

Final report

The carbon impact of bottling Australian wine in the UK: PET and glass bottles



WRAP works in partnership to encourage and enable businesses and consumers to be more efficient in their use of materials and recycle more things more often. This helps to minimise landfill, reduce carbon emissions and improve our environment.

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Front cover photography: Examples of Wine bottles

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Executive summary

This report analyses the carbon dioxide (CO₂) emissions from bulk importing wine from Australia and bottling it in the UK. The study considers a comparison between using Amcor-designed PET bottles versus typical glass bottles used by UK-based bottlers. One challenge in this study was determining the conditions for comparing PET and glass. Several variables were considered and are explained in the body of this report, but the core comparison was between:

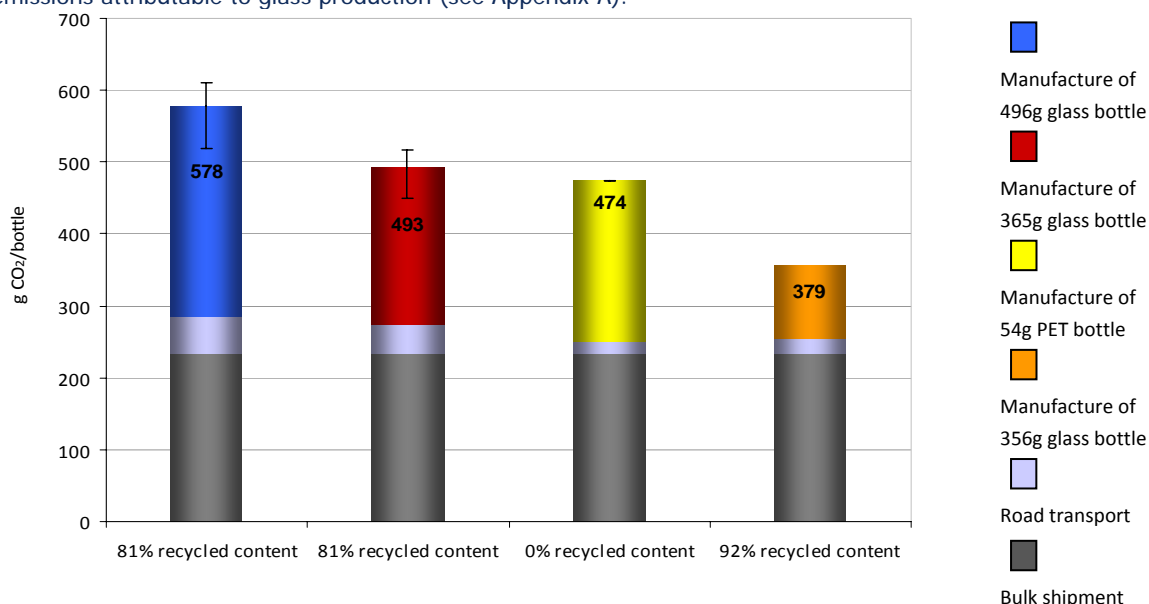
- Amcor-produced PET bottle = 54g with 0% recycled content
- Typical glass bottle available in UK = 496g with 81% recycled content
- Lightweight glass bottle available in UK¹ = 365g with 81% recycled content

One significant element which was considered was the treatment of empty containers at end-of-life scenarios included landfill disposal and recycling². The overall results, compared to a UK-produced very light glass bottle are shown in Figures 1.2 and 1.3, and summarised below

Figure 1.1 Emissions per bottle for each bottle type

Bottle Type	Emissions per bottle (gCO ₂) ³	
	Average	Range
	Without end-of-life recycling	
54g PET	474	474-474
365g glass	493	450-517
496g glass	578	519-610
With end-of-life average recycling rates		
54g PET	446	446-446
365g glass	453	416-472
496g glass	523	476-550

Figure 1.2 Total CO₂ emissions: Bulk shipped Australian wine bottled in 496g and 365g European produced glass bottles, in 356g UK produced glass bottle, and in 54g PET bottles. The black lines depict the range of CO₂ emissions attributable to glass production (see Appendix A).

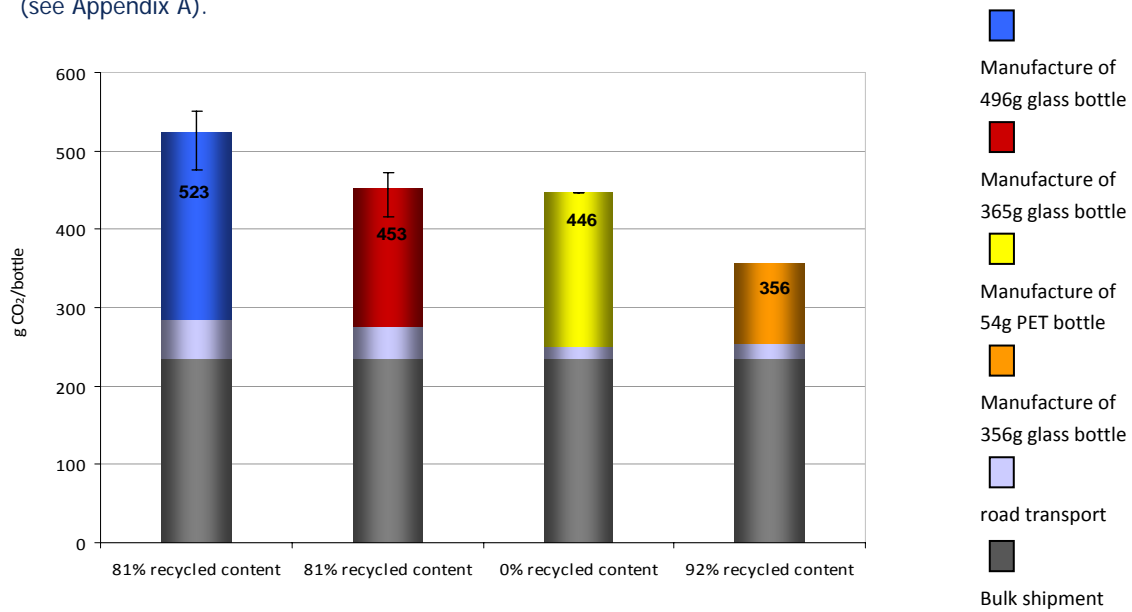


¹ The remit of this study was to compare the Amcor manufactured 54g PET bottle with the lightest bottle currently manufactured in the UK, as this would compare products manufactured in the UK. It was not part of this study's remit to compare the PET bottle with the lightest available glass bottle, which is circa 340g and made in France (see page 11).

² End-of-Life detailed considerations were outside the scope of the study. Landfilled has been treated as 'loss' of material from the system, while recycling has been treated as recovery of resources back into the system.

³ Only one source for PET was selected, as the aim of this study was to assess the Amcor manufactured 54g PET bottle only versus variations of glass wine bottle weights.

Figure 1.3 Total CO₂ emissions: Bulk shipped Australian wine bottled in 496g and 365g European produced glass bottles, in 356g UK produced glass bottle, and in 54g PET bottles (including CO₂ savings from recycling at end-of-life)⁴. The black lines depict the range of CO₂ emissions attributable to glass production (see Appendix A).



The results show that the most significant impacts on the distribution system were the bulk shipment from Australia and the manufacture of the bottles. Once the wine arrives, the UK produced 356g glass bottle is the lightest glass option currently available for UK-bottling and distribution. The PET and lightweight glass bottles at 365g have similar overall emissions. The lightweight glass bottle is more efficient in production than the PET bottle, but importing empty glass bottles from Europe is less efficient than transporting empty PET bottles within the UK. The PET bottle also makes some savings during UK wine distribution because of its low weight, but the distances involved are short so the extent of these savings is relatively low (road transport accounts for a maximum of 9% of all emissions).

Glass bottles have higher recycled content than PET, which is zero under current production systems. Also, existing systems for glass recycling are more sophisticated than for PET recycling, so additional carbon savings are obtained for glass when end-of-life impacts are considered.

Two further comparisons are made in this report:

- UK-produced glass bottles (typical and company specific) versus PET bottles; and
- PET bottles with different recycled content.

⁴ CO₂ savings derived from recycling PET were calculated from data provided by Amcor and differs from publicly available data. In general, -1.5 tonnes of CO₂ are saved per tonne of plastic recycled. Using Amcor data, approximately 2.5 tonnes of CO₂ are saved per tonne of PET recycled.

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1.0 Introduction and scope

This analysis was undertaken for Amcor PET packaging (now known as Artenius PET Packaging) as part of a project part-funded by the government's WRAP programme. Amcor has its headquarters in Melbourne, Australia and is a global leader in manufacturing metal, plastic and paper packaging materials. Amcor is the largest PET manufacturer in the world. At its UK division, Amcor PET Packaging produces injection moulded pre-forms and blow-moulded bottles for the beverage market.

This study analyses the carbon dioxide (CO₂) emissions attributable to bottling wine in Amcor-designed PET bottles versus conventional glass bottles. The wine is produced in Australia and shipped in bulk using 24,000 litre Flexitanks to the UK where the bottling occurs. Two types of bottles have been used in this analysis: average wine glass bottles weighing 496 grams and a newly developed wine PET bottle weighing 54 grams.

The study includes the CO₂ emissions arising from:

- Transportation of empty Flexitanks to the winery in Australia;
- Transportation of filled Flexitanks from the winery to an Australian port;
- Transportation of filled Flexitanks by ship from Australia to the UK;
- Transportation of filled Flexitanks from the UK port to the bottling plant;
- Production of the different types of bottles and pallets used in transport;
- Transportation of empty bottles from the manufacturer to the bottling plant;
- Transportation of filled bottles from the bottling plant to a distribution centre;
- Transportation of filled bottles from the distribution centre to the retail outlet; and
- Transportation of filled bottles from the retail outlet to the customers' homes.

It does not include the CO₂ emissions arising from:

- Cultivation of grapes and production of wine;
- Production of labels or corks (stoppers) used for the bottles;
- Disposal of used Flexitanks;
- Filling operations;
- Secondary packaging of bottles (primarily shrink wrap);
- Disposal of filled bottle packaging, such as pallets or wine cases; and
- Incineration of the different types of bottles at waste management or energy recovery facilities.

For a full explanation of the assumptions used in this report, please see Appendix A.

1.1 Data quality assessment

The following data were provided by Amcor:

- Weight and dimensions of one PET bottle;
- Weight and composition of an empty load of PET bottles;
- Weight and composition of a full load of PET bottles;
- Distance from PET manufacturer to bottling plant;
- Distance from bottling plant to distributor; and
- Composition and use of secondary and tertiary packaging of empty PET bottles.

The following data were provided by Fosters Group:

- Transport route of wine from Australian winery to UK bottling plant;
- Distance from bottling plant to distributor;
- Weight of full wine cases for both PET and glass; and
- Composition of a full load of both PET and glass bottles.

The following data were provided by Corby Bottlers:

- Origin of glass bottles used at the bottling plant; and
- Secondary use of pallets initially used to transport empty glass bottles.

The following data were provided by Quinn Glass:

- Energy use for manufacture of glass bottles at their UK facility.

There were slight discrepancies in the data obtained from the different sources and certain assumptions were made (see Appendix A). Overall, the quality of the data was good.

