Material change for a better environment

Final report

CO_2 impacts of transporting the UK's recovered paper and plastic bottles to China

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WRAP helps individuals, businesses and local authorities to reduce waste and recycle more, making better use of resources and helping to tackle climate change.

Executive Summary

Context and Objectives

Exports of recovered materials for recycling overseas have grown at a rapid pace over the past decade. In 2007, 4.7 million tonnes of recovered paper and half a million tonnes of recovered plastics were exported. The principal destination for these exports was China.

The environmental benefits of domestic recycling are well understood. However, one question often asked in respect of exports is whether the benefits of recycling are outweighed by the emissions associated with transporting the material to China.

To provide guidance on the subject, WRAP recently commissioned a study to quantify the carbon dioxide (CO_2) emissions associated with the transport of recovered paper and plastic bottles from the UK to China.

Methodology

The study identifies real-world export routes and modes of transport – including land emissions both within the UK and China and shipping emissions – and calculates CO_2 emissions for each transport stage.

A number of scenarios have been assessed to produce a range of estimates and sensitivity analysis has been undertaken to test the robustness of the conclusions.

Findings

The CO_2 emissions associated with transporting one tonne of recovered paper from the UK to China are estimated to lie between 154kg and 213kg of CO_2. The emissions associated with transporting one tonne of recovered plastic bottles range between 158kg and 230kg of CO_2.

These CO_2 emissions levels represent less than a third of the carbon savings from recycling identified by a majority of the life cycle assessments (LCAs) reviewed in the study (Table E1). This suggests that there are CO_2 savings to be made from recycling, even if the recovered materials have to be transported to China.

This conclusion becomes even more compelling if the reverse haulage nature of recovered materials export is taken into account. Due to the trade imbalance between the UK and China, the majority of containers heading back to China are empty. The conventional method of calculating transport emissions is to include the emissions associated with transporting the entire vessel weight ('absolute' emissions), not just the cargo. However, since the ship and containers will be returning to China, regardless of whether or not the ship is loaded with recovered materials, the case can be made that only the emissions incurred in shipping the incremental cargo weight ('marginal' emissions) should be considered.

If only the marginal shipping emissions are calculated, the CO_2 emissions associated with transporting recovered materials to China drop to below 10 per cent of the benchmark carbon savings for the vast majority of the scenarios considered.

Table E1: Summary of transport emissions from exports to China compared with benchmark savings from recycling

kg CO_2 per tonne of recyclate	**Absolute transport emissions**	**Marginal transport emissions**	**Median saving from recycling**
Paper	154 – 213	20 – 47	1300
Mixed plastic bottles	158 – 230	24 – 78	1550
PET bottles	174 – 210	29 – 47	1510
HDPE bottles	184 – 221	29 – 48	1610

Note: Mixed plastic bottles – which are assumed to comprise a mix of 60 per cent PET and 40 per cent HDPE – are treated separately from segregated PET and HDPE bottles because the evidence suggests that mixed bottles tend to be shipped via Hong Kong whereas segregated bottles tend to be shipped directly to a Chinese mainland port.

Boundaries

This study was designed to answer the specific question of whether or not the CO_2 emissions associated with transporting recovered materials outweigh the CO_2 savings that arise from recycling materials rather than landfill and virgin material use.

Accordingly, this study is not an LCA and has tightly defined boundaries as follows. First, the study looks at the transport stages only, and assumes that the recycling processes in China are similar to those in the UK and that the paper and plastic sent to China are destined to displace the equivalent virgin material. These assumptions have been broadly supported by industry experts. Second, the research focuses on CO_2 emissions only – rather than CO_2 equivalents – since these comprise the vast majority of CO_2 equivalent emissions from transport in this study. Finally, the study does not address other potential social, economic and environmental impacts, such as non-greenhouse gases, toxicity or labour standards.

Conclusions

This study suggests that there are CO_2 savings to be made from recycling relative to the alternative of landfill and using virgin materials, even if the recovered materials have to be transported to China. That is, the emissions associated with exporting material to China do not outweigh the CO_2 benefits of recycling.

This study forms a *necessary* part of the evidence base to demonstrate that exporting recovered material for export is environmentally sustainable. However, it is not *sufficient* to demonstrate that exporting is a desirable outcome. In particular, it makes no assessment of the relative benefits of recycling domestically versus recycling in China.

Contents

1. Context

Exports of recovered materials for recycling overseas have grown at a rapid pace over the past decade. For example, exports of recovered paper have increased from 400,000 tonnes in 1998 to around 4.7 million tonnes in 2007. Similarly, exports of recovered plastics increased from less than 40,000 tonnes to over half a million tonnes over the same period.

The principal export destination for the UK's recovered paper and plastics is China. China accounts for more than half of the UK's exports of recovered paper and more than 80 per cent of recovered plastics exports.

