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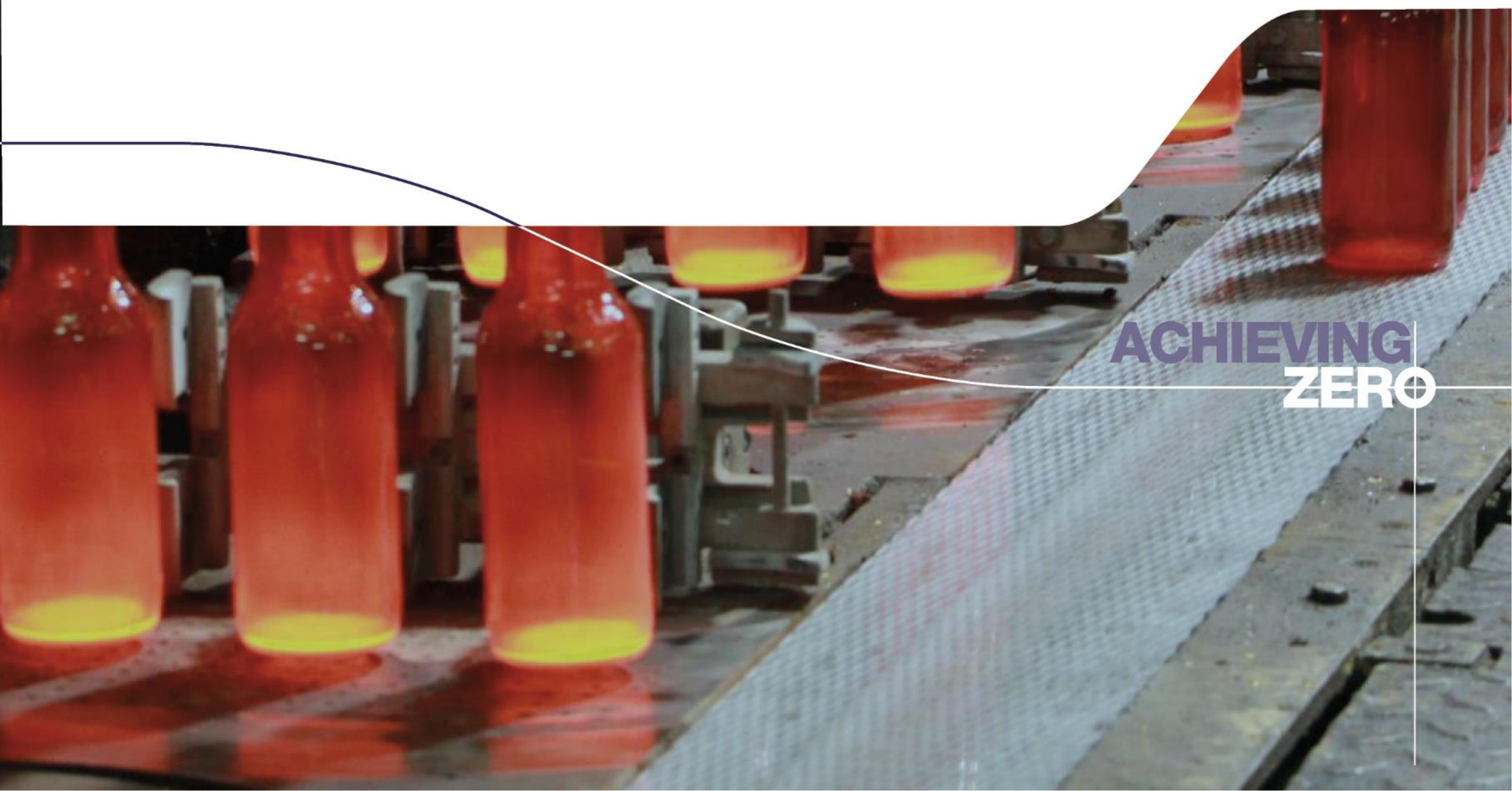
Glass sector deep dive: How could demand drive low carbon innovation in the glass industry



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Citing this report

Sheikh, A.Y., Barker, B., Markkanen, S. and Devlin, A. (2023). "Glass sector deep dive: How could demand drive low carbon innovation in the glass industry." Cambridge: Cambridge Institute for Sustainability Leadership (CISL).

Acknowledgements

We would like to thank Beverley Cornaby, Eliot Whittington, Isabelle Cross and Jenifer Elmslie for their contributions. We would like to thank Encirc for reviewing this document. We would also like to thank SMART Group members Aldersgate Group, Climate Group, Ecocem, Encirc, Green Alliance, High Value Manufacturing Catapult, JLL, Kraft-Heinz, Liberty Steel, Lucideon, NSG Group, Responsible Steel, Rolls-Royce, Schaeffler, Scottish Power, Skanska, and Tata Steel for their inputs and feedback.

This document was published as part of a larger research project supporting the foundation industries on their journey to net zero and supported by Innovate UK, UKRI [Transforming the Foundation Industries Research and Innovation (TransFIRe) Hub, Grant number: EP/V054627/1]. The other research in this project is available online from the CISL project page: https://www.cisl.cam.ac.uk/resources/publications/market-driven-decarbonisation.

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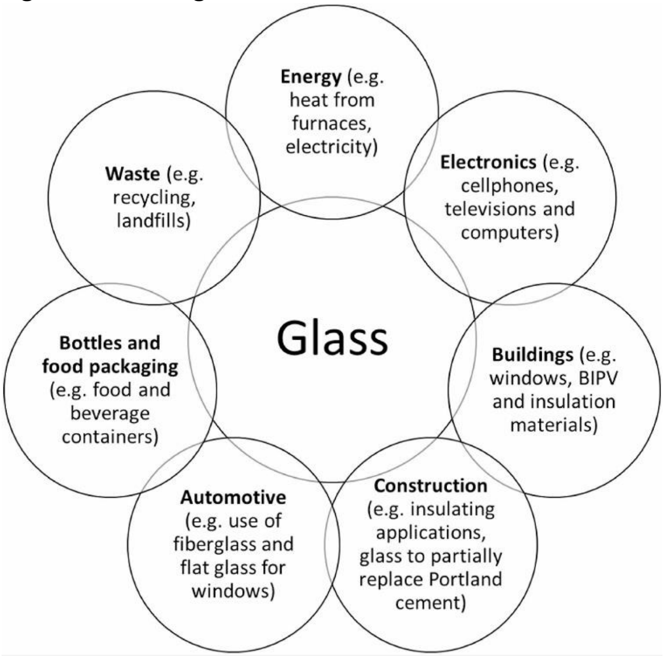
1. Introduction

In this sectoral deep dive, we provide an overview of the UK glass industry value chain and production processes. This deep dive examines the most viable decarbonisation pathways for the UK glass industry, and how demand can drive them forward. In the final section, we also provide recommendations for a demand-driven decarbonisation strategy for the UK.