2.0 Bulk shipment of wine from Australia to the UK: CO₂ emissions from wine imported

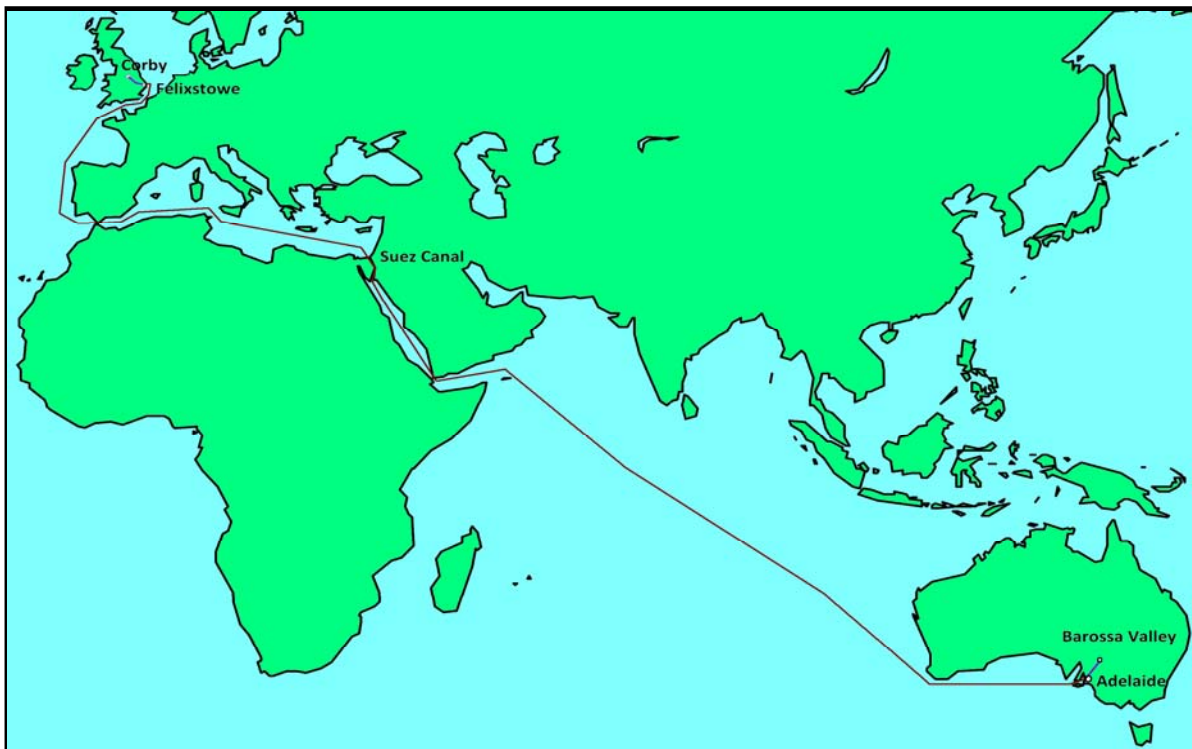
Between 42 and 50% of the CO₂ emissions identified in this study arise from bulk shipping Australian wine to the UK. This accounts for 235g CO₂ / bottle.

Data on the origin of the wine to be packaged in polyethylene terephthalate (PET) bottles and on the route taken by the wine shipped in bulk from Australia were provided by Fosters Group. Several online calculators were used to determine distances between the different localities (see Appendix A). It was assumed that bulk transportation of wine was consistent for glass and PET bottling.

The most common container used for long-distance wine bulk transport is the Flexitank⁵. Flexitanks are soft, disposable plastic bags with a nozzle opening for filling and emptying operations. They are inserted into typical 20 foot rigid containers and are used for transporting non-hazardous liquids. The Flexitanks used in this study weigh 80 kg each and have a carrying capacity of 24,000 litres. When empty, twenty Flexitanks fit in a 20 foot container.

The Australian wine used in this analysis originates from the Barossa Valley region of Southern Australia, more specifically from Nuriootpa. Barossa Valley is one of the best known wine regions in Australia⁶. Wine produced at Barossa Valley is loaded onto Flexitanks which have previously been placed in 20 foot containers (TEU). The filled Flexitanks are taken by road to the docks at the Port of Adelaide. From Adelaide they are carried by large container ships, through the Suez Canal, to the Port of Felixstowe. At Felixstowe the Flexitanks are loaded onto diesel 38 t Artic lorries and transported by road to Corby Bottlers at Corby, Northamptonshire, where they are emptied and disposed of. Figure 2.1 illustrates the route described above:

Figure 2.1: Route taken by wine filled Flexitanks from Barossa Valley to Corby



The wine bottles used for this study have a volume of 75 cl. Figure 2.2 breaks down this bulk transportation process and allocates CO₂ emissions to each leg of the journey, and figure 2.3 shows these results on a 'per bottle' basis:

⁵ WRAP, 2007. The life cycle emissions of wine imported to the UK. Oakdene Hollins Ltd., United Kingdom.

⁶ <http://www.barossa.com>

Figure 2.2: CO₂ emissions: Transportation routes, distances and load weights of Australian wine imported in bulk to the UK.

Container / Route	Distance (km)	Vehicle	Load weight (t)	kg CO ₂ /load
Flexitank from Barossa Valley, Australia to Corby, UK	20,150	-	-	7,586
Of which...				
Twenty empty Flexitanks to the winery	71	38 t Artic	1.6	57
Filled Flexitank from winery to Adelaide	71	38 t Artic	24.08	81
TEU containers + Filled Flexitank from Adelaide to Felixstowe	19,824	Large Container Ship	26.08	7,238
Filled Flexitank from Felixstowe to Corby	184	38 t Artic	24.08	210

Figure 2.3: CO₂ emissions: Transportation routes, distances, load volumes and equivalent bottles of Australian wine imported in bulk to the UK.

Container / Route	Distance (km)	Load volume (l)	Equivalent bottles	Total kg CO ₂	g CO ₂ per 75cl wine (bottle)
Flexitank from Barossa Valley, Australia to Corby, UK	20,150	-	-	7,586	235
Of which...					
Twenty empty Flexitanks to the winery	71	480,000	640,000	57	0.09
Filled Flexitank from winery to Adelaide	71	24,000	32,000	81	2.53
TEU containers + Filled Flexitank from Adelaide to Felixstowe	19,824	24,000	32,000	7,238	226.19
Filled Flexitank from Felixstowe to Corby	184	24,000	32,000	210	6.56

Although bulk freight shipments are the most carbon efficient method of transport, the distance from Australia to the UK is great and therefore the CO₂ emissions attributable to this shipment are between 42 and 50% of the total CO₂ emissions of each bottle (using the parameters analysed in this study).

Savings from bulk shipping

A previous study (*The life cycle emissions of wine imported to the UK*) commissioned by WRAP analysing the benefits of bulk importing wine states that there is “huge potential for reducing CO₂ emissions during the transportation and packaging stages in the total life cycle for wine imported into the UK”. The most significant factor for reducing emissions of wine transported from Australia is bulk shipping. On average **164g of CO₂** per bottle are saved when importing Australian wine in bulk as opposed to importing pre-bottled Australian wine.

3.0 PET bottles: CO₂ emissions from manufacture

The manufacture of a 54g virgin PET bottle releases 222g CO₂.

The production of PET bottles has three main phases. First, the polymer is synthesised from crude oil usually using antimony trioxide as a catalyst and pure PET flakes are produced. Then, small and dense test-tube like pre-forms which weigh the same as the final bottle are injection moulded from the PET flakes. Finally, the bottles are formed by stretch-blow moulding of these pre-forms⁷. These industrial processes require energy derived from electricity or other fuels, and therefore will have CO₂ emissions associated with them. When PET bottles are made from recycled PET flakes instead of virgin PET, less energy is required, as the first phase (crude oil synthesis) is avoided.

The Association of Plastic Manufacturers in Europe holds data on the average fuel mix and fuel quantity used to obtain the energy required to make PET bottles within Europe. These data were used to determine the amount of CO₂ emissions arising from the manufacture of a 54g PET bottle. On average, the production of a 54g PET bottle in Europe emits 222gCO₂. This includes extraction and transport of raw materials as well as material and energy inputs and outputs in the form of emissions to air. This total increases to 223gCO₂ per bottle when use of tertiary packaging to transport bottles from the manufacturer to the bottler is included in the calculations. The PET bottles are manufactured in the UK by Amcor and shipped to the bottling plant at Corby where they are filled. As PET is shatter proof, accidental breakage during filling is avoided. However, there is a 2% loss of bottles during filling due to under-filling (1%), as it is not practical to remove the bottle cap once it has been applied, and to scuffing (1%)⁸. These losses are not included in this analysis since they are equal to the losses occurring during glass bottle filling.

Amcor produced PET bottles are palletized using High Density Polyethylene (HDPE) pallets which are returned to the manufacturing plant for reuse. According to Amcor, HDPE pallets have a useful lifetime of fifty cycles, that is, they can be reused up to fifty times. The CO₂ emissions arising from the manufacture of the HDPE pallets used by Amcor is included in the total emissions arising from manufacturing PET bottles. Return transport of the pallets is not included in this analysis as data were incomplete for pallets used in transporting glass bottles.

⁷ Petcore, 2004. World Largest PET Life Cycle Assessment – One-way PET levels with refillable glass.

⁸ Personal Communication, Peter Roberts, Corby Bottlers. (21.08.07)

4.0 Glass bottles: CO₂ emissions from manufacture

The manufacture of a 496g glass bottle releases 293 gCO₂.
The manufacture of a 365g glass bottle releases 216 gCO₂.

Traditionally, glass has been used to package wine because, being an inert material it does not alter the chemical properties of wine. The production of glass bottles includes the extraction and transport of raw materials and the melting of these materials to produce glass. Melting the raw materials requires large amounts of energy, usually provided by fossil fuels which when combusted release CO₂. When glass is recycled, however, there is no need for extraction of raw materials and the overall temperature needed to melt glass cullet (broken or waste glass returned for recycling) is significantly less than that needed to melt 'virgin' raw materials. Glass wine bottles can be recycled indefinitely⁹.

There is no readily available 'standard' glass bottle to use in this study. There are three key variables that need to be considered: weight of bottle, location of manufacture and recycled content. To treat these in turn, the authors used the following approach:

1 Bottle weight – Wine glass bottles vary in weight. The UK market weighted average wine bottle weight is 496g but recently much work has focussed on the opportunity to lightweight glass bottles and the lightest bottle available is 300g¹⁰ (see Appendix D). In this report, glass wine bottles weighing 496g (heavy) are analysed for the main comparison of the study as this is the weight of the UK average wine bottle. Additionally, 365g (light) were analysed as this is the weight of the lightest bottle used at Corby Bottlers.

2 Location of manufacture – the carbon intensity of fuel and electricity varies between countries, as does the efficiency of the manufacturing process and transport distances of materials and finished products. Best Foot Forward (BFF) were briefed to consider the 'typical' UK glass bottle, so Corby bottlers were contacted to determine the mix of bottles used at their facility. Corby bottlers use bottles from several European suppliers. On average about 55% of the bottles are sourced from France, 15% from Belgium, 20% from Bulgaria, and the remainder 10% from the UK. It was assumed that the British glass bottles are non-site specific, and an average carbon intensity for UK produced bottles was used. There is limited or no availability on energy used by the glass industry from different European countries, so three approaches were used to determine CO₂ emissions arising from bottle manufacture in each country (see Appendix A). BFF recognise that this is not an exact country comparison, but more detailed investigation was outside the scope of this study. The manufacture of European sourced bottles was assumed to be Lyon in France, Brussels in Belgium and Sofia in Bulgaria so transport distances were calculated from these locations to the bottling plant at Corby where they are filled. There is about a 2% loss due to under-fill (1%) and to breakage (1%)¹¹ but this loss was not included in the calculations because it is the same as the loss incurred by filling PET bottles.

3 Recycled content – the recycled content of glass also varies by region. Average green glass bottles manufactured in Europe have a weighted average recycled content of about 80.9%, ranging from 30% in Bulgaria¹² to 99% in France¹³.

The energy required to make the 496g and 365g wine glass bottles analysed here was derived using several approaches and data sources which are currently available. Consequently, different results were obtained depending on the approach taken (see Appendix A) and the range of results obtained is shown in Figure 3.1. BFF consider this approach to be most robust and transparent when conducting an analysis of this type which depends on several secondary data sources.