In part, the growth in exports is a success story. It reflects the rapid development of the UK's collection infrastructure and increase in recovery rates. The UK now recovers more paper for recycling than can be used by the UK paper industry, but there is strong demand for the UK's recovered paper from rapidly growing economies – such as China – that have limited forestry resources. For plastic bottles, by contrast, the export market has acted as a valuable sink market. Exports to China are bridging the gap between plastic bottle collections being established and the future development of domestic reprocessing capacity. There has been substantial investment in new domestic reprocessing capacity in recent months, which could lead to a smaller fraction of plastic bottles being exported in the future.

But the growth in exports also raises questions. In particular, although the environmental benefits of domestic recycling are well understood, to date there has been little evidence on the extent to which these benefits are offset by environmental impacts of transporting the recovered materials to China for recycling.

In the interest of providing timely guidance on the subject, therefore, WRAP recently commissioned a report to examine the carbon dioxide (CO_2) emissions associated with the transport of recovered materials from the UK to China.

2. Objectives

The study, carried out by Oakdene Hollins and critically reviewed by ERM, quantifies the CO_2 emissions from transporting 1 tonne of recovered mixed paper or recovered plastic (PET/HDPE) bottles to China. It considers the CO_2 emissions resulting from each of the three main modes of transport used to export recovered materials to China: truck, rail and container ship. Although there are synergies in the analysis of the two materials (paper and plastics), there are a number of key differences as well and they are therefore presented separately.

The study uses evidence from existing life cycle assessments (LCAs) to provide benchmark CO_2 savings from recycling compared with landfill and virgin material use. No studies dealing specifically with China were found in the existing literature[1] so this study assumes that: a) there are net carbon benefits from recycling in China relative to landfill and virgin material use; and b) the magnitude of these benefits are at least as great in China as elsewhere. Under these assumptions, the key missing element is the CO_2 emissions associated with the transport phase from the UK to China.

[1] The Eco-materials Institute Centre for Materials LCA, part of the Beijing University of Technology, has developed a Chinese methodology and database for LCAs (Xu Jincheng et al. 2001). Due to time and language constraints, it was not possible to incorporate data from this source into the study, however the database provides a potentially invaluable source of information that could be incorporated into future studies.

3. Assumptions and limitations

As already noted, the boundaries to this study have been drawn very tightly: specifically the CO_2 emissions incurred in the additional transport stages necessitated by shipping recovered materials to China. This study does not assess other potential social, economic and environmental impacts, such as non-greenhouse gas emissions, biodiversity, acidification, eutrophication, toxicity or labour standards.

The quantitative results presented are intended as indicative only and must be treated as such.

The following additional assumptions and limitations are worth noting:

- It is assumed that the paper and plastic sent to China are destined to displace the equivalent virgin material. That is, the recovered paper and plastic bottles are assumed to manufacture new products that would otherwise be made from virgin pulp and polymers, rather than being used to replace materials with lower embodied environmental impact, such as timber (e.g. in the case of plastic lumber). Industry contacts indicate that this assumption is valid.
- This report calculates CO_2 emissions arising from the combustion of fuel only. An assessment of the impact of including emissions arising from primary production of the fuel is included within the discussion section.
- Other greenhouse gas emissions (such as methane and nitrous oxide) are not assessed. However, CO_2 emissions account for almost 98 per cent of the CO_2 equivalent (CO_{2e}) emissions from heavy fuel oil consumption in container vessels,[2] so the analysis in this report captures the vast majority of CO_{2e} emissions.
- Combustion of shipping bunker fuel produces other emissions species, such as sulphur and nitrogen oxides. An analysis of these pollutants is outside the scope of the present study.

[2] Source: Ecoinvent Version 2

- Emissions arising from the following more indirect transportation processes were also not considered in this study as they were deemed insignificant compared to those incurred in the major transport stages: loading containers; transferring containers to/from trucks, rail, ships; transferring containers to/from storage yards at ports; equipment malfunction.
- Emissions from the following processes are assumed to be captured within the shipping emissions factors used: stopping off at ports en route to hub ports or to China discharge ports; rough sea conditions; and other seasonal factors.

4. Methodology

'Real world' export routings for paper and plastic bottles were identified through desk research and consultation with key stakeholders. Published CO_2 emissions factors for each transport mode (road, rail and container vessel) were obtained and verified against alternative sources. These were used to calculate estimates of per tonne emissions for each transportation stage and hence for the full journey from a consolidation centre in the UK to the reprocessor in China.

