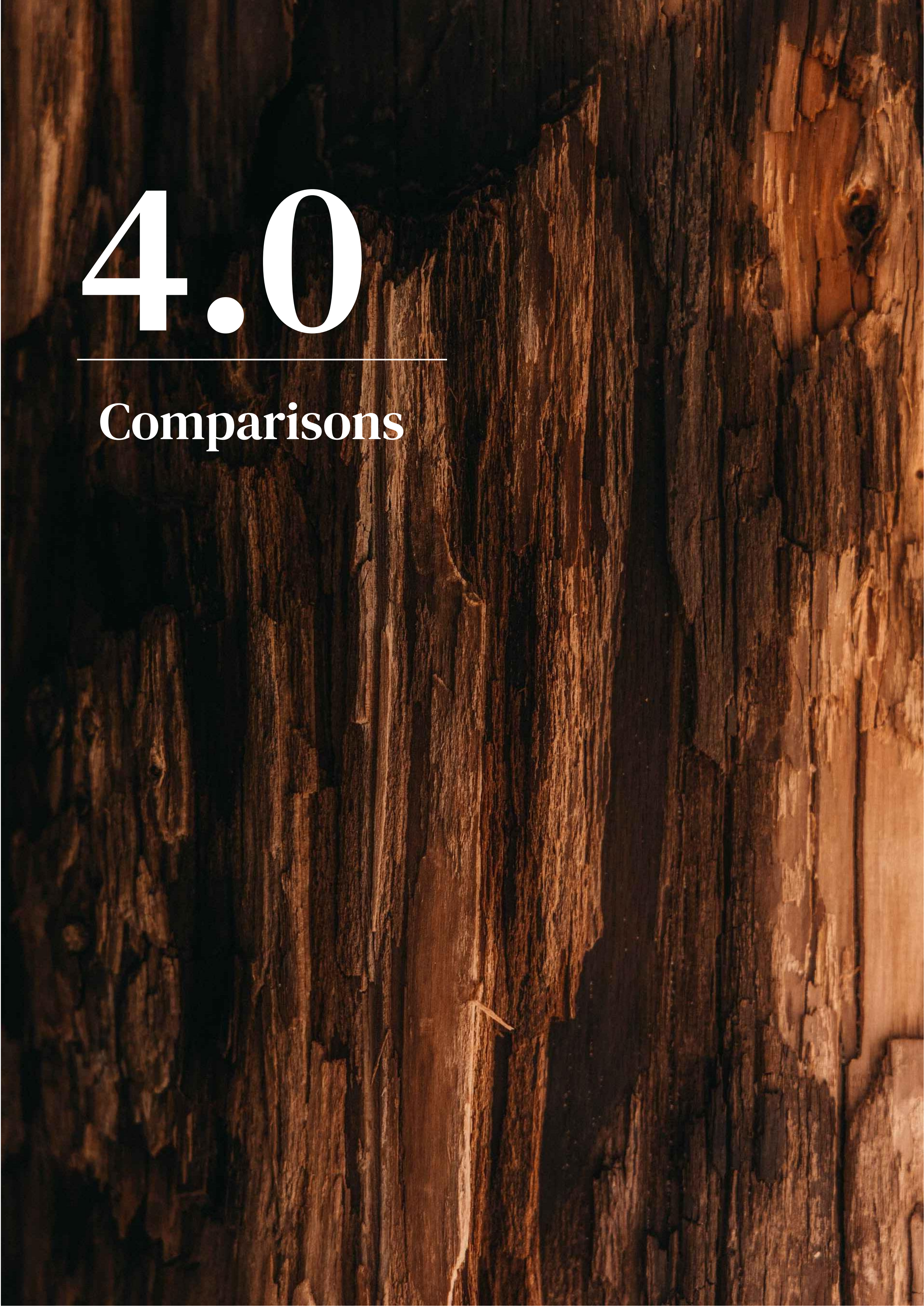
[18] ibid

[19] Zier M, Pflugradt N, Stenzel P, Kotzer L and Stolten D (2023) Industrial Decarbonization Pathways: the Example of the German Glass Industry, Energy Conversion and Management, X 17, 100336

[20] Wine Society (2023), Tackling climate change: how we will cut carbon emissions.

[21] https://feve.org/ppwr-design-innovation-sustainable-growthy/



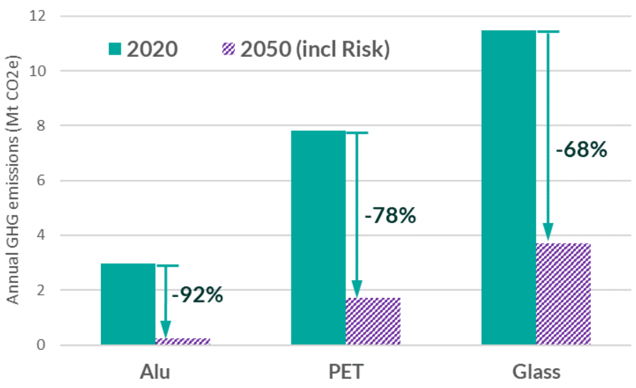
4.0

Comparisons

4.1 Reaching Net Zero

Figure 4-1 shows each of the materials ***annual*** GHG emissions estimated for 2020 and projected for 2050 for key materials used in the EU beverage sector. Whilst the aim is Net Zero by 2050, when the risk associated with the different interventions is included, all materials may miss this target. With risk accounted for, the scenarios modelled for this study show that glass used for European beverage packaging could see an emissions reduction of 68% between 2020 and 2050; PET has a larger reduction of 78%, and aluminium gets closest to Net Zero with a 92% reduction.