1.1 Overview of the UK glass industry

Glass is omnipresent in our societies. As shown in Figure 1, glass is used in many everyday products and technologies, from windows to the screens of our phones and TVs, to containers in our cupboards. It is also a crucial material for many less widely known applications, such as biomedical devices and implants in medicine and dentistry, nuclear waste encapsulation, fibreglass for insulation and reinforcement, fibre optic cables for telecommunications, and waste glass for construction materials, such as cement.

Figure 1: Uses of glass in modern societies



Source: Furszyfer del Rio et al., 2022

The global production of 150 million tonnes of glass annually is responsible for 0.3 per cent of global greenhouse gas (GHG) emissions (86 $MtCO_2e$). Just under half of this glass (48 per cent) is container glass (for use in bottles and jars, etc), 42 per cent is flat glass (for use in windows, doors, the automotive industry, mirrors and solar panels), 5 per cent is tableware and 6 per cent is used in other products (eg glass fibres and medical uses) (Westbroek et al., 2021).

In the UK, 2.4 million tonnes of glass are produced annually (Zero Waste Europe and Eunomia, 2022), which have an average recycling content of 38 per cent and an emission intensity of 0.9 kg CO_2/kg glass (FEVE, 2016). In 2021, the UK glass industry emitted 2.2 million tonnes of CO_2, equivalent to 2.7 per cent of the UK's industrial GHG emissions (or 0.5 per cent of total UK GHG emissions) (ONS, 2022). However, the UK is fairly self-sufficient when it comes to glass demand, importing only 0.1 million tonnes of glass each year (Zero Waste Europe and Eunomia, 2022). Although the UK glass sector is relatively small at the global level, and responsible for only ~3 per cent of the total global glass industry's emissions, it still has a significant impact on climate change, which must be abated (Westbroek et al., 2021).

Although the UK glass industry is fairly small in macroeconomic terms, contributing £1.3 billion to the UK economy annually, it employs ~6,000 staff directly and ~150,000 indirectly (British Glass, 2021), and many of these jobs are geographically concentrated in Northwest England. Most of the domestic production facilities are either medium-sized or large (>20 tonnes/day), located at 17 sites throughout England, Scotland and Northern Ireland, and owned by ten different companies (British Glass, 2021). The UK glass industry specialises in developing novel compositions and treatments for specific uses, such as in medicine, and very high-quality glass for thermally efficient windows (British Glass, 2021).

1.2 Glass production energy demand and emission sources

There are two routes for glass production: using raw materials (ie pure sand known as silica, limestone and soda ash); and using cullet (the industry term for recycled glass), which is crushed and remelted for glassmaking. The glass production process cycle can be separated into three main stages:

1) raw material extraction
2) melting, forming and use
3) recycling (as illustrated in Figure 2).

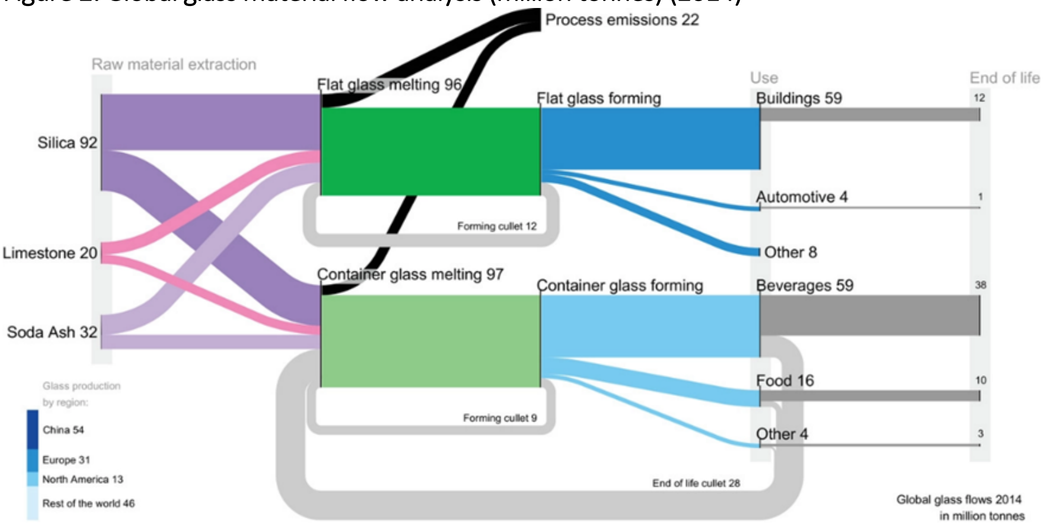
The primary sources of CO_2 emissions in glass manufacturing are:

1) fuel combustion (natural gas) at high-temperature heat (1,300–1,6ful00°C)
2) electricity generation
3) process emissions linked with the decomposition of carbonates.

These emissions represent ~58 per cent, 24 per cent and 18 per cent of total CO_2 emissions, respectively (Fuller et al., 2022).

Most furnaces are gas-fired, and electricity is used to power supplementary processes: in 2019, the UK glass sector consumed 6 TWh of natural gas and 1 TWh of electricity (British Glass, 2021). Energy efficiency has already been optimised to improve cost competitiveness: during the past three decades, energy consumption has halved to 1.47 MWh/t glass (BEIS/British Glass, 2017).

Figure 2: Global glass material flow analysis (million tonnes) (2014)



Source: Westbroek et al., 2021

In addition to the reduction in GHG emissions, there is a need to reduce the demand for the extraction of finite virgin materials that are used in glass production (sand, soda ash, limestone). The reduction of demand for the high-purity silica sand that is used in glassmaking (termed 'industrial sand') is of particular importance because of the global shortage: <1 per cent of the 50 billion tonnes of sand extracted annually is appropriate for glass manufacture (the remainder is construction sand) (FEVE, 2022). Mining operations that serve the glass industry are generally local and maintain close relationships along the supply chain to ensure the strict sand purity requirements are met (FEVE, 2020).

It is also important to consider the role that glass plays in supporting the decarbonisation of other sectors of the economy. For example, double-glazed and thermally efficient windows provide better insulation for buildings than single-glazed windows; they improve a building's energy performance, by reducing its energy demand and heating- and cooling-related emissions. However, the production of thermally efficient glass typically involves additional steps to apply coatings or assemble multiple layers. While these additional steps do not necessarily result in a substantially higher mass of glass being used, they may increase the emissions from the production process, or the demand for certain raw materials. As another example, container glass is a preferred material to plastic because it is an infinitely recyclable, non-fossil-fuel, product. Glass is also an essential component in some renewable energy technologies, such as solar photovoltaic panels (PVs) and wind turbine blades (Glass Alliance Europe, 2019).