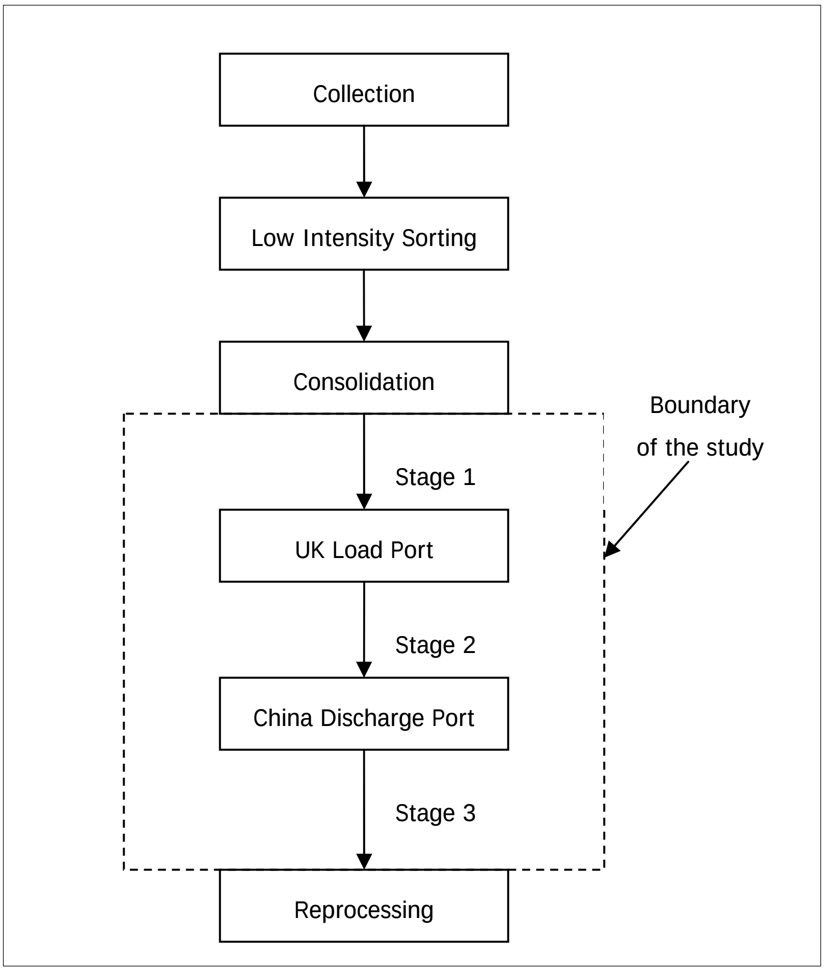
Representatives from the recovered plastics and paper, shipping, and freight forwarding industries were interviewed, as were regulatory authorities such as the Environment Agency. The study received guidance from a steering group and was also the subject of a peer review.

Figure 1 illustrates the boundaries of this study: namely, that it concentrates solely on the incremental transport emissions incurred in transporting the recovered materials to a reprocessor based in China rather than one based in the UK.

The recovered materials are baled and containerised at UK consolidation centres, then shipped to China, often via Hong Kong, in large ocean-going container vessels. The transportation is divided into three broad stages:

- Stage 1: Consolidation centre to UK load port (by road or rail);
- Stage 2: UK load port to China discharge port (by container vessel); and
- Stage 3: China discharge port to reprocessor (by road).

Figure 1: Identification of study boundaries and transport stages



The transport emissions at each stage depend on a number of key variables including:

- packing densities;
- land and ocean distances;
- mode of land transportation;
- size of container ship; and
- location of Chinese reprocessor.

Flexing these variables allowed 'typical' and 'high' cases to be characterised and a number of routing scenarios to be tested.

The study also considered both absolute and marginal allocation of shipping emissions. The conventional method of allocating transport emissions in LCA studies is to include the emissions associated with transporting the entire vessel weight, not just the cargo. These are termed 'absolute' emissions. However, due to the trade imbalance between the UK and China, more container capacity is required to transport goods from China to the UK than is required in the opposite direction. In fact, more than 60 per cent of containers return to China empty.[3] If the ships and containers are travelling to China regardless of whether or not they are loaded, then the emissions associated with transporting that weight will occur regardless of whether or not the ship is loaded with recyclate.

The case can be made, therefore, that only the emissions incurred in shipping the incremental weight of recovered materials – the 'marginal' emissions – should be considered. It turns out that these are effectively zero. The current trade imbalance is such that eastbound ships are sailing at below optimal loadings,[4] which means that carrying the weight of the recovered materials does not increase the ships' fuel consumption. Hence there are no additional emissions.

The question of allocation methodology does not apply to truck and train emissions as these transport stages involve dedicated trips.

4.1 Stage 1: Consolidation centre to UK load port

Waste management companies and recovered paper and plastics merchants bale and containerise the recovered materials at consolidation centres distributed throughout the UK. The bales are packed into 40 foot containers (with an empty weight of 4 tonnes) delivered from a local container freight station, which is assumed to be an average 45 km from the consolidation centre.[5]

For recovered paper, the weight is normally constrained by axle load restrictions to around 25 tonnes per container. For recovered plastics, packing densities are normally the limiting factor. The typical weight of plastic bottles per container is normally around 20 tonnes, although a range of 18 – 25 tonnes was reported. The

[3] Source: Far Eastern Freight Conference
[4] Source: Far Eastern Freight Conference
[5] Source: Consensus industry view gathered by Oakdene Hollins

emissions associated with baling and loading have been excluded on *de minimis* grounds.

Once filled, the container is transported to the UK load port by road or rail. More than half of the recovered materials destined for China leave the UK from Felixstowe or Southampton.[6] Industry contacts indicate that the typical haulage distance for materials travelling by road is 240 km, with an upper estimate of 400 km. For material travelling by train, the typical distances involved are 45 km by road to a rail-connected container freight station, then 350 km – 470 km to the port.