Figure 4-1: Annual GHG Emissions for EU Beverage Containers – Present and 2050 *with implemented decarbonisation strategies.

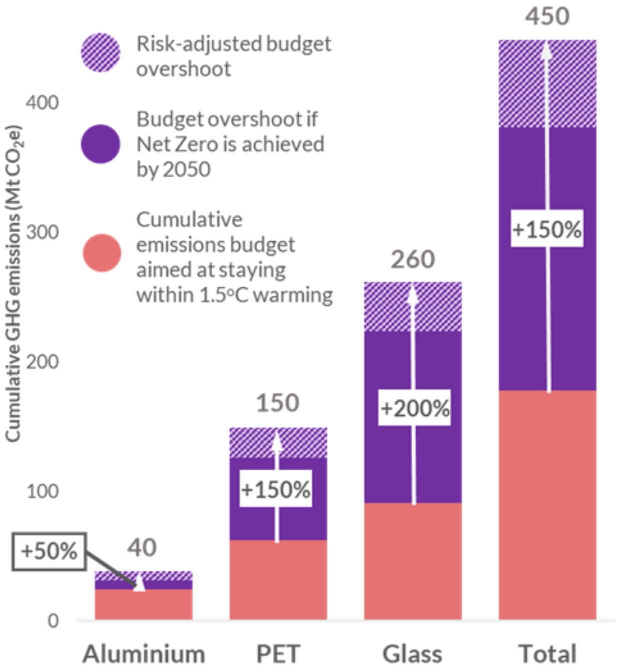


4.2 Comparing to the Budgets

Figure 4-2 illustrates the cumulative GHG emissions of each material compared to the 1.5°C aligned budget, including the combined budget for beverage packaging using these three materials. The projections indicate that, collectively, the materials are expected to surpass the allocated budget by +150% including risk adjustment, with glass and PET being significant contributors to this exceedance at +200% and +150% respectively. Aluminium's budget overshot is estimated to be around 50%.

Although aluminium's contribution to overall GHG emissions is relatively low, it is responsible for 20% of the packaging units—which is half that of both glass and PET—whilst delivering around 10% of beverages by volume as it generally appears in the smaller container sizes. Because of this, comparisons of performance per unit of packaging are made in the following section.

Figure 4-2: Cumulative EU Beverage Container GHG Emissions to 2050



The growth rate for the consumption of all materials by the beverage packaging sector is assumed to be zero (i.e. the same demand in 2050 as 2020). It is considered unlikely that overall container use can continue to grow indefinitely. Alongside this, the EU population is expected to be lower by 2050 than it is today,[22] and we would expect container use to have a close relationship to population size. Nevertheless, the results show that even with no growth in material consumption, the beverage container industry is likely to significantly overshoot the proposed cumulative emissions budget.

Staying within the budget is therefore likely to require a number of strategies to ***reduce material demand*** overall which can include:

- Developing reuse systems, particularly for glass, while being cautious of potential shifts in emissions burdens to other sectors beyond material production.
- Incentivising the transition to single-use packaging materials that have more credible decarbonisation pathways and require less material usage.; and,
- Exploring alternative packaging innovations, such as various paper or card-based options, to determine if they offer more preferable environmental characteristics.

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[22] https://ec.europa.eu/eurostat/web/population-demography/population-projections

4.3 Comparing GHG Emissions Pathways on a Unit Basis

To provide further contextualisation of the differences between the materials, results are shown in Figure 4-3 per container rather than as total industry emissions shown in the previous sections.

This figure considers the projected GHG emissions for each year, including the risk factor, divided by the weight of material used in a hypothetical 500ml container. Different typical weight ranges for containers of each material are considered, particularly for PET, where packaging weight limitations are often more technical than commercial—thicker bottles are required for carbonated drinks compared with beverages such as water (see Table 4-1). Aluminium exhibits a narrower weight range per container due to the need for pressurisation in all cans, resulting in greater standardisation across brands. In contrast, glass containers have a wider weight range as they can vary significantly between brands and drink types with limited standardisation. Midpoints are shown for context.