Given the multiple use-cases for glass and its linkages with other sectors, it is important to take an end-to-end value chain approach to the decarbonisation of the glass industry. This will be a particularly important consideration when developing demand-led decarbonisation policies, so that they can be targeted not just at *how* the glass is manufactured but also at *where* and *why* it is being used by other consumers.

2. Glass industry decarbonisation strategies and progress

As set out in British Glass' (2021) Net Zero by 2050 Strategy, incremental measures such as energy-efficiency improvements and waste heat recovery will play an important part in immediate decarbonisation efforts. However, reducing emissions from energy use is essential for deep decarbonisation. This will necessitate more systemic industrial changes, including technology development, fuel switching and capital investment. Eighty-two per cent of glass production emissions are energy related (coming from a mixture of fossil-fuel combustion and emissions associated with electricity generation), which means the reduction of energy demand and the substitution of fossil fuels with renewable energy sources are a priority. To eliminate the other 18 per cent of emissions, process-related CO_2 must be reduced by reducing the amount of raw material inputs or the application of carbon capture, utilisation and storage (CCUS) technology. Partial (increased circularity, fuel substitution) and deep (electrification, CCUS) decarbonisation measures are discussed in more detail below.

2.1 Circular production models

Glass is completely and infinitely recyclable and can be remelted repeatably without losing quality (British Glass, 2021, p. 6), as long as the recycled glass (known as cullet) is of high quality. Using cullet reduces the requirement for raw materials and the energy intensity of the production process. The addition of 10 per cent cullet reduces energy consumption by 3 per cent and CO_2 emissions by ~5 per cent (the exact figure depends on the power mix) (British Glass, 2021). Increasing cullet use in glass production is an industry priority for decarbonisation, as it will enable the reduction of both energy- and process-related emissions; however, there are challenges associated with increasing the recycled content of glass.

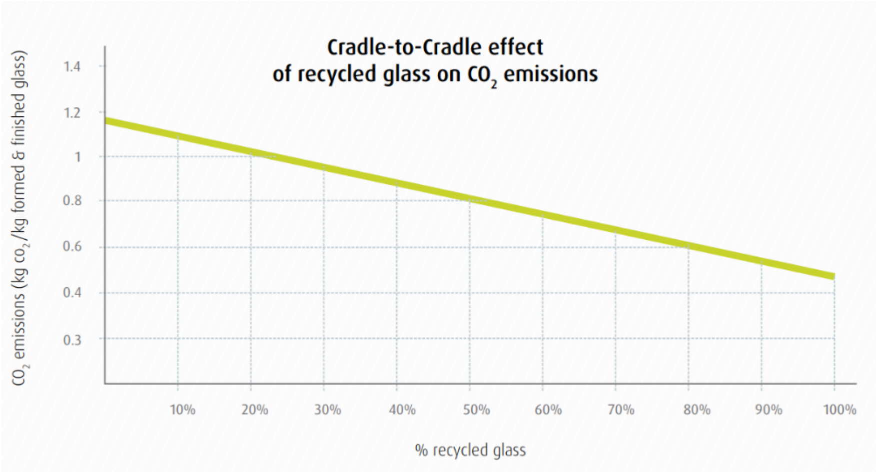
Glass product reuse, especially for packaging, will be an essential part of a circular economy and can complement recycling/remelting targets (Verallia, 2022). Although no official statistics for UK glass container reuse exist, industry representatives believe that <1 per cent of glass packaging is reused directly by the end consumer. However, reusing glass packaging is an extremely effective way to cut a product's life-cycle carbon emissions, as glass needs to be reused 2–3 times to achieve the breakeven point before its total environmental impacts fall below those of single-use aluminium or plastic packaging (Zero Waste Europe, 2020). The following case study discusses the decarbonisation potential that glass recycling provides.

Case study 1: Waste container glass

Glass is infinitely recyclable. This means that the value of waste container glass (known as 'cullet' in the glass industry), primarily from the food and beverage industry, can be retained indefinitely through closed-loop recycling, whereby waste glass is crushed and melted down to create glass – again and again.

Using technologies that are available today, glass produced using 100 per cent cullet could reduce the embodied carbon of glass by 58 per cent (FEVE, 2016) compared with glass with no cullet (see Figure 3). These savings arise primarily from the reduced demand for carbon-based energy (natural gas, electricity) used in glass production, carbon-containing materials (limestone, soda ash) within the raw material mix, and carbon-based fuels used in quarrying, processing and transporting virgin materials. The Federation of European manufacturers of glass containers (FEVE) conducted a life-cycle analysis (LCA) (FEVE, 2016) which showed that, on a cradle-to-cradle basis, every tonne of cullet can mitigate approximately 670 kg of CO_2 (EU average).

Figure 3: extracted from FEVE, 2016 (38 per cent average recycling content = ~0.9 kg CO_2/kg glass)



Although greater use of cullet offers a significant decarbonisation resource to glass manufacturers, the UK has not yet realised the full potential of cullet. In 2019, 71 per cent of waste container glass on the market was recycled (1,824 kt), with 29 per cent being lost to landfill (750 kt). Moreover, just 36 per cent of cullet was returned to glass container manufacturing (925 kt), while 5 per cent was recycled in other remelt applications (132 kt), 18 per cent down-cycled as aggregate in construction (475 kt) and 11 per cent exported (292 kt). The balance between waste glass supply and new glass demand results in an average recycled content rate in new glass products in the UK of 38 per cent (Zero Waste Europe & Eunomia, 2022).

The melting down of cullet for reuse should be maximised in a circular, low carbon economy. Closed-loop recycling, whereby products are recycled into the same products repeatedly, is preferable to recycled material being used as an input in other sectors (such as low-grade cullet being used in construction), as it enables the highest possible value-adding potential of waste, maximising the emission and energy reduction potential. It is for this reason that the glass industry has targets for remelting as well as recycling: DEFRA has proposed a recycling rate target for 2030 of 83 per cent and a remelt target of 80 per cent (Eunomia, 2022). British Glass, the trade association for the UK's glass industry, which is leading the Close the Glass Loop (2020) project, seeks to achieve a 90 per cent glass recycling rate by 2030. The aim is to improve the quantity of glass scrap that is collected to increase the share of it that is suitable for remelt, ultimately increasing the recycled content of glass packaging.

To achieve these targets, and thus to help the glass industry reduce its emissions, the UK's waste management system must undergo some important changes.