The CO_2 emissions generated in this leg are shown in Tables 1 and 2. The most common vehicles to haul shipping containers of recovered materials in the UK are 44 tonne articulated trucks running on diesel. The truck emissions are calculated using diesel freight road mileage conversion factors published by Defra[7] for articulated trucks. Given the per cent weight laden, and the corresponding number of litres of fuel used/km, the conversion factor gives the emissions in kg of CO_2 per km. Rail emissions are calculated based on an emission factor of 32g CO_2/tkm. A literature review of rail freighting emissions found a wide range of results from 13.9g CO_2/tkm to 49g CO_2/tkm. The emissions factor of 32g CO_2/tkm used in this report is the mid-point of this range.

Table 1: Stage 1 CO_2 emissions for recovered paper

	Emissions factor (gCO_2/tkm)	Distance (km)	Total emissions ($kgCO_2$ /tonne)	Total stage 1 emissions ($kgCO_2$ /tonne)
Container delivery to consolidation centre and return of lorry to local freight station (45km each way)	33.7	90	3	
Container filled with recyclate, transported:				
By road to port (typical)	47.1	240	11	**14**
By road to port (high)	47.1	400	19	**22**
Or:				
By road to railway station then:	47.1	45	2	
By rail to port (typical)	32	350	11	**16**
By rail to port (high)	32	470	15	**20**

Note: Based on 25 tonnes of recovered paper per container, the latter weighing 4 tonnes empty.

[6] Source: Confederation of Paper Industries / HM Revenue and Customs
[7] Source: Defra (2005) Guidelines for Company Reporting on Greenhouse Gas Emissions

Table 2: Stage 1 CO_2 emissions for recovered plastic bottles

	Emissions factor (gCO_2 / tkm)	Distance (km)	Total emissions ($kgCO_2$ / tonne)	Total stage 1 emissions ($kgCO_2$ / tonne)
Container delivery to consolidation centre and return of lorry to local freight station (45km each way)	42.1	90	4	
By road to port (typical)	55.8	240	13	**17**
By road to port (high)	55.8	400	22	**26**
Or:				
By road to railway station	55.8	45	3	
then:				
By rail to port (typical)	32	350	11	**17**
By rail to port (high)	32	470	15	**21**

Note: Based on 20 tonnes of recovered plastics per container, the latter weighing 4 tonnes empty.

4.2 Stage 2: UK load port to China discharge port

4.2.1 Shipping emissions

Shipping emissions are determined by a wide range of factors including the size and type of ship, the type of engine, the fuel grade burnt, as well as the weather and speed of travel. Notwithstanding this complexity, shipping lines publish typical emissions factors per unit of cargo, per distance travelled and per size of ship.

Emissions data from Maersk have been used in this study. Maersk is the world's largest container shipping line, with a market share of almost 30 per cent, and its vessels are thought to be typical of those transporting UK recovered materials to China. Three vessel sizes are relevant in the route from the UK to China: <2,000 TEU[8]; 6,000 TEU and 11,000 TEU. The emissions factors for each size are shown in Table 3.

The Maersk data were checked for consistency with alternative sources, including Germanischer Lloyd (a classification society) and the Danish Shipowners' Association. Sensitivity analysis was

[8] TEU refers to the capacity of the ship and stands for 'twenty-foot equivalent units'

also undertaken to assess the impact of using different shipping emissions factors.

Table 3: Absolute emissions factor for Maersk Line container ships

Vessel Size (TEU)	Emissions Factor
	gCO_2/tkm
<2,000	**11.9**
2,000 – 3,500	12.0
3,5000 – 5,000	9.1
5,000 – 10,000	**7.6**
>10,000	**7.0**

Source: Maersk Line, 2007. Constant Care for the Environment. Data in gCO_2/TEU.km have been converted into gCO_2 /tkm based on tonne per TEU assumption obtained from Maersk Line.