⁹ Wasteonline, 2006. Glass Recycling Information Sheet. Available from: <http://www.wasteonline.org.uk/resources/InformationSheets/Glass.htm>

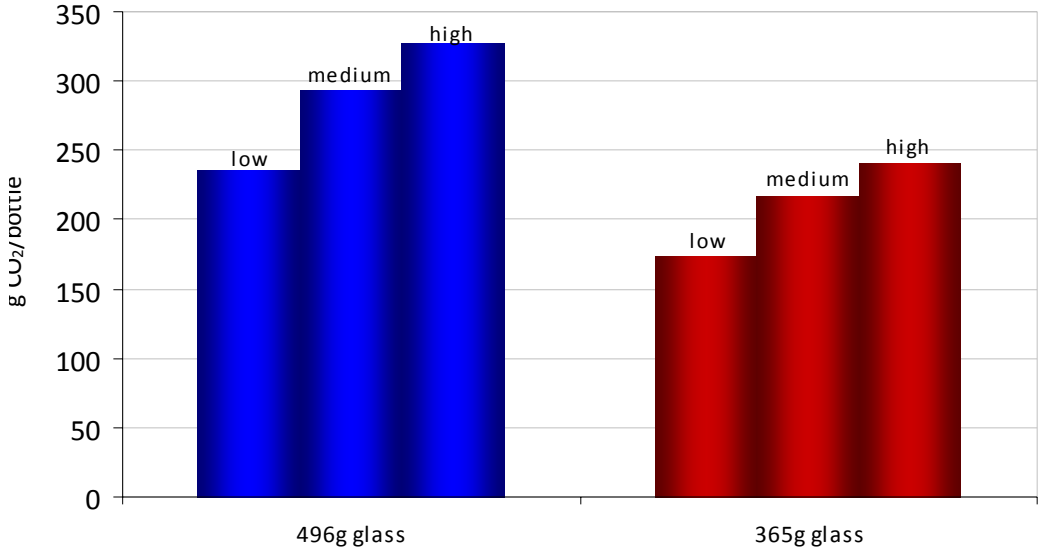
¹⁰ WRAP, 2006. More Bulk. Less Bottle. The Wrap Wine Initiative. Banbury, United Kingdom.

¹¹ Personal Communication, Peter Roberts, Corby Bottlers. (21.08.07)

¹² Personal Communication, Peter Roberts, Corby Bottlers. (22.08.07)

¹³ Bilan Carbone, 2007. Guide des Facteurs d'Emissions. France.

Figure 4.1 Emissions arising from glass bottle manufacture



The totals calculated include the use of tertiary packaging to transport the bottles from the manufacturer to the bottler but not the return journey of the pallets, as the destination of used pallets varies considerably and data were not readily available. Glass bottles are palletized using Euro-pallets made from wood. Pallets from all French sourced glass are returned as full loads to the bottle manufacturer, Belgium pallets are reused within the distribution system of Corby bottlers and Bulgarian pallets are used for exporting to Nordic markets. It was assumed that on average, wooden pallets have a useful lifetime of 10 cycles, that is, they can be reused up to ten times¹⁴. The CO₂ emissions arising from the manufacture of the wooden pallets used by the different bottle manufacturers is included in the total emissions arising from manufacturing glass bottles.

The attributable CO₂ emissions for each bottle weight vary depending on the approach used. In this study, the medium estimate is commonly referred to but when comparing glass bottles to PET bottles the range is depicted graphically by a black line. The values represented in figure 4.1 do not include CO₂ savings from any waste management activity at the end of their useful life. CO₂ savings from recycling are covered in later sections of this report. There are significant CO₂ savings related to recycling glass which impact upon the CO₂ emissions attributable to glass production.

¹⁴ <http://www.ciwmb.ca.gov/Packaging/Wood/pallet.htm>

5.0 PET bottles: CO₂ emissions from road transport

Amcor has developed a 75 cl PET bottle which protects wine from UV light and other damaging agents, in a manner similar to glass wine bottles. The benefit of the PET wine bottle is that it is lightweight compared to traditional glass bottles, thus saving fuel in transport and consequently CO₂ emissions arising from burning those fuels. Figure 4.1 breaks down the route taken by the PET wine bottles analysed in this study and allocates CO₂ emissions to each leg of the journey:

Figure 5.1: CO₂ emissions: Transportation routes, distances and load weights of PET bottles.

Container / Route	Distance (km)	Vehicle	Load weight (t)	kg CO ₂ /load
<i>PET bottles from manufacturer to consumer</i>	496	-	-	476
Of which...				
67,500 empty bottles from manufacturer to Corby	226	38 t Artic	5.33	195
21,840 filled palletized bottles from Corby to Daventry	63	38 t Artic	19.06	67
21,840 filled palletized bottles from Daventry to retail outlet	200	38 t Artic	19.06	213
6 filled bottles and case from the retail outlet to consumer	7	Average UK car	0.01	0.564

The filled bottles are packaged in cases containing six bottles each. The cases are then palletized using wood pallets. Each pallet contains 140 cases which equals 840 bottles. The pallets are loaded onto a diesel powered 38 t Artic lorry which has capacity for 26 pallets. A full load is 21,840 bottles and weighs 19,064 kg. The lorries transport the bottles to a national distribution centre at Daventry from where they are delivered to retail outlets. It was assumed that delivery to retail outlets was performed in the same way as delivery to the distribution centre (i.e. 21,840 bottles at a time). Consumers then purchase bottles at the retail centre and typically drive (with other shopping) to their home.

6.0 Glass bottles: CO₂ emissions from road transport

Reducing glass bottle weight from 496g to 365g saves about 17% of CO₂ emissions per bottle attributable to transporting glass wine bottles within the UK.

One of the key purposes of this study was to consider the effect of transporting heavier glass bottles as opposed to lighter PET equivalents. Figure 6.1 breaks down the route taken by typically heavy UK glass wine bottles if produced in Europe¹⁵. Figure 6.2 breaks down the route taken by typically light European produced glass wine bottles. Both figures allocate CO₂ emissions to each leg of the journey:

Figure 6.1: CO₂ emissions: Transportation routes, distances and load weights of 496g glass bottles.

Container / Route	Distance (km)	Vehicle	Load weight (t)	kg CO ₂ /load
glass bottles from manufacturer to consumer	1487	-	-	1570
Of which...				
37,530 empty bottles from manufacturer to Corby	1217	38 t Artic	19.45	1260
20,160 filled palletized bottles from Corby to Daventry	63	38 t Artic	26.51	74
20,160 filled palletized bottles from Daventry to retail outlet	200	38 t Artic	26.51	235
6 filled bottles and case from the retail outlet to consumer	7	Average UK car	0.01	0.863

Figure 6.2: CO₂ emissions: Transportation routes, distances and load weights of 365g glass bottles.

Container / Route	Distance (km)	Vehicle	Load weight (t)	kg CO ₂ /load
glass bottles from manufacturer to consumer	1487	-	-	1551
Of which...				
46,800 empty bottles from manufacturer to Corby	1217	38 t Artic	18.54	1244
21,840 filled palletized bottles from Corby to Daventry	63	38 t Artic	25.86	73
21,840 filled palletized bottles from Daventry to retail outlet	200	38 t Artic	25.86	233
6 filled bottles and case from the retail outlet to consumer	7	Average UK car	0.01	0.773

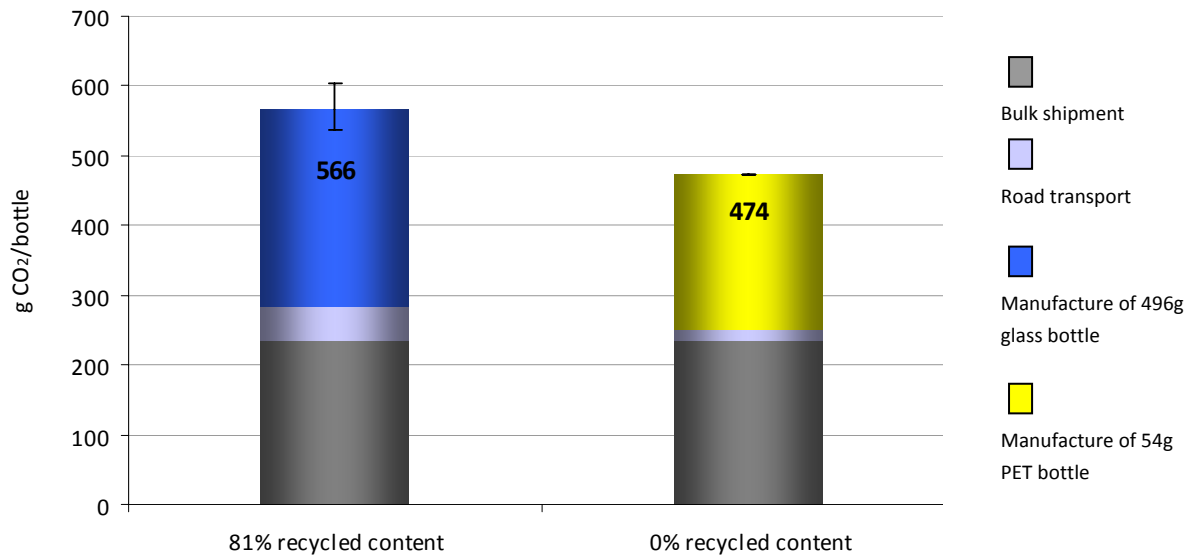
Filled glass bottles are packaged in cases containing six bottles each. The cases are palletized, each pallet containing 140 cases which equals 840 bottles per pallet. The pallets are loaded onto a diesel powered 38 t Artic lorry which has capacity for 26 pallets. A full load for 496g bottles is 24 pallets which contain 20,160 bottles and weighs 26,508 kg. For 365g bottles, a full load is 26 pallets which contain 21,840 bottles and weighs 25,856 kg. The lorries transport the bottles to a national distribution centre at Daventry from where they are delivered to retail outlets. It was assumed that delivery to retail outlets was performed in the same way as delivery to the distribution centre (i.e. 20,160 or 21,840 bottles at a time, depending on individual bottle weight). Consumers then purchase the case of bottles at the retail centre and drive with the load to their home.

¹⁵“Heavy” European produced bottles used at Corby Bottlers weight 460g, whereas, the typical glass wine bottle weight in the UK is 496g.

7.0 Comparison of PET versus glass bottling

The previous sections of this report have outlined the CO₂ emissions attributable to shipping wine in bulk from Australia to the UK, the manufacture and transport of PET bottles, and manufacture and transport of glass bottles. Combining these figures gives total emissions per bottling scenario where the average recycled content of glass bottles is 81% and the average recycled content of PET bottles is 0% (see Appendix B).

Figure 7.1: CO₂ emissions from bottling Australian wine in the UK excluding end-of-life considerations: 496g glass bottles and 54g PET bottles.



It can be seen from figure 7.1 that there are considerable CO₂ savings from bottling wine in lighter bottles since they require less energy to transport.

7.1 End-of-life

CO₂ emissions attributable to both types of bottles materials are affected by the fate of the bottles once they are disposed of by the consumer. To account for CO₂ savings from recycling used PET bottles, the UK municipal plastic recycling rate of 20%¹⁶ was used along with the CO₂ savings arising from manufacturing new PET bottles from recycled PET flake¹⁷. The calculations to determine recycling savings from PET include transport of the bottles to the recycling plant, washing and flaking, and a plant overhead following the methodology described by Eco-profiles of the Plastic Industry¹⁸. To account for energy savings from recycling used glass bottles, the UK municipal glass container recycling rate of 50%¹⁹ was used along with the CO₂ savings arising from manufacturing new glass bottles from recycled cullet. Recycling benefits for glass were derived from Enviros 2003 and include: Recycled material preparation, collection and transport to bulking site, transport from bulking site to processor and transport from processor to the glass factory. Please see Appendix A for complete details on recycling savings applied. The figure below shows the emissions per bottle including end-of-life recycling are shown overleaf:

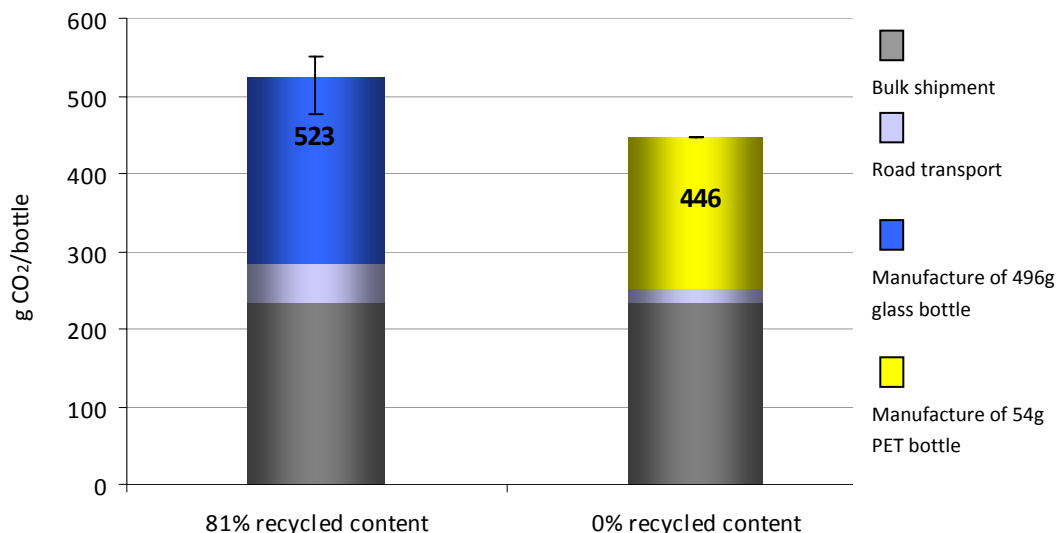
¹⁶ Wrap, 2007. Realising the Value of Recovered Plastics. Market Situation Report-Autumn 2007. See Appendix A for full details.