2.2 Fuel substitution

Reducing (or eliminating) the use of natural gas in glass production is critical to sectoral decarbonisation. This can be achieved via increased use of biofuels and/or hydrogen, or through electrification. Glass Futures, a project that is co-funded by UK Research and Innovation (UKRI) and local authorities in Northwest England, has piloted the use of various low carbon fuel alternatives (Glass Futures, undated).
Preliminary results from projects running during 2020–22 (Fuller et al., 2022) showed that 70–80 per cent emissions reductions could potentially be achieved by substituting 100 per cent of natural gas with biofuels (proven on an industrial scale but subject to the availability of sustainably sourced biofuel), and also positive developments towards the hybrid use of biofuels and hydrogen (in laboratory conditions).

Currently, five projects in the UK and Europe are looking at the feasibility of replacing 100 per cent of natural gas with hydrogen, as well as different proportions of hydrogen blended with natural gas (British Glass, 2021). Encirc has announced that it will produce the world's first net zero glass bottles at scale by 2030, using a production process powered by a combination of renewable electricity and low carbon hydrogen (Encirc, 2022). The plant, which will be powered by the HyNet project in Cheshire, is expected to reduce emissions from glass production by up to 90 per cent.

In principle, all low carbon or zero carbon energy carriers could be suitable substitutes for fossil fuels, including biogas, synthetic methane, green hydrogen and oxyfuels; however, none of these alternative gaseous energy carriers can currently be purchased at competitive prices compared with natural gas (Zier et al., 2021).

2.3 Full electrification

In their literature review of the decarbonisation options for the glass industry, Furszyfer del Rio et al. (2022) concluded that electrification presents a promising method for emissions reductions from the glass sector. However, the technology is currently commercially available only at a small scale, and it remains unclear if electric melting technology can be upscaled to more extensive production processes (ie >200–250 tonnes per day). This is because flat glass melting requires extremely high temperatures of more than 1,600°C and the furnaces are quite large and constantly operating. It has been suggested that 99 per cent furnace electrification is achievable with emerging technology, while 78 per cent furnace electrification is achievable using already established technology (Furszyfer Del Rio et al., 2022).

The main advantage of electrical melting compared with fossil-fuelled melting is its higher efficiency. For instance, considering a typical container glass furnace with a pull rate (the industry term for the mass of molten glass produced by a furnace in a stipulated timeframe) of 300 tonnes per day, the thermal efficiencies of an electric furnace and a conventional regenerative end-fired furnace (the workhorse of the glass industry that is typically powered by gas combustion) are 85 per cent and 45 per cent, respectively (Zier et al., 2021).

2.4 Carbon capture, utilisation and storage (CCUS)

Carbon capture presents a crucial pathway towards decarbonisation for industries like glass and cement manufacturing, which release CO_2 from the production processes. In these sectors, energy efficiency and fuel switching cannot eliminate all emissions from currently available production processes, meaning that CCUS technologies may be needed to achieve full decarbonisation.

The implementation of CCUS in glass manufacturing is challenging because of the release of significant impurities in the flue gas that is emitted from glass production, particularly sulphur oxide and nitrogen oxide (both highly poisonous and indirect GHGs). Currently, the state-of-the-art CCUS technologies rely on amine-based solvents developed in the 1930s. Although these solvents are effective in many aspects, they do have limitations, including:

1) an energy-intensive absorption-regeneration loop
2) susceptibility to degradation, especially under harsh conditions

3) high levels of corrosiveness
4) potential human and environmental toxicity
5) potential for either the components themselves or their degradation products to be carcinogenic (Lewis, 2021)

These factors, when considered collectively, have hindered the widespread adoption of amine-based solvents, particularly in challenging applications such as glass manufacturing. Furthermore, CCUS can incur high initial capital costs (from retrofitting the CCUS infrastructure to existing plants), and also considerable operational and storage costs.

However, there have been some advancements in the CCUS technology in the glass industry. Carbon capture technology can be retrofitted to existing glass furnaces and some companies, such as C-Capture, are using novel solvent agents that mitigate some of the technical limitations and improve the overall economics. The technology is being trialled at two of NSG's Pilkington's sites (Doneva, 2022), with promising results from the early stages of the piloting process.

Other important barriers to CCUS relate to CO_2 transport and the storage site. Transport is a particularly prominent challenge, considering that most of the glass manufacturers in the UK operate reasonably small, disseminated units (Furszyfer del Rio et al., 2022). However, given the concentration of many glass manufacturing facilities in Northwest England (as well as the closeness of the proposed Merseyside CCUS cluster), the feasibility of CCUS for the glass industry may improve with increased industrial collaboration and government support for holistic infrastructure. The development of CCUS clusters, or GHG pipeline networks, between the carbon capture systems of electricity generators and industrial process plants and offshore storage facilities, is a key requirement for this to happen (Griffin et al., 2021).

Table 1 provides an overview of the decarbonisation approaches discussed above. It identifies the advantages and disadvantages of each option to set the context for how demand-led policies could help to remove some of these challenges and what strategies could be used to accelerate their development and adoption.

Table 1: The advantages and disadvantages of different decarbonisation technologies in the glass industry

Approach	Decarbon-isation option	Technology readiness level (TRL)	Advantages	Disadvantages	Potential CO_2 emission reduction (% of emissions)	Additional comments
Fuel substitution	Hydrogen	3–4	Synergies with future infrastructure Co-firing with other fuels	Different flame characteristics requiring technical changes Infrastructure not currently available at scale Expensive	75–85	
	Synthetic methane	9	No technical changes	Expensive	75–85	
	Biogas	5–6	Existing market Co-firing with other fuels	Limited resource planning Fluctuating composition	75–85	
Full electrification		9 (small furnaces) 5 (large furnaces)	Efficiency Footprint Low investment costs Reduced maintenance Reduced dusting	Limited capacity Electricity price Limited cullet use Not for every glass type Lower lifetime Load on power grid	75–85	Maximum reported capacities are 200–250 t/day If no breakthrough in melting capacity is achieved in the future, it is conceivable to replace large fossil-fuel melting furnaces with smaller modular electric melting furnaces Hybrid melters (eg natural gas, hydrogen and electrodes) may help to mitigate the disadvantages of both technologies)
CCUS		N/A			Maximum of 90%	
Circularity/ recycling		9	Efficiency Can be improved without the need for technological investment	Shortcomings in current infrastructure Planning processes might cause delays	Maximum of 20% for container glass and 5% for float glass	

Sources: Adapted from information from Furszyfer del Rio et al. (2022) and Zier et al. (2021)

Zier et al. (2021) have also conducted a qualitative comparison for the capital expenditure (CAPEX) and operational expenditure (OPEX) of several of the decarbonisation technologies discussed above, using conventional natural gas glass production processes as a benchmark. Within the parameters of their assumptions and based on their analysis, the study concludes that the costs of all low carbon fuel options are likely to pose a significant challenge to glass industry decarbonisation. Table 2 (below) summarises their findings; yellow suggests neutral effects, green suggests positive effects and red suggests negative effects.