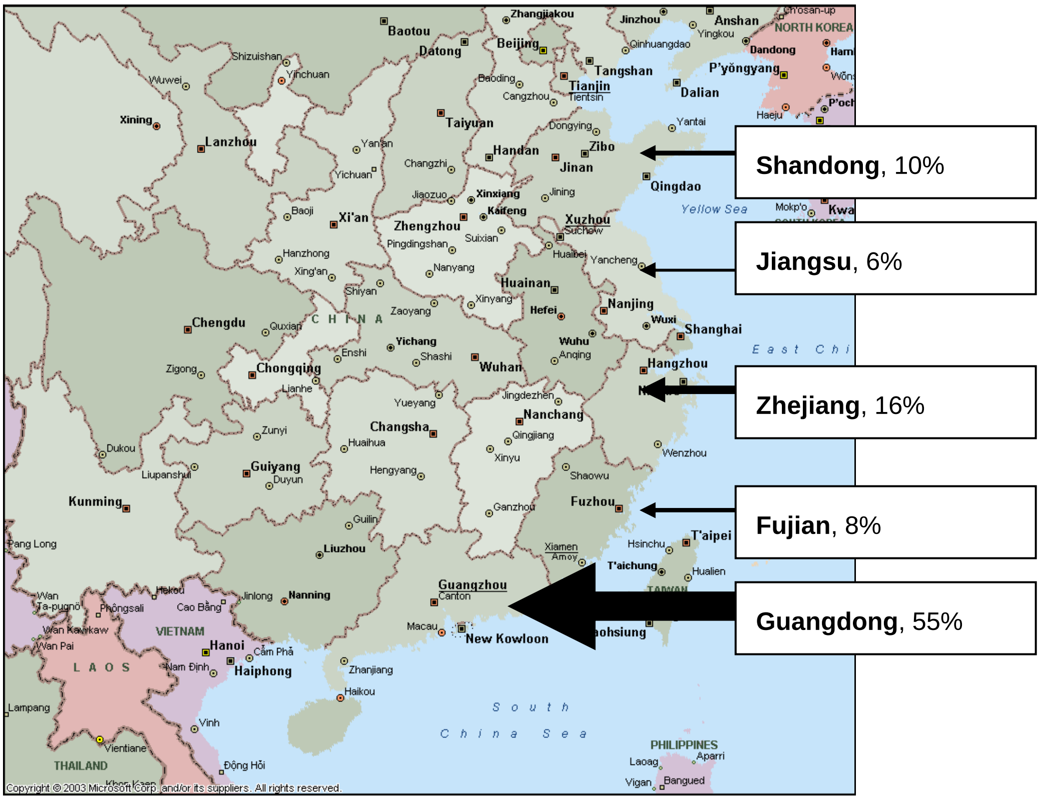
4.2.2 Recovered paper

The majority of recovered paper is shipped directly from a major UK port (such as Southampton or Felixstowe) to a Chinese port on large (6,000 TEU and 11,000 TEU) container ships. A small fraction is taken by small feeder vessels (2,000 TEU) to larger hub ports (such as Rotterdam) for transhipment. Both of these options were modelled.

The discharge port in China will vary depending on the province to which the recovered paper is destined. More than 90 per cent of recovered fibre exported from the UK is shipped to one of five provinces on the south and east coast of China where the Chinese paper industry is concentrated (Figure 2). Shipping distances from Southampton to these ports range from 17,635 km (Shekou port in Guangdong) to 19,492 km (Qingdao port in Shandong province).

Absolute emissions for various shipping routes are shown in Table 3. As previously discussed, given the reverse haulage nature of the export of recovered materials, if only the marginal emissions associated with transporting the incremental weight are considered, then the shipping emissions fall to zero.

Figure 2: The five biggest provinces in China for imported recovered paper from the UK



Source: Chinese Customs Authority (Jan – Aug 2007)

Table 4: Stage 2 emissions for paper

	Emissions factor (gCO_2 / tkm)	Distance (km)	Total emissions ($kgCO_2$ / tonne)	Total stage 2 emissions ($kgCO_2$ / tonne)
Southampton – Shekou[1,2]	7.6	17,635	134	**134**
Southampton – Qingdao[1,2]	7.6	19,492	148	**148**
Liverpool – Rotterdam[3]	11.9	1,283	15	
Rotterdam – Shekou[1]	7.6	18,042	137	**152**
Rotterdam – Qingdao[1]	7.6	19,899	151	**166**

1. Based on a 6,000 TEU vessel. Emissions from an 11,000 TEU vessel were slightly lower.
2. Emissions for journeys from Felixstowe were within 2kg CO_2 / tonne of the results presented here.
3. Based on a 2,000 TEU vessel.

4.2.3 Recovered plastic bottles

The typical route for recovered plastic bottles shipped to China is slightly more complex than that for paper. Plastics exporters have traditionally tended to ship to China via Hong Kong rather than directly. In part, this is because of the more lenient customs regulations and faster customs clearance, but it might also be because it is easier to establish relationships with Hong Kong-based customers than those on the Chinese mainland.

Roughly 80 per cent of bottles are transhipped via Hong Kong, with the remainder shipped directly to a Chinese port. Bottles shipped directly to China tend to have been sorted into separate polymer types, while those shipped via Hong Kong are likely to be mixed bales of PET and HDPE bottles. The principal mainland China ports are Qingdao and Tianjin for HDPE bottles and Shanghai for PET bottles (Figure 3).

Figure 3: China discharge ports for UK-segregated and mixed HDPE and PET tested in the current study

Source: Chinese Customs Authority (Jan – Aug 2007)

Table 5 shows the emissions factors for mixed and separated bales of plastic bottles. The same vessel size assumptions were made as for paper. As with paper, the marginal shipping emissions are zero.