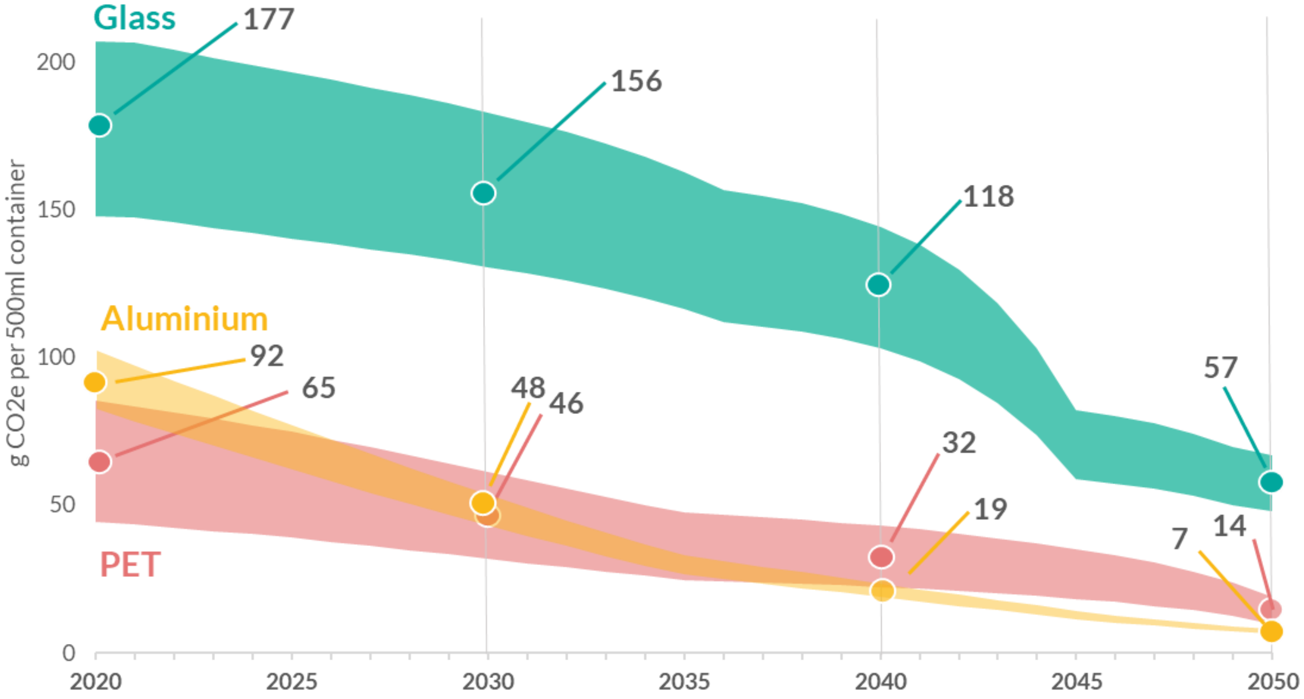
These results indicate that the GHG emissions per unit of packaging material are consistently three to four times higher for glass bottles compared to aluminium and PET throughout the decarbonisation pathway. Even when accounting for uncertainties in each material's pathway, it seems unlikely that this performance gap can be bridged, especially considering that glass's projected endpoint by 2050 is similar to or higher than the emissions of aluminium and PET by 2030. Such a significant difference in magnitude would pose a considerable challenge to overcome.

Both aluminium and PET exhibit similar trends along the pathway, and the speed and effectiveness of decarbonisation interventions could lead to one outperforming the other, particularly from 2030 onwards. However, both materials need to prioritize the development of credible pathways towards net-zero emissions since they are expected to exceed their respective budgets.

Table 4-1: 500ml Beverage Container Mass Ranges[23]

Container	Lower	Upper
Aluminium Can	14.5g	18g
PET Bottle	13g	25g
Glass Bottle	250g	350g

Figure 4-3: EU Beverage Container Decarbonisation Projections – per Typical 500ml Container Range



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[23] Note that the results are based on typical ranges and do not account for the potential extremes that may exist in the market in practice. It is important to acknowledge that certain PET bottles, for instance, can weigh 30 grams or even more.

5.0

Key Findings & Recommendations

5.1 Key findings

The following summarises the key findings of this report:

- All three materials face significant challenges in decarbonization, posing a risk to achieving net-zero emissions by 2050. The most pressing challenges are as follows:
    - ***Aluminium*** **–** Transitioning the smelting process to run on green energy will necessitate substantial investments due to its high energy requirement (~15MWh/tonne).
    - ***PET*** **–** A fundamental shift in the value chain to bio-based feedstock is necessary, but technical hurdles currently exist and may conflict with the fossil-focused nature of the industry.
    - ***Glass*** **–** electrifying gas furnaces will require either a costly and complete infrastructure upgrade or a gradual replacement of legacy systems. Despite efforts, glass manufacturing will continue to have high energy consumption (~2MWh/tonne).
- All three materials are projected to surpass their allocated carbon budget, with glass exhibiting the highest proportional exceedance. The beverage packaging sector in the EU as a whole is expected to exceed its total carbon budget. It is evident that sustaining or increasing current demand for beverage packaging materials is incongruent with achieving a future of less than 1.5°C global warming.
- The inferior performance of glass becomes more pronounced when comparing the specific unit weights of glass containers to those made of aluminium and PET. The findings consistently demonstrate that the production of glass bottles results in three to four times higher greenhouse gas (GHG) emissions compared to aluminium and PET throughout their respective decarbonisation pathways.
- Enhancing recycling and circularity practices appears to be of utmost importance for aluminium and PET, but it holds significantly less significance for glass. This disparity arises from the fact that producing aluminium from recycled content has a significantly lower impact than using virgin materials, whereas PET that is not recycled is often incinerated. In contrast, glass lacks these drivers, and substantial energy consumption persists even with high levels of recycled content.
- Recycled glass still requires 75% of the energy needed for virgin glass production, whereas aluminium only requires approximately 10%. Consequently, both materials require approximately 1.5MWh/tonne for recycling. However, it's important to note that aluminium cans fulfil the same container function as glass while requiring significantly less mass. These characteristics are inherent to the properties of the materials and are unlikely to change over time.