¹⁷ Data on energy required to recycle PET obtained from AMCOR.

¹⁸ Boustead, I. 2005. Eco-profiles of the Plastic Industry. Methodology.

¹⁹ Extrapolation of data held by Defra (2003): UK glass recycling rates for period 1984-2004 and for 2003. See Appendix A for full details.

Figure 7.2: CO₂ emissions from bottling Australian wine in the UK including CO₂ savings from recycling at end-of-life: 496g glass bottles and 54g PET bottles.



In this study, the total CO₂ emissions per PET bottle would be considerably reduced with higher municipal recycling rates for plastic. Similarly, if glass container municipal recycling rates in the UK were comparable to recycling rates in other EU countries, the CO₂ emissions from manufacturing glass bottles would decrease significantly.

PET, as most plastics, degrades when recycled. The economic and technological feasibility of recycling PET bottles back into food-grade PET within the UK is challenging and most PET bottles are recycled into PET fibre or shipped to Asia for recycling. Nonetheless, there have been recent technological gains, along with economic incentives in the form of tax cuts that make some bottle to bottle recycling of PET viable.

The economic feasibility of glass recycling is established and glass can be recycled indefinitely without losing material quality. However, the relatively low amount of green glass bottles manufactured in the UK, coupled with large imports of green glass as drinks packaging, have contributed to the existence of an excess of green glass cullet. A portion of this cullet is exported to other European countries, such as France, where the scale of green glass bottle production can easily incorporate this excess cullet.

Green Glass excess and the export of cullet

The inclusion of CO₂ emissions from exporting green glass cullet to France has a minimal impact on the overall emissions attributed to the processes analysed in this study (see Appendix C). According to WRAP (2006. *Bulk it bottle it and buy it in Britain*) one way to approach the increasing excess of green glass is to encourage green glass bottle production within the UK, thus minimizing the need to export cullet to other countries. Importing wine in bulk and bottling it in the UK would create a domestic market for green glass bottle production.

According to Defra in 2006-2007, about 11% of municipal waste was incinerated. Incineration is often cited as the best alternative to manage plastic wastes since some energy is recovered in Combined Heat and Power (CHP) plants. Glass is less likely to be incinerated and cullet which is not used to produce new glass is usually used as road fill material in substitution for other aggregate. Incineration was not included in the analyses because data were not available on incineration figures or energy obtained from this type of waste management.

7.2 Lightweighting bottles

The UK average glass wine bottle weight is 496g, but Corby Bottlers which are the only fillers currently using PET wine bottles, typically use 460g or 365g glass bottles. Lightweighting bottles has been shown to have benefits in terms of CO₂ savings from transport of loads. Consequently, reducing glass bottle weight reduces the quantity of CO₂ emissions associated with wine packaging, as shown in figure 7.3 and 7.4 below, where a comparison is made between European produced lightweight 365g bottle (used by Corby Bottlers) and the two bottle types analysed throughout this report.

Figure 7.3: CO₂ emissions from bottling Australian wine in the UK excluding end-of-life considerations: 496g glass bottles, 365g glass bottles, and 54g PET bottles.

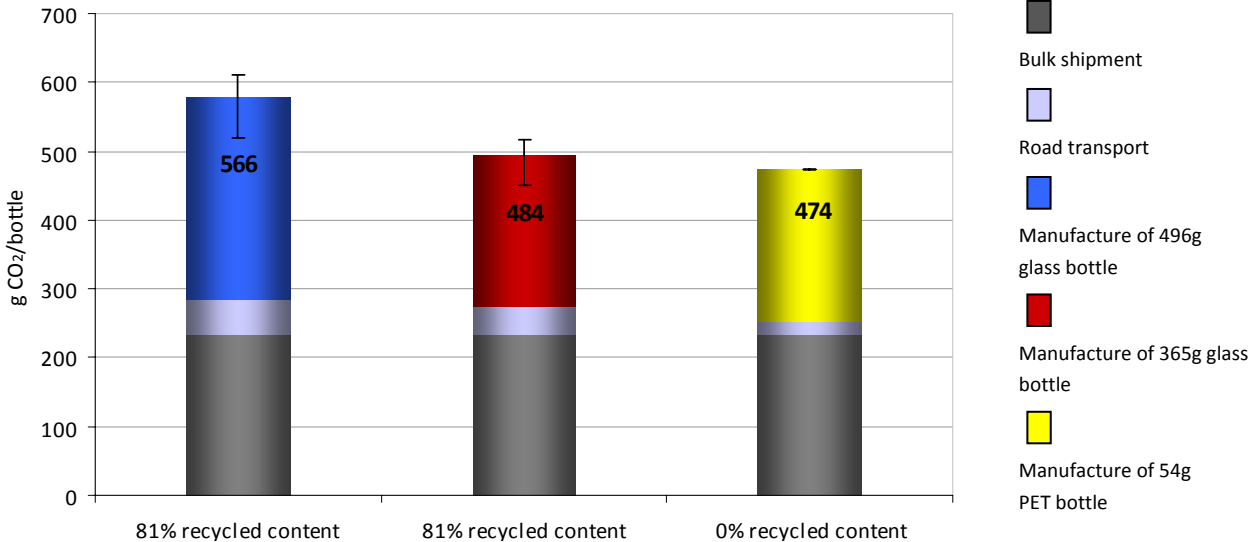
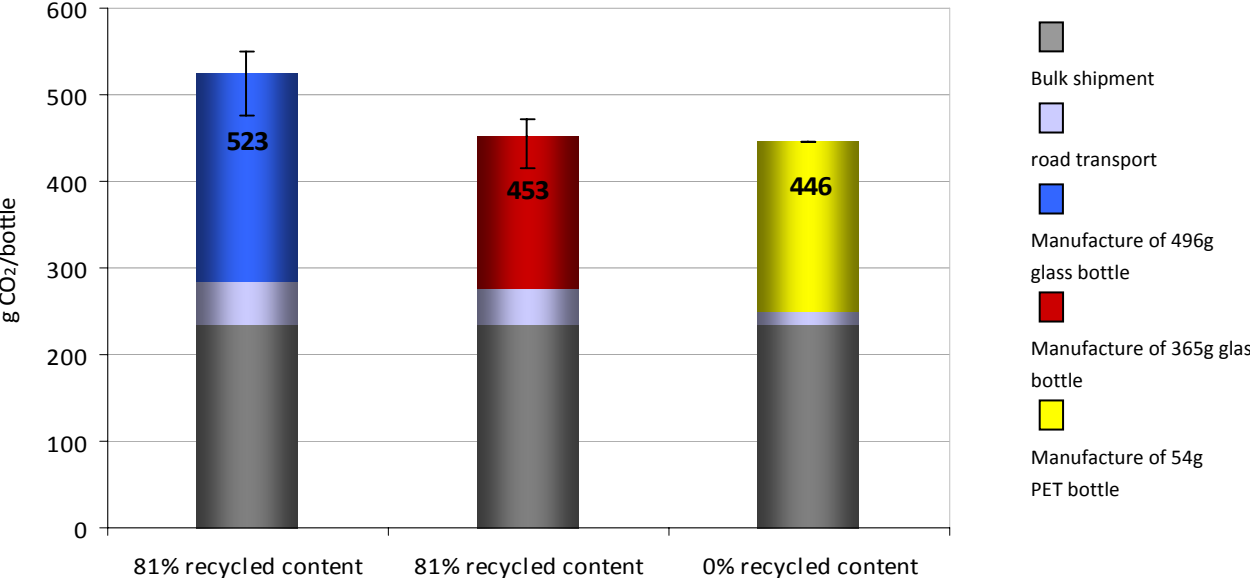


Figure 7.4: CO₂ emissions from bottling Australian wine in the UK including end-of-life considerations: 496g glass bottles, 365g glass bottles, and 54g PET bottles



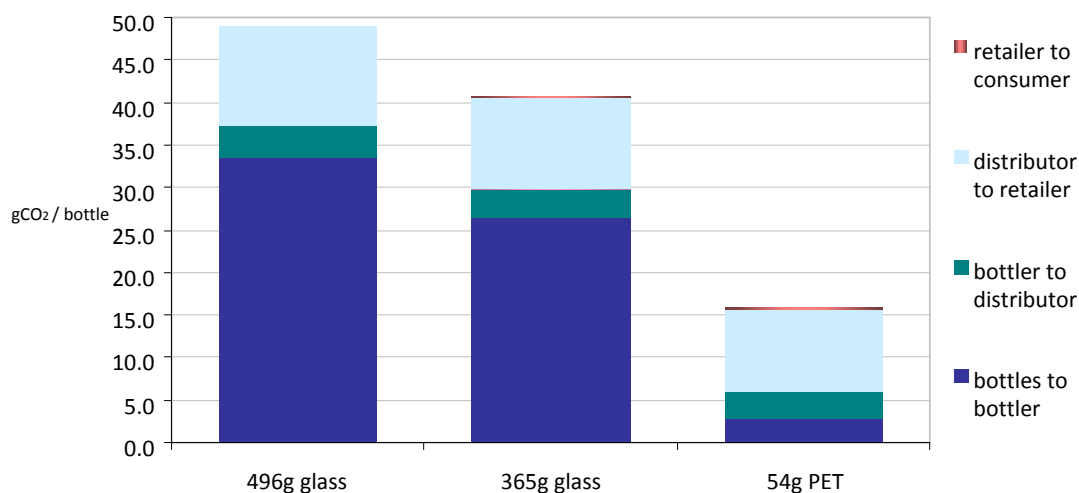
PET comes out marginally lower than the 365g glass bottle when using the medium estimate for glass production emissions, although the higher CO₂ emissions arising for PET from manufacture offset much of the savings obtained from its low weight. In both scenarios, excluding or including end-of-life, the emissions attributed to the 54g PET bottle lie within the range of emissions attributable to the 365g glass bottle.

7.3 Relative contributions to CO₂ emissions

The production of the different types of bottles and bulk shipping Australian wine to the UK are the two most significant contributors to the overall CO₂ emissions analysed in this study. Changing bottle material composition from a heavy and relatively low carbon intensive material (glass) to a light but relatively carbon intensive material (PET) actually has little impact on the final results as the savings from light-weighting are balanced by the higher emissions of manufacturing.

As can be seen in figures 7.3 and 7.4, as bottles become progressively lighter (from 496g to 54g) the relative importance of bulk shipping as the main contributor to the total CO₂ emissions increases. The major component of carbon emissions for 365g glass bottles and 54g PET bottles is the bulk shipment of wine from Australia to the UK. The second most important factor for these two bottle types is the manufacture of the bottle, whilst road transport is a relatively insignificant factor. For the 496g glass bottle, CO₂ emissions arising from manufacture (49%) are slightly more significant than those arising from bulk shipment (42%).