Table 5: Stage 2 emissions for plastic bottles

	Emissions factor (gCO_2 / tkm)	Distance (km)	Total emissions ($kgCO_2$ / tonne)	Total stage 2 emissions ($kgCO_2$ / tonne)
Mixed bottles				
Southampton – Hong Kong[1,2]	7.6	17,635	134	**134**
Or				
Liverpool – Rotterdam[3]	11.9	1,283	15	
Rotterdam – Hong Kong[1]	7.6	18,042	137	**152**
PET bottles				
Southampton - Shanghai[1,2]	7.6	19,074	145	**145**
Or				
Liverpool – Rotterdam[3]	11.9	1,283	15	
Rotterdam - Shanghai[1]	7.6	19,481	148	**163**
HDPE bottles				
Southampton - Tianjin[1,3]	7.6	20,352	155	**155**
Or				
Liverpool – Rotterdam[3]	11.9	1,283	15	
Rotterdam - Tianjin[1]	7.6	20,759	158	**173**

1. Based on a 6,000 TEU vessel. Emissions from an 11,000 TEU vessel were slightly lower.
2. Emissions for journeys from Felixstowe were within 2kg CO_2 / tonne of the results presented here.
3. Based on a 2,000 TEU vessel.

4.3 Stage 3: China discharge port to reprocessor

4.3.1 Recovered paper

After it has cleared through Chinese customs, the recovered paper is transported by truck to the paper mills. The container is then returned to a local container freight station. Chinese trucks are assumed to meet Euro II emission standards, which in turn implies that their CO_2 emissions are roughly 10 per cent higher than UK vehicles.

Detailed information on the paper mills purchasing imported recovered fibre is available from the Chinese Customs Authority. For the purposes of this study, the largest mills in Guangdong and Shandong provinces were used to represent the typical and high cases, respectively.

Table 6: Stage 3 CO_2 emissions for recovered paper

	Emissions factor (gCO_2 /tkm)	Distance (km)	Total emissions ($kgCO_2$ /tonne)	Total stage 3 emissions ($kgCO_2$ /tonne)
Return of empty container to freight station	38	45	2	
Shekou – Dongguan (typical)	52	80	4	**6**
Qingdao – Yanzhou (high)	52	440	23	**25**

Note: Based on 25 tonnes of recovered paper per container.

4.3.2 Recovered plastic bottles

Mixed plastic bottles shipped to Hong Kong are taken by truck to segregation facilities, assumed to be around 20km away from the discharge port.[9] Once sorted, the PET and HDPE bottles are bagged and transported on a curtain-sided vehicle to the reprocessor. The container is no longer required and is returned empty to the port. The reprocessors are typically based in the neighbouring province of Guangdong, in particular Dongguan (80km away). However, market contacts have indicated that some PET bottles are trucked over 1200km north to the Shanghai area. For HDPE bottles, the high case was assumed to be a reprocessor based in Shantou in the far east of Guangdong.

Segregated PET and HDPE bottles arriving directly in mainland China are hauled directly to reprocessors (including fibre manufacturers) who typically lie within a 150km radius of the port. High cases (300km) were also tested. For HDPE bottles, a known importer is located in Shijiazhuang, 320km from Tianjin so this specific case was tested.

In all cases, the empty container is assumed to be transported 45km to a local container freight station.

[9] Source: Consensus industry view gathered by Oakdene Hollins

Table 7: Stage 3 CO_2 emissions for recovered plastic bottles

	Emissions factor (gCO_2 / tkm)	Distance (km)	Total emissions ($kgCO_2$ / tonne)	Total stage 1 emissions ($kgCO_2$ / tonne)
Segregated bottles:				
Return of empty container to freight station	48	45	2	
Shanghai – reprocessor (PET, typical) Tianjin – reprocessor (HDPE, typical)	61	150	9	**11**
Shanghai – reprocessor (PET, high)	61	300	18	**21**
Tianjin – reprocessor (HDPE, high)	61	320	20	**22**
Mixed bottles:				
Hong Kong port to segregation plant and container return (20km each way)	55	40	2	
Hong Kong – Dongguan (typical)	59	80	5	**7**
Hong Kong – Shantou (HDPE, high)	59	290	17	**19**
Hong Kong – Shanghai (PET, high)	59	1,229	72	**74**

Note: Based on 20 tonnes of recovered plastics per container.

The Stage 3 emissions for the functional unit of one tonne of mixed plastics bottles can be calculated by pro-rating the emissions of transporting 1 tonne of PET plus 1 tonne of HDPE according to the mix of polymers in the bale. A typical bale is assumed to contain 60 per cent PET and 40 per cent HDPE.[10]

[10] Source: WRAP Annual Local Authority Plastics Collection Survey (2007). This study predates the release of the 2008 survey which suggests a split of roughly 50:50.

5. Summary of findings

The CO_2 emissions associated with transporting recovered paper from the UK to China range from 154 kg to 213 kg of CO_2 per tonne of recovered paper using an absolute emissions allocation. Using a marginal emissions allocation, the CO_2 emissions range from 20 kg to 47 kg of CO_2 per tonne (Table 7).