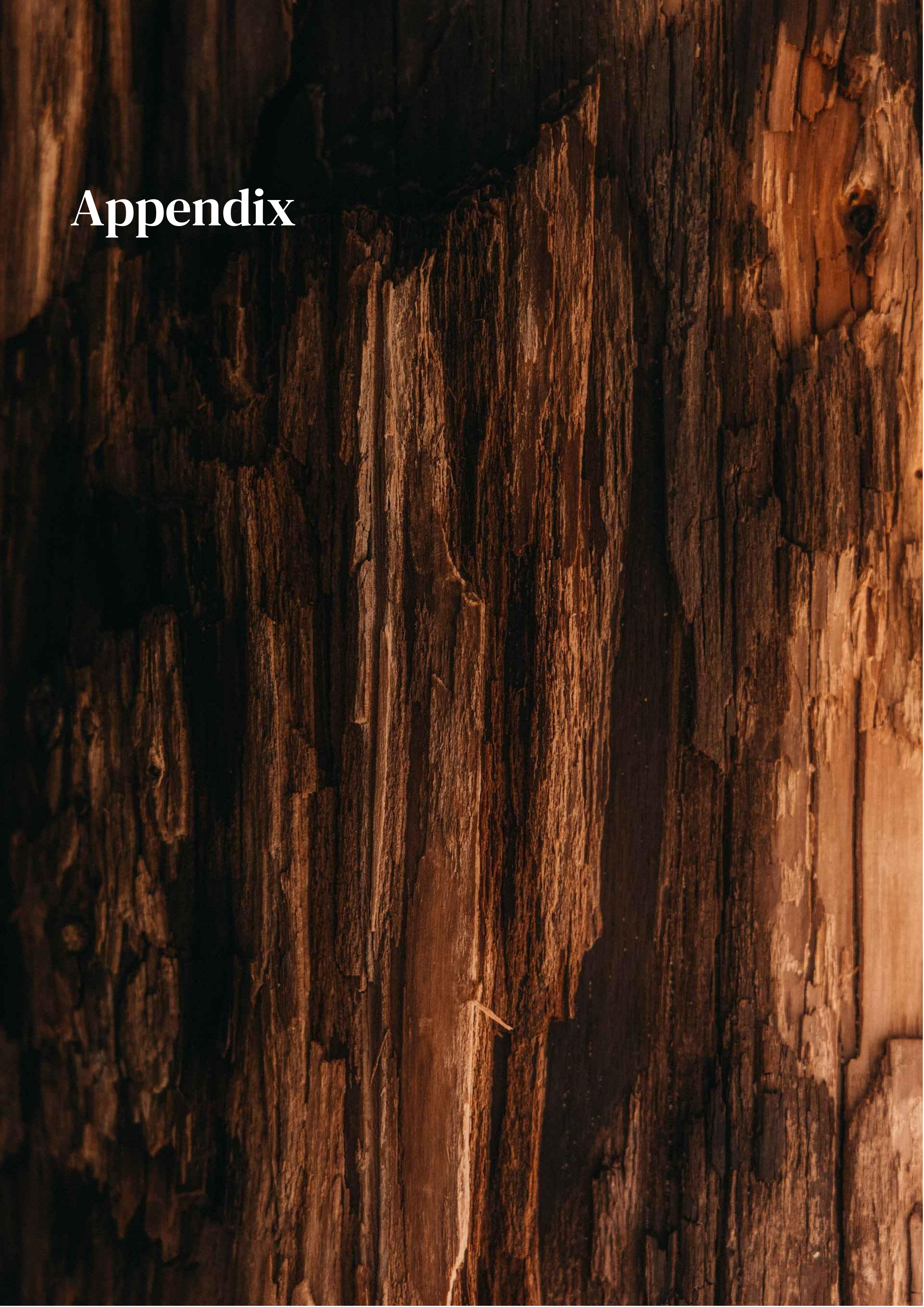
5.2 Recommendations

The challenge lies in the fact that all the materials in this study require significant technological investment to transition towards Net Zero. However, it is evident that reducing material demand should be a top priority. Under current business models in a market-driven economy, these two ideas are conflicting. Hence, it is crucial to separate the amount of material sold from the value derived from it. Developing reuse systems for beverage containers appears to be the most promising approach to achieve this goal. Nonetheless, it is important to ensure that reduced material demand does not result in a transfer of emissions burdens elsewhere, including sectors outside of material production.

Furthermore, it is evident that both PET and aluminium offer more compelling options compared to glass in single use applications. From a purely climate change perspective, switching to these materials may be preferable. However, reducing demand for glass presents challenges, as weight reduction can only go so far. Given that glass is highly suitable for reuse, adopting a system that promotes reuse is likely to significantly decrease glass demand in terms of mass (but maintaining unit use). Therefore, it would informative to examine decarbonisation pathways for beverage container materials while accounting for reuse. It is important to expand the system boundaries to encompass the entire lifecycle, as the impacts of reuse systems extend beyond material use.