Table 2: Relative effects of decarbonisation options on capital expenditure (CAPEX) and operational expenditure (OPEX)

	Natural gas	Hydrogen	Synthetic gas	Electric melting
CAPEX				
OPEX				

Considering that the cost of low carbon fuels can adversely affect the glass industry's competitiveness and increase the risk of carbon leakage, policies and strategies that improve the financial viability of decarbonisation in this sector are urgently needed. The subsequent sections discuss how the decarbonisation of the glass industry can be supported by demand-led policies, and what strategies could be implemented to accelerate these decarbonisation pathways.

3. How could demand drive low carbon innovation in the glass industry?

As illustrated in the modelling study in Section 7.2 of the technical report, basing the implementation of low carbon technological solutions solely on their price competitiveness can lead to long delays in the technology emerging and being adopted by industries (Markkanen et al, 2023). The modelling results suggest that policies that create demand for specific low carbon materials, such as glass (and the technologies to produce such low carbon materials), can accelerate the price decline of these types of products and production technologies by enabling producers to achieve economies of scale much faster than is currently the case.

The 'conscious consumer' plays an important role in glass sector decarbonisation and the impact it can have on emissions from other sectors. Demand for glass products, both plate glass (such as windows) and containers (such as bottles and jars), can be driven by consumer demand. For example, consumers (including households, businesses and property developers) may decide to buy thermally efficient windows to improve the energy efficiency of homes and other buildings (British Glass, 2021, p.7), or choose a recyclable or reusable glass container over other alternatives, provided that these are available.

Markets for low carbon glass can also be supported by policy interventions, such as regulations that create demand across the value chain. As shown throughout the technical report (Markkanen et al., 2023), demand for low carbon production technologies and materials is driven by all actors across the industry value chain, rather than just the end user of a consumer product. According to ONS input–output analysis data, 63 per cent of the products of the glass and ceramics industry are purchased by the construction industry, 9 per cent by beverages manufacturers and 6 per cent by households directly, while the rest is distributed across other economic sectors (ONS, 2022a). This distribution suggests that the construction industry and to a lesser extent beverage companies and households have the biggest potential to accelerate decarbonisation at the glass production point through their demand pressures.

Construction companies that are committed to reducing their scope 3 emissions can explore opportunities for more efficient use of materials, including steel, cement and glass. They can also commit to purchasing the most thermally efficient building materials that reduce operational emissions from the properties they develop. In terms of glass, they can demand window glass that has a low embodied carbon content, selecting to buy their windows from manufacturers that purchase the plate glass from low carbon manufacturers. Construction companies themselves face demand pressures from real-estate asset managers and owners. This trickle-down demand pressure can drive forward glass producer investment in fuel substitution, electrification, energy efficiency, waste heat recovery, and carbon capture and storage.

However, for glass manufacturers to make these (often substantial) investments in new production technologies, they need to be confident that the demand for glass products with a low embedded carbon content will grow over time. In other words, although the changes in production technologies are largely in the hands of glass producers, the technology choices that they make are driven by demand further down the value chain as well as the cost and supply of low carbon fuels or cullet.

Several contextual conditions affect the financial and physical viability of certain solutions, such as electrification, circularity and fuel switching. Circularity, for example, is enabled (or disabled) by the availability of cullet, which in turn depends on consumer behaviour and recycling infrastructure. At present, the reuse of plate glass and containers is challenging because of the geographical disconnect between supply and demand and product specificity, including beverage producers using non-standard containers. As illustrated in the waste container glass case study above, the recycling of glass has huge potential for reducing both energy and raw material demand and emissions. However, it requires glass producers to adjust their production processes to create demand for recycled glass, as well as other actors in the value chains to supply the glass scrap for recycling. For this to work, the final product consumers, property demolition and car scrappage services need to work with used product or waste glass collectors, sorters and transporters to get the cullet back to glass producers. The system can become truly circular only if all actors along the value chain participate in the recycling process, and the enabling infrastructure to avoid contamination of glass scrap is widely available.

Similarly, operational emissions, such as those from transporting products, are dependent on actions of various actors across the value chain. Encirc's 360 service is a good example of innovation in this area (see case study below). Given that the glass industry is interlinked with many other industries (primarily in the property development and beverage industries), there is great scope for broad-based business-to-business collaboration to decarbonise embedded as well as operational emissions from glass.

The following case study discusses how a glass manufacturer is employing some of the strategies discussed above to accelerate its decarbonisation.

Case study 2: NSG – Building for the future glass industry's journey towards decarbonisation

NSG Group (Nippon Sheet Glass Co., Ltd and its group companies) is one of the world's leading suppliers of glass and glazing systems in the architectural, automotive and creative technology sectors, and has principal operations around the world and sales in over 100 countries. The NSG Group is committed to reducing its greenhouse gas (GHG) emissions by 30 per cent by 2030 compared with 2018 levels – a target certified by the Science Based Targets initiative (SBTi) – and achieving carbon neutrality by 2050. These reductions will come from emissions directly associated with manufacturing and carbon produced in the company's upstream and downstream value chain.

However, the flat glass industry has a long road ahead towards decarbonisation. No one specific technology is known to be the most effective to decarbonise glass production, so the NSG Group is trialling several different routes to explore which pathways might be most viable for scaling up in the future.

At present, the company is testing several new technologies and methods. These include collaborative landmark trials of alternative fuels. In 2022, Pilkington United Kingdom Limited, part of the NSG Group, became the world's first flat glass manufacturer to fire its furnace on 100 per cent biofuel, resulting in the creation of 165,000 m^2 of lower carbon glass. This innovative trial was part of a multimillion-pound project, which demonstrated how biofuel can present a realistic alternative to natural gas.

This achievement built on the progress made towards decarbonisation in 2021, when float glass was successfully manufactured using hydrogen in another world-first trial. A project with KEW Technology will pilot onsite fuel switching from natural gas to KEW's syngas, which is produced by onsite modular gasification units.

The potential use of carbon capture technology in glass manufacturing is also under review. Alongside these specific initiatives, the NSG Group is exploring how it could use more cullet (ie recycled glass) in the manufacturing of new glass, to enhance energy efficiency and to reduce the embodied carbon content of their glass products.