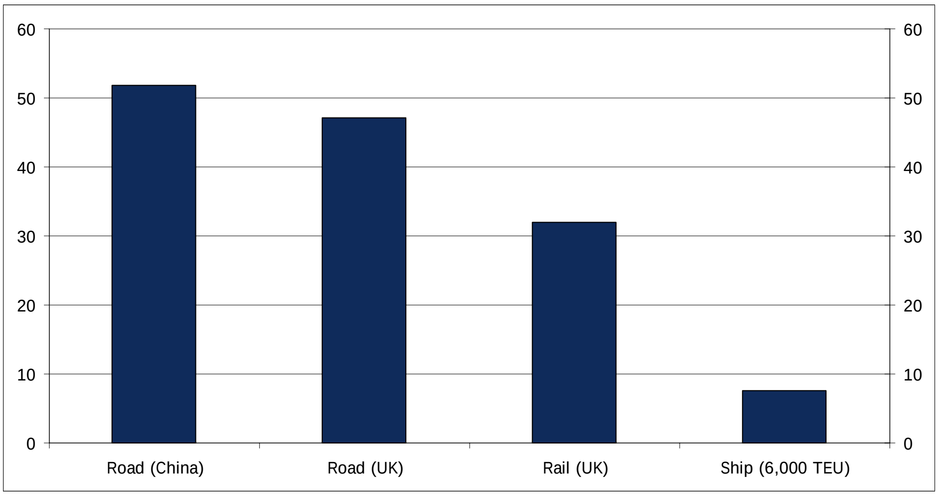
As plastic bottles can be shipped as mixed or separate polymer bales, there are more options to consider. Emissions for transporting mixed bottles run from 158 kg to 230 kg of CO_2 per tonne of plastic bottles using absolute emissions, while those for segregated plastic bottles range from 174 kg to 221 kg of CO_2 per tonne of bottles. On a marginal emissions basis, the emissions range from 24 kg to 78 kg of CO_2 per tonne of bottles. The slightly higher emissions for plastic bottles than for recovered paper in large part reflect the lower packing densities.

Table 8: Summary of the range of CO_2 emissions

kg of CO_2 per tonne	Absolute	Marginal
Paper	154 – 213	20 - 47
Mixed PET/HDPE	158 – 230	24 - 78
Pre-sorted PET	174 – 210	29 - 47
Pre-sorted HDPE	184 – 221	29 - 48

When absolute emissions are considered, around 80 per cent of the CO_2 emissions are incurred during the shipping stage (Stage 2). This reflects the extreme distance travelled (up to 20,000km), rather than the carbon intensity of container transport *per se*. Transporting one tonne of recyclate one kilometre by container ship typically generates about one sixth of the CO_2 emitted by a truck performing the same task (Figure 4).

Figure 4: CO_2 emissions by mode of transport
grammes of CO2 per tonne of recyclate per km



Based on transport of 25t recovered paper, in a 4t container.

The study identifies a number of ways in which the total emissions could be reduced, albeit perhaps to a minor extent. Exporters do not always have influence on them given economic and other constraints, but for reference these include:

- an increased packing density per container (especially for plastic bottles);
- a closer proximity of consolidation centre to the UK load port;
- use of rail rather than road transportation within the UK for some routes;
- use of larger container vessels; and
- direct shipment to Chinese ports close to the end reprocessor, rather than transhipment via hub ports such as Rotterdam or Hong Kong.

6. The findings in context

In order to place some context around the transport emissions figures, the results from the various scenarios tested were compared against data on the CO_{2e} savings drawn from existing LCAs.

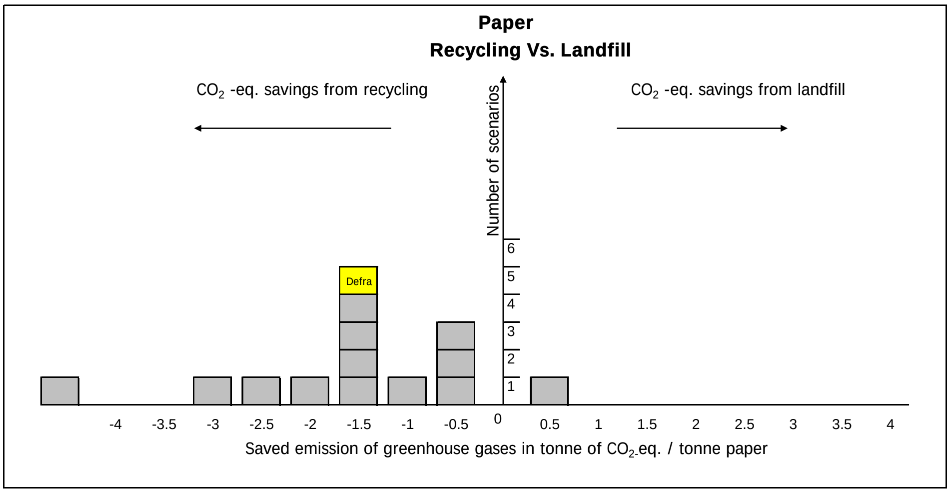
Key publications included a comprehensive review of international studies carried out by the Technical University of Denmark for WRAP in 2006, and a UK-focused research paper produced for the Defra 2007 Waste Strategy. None of the LCAs reviewed were specific to China, and all of them assume that the recycling stage occurs in the same country as the material was recovered.