Moreover, it is essential to conduct comparative studies that consider the decarbonisation pathways rather than focusing on a single point in time, typically the present day. Such studies will provide a more comprehensive understanding, particularly when the burdens shift from material to energy in reuse systems (e.g. reducing materials, but increasing transport). This aspect warrants further investigation, along with broader efforts to optimise reuse systems.

Appendix



A 1.0 Decarbonisation Risk Ratings

The following tables summary the key interventions and the risk rating given. As this is a qualitative assessment, the justification for the ratings is also described.

Table A 1 – Risk Ratings for Aluminium Interventions

Intervention		Risk Rating	Justification
Electricity Decarbonisation		Medium	Technical feasibility of electricity decarbonisation for the smelting process is proven and being used 93% of the time in Europe, but only 31% globally. For aluminium sourced outside of Europe, decarbonisation is therefore more challenging.[24]
Resource Efficiency		Low	Incremental gains to the overall efficiency of aluminium production are likely to continually take place.
Recycled Content		Low	There are strong policy drivers in place to drive recycling in the EU and no technical limitations to achieving 90% recycled content.
Direct Emissions	**CCUS**	High	Expensive and unproven at scale technology.
	Inert Anode Technology	Medium	Technical feasibility is likely to be proven soon at a commercial scale and plants can be retrofitted. It is claimed that operating costs can be reduced as a result, so there will be a strong incentive to switch. [25]
	Hydrogen	High	Natural gas is used in alumina refining and can be replaced with hydrogen. This is in a very early technical stage and access to green hydrogen will be subject to high competition and it is unclear how the required amounts can be feasibly produced.
	Mechanical Vapour Recompression	Medium	Potentially a large contributor to reducing alumina refining GHG emissions by reducing reliance on natural gas for steam production. Retrofit trials are currently underway in Australia.[26]

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[24] https://international-aluminium.org/statistics/primary-aluminium-smelting-power-consumption/

[25] https://www.alcoa.com/sustainability/en/elysis

[26] https://arena.gov.au/projects/mechanical-vapour-recompression-for-low-carbon-alumina-refining/

Table A 2 – Risk Ratings for PET Interventions

Intervention	Risk Rating	Justification
Recycled Content	Low	There are strong policy drivers in the EU towards increasing the separate collection and recycling of PET and inclusion of recycled content. There are no technical barriers to reaching 75% recycled content if the supply of material is available. This could go higher if chemical recycling (notably depolymerisation) technologies come online.
Bio-based Plastics	High	There are significant challenges in the transition to bio-based plastics in general which include the relative lack of policy drivers and incentives. Combined with the immaturity of the sector, means that costs can be higher than fossil-based versions. For PET, the technical feasibility of 100% bio-based is yet to be proven at a commercial scale as there are still challenges in producing bio-based MEG at present. Furthermore, there are challenges from other bio-based polymers such as PLA and PEF which may make PET obsolete, but also make the transition pathway uncertain.
Low Carbon Production	Low	This specifically references the downstream conversion processes (and not the production of the polymer itself). Decarbonisation of the national electricity grids will naturally lead to a reduction in production impacts.
CCUS	High	Expensive and unproven at scale technology, plus it is unclear how it will be implemented in this sector.

Table A 3 – Risk Ratings for Glass Interventions

Intervention		Risk Rating	Justification
Furnace	**Electricity**	Medium	The conversion to electricity requires significant capital investment and has yet to be fully commercialised at scale. A hybrid (80% electricity, 20% gas) furnace is being installed in Germany with a 100kt+ capacity, although the electricity will be from the grid and hence not entirely renewable.[27] Fully electric and renewable European furnaces are therefore some way off.
	Hydrogen	High	Any residual need for natural gas can be filled by replacing with hydrogen. This is in a very early technical stage and access to green hydrogen will be subject to high competition and it is unclear how the required amounts can be feasibly produced. Trials are ongoing for *sheet* glass in the UK[28], and announcements have been made that *container* glass facilities could be built by the end of the decade.[29]
	Biomethane	Low	Any residual need for natural gas can be filled by replacing with biomethane. This should technically be a like for like replacement and successful trial have been run.[30] Access to the required volumes is the principal risk here.
Raw Materials	**Electricity**	High	Very little is known or proposed around the decarbonisation of raw materials such as soda ash and therefore it is assumed that similar energy transition technologies will be needed, but given the lack of commitment, the risk is assumed to be higher more generally.
	Hydrogen	High	
	Biofuels	Medium	The coal used in the soda ash process can be replaced with biomass (wood chips), and this is being trialled in Germany at present.[31]
Recycled Content		Medium	The drivers towards increasing recycled content (from an estimated 42% to 80%) are not as strong as the other materials and there are challenges in the collection systems that create a natural ceiling of around 65% currently.[32] This is paired with reported technical issues preventing high levels of recycled content being included in electric only furnaces.
Lightweighting		Medium	A 10% reduction in average mass is likely to be technical feasible, but there is resistance from the glass industry and a lack of policy drivers to make this happen. Brand owners may be key to pushing this change where the mass of the bottle is not associated with premiumisation.
CCUS		High	Expensive and unproven at scale technology, plus it is unclear how it will be implemented in this sector.