Pilkington United Kingdom Limited has manufactured glass for decades with thermal insulation and solar control properties that contribute to a building's energy efficiency. These high-performing architectural glass products are essential to improve building energy efficiency and living comfort in the UK, and to help deliver the government's decarbonisation targets for the buildings sector. The pioneering innovation at Pilkington UK means that thermally efficient glass products with lower levels of embodied carbon are becoming accessible to architects.

A significant amount of research and investment will be needed before hydrogen, or perhaps even electrification, becomes a feasible alternative to natural gas for powering glass furnaces. However, some early, important strides are being made through the collaboration of pioneering manufacturers like the NSG Group, innovative specialists in sustainable solutions and the backing of government. These developments in the glass industry will play a fundamentally important role in enabling decarbonisation of the UK's building stock in line with the 2030 and 2050 targets.

4. Developing a demand-driven glass decarbonisation strategy for the UK glass industry

Given the many challenges of decarbonising the glass sector discussed in this deep dive, the decarbonisation process must be driven by the government in collaboration with the private sector. By developing a holistic strategy for the sector to achieve net zero targets within the stipulated timeframes and in conjunction with other sectors, the government can play a key role as a facilitator that enables and supports effective business action. The increase in CAPEX and/or OPEX with each of the decarbonisation options remains a major barrier to large-scale decarbonisation in the glass industry. Supporting the producers with capital investment and operating costs, while also ensuring that demand for the low carbon products is high enough to make investments financially feasible, is important.

To provide an enabling policy environment for the glass industry and the downstream and upstream value chains to invest in the production and consumption of low carbon glass, the government must develop a strategy and policy mix that maps interactions and inter-dependencies. It also needs to identify the optimal points for intervention across the value chain and ensure the competitiveness of the industry by aligning new policies with international standards. As mentioned in Section 6 of the technical report (Markkanen et al., 2023), there is a pressing need for the UK government to work together with trade partners to develop shared standards for embodied emissions data collection, rigorous criteria and verification methodologies, and secure but reliable data sharing mechanisms.

Businesses and government both need to acknowledge the industry's long-term perspective and the risks of carbon lock-in, and mitigate that risk through transparency and collaboration in policy and planning (PA Consulting, 2021). These issues must be at the forefront of a successful strategy to decarbonise the glass industry, while ensuring its competitiveness and continuing presence in the UK. To achieve these objectives, such a strategy could focus on the six key areas discussed below:

4.1 Ensuring the availability of cost-competitive electricity and low carbon fuels at scale

A significant barrier to the adoption of electrified furnaces is the cost of electricity in the UK: it is currently 4.5 times more expensive than gas, having been subject to even steeper price increases than natural gas since early 2021. Glass manufacturers feel that not enough support has been made available for them to continue to partially fuel their furnaces with electricity, and they are lobbying for an exemption from having to contribute to various costs that helped to fund the rollout of renewable electricity and decarbonisation of the grid (Balderson et al. 2022, p. 18).

There has also been concern that the industry has been excluded (apart from fibreglass) from eligibility to claim recompense for the indirect costs of electricity associated with the UK Emissions Trading Scheme (UK ETS) and the carbon price support (CPS) mechanism. British Glass feels that the container glass industry, at the very least, should have been considered eligible. The high cost of energy reduces the availability of money for transformative decarbonisation investments, while the high cost of electricity (compared with more carbon-intensive natural gas) disincentivises electrification.

Adapting furnaces from gas to electric would lead to an intensification in the overall electricity demand, which would require power sector reforms, including increased generation from renewable sources and an enhanced transmission and distribution infrastructure. The glass industry melts around 3.5 million tonnes of glass per year, using 6 TWh of natural gas and 1 TWh of electricity. If the gas was exchanged for electricity, ~1.2 GW of installed wind production capacity would be required (Energy and Climate Intelligence Unit, 2021; British Glass, 2021), which is equal to 2.4 per cent of the overall installed capacity of 50 GW by 2030 (HM Government, 2022). It is possible that future electrification projects could be hindered by a lack of capacity, or a stable supply (as storage solutions or alternative power sources would need to be available for times when wind generation falls below typical levels).

Alternative, low carbon, fuels for powering glass melting processes present a similar problem. As mentioned earlier, synthetic natural gas, biofuel and green hydrogen are currently unavailable at competitive prices to spur a shift away from natural gas. However, ongoing and recently launched projects such as HyGlass, HyNet and Kopernikus P2X are testing hydrogen and its feasibility as an alternative energy carrier for combustion in the glass industry, signifying an increased interest from the glass sector in hydrogen as a potential decarbonisation pathway (Zier et al., 2021). An essential prerequisite for the use of hydrogen as a feasible, low carbon, alternative to natural gas is that its production does not release CO_2 into the atmosphere. Potentially suitable production routes include: blue (coal gasification or the reforming of natural gas with CCUS), turquoise (methane pyrolysis), yellow (water electrolysis using nuclear power) and green hydrogen (water electrolysis using renewable power sources). However, apart from green hydrogen, all of these routes either rely on technology that is not currently commercially available (CCUS) or produce other toxic waste.

Developing the infrastructure for hydrogen distribution would be an important prerequisite for hydrogen to constitute a sustainable decarbonisation pathway, and it is likely that the formation of industrial clusters will be important for facilitating this. The use of existing natural gas pipelines is not always feasible and would need to be examined on a case-by-case basis. For a swift market upgrade, hydrogen could be blended into natural gas and transmitted using the gas network (although this may not always be possible if the existing infrastructure is leaky). Thus, energy-related CO_2 emissions could be reduced by steadily increasing the proportion of low carbon hydrogen in the gas–hydrogen blend. However, as hydrogen burning requires retrofits to glass furnaces, it would require sectoral buy-in and the provision of support for OPEX and CAPEX throughout the transition.

In addition to infrastructure upgrades, all alternative fuels (including renewable electricity) would need to be available to the glass industry at affordable prices to incentivise companies to switch away from natural gas. These prices would also need to be internationally cost-competitive to mitigate the risk of industry relocation abroad. While assurance of demand for low carbon products and more stringent product standards may encourage glass producers to switch their fuel supply, the price for electricity and any alternative fuel would still need to be within the parameters of financial viability and international cost-competitiveness (British Glass, 2021). Although the costs of alternative fuels are expected to come down as the technology readiness level increases, the government may need to provide support in the interim to companies that are willing to commit to fuel switching, such as targeted subsidies or grants that taper off over time as the economics improve and decarbonisation accelerates.

4.2 Developing targeted product standards

Product standards are important to create demand for low carbon products, and to reassure manufacturers of growing future demand for low carbon materials if they invest in decarbonisation processes and technologies. However, the development of standards for the glass industry's outputs is complicated, as a one-size-fits-all mandatory product standard would not work because glass is used in a variety of ways across the value chains in many industries, such as property development, automotive manufacturing and beverage packaging. For some sectors, thermal efficiency or weight can substantially reduce emissions across the value chain, but may *increase* emissions from the production process.