Figure 7.5: CO₂ emissions from transport of empty and filled bottles



As can be seen from figure 7.5, the majority of the CO₂ savings from transporting lighter bottles occur when transferring the empty bottles from the bottle manufacturer to the bottling plant where the difference of load weights and distances is largest. There is a savings of 7gCO₂/bottle between transporting empty 496g glass bottles and empty 365g glass bottles. There is a savings of 31gCO₂/bottle if 54g empty PET bottles are transported instead of 496g empty glass bottles. This totals 91% less CO₂ emissions per bottle when transporting empty 54g PET bottles than when transporting empty 496g glass bottles, mainly due to the longer distances glass bottles travel in this analysis (i.e. from European manufacture).

Differences in CO₂ emissions from transporting the filled bottles to the distributor and from the distributor on to the retailers are relatively small and amount to about 2gCO₂ when comparing the heaviest bottle (496g) to the lightest bottle (54g). CO₂ emissions arising from transporting the bottle to the customer are insignificant and do not show up on the graphical scale used.

The total CO₂ savings from transporting 54g PET bottles (empty bottles to the bottler and filled bottles to the final consumer) as opposed to 496g glass bottles is 33gCO₂/bottle. This totals 68% less CO₂ emissions when transporting 54g PET bottles than 496g glass bottles. If 365g glass bottles are compared to 54g PET bottles, then the total CO₂ savings from road transport are reduced to 25gCO₂/bottle. This totals 61% less CO₂ emissions when transporting 54g PET bottles than 365g glass bottles. It is worth noting, that although the savings from light-weighting bottles are considerable for road transport, this accounts for at most 9% of the total emissions attributable to bulk import of Australian wine to the UK. As explained before, some of these savings are counter-balanced by the emissions arising from the actual production of the different bottle types since glass is less carbon intensive and more efficiently recycled than PET.

In this study CO₂ savings attributable to light-weighting bottles occur during road transport, which accounts for only about 9% of the total CO₂ emissions from bulk importing Australian wine to the UK and bottling it within the country. Figure 7.6, below, shows the CO₂ savings per load by type of bottle used compared to the 496g glass bottle baseline:

Figure 7.6: CO₂ savings per bottle: road transport.

Type of bottle	Bottles per load (empty bottles / full bottles)	Load weight empty bottles (t)	Load weight full bottles(t)	gCO ₂ per bottle	g CO ₂ savings ²⁰ per bottle: ROAD transport	% CO ₂ savings from road transport
496g glass bottle	37,530/ 20,160	19.46	26.51	49	0	0%
365g glass bottle	46,800 / 21,840	18.54	25.86	41	8	16.8%
54g PET bottle	67,500 / 21,840	5.33	19.06	16	33	67.9%

²⁰ Emissions for 365g bottles and 54g bottles are compared to emissions from 496g bottles.

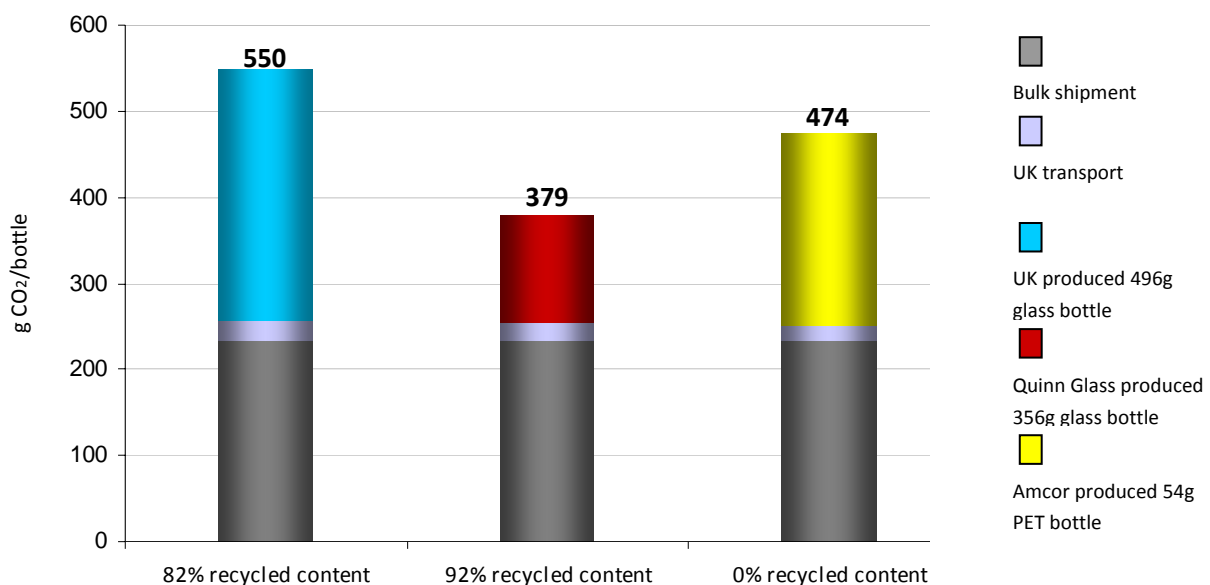
8.0 UK produced glass bottles versus PET bottles

It is useful to consider the effects of manufacturing location on producing glass bottles. The UK imports more than 1 million tonnes of green glass bottles from continental Europe each year²¹. However, green glass bottle manufacture is increasing in the UK as more wine is being bulk imported and demand for domestically produced green glass bottles is rising. On average, green glass produced in the UK has 82% recycled content. Specifically, green glass bottles produced at Quinn Glass have 92% recycled content. For consistency of comparison, it is useful to consider how UK-manufactured PET compares to UK-manufactured glass.

In this section, a comparison between the average weight of bottle available in the UK market (496g) with an 82% recycled content, a specific Quinn Glass bottle (356g)²² with a 92% recycled content, and the Amcor²³ 54g PET bottle with a 0% recycled content is performed. Transport figures and assumptions are the same as those described earlier in this report with the exception of empty glass bottles which originate at Quinn Glass²⁴.

Figure 8.1 shows the CO₂ emissions related to bottling bulk imported Australian wine in UK produced glass and PET bottles without including end-of-life recycling savings:

Figure 8.1: CO₂ emissions from bottling Australian wine in the UK using bottles manufactured domestically: 496g glass bottles, 356g glass bottles, and 54g PET bottles (excluding recycling savings).



When comparing the above figure to figure 7.1, it can be seen that bottling bulk shipped Australian wine in glass bottles manufactured within the UK emits less CO₂ than bottling the wine in glass bottles imported from Europe. This is due to shorter transport distances from the bottle manufacturer to the bottler. However, higher CO₂ emissions arise from average glass bottle production in the UK than from the average glass bottle produced in Europe because of higher carbon intensities of electricity produced in the UK.

CO₂ emissions linked to the production of the 496g bottle are calculated using average UK emission figures for the production of green glass and average UK recycled content for green glass. Compared to this, glass bottles produced by Quinn Glass have lower associated CO₂ emissions because of the higher recycled content, lower weight and high efficiency of production at the plant (Quinn Glass have a modern, efficient plant and use only natural gas as fuel instead of the typical glass industry fuel mix of 77% Gas, 5.1% Fuel Oil, and 17.9% electricity).

²¹ Wrap, 2006. Colourite Project – Maximising Cullet Additions in the Glass Container Industry. Glass Technologies Services Ltd, Sheffield, UK.

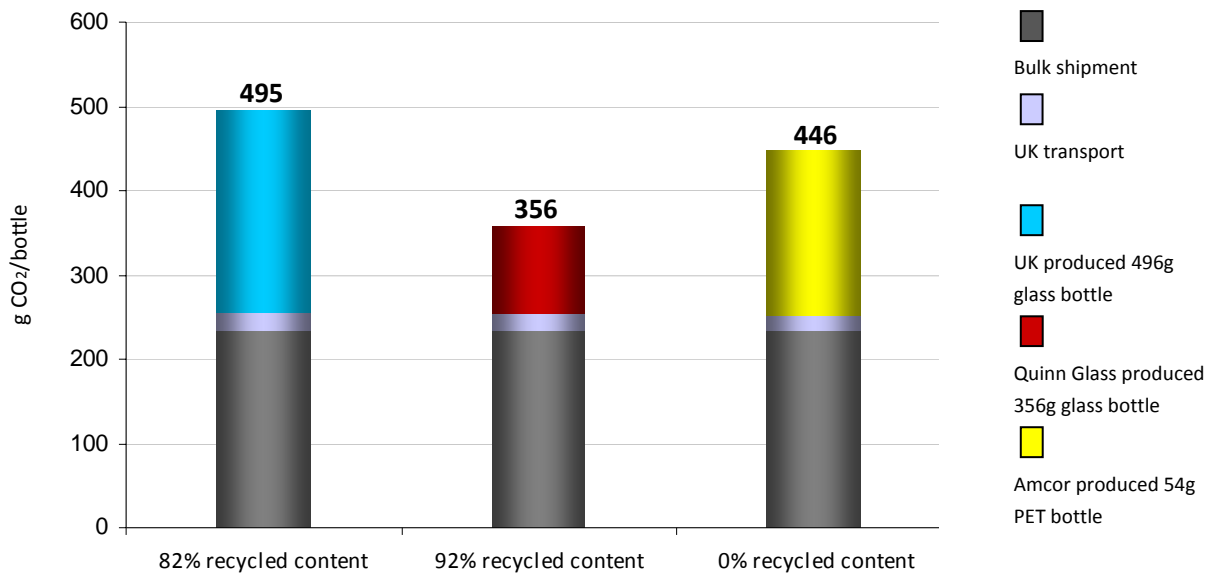
²² Data on bottle weight provided by Quinn Glass. Personal Communication 23.08.07

²³ Data on Amcor produced PET bottles were unavailable and average European PET bottle production figures were used derived from Boustead, 2005.

²⁴ It was assumed, for consistency with other calculations performed throughout this study, that bottles produced at Quinn Glass were filled by Corby Bottlers. In actuality, Corby Bottlers do not purchase bottles from Quinn Glass.

When end-of-life recycling is taken into account, additional CO₂ savings can be allocated to each bottle type. These savings are shown below in figure 8.2:

Figure 8.2 CO₂ emissions from bottling Australian wine in the UK using bottles manufactured domestically: 496g glass bottles, 356g glass bottles, and 54g PET bottles (including recycling savings).

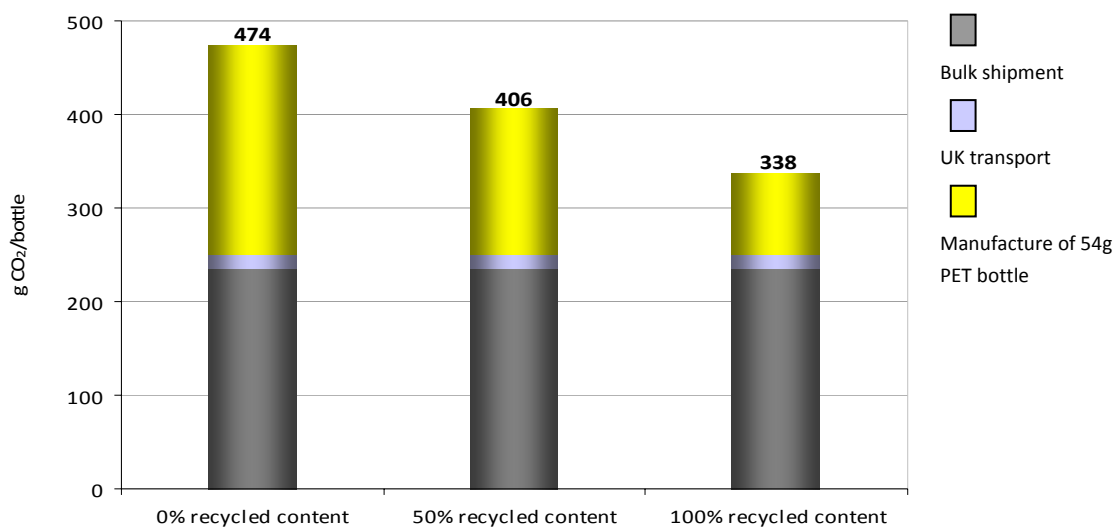


8.1 PET bottles with varying recycled content

No facilities exist in the UK for bottle-to-bottle recycling of PET, although there are plans for a plant to open near London in December²⁵ and other facilities are expected to be completed before 2009. Nonetheless, trials of incorporating post-consumer recycled PET into food, beverages and beauty product packaging have been undertaken recently by WRAP²⁶ and it was deemed feasible to include up to 50% recycled content in several types of packaging.