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[27] https://www.ardaghgroup.com/news-centre/ardagh-glass-packaging-builds-breakthrough-nextgen-furnace-in-germany
[28] https://hynet.co.uk/wp-content/uploads/2021/08/24082021-World-first-as-100-hydrogen-fired-at-Pilkington-Glass.docx.pdf
[29] https://www.diageo.com/en/news-and-media/press-releases/2022/encirc-and-diageo-announce-hydrogen-powered-furnace-to-change-the-face-of-uk-glass-manufacturing-industry
[30] https://www.renewableenergymagazine.com/biofuels/20210208
[31] https://www.solvay.com/en/press-release/solvay-to-phase-out-coal-energy-use-in-rheinberg-soda-ash-plant
[32] https://zerowasteeurope.eu/wp-content/uploads/2022/08/HOW-CIRCULAR-IS-GLASS.pdf

A 2.0 Glass

A 2.1 General Approach to Modelling the Decarbonisation of Glass

Unlike for other materials sectors such as aluminium, there is no one single source for modelling a decarbonisation pathway or sectorial emissions for overall glass production at a global level. Given this, it was necessary to calculate the carbon emissions of European glass container production on a bottom-up basis. Impacts were calculated per tonne of glass and then scaled up based on tonnage figures for containers.

Two main types of glass are manufactured on a global scale – flat glass, used for windows; and container glass. The production process differs somewhat for the two different types of glass as a consequence of quality requirements, and this, in turn, has an impact on some aspects of the decarbonisation pathway. This report is focussed on container glass, and so assumptions have been developed on that are relevant for this type of product.

The UK association British Glass has published a Net Zero strategy[33] for the UK glass industry. This is felt to be a reasonable starting point for the modelling developed here, as much of UK production is focussed on the manufacture of containers. There is a lack of detail in the UK strategy with regards to the impact of some processing stages and the decarbonisation of inputs; as such, further support for the approach is also provided in the academic literature for China[34] and Germany[35].

Carbon emissions from glass production comprise of:

- **Embodied emissions** from manufacturing the key inputs to the glass production process; impacts are more significant for soda ash and carbonates such as limestone, with a smaller contribution from the use of silica.
- **Process emissions** from combusting the inputs. Glass manufacture typically results in direct emissions of CO_2 as a result combustion of the carbonates that are added as a raw material in manufacture, which are subsequently combusted as part of the process.
- **Energy** used in the manufacturing process – a relatively large amount is used directly for melting the inputs in the furnace, since this requires high temperatures to be reached.

The modelling work considers these three elements separately in terms of the contribution made from each towards emissions totals, and then looks at how the decarbonisation pathway would affect each of these aspects.

A 2.1.1 Embodied Emissions

Raw material inputs to the glass manufacturing process in tonnage terms are set out in Table A 4, with values provided for production in 2020 and 2050. The cullet contributions are based on closed loop recycling. There is a lack of published data on performance in this respect for Europe as a whole; as such, the figure here is based on a more detailed exploration of the situation in France which is taken to be more representative of the European situation as a whole. It is noted that some countries have higher performance, such as Germany, although many others will also be performing less well than this.

As is the case with other materials used in container manufacture, recycling is assumed to increase significantly by 2050, and this in turn reduces the need for raw material inputs (scaled down accordingly), thereby reducing emissions.

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[33] British Glass (u.d.) Glass Sector Net Zero Strategy 2050

[34] Hu P, Li Y, Zhang X, Guo Z & Zhang P (2018) CO2 emission from container glass in China, and emission reduction strategy analysis, Carbon Management, 9:3, pp303-310

[35] Zier M, Stenzel P, Kotzer L and Stolten D (2021) A Review of Decarbonization Options for the Glass Industry, Energy Conversion and Management, X 10, 100083

Table A 4: Raw material input assumptions for the glass manufacturing process

	Inputs to glass container production	
	2020	2050
Soda ash	11%	4%
Limestone	7%	3%
Silica	32%	13%
Cullet use (from recycling)	42%	80%
Notes 1.2 tonne of inputs needed per tonne of glass manufactured (British Glass)		

Sources: British Glass (u.d.) Glass Sector Net Zero Strategy 2050; Westbroek C, Bitting J, Craglia M, Azevedo J and Cullen J (2021) Global Material Flow Analysis of Glass: From Raw Materials to End of Life, Journal of Industrial Ecology, 25, p333-343

There is no reliable data available for the recycled content of European container glass. Current day assumptions on cullet use are based on data obtained in a previous Eunomia study which explored the use of recycled content in France.[36] Data is also available from the same study for Germany but this has a better performing system and is felt to be less appropriate for modelling the performance of the whole of Europe in the current day. The modelling assumes 80%.

Energy requirements related to soda ash production are shown in Table A 5. This confirms that soda ash production itself also requires a significant amount of thermal energy, primarily for ammonia production.

In addition, there is an additional energy requirement associated with the use of limestone of 745 kWh per tonne (split equally between electricity and gas); this relates to the use of precipitated calcium carbonate, based on Ecoinvent data.