The government will need to be cognisant that one standard will not accelerate decarbonisation or minimise emissions across all uses and companies across the glass industry value chains. For example, double-glazed or thermally efficient windows would make a building more thermally efficient and reduce operational emissions but may increase the raw material or energy demand during the production process. Therefore, the government will need to update building regulations for new builds and property refurbishments to install the best available glazing products instead of focusing on the embodied carbon content of the glass products. The public building sector could lead the way by specifying high-efficiency glazing product standards via the public sector decarbonisation fund and public sector procurement rules (British Glass, 2021, p. 30). Similarly, lighter glass in cars and containers would make transportation more energy efficient (but may have a quality differential), and any product standard that targets those industries would need to reflect that to create demand for such lighter glass.

The public sector could also create demand for low carbon glass through public procurement strategies and by mandating that locally manufactured glass is used in sectors that are susceptible to importing cheaper glass with a higher embodied carbon content. In this regard, British Glass (2021) suggests that the government ensures that UK-manufactured glass fibre is used in the manufacture of UK-based wind turbines (p. 30). Alternatively, a carbon border adjustment mechanism (CBAM) for imported glass (especially when used by industrial consumers) could potentially preserve demand for locally manufactured glass by keeping its price competitive if it would otherwise become more expensive because of compliance with more stringent product standards.

4.3 Data and digitalisation to facilitate better standards and monitoring

A vital facilitating aspect to demand-led decarbonisation and its positive feedback loops is data collection, gathering, reporting and disclosure to allow embodied emissions data to be understood, traced and compared. Therefore, investment and innovation in data collection and processing is essential. Improved data collection will both require and support enhanced regulatory frameworks and standardised methodologies for emissions accounting and reporting. As discussed in the technical report (Markkanen et al., 2023), shared accounting and reporting standards will need to be used by all suppliers to enable companies further down the value chain that use large quantities of energy-intensive materials to make informed choices about how best to reduce their scope 3 emissions. Ideally, these standards will be aligned internationally to make it easier to compare the embodied carbon content of materials and intermediate products in multiple countries, ensuring that product standards are sensible, carbon border adjustments are accurate, and the risk of carbon leakage is low. The EU has already announced plans to implement a mechanism for information sharing, the digital product passport (DPP); however, this is not (yet) complemented by a shared standard for embodied carbon accounting and reporting.

4.4 Cross-sectoral business and industrial collaboration

As mentioned earlier, the inter-dependencies as well as the interaction of the actors across the glass industry value chains provide a wealth of opportunities to collaborate within the industry and also across it. Both the government and business associations can broker and facilitate such partnerships to accelerate decarbonisation. The ‘conscious consumer’ could also generate pressure for companies to do so through their buying power, citizen action and non-governmental advocacy. The case study by Encirc (below) provides a good example of how collaboration among multiple stakeholders can generate emission savings.

Case study 3: Encirc's 360 service – Inviting partners to join the journey to a greener supply chain

Encirc is a leading UK glass bottle manufacturer, filler and distributor. The company's 360 solution (Encirc, 2023) is an example of a unique supply chain service that allows stakeholders from across the beverage industry to work together towards a significantly greener operation.

Cutting emissions from the shipping of beverages that are sold in glass bottles presents a key challenge to the global beverage industry. Encirc's 360 service shows how innovative thinking at the systemic level can help to cut emissions not only from the manufacturing of glass bottles, but also through improved supply chain management. It involves transporting liquid in bulk from producers around the world to Encirc's UK site, where the beverages are bottled using a closed-loop system in containers manufactured using industry-leading technology and experience. The bottles are then stored in a warehouse, where artificial intelligence (AI) and automation are used to package them in bespoke, consolidated loads (ie mixed pallets) for direct shipping to retailers.

The 360 service reduces emissions and waste through breakage at various points of the supply chain. Transporting liquid in bulk instead of glass bottles directly targets a major source of emissions in the beverage industry by tripling the quantity that can be transported in a given space and weight compared with shipping pre-filled bottles on pallets. Bottling onsite once the product has arrived in the UK also reduces waste from breakage and spoilage during transit.

The automated warehouse operations used by Encirc make it possible for wine and carbonated beverages to be sent to retailers in mixed pallets that contain drinks from multiple producers, cutting the number of journeys between producer and retailer. Analysis commissioned by Encirc from Carbon Intelligence (Accenture, 2023) found that wine producers from New Zealand, Chile, Argentina and South Africa could nearly halve their transport-related emissions by switching from transporting their products in glass bottles to the 360 service when shipping their products to the UK. For Encirc customers, this equals 31,000 tonnes of CO_2 equivalent savings per year.

The 360 service is a key component of the efforts that Encirc and its parent company Vidrala (Vidrala, 2023) are making to implement their science-based targets for 2030, and also to empower others in the industry to decarbonise and to reduce the carbon footprint of the glass and beverage industries.

"By combining our pioneering sustainability initiatives with our unique 360 programme, we are able to work with our partners and the wider sector to build a more environmentally-friendly industry as a whole. Working with like-minded partners from across the world, we're helping to decarbonise the sector and showcasing the necessity of bulk shipping for the future of how we work." (Fiacre O'Donnell, Director of Sustainability, Encirc)

4.5 Public–private investment in technology innovation

Most of the decarbonisation pathways for glass, whether they be retrofitting furnaces to use alternative fuels or to electrify them, or investment in research, development and demonstration of new innovations, tend to be expensive. As a result, a common obstacle across the glass industry is a reluctance to invest in energy-efficient and low carbon initiatives that take longer than 3–5 years to recoup the investment, largely because there is lack of funds for leaseback schemes and external financing options are also limited (Furszyfer del Rio et al., 2022). Some companies are unable to afford the necessary upgrades, making government subsidies (including financial and fiscal incentives) the only viable solution to stimulate investment.

Public–private partnerships for deploying existing solutions and developing new ones are likely to be critical for the glass industry to eliminate CO_2 emissions. A pertinent example of this is the collaboration between UKRI, the Department for Business, Energy and Industrial Strategy (BEIS) – now renamed the Department for Energy Security and Net Zero (DESNZ) – and Glass Futures, whereby the latter received £15 million of government funding under the Industrial Strategy Challenge Fund to establish a research and development centre. This centre, which was inaugurated in February 2022, will contribute to innovation for glass sector decarbonisation (UKRI, 2022).