Recycling PET involves transport and preparation of the recyclate before a food-grade flake is obtained. Data were provided on the energy requirements and fuel mix used to prepare recycled PET flakes, but data did not include energy required for transporting of recycled material to the plant. Several calculations were performed to include transportation and overhead to obtain CO₂ emissions per kilogram of recycled PET (Appendix A).

Figure 8.3 CO₂ emissions from bottling Australian wine in the UK using PET: 0%, 50%, and 100% recycled content (excluding recycling savings).

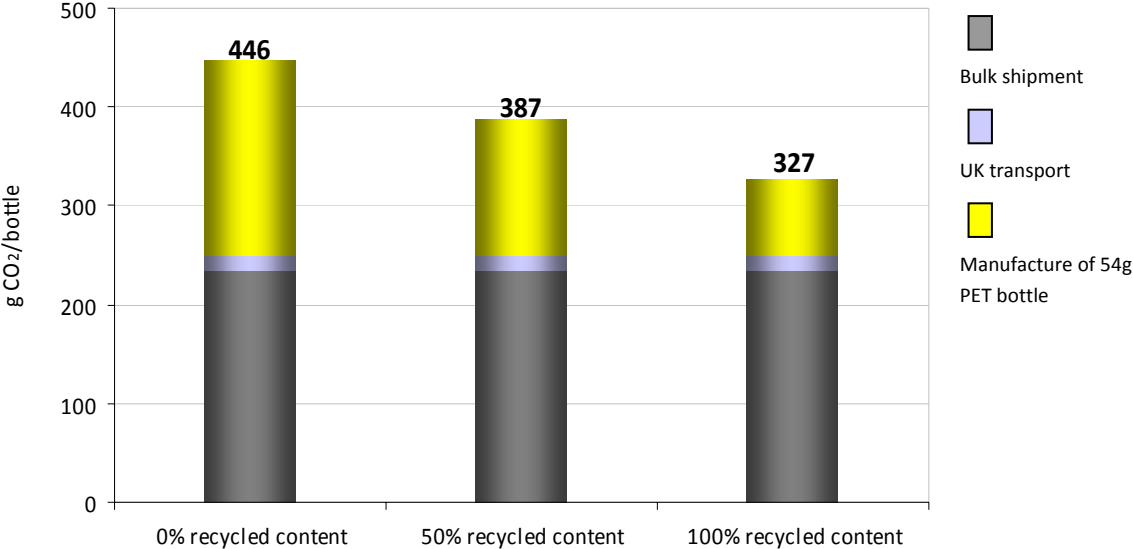


²⁵ Reilly, M. Recycled plastic to get clean bill of health. New Scientist, 09.05.2007.

²⁶ WRAP, 2007. Using recycled content in plastic packaging: the benefits. Banbury, United Kingdom.

CO₂ emissions are reduced when incorporating recycled PET into new bottle manufacture, primarily because extraction, transport and synthesis of crude oil are avoided. However, recycling PET to create food-grade PET flakes is often an energy intensive process in itself. It is also possible that PET will be coated with different materials to reduce its permeability and to enhance its capability to store alcohol which may reduce the recyclability of the container. In any case, it is more energy and resource efficient to incorporate recycled PET into bottle manufacture than to produce PET bottles using only virgin material.

Figure 8.4: CO₂ emissions from bottling Australian wine in the UK using PET: 0%, 50%, and 100% recycled content (including recycling savings).



9.0 Conclusion

Lightweighting bottles is a proven method to reduce CO₂ emissions arising from transport of bottle loads. For the light glass bottles (365g) and the PET bottle, the largest contributor to CO₂ emissions from bulk shipped Australian wine for UK-bottling is shipping the wine from Australia. For heavy (496g) glass bottles, CO₂ emissions arising from the manufacture of the bottle are slightly more significant than bulk shipping the wine.

This study analyses only CO₂ emissions and not other greenhouse gases such as N₂O or CH₄ as these were outside the scope of work provided. These other environmental impacts are more often than not covered in more in depth life cycle analyses. The inclusion of other greenhouse gases, generally known as CO₂ equivalents would increase the emissions from manufacturing PET by almost 14%²⁷. For glass, there would be an increase in the emissions arising from electricity, gas and fuel oil used in manufacture. This is estimated at about 10%²⁸.

The CO₂ emissions from bottle manufacture are calculated on the basis of the weights and types of materials used, including recycled content. Life cycle studies 'to factory gate' have consistently shown that manufacturing glass is less carbon intensive than manufacturing PET on a per unit weight basis. However, the properties of PET are such that a wine bottle can be manufactured which is of considerably lower weight than the 'best practice' glass equivalent. When the total emissions from manufacturing are compared, the lower weight of the PET bottle is offset by the carbon intensity of the material to give similar overall results to the light weight glass equivalent.

Perhaps contrary to expectations, European and UK road transport of empty bottles and the successive transport of filled bottles to retailers is in fact a relatively minor factor affecting the total CO₂ emissions analysed in this study. However, the difference in emissions does elucidate the CO₂ savings arising from lightweighting wine bottles. Using 54g PET bottles manufactured in the UK as opposed to European produced 496g glass bottles could save up to 68% of the CO₂ emissions attributable to road transport.

This study therefore clearly illustrates that the CO₂ emissions for a lightweight glass container with a high recycled content and a PET bottle are almost equivalent. What is even more apparent is that by lightweighting and increasing recycled content, significant reductions in CO₂ for both PET and glass can be achieved. As with all studies of this nature that focus on one environmental impact, they should be taken into consideration with other factors for a particular product, for example, brand equity, recyclability and other environmental factors.

²⁷ Data derived from the Association of Plastic Manufacturers of Europe.

²⁸ Greenhouse gas emissions from electricity depend on the country specific fuel mix used to generate the electricity. As stated above, other GHGs were outside the scope of the analysis so no detailed calculations were made for this report. Unlike the readily available figure for PET, the GHG emission increase cited (10%) for glass is an estimate only.

Appendix A: Assumptions used in this study

Bulk wine shipping

From the WRAP report, *The life cycle emissions of wine imported to the UK*. GLAS01 123 (2007), the following assumptions were made on the method of transporting wine in bulk from Australia to the UK:

- The density of wine is assumed to be 1 for this study; and
- Wine is transported in disposable Flexitanks, which hold 24,000 litres and weigh 80 kg when empty, from the winery in Australia to the bottler in the UK.

Additionally, the following data were used for the bulk shipment of wine from Australia to the UK:

- The wine analysed in this study is produced by the Barossa Valley winery, 71.1 km north-east of Adelaide, Australia. (Winery location provided by Fosters Group; road distance calculator: <http://maps.google.com>);
- The empty Flexitanks are transported, 20 at a time, to the winery. Distance: 71.1 km (Route provided by Fosters Group; road distance calculator: <http://maps.google.com>);
- The filled Flexitanks are transported to the docks in Adelaide, Australia. Distance: 71.1km (Route provided by Fosters Group; road distance calculator: <http://maps.google.com>);
- Each filled Flexitank is placed in a TEU container and shipped from Adelaide, Australia to Felixstowe, UK. Distance: 19,824 km (Route provided by Fosters Group; sea distance calculator: www.world-register.org); and
- The filled Flexitanks are placed on a flatbed lorry and transported from the docks at Felixstowe, UK to the bottling facility at Corby, UK. Distance: 184 km (Route provided by Fosters Group; road distance calculator: www.theaa.com).

Bottled wine transport

Glass bottle weight derived from:

- WRAP, 2006. More Bulk. Less Bottle. The Wrap Wine Initiative. Banbury, United Kingdom.
- Personal communication Fosters (25.07.07)
- Personal communication Corby (21.08.07)
- Personal communication Wrap (10.10.07)

PET bottle weight provided by Amcor

To calculate the carbon emissions from bottled wine road transport within the UK the following data were used:

- Empty UK-produced glass bottles (of both weights) are transported from Quinn Glass at Elton, Cheshire to the bottling facility at Corby, UK. Distance: 233 km (road distance calculator: www.theaa.com);
- Empty plastic bottles are transported from the PET bottle manufacturer to the bottling facility at Corby. Distance: 226 km (distance provided by AMCOR: 142 miles);
- Cases of glass and PET wine bottles are transported from Corby, UK to a distribution centre at Daventry, UK. Distance: 62.6 km (Route provided by Amcor; road distance calculator: www.theaa.com);
- Fully loaded lorries transfer palletised bottles from the distribution centre to retail outlets within the UK. Distance: 200 km (estimated by BFF); and
- Consumers purchase bottles and transport them by average UK car from retailers to house. Distance: 4.3 miles (Average length of shopping trip in 2005; data from: www.dft.gov.uk)

Data were provided by Corby Bottlers on the origin and national proportion of bottles typically filled at the plant. To determine the average distance European bottles are transported to Corby bottlers in the UK, the following assumptions were made:

- French bottles originate in Lyon (1074km), central France;
- Belgium bottles originate in Brussels (514km), central Belgium;
- Bulgarian bottles originate in Sofia (2628km), by far the largest city in Bulgaria; and
- British bottles originate in Elton (233km), home of Quinn Glass.

It is worth noting that these distances are high compared to the European Commission (2000) estimate of a maximum distance travelled of 500km for most empty glass packaging.

Data were received on loads of empty bottles as follows:

- Full truck load of empty 496g glass bottles = (34,920 or 40140 [depending on shape] bottles per load*496g per bottle) + (30 pallets*28 kg per pallet) ≈ 19,455 kg [depending on shape];
- Full truck load of empty 365g glass bottles = (46,800 bottles per load*365g per bottle) + (52 pallets*28 kg per pallet) = 18,538 kg;
- Full truck load of empty 356g glass bottles = (46,800 bottles per load*356g per bottle) + (52 pallets*28 kg per pallet) = 18,117 kg; and
- Full truck load of empty 54g PET bottles = (67,500 bottles per load*54g per bottle) + (60 pallets*28 kg per pallet) = 5,325 kg.

For the 496g glass bottle, data provided by Corby Bottlers on 460g glass bottles were used. It was assumed that the loading factors were the same for 496g glass bottles as for 460g glass bottles. Loading factors provided by Corby Bottlers for 460g glass bottles varied depending on the shape of the bottle, therefore, the average load weight was used, as the exact bottle shape is unknown. Calculations were performed using *only* the 496g glass bottle.

Figure A.1 CO₂ emissions from transport of empty glass bottle loads to Corby Bottlers:

				average load weight (t)			kgCO ₂ from transport of average load			gCO ₂ average emissions per bottle		
Origin	%	distance (km)	of which channel is	496g bottles	365g bottles	356g bottles	496g bottles	365g bottles	356g bottles	496g bottles	365g bottles	356g bottles
Fr	55	1074	41	19.5	18.5	18.1	1107	1093	1086	34	27	26
Bel	15	514	41				508	501	496			
Bul	20	2628	41				2770	2735	2718			
UK	10	233.3	41				207	204	203			

The following data were provided by Amcor and Fosters on the quantity of pallets and the weight of wine cases transported:

- For glass bottles:
 - Weight of 6-bottle case (with bottles) = 7.5 kg (heavy glass bottles) 7kg (light glass bottles (data provided by Fosters));
 - 140 cases are stacked onto pallets (empty weight of pallet: 28 kg; data provided by Fosters);
 - Maximum load per lorry is 24 pallets for heavy bottles, 26 pallets for light bottles (data provided by Fosters);
 - Weight of label = 1.9g (data provided by Fosters); and
 - Weight of capsule = 4.5g (data provided by Fosters).