Emissions impacts from inputs to the process are relatively significant; this is reflected in the British Glass strategy where the inputs account for 26% of total emissions even with a 70% recycling rate.[37] Further increases in the use of recycled content reduces these impacts.

Table A 5: Energy requirements for the soda ash production process

kWh per kg of soda ash	Input energy requirements for constituent components of soda ash			Production process energy
	Ammonia	Carbon Dioxide	Sodium chloride	
Electricity	0.035	0.079	0.089	0.301
Thermal	2.767	0.667	0.103	0.503

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[36] Eunomia (2022) How Circular is Glass? A report on the circularity of single-use glass packaging, using Germany, France, the UK and the USA as case studies. Report for Zero Waste Europe, July 2022

[37] The recycling rate is higher than the recycled content figure as, in the UK sector, a lot of glass is not recycled through closed loop routes

A 2.1.2 Process Emissions

The combustion in the furnace of carbonate inputs to the glass manufacturing process - such as limestone - results in CO_2 emissions. Process emissions also occur during the manufacture of limestone.

Table A 6: Process emissions

Process emissions (tCO2e)	Soda ash	Limestone
Process emissions from input stage, per tonne of input	0.00	0.83
Furnace process emissions, per tonne of glass	0.34	0.37

Source: Derived from Zier M, Stenzel P, Kotzer L and Stolten D (2021) A Review of Decarbonization Options for the Glass Industry, Energy Conversion and Management, X 10, 100083

A 2.1.3 Energy Use in Glass Manufacture

There is considerable variation in the MJ / tonne of glass energy figures in the published literature. Some sources suggest this is as little as 2,000 MJ[38] per tonne of production, but this does not seem supported by other detailed analyses elsewhere, such as Chinese analysis (which says its figures come from actual site data)[39] and the total site energy figures cited in the British Glass Net Zero strategy. Data published by British Glass with regards to total site energy figures indicate the energy requirement is in the order of 6,000 MJ of gas and 1,000 MJ electricity per tonne of glass;[40] the average site energy use for the Chinese facilities is somewhat higher at 9,000 MJ (although it is noted there is a considerable range in the dataset with the top end of the range up at nearly double this figure)[41].

Whilst furnaces outside Europe may use a range of fuels including coal, in Europe, they are currently largely fuelled by natural gas, as is the case in the UK.[42] There are only modest energy savings associated with increased use of cullet, and significant energy requirements remain for the furnace even at high cullet levels for melting to take place.[43]

A 2.2 Modelling Decarbonisation Pathways

Although UK has set out a specific pathway some details are not clearly set out – in particular, the approach for decarbonising the embodied carbon in the inputs is not well explained. The decarbonisation options for the industry are also explored to a certain extent in other papers but these do not make clear the need to also decarbonise key inputs such as soda ash.[44]

A 2.2.1 Process Emissions and Inputs

There are some process emissions remaining even at relatively high cullet levels – these include emissions from the limestone production process. It is assumed that CCS is largely used to mitigate these impacts, in line with British Glass strategy. The UK strategy also mentions the use of calciners to reduce raw material inputs but use of these is modest in terms of its reduction potential.

Inputs to the process – such as soda ash and limestone – make a relatively significant contribution to remaining emissions. Around a quarter of current emissions are from raw inputs

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[38] Zier M, Stenzel P, Kotzer L and Stolten D (2021) A Review of Decarbonization Options for the Glass Industry, Energy Conversion and Management, X 10, 100083

[39] Hu P, Li Y, Zhang X, Guo Z & Zhang P (2018) CO_2 emission from container glass in China, and emission reduction strategy analysis, Carbon Management, 9:3, pp303-310

[40] British Glass (u.d.) Glass Sector Net Zero Strategy 2050

[41] Hu P, Li Y, Zhang X, Guo Z & Zhang P (2018) CO_2 emission from container glass in China, and emission reduction strategy analysis, Carbon Management, 9:3, pp303-310

[42] Zier M, Stenzel P, Kotzer L and Stolten D (2021) A Review of Decarbonization Options for the Glass Industry, Energy Conversion and Management, X 10, 100083

[43] Westbroek C, Bitting J, Craglia M, Azevedo J and Cullen J (2021) Global Material Flow Analysis of Glass: From Raw Materials to End of Life, Journal of Industrial Ecology, 25, p333-343

[44] Sources include: Zier M, Pflugradt N, Stenzel P, Kotzer L and Stolten D (2023) Industrial Decarbonization Pathways: the Example of the German Glass Industry, Energy Conversion and Management, X 17, 100336; BEIS (2019) Industrial Fuel Switching Phase 2: Alternative Fuel Switching Technologies for the Glass Sector

even with significant cullet use in UK production. The mitigation approach to tackling these impacts is not clearly set out in the British Glass strategy. There is a significant “decarbonisation of grid” element which accounts for a larger share of emissions than would be accounted for by the furnace energy use alone. Given that the approach to soda ash decarbonisation is not explained specifically, the shift of soda ash production processes towards the use of electrification also appears plausible.