On the other hand, lack of funding, especially public funding, can delay innovations. For example, the large collaborative project Furnace for the Future (F4F) was developed in conjunction with 19 European and UK glass manufacturers representing 90 per cent of the European market share of container glass (FEVE, 2021; Ardagh Group, 2021). The project had hoped to receive a share of the EU's €10 billion Innovation Fund to help cover the CAPEX and OPEX associated with the project. However, their bid was not successful, halting the project before it properly started (FEVE, 2022).

4.6 Improving circularity by developing the recycling infrastructure

As mentioned earlier, the recycling of glass can provide a significant decarbonisation opportunity. It can reduce the need for mining and the production of virgin materials, and also improve energy efficiency as the temperature required to melt cullet is lower than the temperature required to melt raw materials. However, to enable greater circularity, the infrastructure for glass recycling and waste management would need substantial changes.

At present, household glass recycling targets are not ambitious enough to facilitate the large-scale, closed-loop recycling of glass. There are calls from businesses and industry to set the glass recycling rate target at 90 per cent, rather than the current EU target of 70 per cent by weight (Balderson et al., 2022, p. 18). In 2015, the UK had the largest tonnage of unrecycled glass in Europe: 822,000 tonnes. One of the reasons for this is the approach taken to meeting the recycling target set by the Packaging and Packaging Waste Directive 94/62/EC, which introduced a tradeable permit system that renders recycling uneconomic once the target of 70 per cent has been met, effectively reducing the incentive to recycle beyond the targets set by European legislation (Lee et al., 2018).

Furthermore, not enough flat glass waste is returned to the furnaces once it has reached the end of its life. Approximately 750,000 tonnes of flat glass waste is created each year, most of which, 500,000 tonnes, goes to landfill, and 250,000 to aggregates (road filler) in the construction industry (British Glass, 2021). The glass industry is lobbying for policy changes that would facilitate the collection of waste glass from the automotive industry, glaziers and building (and building demolition) sites. As glass is considered as inert or non-hazardous waste, it can be disposed of in landfills at only £3.25 per tonne (HMRC, 2023). However, policy changes such as a radical increase to landfill fees could remedy this situation. For example, the reclassification of glass as hazardous waste (because of the time it takes to naturally disintegrate) would raise the cost of sending it to landfill to £102.10 per tonne, incentivising businesses to recycle it.

Another barrier to glass reuse and recycling in the UK is consumer preferences. Approximately 64 per cent of the glass made in the UK is clear (British Glass, 2021), of which a portion is also exported. To make clear glass, only cullet from clear glass can be reused. If glass cullet is not separated by colour, it can be used to manufacture only brown glass. The UK also has an excess of green cullet because of the import of wine bottles. This green cullet is also unsuitable for manufacturing clear glass, and therefore cannot be used by manufacturers to fulfil their orders for clear glass (such as windows). Although changing the norms around packaging to make dark glass more acceptable for containers would be one way to mitigate this, improving glass recycling mechanisms at the household and business level and retooling the overall infrastructure would be more effective. However, to improve the quality and quantity of recycled glass, the UK would need to implement some crucial changes.

First, waste contamination would need to be minimised by separating waste glass at source rather than mixing it with other recyclables – a practice that currently reduces the quality of cullet and therefore the share of recycled glass that can be used as an input in closed-loop glass manufacturing. The UK's glass container collection avenues are: 55 per cent kerbside co-mingled, 32 per cent kerbside as a separate waste stream, 10 per cent bring banks (a communal waste deposit location with separate stream collection), and 3 per cent household recycling centres. In the UK (as in many other countries), co-mingled collection of glass produces cullet that is inferior to the cullet that can be collected through separate collection services that support closed-loop recycling; less than half (44 per cent) of co-mingled collected glass is reusable by the glass industry, compared with nearly all (90 per cent) of separately collected glass (Zero Waste Europe & Eunomia, 2022). Shifting kerbside co-mingled collection to separate waste streams and expanding the use of bring banks have proven successful in increasing the amount of high-quality cullet in countries such as Austria and Spain (Lee et al., 2019). As collection and sorting mechanisms also vary greatly at the local council level, the introduction of standards of best practices across the country would be beneficial.

Second, there is a need for regulation to support shared consumer–producer responsibility to drive efficient recycling systems. The current UK regulations focus on downstream demand with partial extended producer responsibility (EPR) regulations, where obligated packaging recyclers are required to purchase packaging recycling evidence known as packaging waste recovery notes (PRNs) or packaging waste export recovery notes (PERNs). These regulations do not cover all types of glass containers or enable consumers to play an active role in supporting a shift towards greater circularity. Consumer-centric deposit return schemes (DRS), whereby consumers pay a small fee for 'loaning' a container, which is paid back when the container is returned to a collection point or a retail centre, have achieved success in certain countries. For example, in Norway, 92 per cent of all bottles and aluminium cans were returned via the DRS in 2020 (Infinitum, 2020). For glass, however, the scheme's ability to effectively prevent waste has not been proven (Agnusdei et al., 2022), and a DRS proposal has received strong objections from the UK's glass industry (British Glass, 2021), flared by Scotland's recent announcement of commitment to the scheme, which is due to commence in August 2023 (Zero Waste Scotland, 2023). This opposition is justified primarily on the grounds that it has a narrow focus on glass bottles, instead of the industry's preference for a more holistic glass recycling scheme that maximises the amount of high-quality cullet that could be reused in glass manufacturing.

Finally, the sharing of knowledge at local authority level will be integral to best practices and to educating the public on how to recycle glass effectively. In addition to easily accessible recycling infrastructure, increased consumer awareness of the emission- and energy-saving benefits of glass recycling through engagement programmes, will be crucial to mobilise consumer engagement in facilitating glass industry decarbonisation through improved circularity.

5. Concluding remarks

The glass sector has significant linkages throughout the economy and makes important contributions to the decarbonisation of the operational emissions in many sectors where glass cannot be easily replaced through material substitutions. However, the sector faces some distinctive challenges as it tries to align its operations with the UK's net zero goals. These challenges include: particularities of the manufacturing process that make emissions hard to abate, limited availability and readiness of decarbonisation innovations and technologies at scale, high CAPEX and/or OPEX associated with technologies that are available, an ill-equipped energy infrastructure, outdated regulatory frameworks and product standards, and insufficient recycling infrastructure to maximise the closed-loop recycling of glass scrap.

All these factors mean that decarbonisation may not be financially viable for the glass sector unless it is assured of adequate demand for its low carbon products. Therefore, it is a sector that would particularly benefit from demand-led policies to support innovations surrounding decarbonisation. A comprehensive policy framework that seeks to facilitate the sector to decarbonise must take all of the challenges the sector faces into account and provide near-term support where needed, while also keeping an eye on the long-term horizon to ensure that the sector will be able to decarbonise in line with the UK's net zero target.

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