■ For PET bottles

- Weight of 6-bottle case (with bottles) = 5 kg (data provided by Fosters);
- Weight of empty wine case: 175g (data provided by Amcor);
- Dimensions of wine case: 297x248x166 (mm) (data provided by Amcor);
- 140 cases are stacked onto pallets (empty weight of pallet: 25 kg; same data provided by Amcor and Fosters);
- Maximum load per lorry is 26 pallets. (Data provided by Fosters); and
- Each loaded lorry transports 25,800 kg of pallets, cases and bottles on 24 pallets. (Data provided by Amcor).

Some of these data lead to conflicting results when calculating the weight of a full load. Load weights per lorry were thus calculated using a bottom up approach: [(weight of label + weight of capsule + weight of bottle + weight of wine)*number of bottles per case + (weight of cases)]*number of cases per pallet + weight of pallet.

Figure A.2 Calculations to establish the weight of each truck load of wine case:

A case of filled 496g glass bottles weighs:	A case of filled 365g glass bottles weighs:
bottles, 6*496g = 2976g	Bottles, 6*365g = 2190g
wine 6*75cl = 4500g	wine 6*75cl = 4500g
caps 6*4.5g = 27g	caps 6*4.5g = 27g
labels 6*1.9g = 11.4g	labels 6*1.9g = 11.4g
case = 175g	case = 175g
TOTAL = 7.6894 kg	TOTAL = 6.9034 kg
Full truck load is then 24 pallets: 26,508kg (20,160 bottles)	Full truck load is then 26 pallets: 25,856kg (21,840 bottles)
A case of filled 356g glass bottles weighs:	A case of filled 54g PET bottles weighs:
bottles, 6*356g = 2136g	Bottles, 6*54g = 324g
wine 6*75cl = 4500g	wine 6*75cl = 4500g
caps 6*4.5g = 27g	caps 6*4.5g = 27g
labels 6*1.9g = 11.4g	labels 6*1.9g = 11.4g
case = 175g	case = 175g
TOTAL = 6.8494 kg	TOTAL = 5.0374 kg
Full truck load is then 26 pallets: 25,660kg (21,840 bottles)	Full truck load is then 26 pallets: 19,064kg (21,840 bottles)

Average weight of shopping load (11kg) derived by AEA for DEFRA using NTS trip data (1999/2001) and DEFRA Food Survey to determine how much food was consumed. Food Miles Final Report (<http://statistics.defra.gov.uk/esg/reports/foodmiles/annex1.pdf>).

Figure A.3 % of full shopping load per type of bottle:

496 g glass bottle	365 g glass bottle	356 g glass bottle	54 g PET bottle
70%	63%	62%	46%

Tertiary packaging

- Pallets for empty glass bottles are 25 kilos made of wood and reused 10 times; and
- Pallets for empty PET bottles are 25 kilos made of HDPE and reused 50 times.

Figure A.4 Breakdown of pallet details:

Weight of pallets per load	type	bottle	lifespan	per trip load	kgCO ₂ /trip	gCO ₂ per empty bottle
1500	HDPE	54g	50	30	59	0.8800
1300	Wood	356g	10	130	57	1.2222
1300	Wood	365g	10	130	57	1.2222
750	Wood	496g	10	75	33	0.8793

It was assumed that each pallet, independent of its type had an additional 3kg of packaging (as total pallet weight is 28 kg for all scenarios), most probably shrink wrap, which was not accounted for here but is consistent for all bottle types. All pallets are reused but distances travelled and load weights for reused pallets were not available and were not included in this study.

The CO₂ emissions attributable to each pallet type were added to the total CO₂ emissions attributable to each bottle type.

Embodied energy of glass bottles

There is no standard data source for carbon dioxide emissions arising from glass container production for the UK. In this study, the following sources and figures were used:

- Enviro Consulting, 2003. Glass Recycling-Life Cycle Carbon Dioxide Emissions. (used for typical UK production).

Figure A.5 Emissions for container glass manufacture in the UK

Emissions for container glass manufacture in the UK		
Kg CO ₂ /tonne of glass (recycled within the UK)	Kg CO ₂ /tonne of glass (recyclate exported to France)	Recycled content
843	843	0
529	533	100

This includes emissions arising from extraction, production and transport of raw materials; preparation of recycled materials; glass melting; and collection and transport of cullet for the glass industry in the UK. Also included is the CO₂ emitted by the process of melting (burning) carbonates. Other data sources used or reviewed for this study are:

- Hammond, G. and Jones, C., 2006. Inventory of Carbon and Energy (ICE)-Version 1.5 Beta, Bath, United Kingdom;
- HMSO, 2003. Environmental Accounts, London, United Kingdom;
- Wrap, 2007. Assessment of the International Trading Markets for Recycled Container Glass and their Environmental Implications. MSG007 (v2);
- British Glass Foundation, 2002. UK Glass Manufacture: A Mass Balance Study. British Glass, Sheffield, United Kingdom;
- Bilan Carbone, 2007. *Guide des Facteurs d'Emissions. Version 5.0;*
- Danish EPA, 1998. Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks. Refillable Glass Bottles No.400, Copenhagen, Denmark; and
- Danish EPA, 1998. Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks. Disposable Glass Bottles No.401, Copenhagen, Denmark.

These sources quote a carbon intensity figure for glass production between 0.057 and 0.0742 kgCO₂/MJ with an embodied energy of 13.5MJ/kg.

A 37% energy savings from recycling glass from Enviro Consulting figures was assumed.

The commissioners of this report asked BFF to calculate the emissions arising from the manufacture of a typical bottle used at Corby Bottlers. Data were provided by Corby Bottlers on the origin and national proportion of bottles typically filled at the plant, although these origins may vary based on market prices of glass. To determine the CO₂ emissions from producing a typical European green bottle, three different approaches were taken and thus, three different results were obtained. Average recycled content of bottles produced in each country were derived from Wrap (2007).

1st approach

- A: Using Bilan Carbone figures for green container glass **France** (99% recycled content):
55% of the bottle was allocated $0.163 \text{ kgC}_{\text{eq}}/\text{kg glass} = 0.557 \text{ kgCO}_2/\text{kg glass}$ ²⁹
- B: Assuming 90% recycled content for bottles produced in **Belgium** and using emission factors from Enviros (including export of cullet):
15% of the bottle was allocated $0.564 \text{ kgCO}_2/\text{kg glass}$
- C: Using 30% recycled content (data from CORBY) for bottles produced in **Bulgaria** and using emission factors from Enviros (including export of cullet):
20% of the bottle was allocated $0.750 \text{ kgCO}_2/\text{kg glass}$.
- D: Using 82% recycled content (average UK) for bottles produced in **UK** and using emission factors from Enviros (including export of cullet):
10% of the bottle was allocated $0.589 \text{ kgCO}_2/\text{kg glass}$.
- The typical bottle, has thus, an 82.15% recycled content and emissions from production equal to $0.600 \text{ kgCO}_2/\text{kg glass}$.

2nd approach

From British Glass Mass Balance Report 2002, the total energy used by the UK Glass Industry was divided by the tonnes of CO₂ emitted by the same, to obtain a figure of 3,075 kWh per tonne of glass.

- A: The fuel split for glass production in **France** was obtained from Wrap³⁰ and carbon intensity figures for electricity were obtained from IEA. Adding CO₂ emissions from the use of the different fuel types, decarbonation, transport and extraction emissions a figure of $854 \text{ kgCO}_2/\text{tonne virgin glass}$ was derived. A 37% reduction in emissions was used for recycled glass so that:
55% of the bottle was allocated $0.541 \text{ kgCO}_2/\text{kg glass}$ (99% recycled)
- B: The fuel split for glass production in **Belgium** was assumed to be the same as in France and carbon intensity figures for electricity were obtained from IEA. Adding CO₂ emissions from the use of the different fuel types, decarbonation, transport and extraction emissions a figure of $970 \text{ kgCO}_2/\text{tonne virgin glass}$ was derived. A 37% reduction in emissions was used for recycled glass so that:
15% of the bottle was allocated $0.647 \text{ kgCO}_2/\text{kg glass}$ (90% recycled)
- C: The fuel split for glass production in **Bulgaria** was assumed to be the same as in UK and carbon intensity figures for electricity were obtained from IEA. Adding CO₂ emissions from the use of the different fuel types, decarbonation, transport and extraction emissions a figure of $1023 \text{ kgCO}_2/\text{tonne virgin glass}$ was derived. A 37% reduction in emissions was used for recycled glass so that:
20% of the bottle was allocated $0.909 \text{ kgCO}_2/\text{kg glass}$ (30% recycled)
- D: The fuel split for glass production in the **UK** was obtained from University of Bath data (2006) and carbon intensity figures for electricity were obtained from IEA. Adding CO₂ emissions from the use of the different fuel types, decarbonation, transport and extraction emissions a figure of $1025 \text{ kgCO}_2/\text{tonne virgin glass}$ was derived. A 37% reduction in emissions was used for recycled glass so that:
10% of the bottle was allocated $.714 \text{ kgCO}_2/\text{kg glass}$ (82% recycled)
- The typical bottle, has thus, an 82.15% recycled content and emissions from production equal to $0.648 \text{ kgCO}_2/\text{kg glass}$.

3rd approach

From the Ecoinvent Database³¹ a European average for green container glass production was obtained:

- $0.473 \text{ kgCO}_2/\text{kg glass}$ (this figure assumes a 78.4% recycled content)

²⁹ Assumed from Bilan Carbone data on emissions arising from the production of different materials that 93.22% of C_{eq} emissions can be attributed to CO₂.

³⁰ Wrap, 2007. Assessment of the International Trading Markets for Recycled Container Glass and their Environmental Implications. MSG007 (v2)

³¹ Citing: European Commission (2001) Integrated Pollution Prevention and Control (IPPC) - Reference Document on Best Available Techniques in the Glass Manufacturing Industry. Institute for Prospective Technological Studies, Sevilla

Combination of the three approaches

Figure A.6 CO₂ emissions attributable to bottle manufacture in Europe

Country of origin	Recycled content of green glass	kgCO ₂ /kg glass (1 st approach)	kgCO ₂ /kg glass (2 nd approach)	kgCO ₂ /kg glass (3 rd approach)
France	99%	0.557	0.541	0.473
Belgium	90%	0.564	0.647	0.473
Bulgaria	30%	0.750	0.909	0.473
UK	82%	0.589	0.714	0.473
European average	80.9% ³²	0.600	0.648	0.473

Using these ranges of emissions and allocating emissions to the percentage of bottles originating from each country, for two glass bottle weights:

- 496g which is the weighted UK market average³³
- 365g which is the typical lightweight bottle used by the bottler at Corby

Figure A.7 The range of CO₂ emissions attributable to bottle imported to the UK:

Country of origin	Range kgCO ₂ /kg glass	Proportion of bottles imported to UK	Range gCO ₂ /bottle(496g)	Range gCO ₂ /bottle(365g)
France	0.473-0.557	0.55	235-326	173-240
Belgium	0.473-0.647	0.15		
Bulgaria	0.473-0.909	0.20		
UK	0.473-0.714	0.10		
European average ³⁴	0.473-0.707			

The range of emissions attributable to the average European bottle used by Corby, which contains about 81% recycled material, is from 0.473 kgCO₂/kg glass to 0.648 kgCO₂/kg glass. This is comparable to UK manufacture of an 80% recycled content bottle, which is 0.595kgCO₂/kg glass. Of all four countries were bottles originate in this study, the UK has the highest carbon intensity for electricity production.

Embodied energy of PET bottles

The embodied energy of 100% virgin PET bottles was derived from:

- Boustead, I., 2005. Eco-profiles of the European Plastics Industry-PET bottles.

³² For 1st and 2nd approach recycled content is 82.2%. For the 3rd approach recycled content is 78.4%. Average recycled content is 80.9%

³³ Average UK glass wine bottle weight is 498g as derived from AC Nielsen UK study in: Wrap, 2006. Colourite Project – Maximising Cullet Additions in the Glass Container Industry. Average UK glass wine bottle weight for 2007 is 496g as stated by Wrap; personal communication (10.10.2007).

³⁴ Average for bottles used at Corby

Additional sources of data for plastic manufacture were as follows:

- Recoup, 2000. Affordable Plastic Bottle Recycling? Analysis and review of collection, sorting, reprocessing and end-market issues and economics.
- Danish EPA, 1998. *Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks*. Refillable PET Bottles No.404, Copenhagen, Denmark.
- Danish EPA, 1998. *Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks*. Disposable PET Bottles No.405, Copenhagen, Denmark.