A 2.2.2 Electrification

A key element of the UK strategy is the electrification of furnace energy use. British Glass strategy assumes an 80% shift towards electrification, with smaller furnaces assumed to be fuelled 100% by electricity. It is further assumed larger ones take a hybrid approach, mixing electrification with other zero carbon fuels, assumed predominantly hydrogen in the UK case. The European glass container association FEVE also appears to be exploring the use of biofuels, considered to be a transition technology in the UK strategy (with respect to the use of biodiesel); a small amount (5%) of biomethane is therefore also considered to contribute to future fuelling.[45]

Electric melting is already well established for smaller furnaces. Under current technologies there are capacity constraints; the largest commercial fully-electric furnaces available have a capacity of upwards of 300t/day and significant further developments in furnace design are required if this is to provide a low carbon replacement for new furnaces that can have a capacity of up to 900t/day.[46] However, container furnaces tender to be smaller than those producing flat glass so this is considered to be less of a limitation for container glass production than it is for the glass industry as a whole.

A 2.2.3 Lightweighting

This was not included in the British Glass decarbonisation strategy. It is, however, included here, as it is already being considered by the industry for some parts of the container industry such as for wine bottles. Lightweighting is therefore considered to account for 10% of the decarbonisation pathway by 2050.

A 2.3 Accounting for Risks in The Pathway

There is considerable risk associated with the shift towards the complete electrification of furnaces. This is associated both with technical constraints – connected with furnace size based on the currently available technologies - as well as impacts associated with the relatively high cost of electricity in comparison with other fuels such as gas on which furnaces currently rely.

Research is currently ongoing with respect to the development of large all-electric glass furnaces. The potential is being assessed with techniques such as computational fluid dynamics (CFD) which considers the behaviour of fluids such as molten glass. An assessment of the potential in the UK by the government department BEIS indicates CFD modelling techniques have demonstrated that large all-electric furnaces are possible, but not with the conventional vertical melting techniques that are currently in use.[47] Horizontal electrical melting is therefore being investigated; this is considered promising, but the demonstration of viability is essential before adoption is likely to occur. The additional advantage of all-electric horizontal melting is that this utilises an almost identical footprint as is the case with existing furnaces.

Whilst the technical feasibility of 100% electric furnaces is considered by such studies to be promising, there remain significant economic barriers to its uptake. In this context the BEIS study notes that greatest concerns relate to the future economic viability of using electricity, primarily due to the higher cost of electricity compared to other fuels in the UK, but also due to the CAPEX costs associated with upgrading site infrastructure. The challenges and costs associated with upgrading the electricity supply to site are also significant and represent a major challenge for the UK glass sector. Similar issues

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[45] Biodiesel is not considered as this not anticipated to be a net zero fuel without the use of CCS

[46] BEIS (2019) Industrial Fuel Switching Phase 2: Alternative Fuel Switching Technologies for the Glass Sector

[47] BEIS (2019) Industrial Fuel Switching Phase 2: Alternative Fuel Switching Technologies for the Glass Sector

have also been raised for electrifying the German glass industry.[48]

Further technical risks are associated with cullet use where furnaces are fuelled 100% by electricity. This appears to be constrained under current technology– the literature indicates the ceiling is currently limited to 55% for container glass.[49] However, the UK strategy does appear to have assumed further increases in recycling occur in the future despite a significant shift towards full electrification, and so appears to have assumed these technical constraints can be overcome. The same approach is therefore taken in the modelling undertaken here but the risk ratio in the strategy modelling has accounted for this additional technical uncertainty.

As previously discussed, there is also currently no clear plan in place for the decarbonisation of key inputs to the glass production process, such as soda ash and limestone. Under current levels of recycling in the UK these account for approximately a quarter of current emissions. Some recently published literature suggests that the electrification of key inputs to the soda ash production process such as ammonia is currently being explored, but this appears to be at a less well-advanced stage than for the electrification of glass manufacture (since some small furnaces are already 100% electric).[50] The move to electrification of these inputs is therefore accorded a higher risk rating than that of the electrification of glass furnaces. Similar considerations apply to both industries in respect of the availability of electricity at a cost that allows production to remain commercially competitive.

Although the lightweighting of glass containers is already occurring to a certain, there is current resistance to this in some parts of the industry; the extent to which this will therefore be taken up by the industry as a whole is not yet clear.[51] This is reflected in the risk rating applied to this element of the pathway.

Finally, the glass industry is also reliant to some extent on both CCS and the use of hydrogen as a fuel – both in the context of the glass production process itself, as well as for the mitigation of embodied emissions to the process. These elements of the strategy are also associated with a higher risk rating.

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[48] Zier M, Pflugradt N, Stenzel P, Kotzer L and Stolten D (2023) Industrial Decarbonization Pathways: the Example of the German Glass Industry, Energy Conversion and Management, X 17, 100336

[49] Zier et al ibid.

[50] See: https://guidehouseinsights.com/news-and-views/green-ammonia-and-the-electrification-of-the-haber-bosch-process-reduce-carbon-emission ; Jain M, Muthalathu R and Wu X (2022) Electrified ammonia production as a commodity and energy storage medium to connect the food, energy, and trade sectors, iScience, 25(8), pp104724

[51] See: https://www.glassonline.com/feve-eu-packaging-regulation-threatens-belgian-business-innovation/

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