These two life cycle studies (NOT USED for the calculations performed in this study) assume a 0% recycled content for both types of bottles (Refillable and Reusable).

Data provided by AMCOR gives total energy requirements for producing 1kg of recycled PET (rPET) flake. A breakdown of the energy sources used for this process was also available.

Figure A.8 Calculations to determine the amount of CO₂ emissions attributable to producing 1kg rPET:

Energy required kWh	source	kgCO ₂
0.672	Electricity	0.351
0.928	gas	0.186
Total kg CO₂ from energy required		0.537

To determine CO₂ emissions from transporting bottles to the recycling plant a distance of 500km³⁵ and an average load of 9.5 tonnes were assumed. To account for overhead, an addition of 33% of the total emissions arising from energy use at the rPET plant were added, following the methodology explained in Boustead. From these, a 61% energy savings from recycling PET was obtained.

Energy requirements for producing bottles from rPET were considered to be the same as those for producing bottles from virgin PET and were added accordingly. The total emissions from producing 1kg of PET bottle from rPET = **1.6kgCO₂/kgPETbottle**

Figure A.9 The following table relates CO₂ emissions to recycled content of PET bottles

recycled content	kgCO ₂ /kg
0%	4.11
50%	2.85
100%	1.60

Energy recovered and CO₂ emitted from incineration of UK plastic was excluded from this analysis.

Figure A.10 Data derived from these sources were used to calculate the embodied energy of a 54g PET bottle with 3 different recycled contents as seen below:

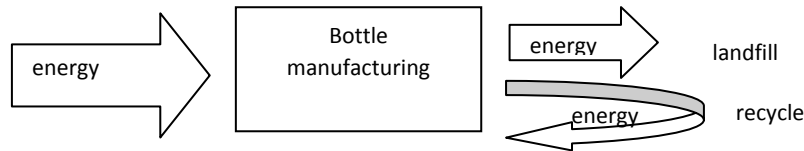
Recycled Content	gCO ₂ /bottle	Recycle gCO ₂ /bottle	gCO ₂ /bottle Including recycling
0%	222	24.0	198
50%	154	16.6	138
100%	86	9.3	77

³⁵ There are currently no PET bottle-to-bottle recycling plants in the UK. Distance from collector to plant was provided by AMCOR based on data from a recycling facility in Beaune, France.

Recycling

The energy saved from recycling glass or PET has been subtracted from the energy required to make the bottles in the first place.

Figure A.11 Diagram of the energy in the PET lifecycle



Energy is derived principally from the combustion of fossil fuels and hence can be directly related to CO₂ emissions.

A UK municipal recycling rate of 50% for container glass in 2006 was assumed derived from data held by Defra on municipal container glass recycling rates for the period 1984-2004. A 37% recycling savings rate was applied as derived from Enviro Consulting (2003).

- Average inter-annual increase of glass recycling (1984-2004) = 2.02%
- UK municipal glass container recycling rate (2004) = 46%
- Estimated UK container glass recycling rate for 2006 = 46% + (2*2.02%) = 50%

It was assumed that 20% of plastic bottles were recycled in the UK in 2006, derived from data found in Wrap, 2007. *Realising the Value of Recovered Plastics*. Market Situation Report-Autumn 2007. A 61% recycling savings rate was applied as derived from data provided by Amcor. This accounts for 1.99 tonnes of CO₂ saved per tonne of recycled PET flake produced, which exceeds the savings of 1 to 1.5 tonnes of CO₂ quoted in the aforementioned Wrap report.

- Approximately 1.27 kgCO₂/kg rPET flake are emitted, including transport
- Approximately 3.27 kgCO₂/kg PET flake are emitted

The CO₂ savings calculated for both plastic and glass recycling include transport and preparation of the recycled material. As mentioned above, glass recycling savings are derived from Enviro Consulting (2003) and plastic recycling savings are derived from data provided by Amcor on energy required for the preparation of recycled PET flake and average transportation distances to Amcor's PET recycling plant in Beaune, France.

Appendix B: Total CO₂ emissions

Figure B.1 CO₂ emissions from bulk shipment, bottle manufacture and domestic transport of Australian wine bottled in 496g glass bottles (produced in Europe and the UK), 365g glass bottles (produced in Europe), 356g glass bottles (produced in the UK), and 54g PET bottles (produced in the UK).

Weight of bottle (g)	Recycled Content	gCO ₂ /bottle	Bulk Transport gCO ₂ /bottle	Domestic Transport gCO ₂ /bottle	Recycling savings gCO ₂ /bottle	Total gCO ₂ /bottle
496 (glass) from Europe	81% (low estimate)	235	235	49	44	476
	81% (medium estimate)	294			54	524
	81% (high estimate)	326			60	549
496 (glass) from UK	82%	290		22	54	494
365 (glass) from Europe	81% (low estimate)	174		41	33	417
	81% (medium estimate)	217			40	453
	81% (high estimate)	241			45	472
356 (glass) from UK	92%	125		19	23	356
54 (PET)	0%	222		16	27	446
	50%	154			19	386
	100%	86			11	327

Note: These figures do not include emissions attributable to secondary packaging (pallets). Figures may not add up due to rounding.

Appendix C: Comparison of CO₂ emissions for glass bottles including export of cullet to France

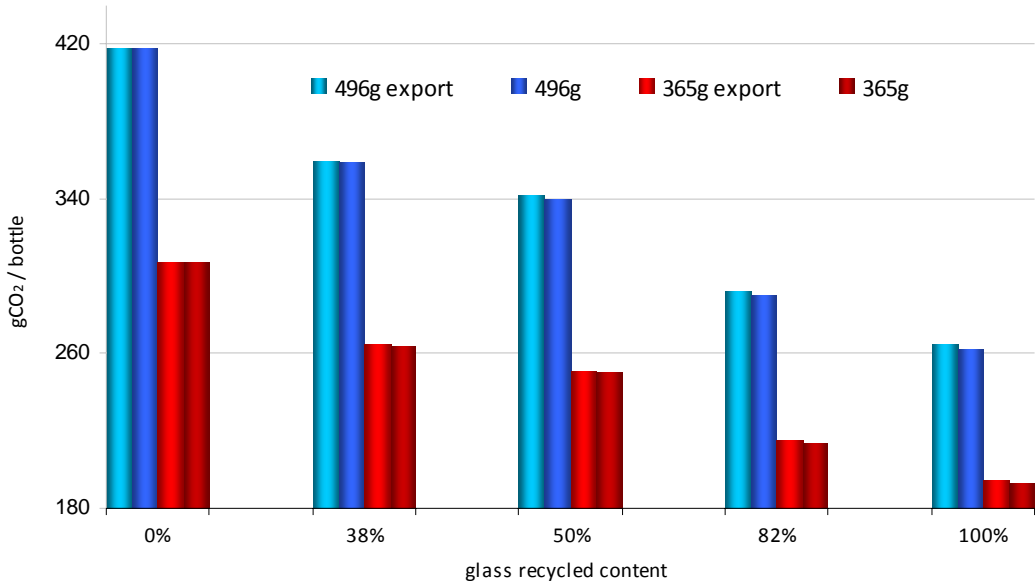
Throughout this study, the energy required to export excess cullet to France has been included in the UK manufacture of glass as part of the life cycle analysis for glass. CO₂ emissions from transporting green glass cullet to France are included, as calculated by Enviros Consulting (2003), to determine the CO₂ attributable to the production of glass bottles with different recycled content. The following results are obtained for CO₂ emissions arising from bottle production and transport, as specified throughout this study (including bulk and UK road transport), for two specific bottles:

Figure C.1 CO₂ emissions from bottle production and transport for two bottles

Recycled Content	gCO ₂ /bottle	Recycle gCO ₂ /bottle	gCO ₂ /bottle Including transport and recycling
496 g bottle			
Enviros 0%	418	77	595
Enviros 38%	360	67	547
Enviros 50%	341	63	532
Enviros 82%	292	54	492
Enviros 100%	264	49	470
365 g bottle			
Enviros 0%	308	57	505
Enviros 38%	265	49	470
Enviros 50%	251	46	459
Enviros 82%	215	40	429
Enviros 100%	195	36	413

When compared to CO₂ emissions arising from producing bottles with cullet recycled within the UK the difference for bottles of the same weight is negligible.

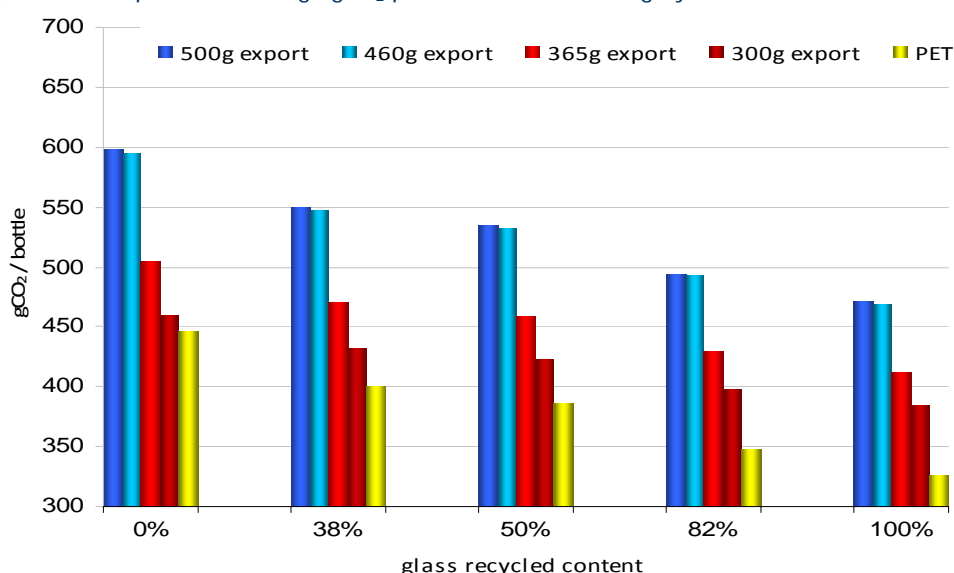
Figure C.2 Graph comparing the CO₂ emissions arising from producing bottles with cullet recycled within the UK



Appendix D: Comparison of other bottle weights

If bottle weight is increased to 500g or decreased to 300g the load weights for transport change accordingly, as do the CO₂ emissions per bottle. Including bulk shipment, bottle production with subsequent export of a proportion of cullet, UK transport and recycling, the following comparison is made between different weight glass and PET.

Figure D.1 Graph of the average gCO₂ per bottle for each category



As can be seen from the above graph, the CO₂ emissions attributable to PET (where all else remains constant, ie. transport, etc.) have a higher rate of decrease when recycled content increases than is the case for glass. Data on CO₂ savings from including recycled content in manufacturing of PET were obtained from Amcor, while data used for savings obtained from using recycled glass in bottle manufacture were obtained from Enviro Consulting (2003). Using these data, the least carbon intensive scenario is for the PET bottle (54g) made from 100% recycled material. This scenario is theoretical as there are no 100% recycled content PET bottles on the market. PET bottles commonly have 0% recycled content, as most recycled PET is used for textiles.

Currently in the UK, recycled content for glass bottles is about 82% and for PET is 0%. If this comparison is made, (0% recycled content PET to the 82% recycled content glass) then PET is less carbon intensive than 500g and 460g glass bottles, but more carbon intensive than the 300g and 365g glass bottles. Note that throughout this study, a recycled content of 81% was used for glass because of the eastern European origin of some of the glass.

Below are the average gCO₂ per bottle for each category represented graphically above. Values are derived using average UK production figures and do not include emissions arising from tertiary packaging.

Figure D.2 Table of the average gCO₂ per bottle for each category

Recycled content	0%	38%	50%	82%	100%
500g export	598	550	535	494	471
460g export	595	547	532	492	470
365g export	505	470	459	429	413
300g export	460	431	422	398	384
PET	446	400	386	347	327

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