The majority of the LCA evidence indicates that recycling recovered paper, PET and HDPE yield significant carbon savings. However, the range of estimates of the magnitude of these savings is broad, mainly due to differences in system boundaries and fuel mixes (Figures 5 and 6).[11]

A key assumption of our study is that – notwithstanding the transport emissions – the CO_{2e} savings that could be obtained by recycling in China would be comparable to the range identified here, although the specific impacts will vary with the technologies employed and the fuel mix used. This assumption is discussed further in the following section.

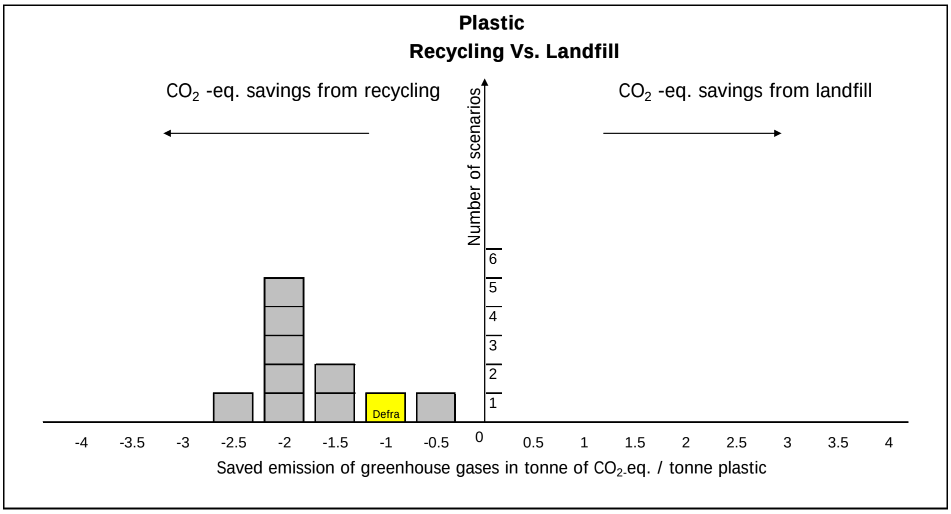
[11] 'Fuel mixes' refers to the specific energy sources used which can vary significantly in carbon intensity from country to country

Figure 5: Whole-life CO_{2e} savings from recycling paper vs. landfill



Sources: WRAP (2006) and Defra (2007)

Figure 6: Whole-life CO_{2e} savings from recycling plastics vs. landfill



Sources: WRAP (2006) and Defra (2007). Includes only PET / HDPE studies

Table 8: CO_{2e} savings identified in previous LCA studies

	Median saving (tonnes CO_{2e} / tonne)	Range of savings (tonnes CO_{2e} / tonne)	Number of scenarios
Paper	1.30	-0.11 to 4.6	14
PET	1.51	1.42 to 1.77	4
HDPE	1.61	0.50 to 2.39	7
Mixed plastic bottles (60% PET / 40% HDPE)	1.55	1.05 to 2.02	10

Sources: WRAP (2006) and Defra (2007). The Defra estimate is for dense plastics and has been used as a benchmark saving estimate for both PET and HDPE bottles in Table 8.

The wide range of savings identified in the LCA literature makes quantifying the relative impact of the transportation emissions difficult. Nevertheless, the data strongly indicate that the carbon savings from recycling outweigh the transport emissions, regardless of whether or not the reverse-haulage nature of the trade is considered.

For paper, in 10 out of 14 cases, the absolute CO_2 emissions associated with transport to China account for one third or less of the estimated savings from recycling. In 2 of the 4 remaining cases, the carbon savings from recycling still outweigh the absolute transport emissions.[12]

For plastics, the evidence is even stronger. Even in the worst case (high transport emissions and low CO_2 benefits from recycling), the CO_2 savings outweigh the absolute transport emissions by a significant margin.

If one considers only the emissions associated with the additional transport stages (the marginal emissions basis), then in the vast majority of scenarios the emissions associated with transporting recovered materials to China account for a small proportion – less than ten per cent – of the potential savings from recycling.

[12] One case estimates negative savings from recycling

7. Discussion and sensitivity analysis

Various scenarios have been run to test the sensitivity of the results to different factors. In all cases, whilst the precise numbers vary, the overall conclusions remain unaffected.

The implications of the use of CO_2 emissions rather than CO_{2e} emissions has already been discussed as has the significant issue of the choice between marginal or absolute allocation of the shipping emissions.

The study focused on the CO_2 emissions from the combustion of fuel and did not take account of the emissions associated with the primary production of fuel. The addition of primary energy emissions would increase overall emissions by around 14 per cent. Although not an insignificant amount, the addition of these emissions does not undermine the key conclusions of the report.

Finally, the assumption that the emissions savings from substituting virgin material with recovered materials in China would be of a similar magnitude to those found in existing LCAs is pragmatic and warrants further testing. However, there are a number of reasons to believe that this assumption is, if anything, conservative. First, reprocessing is more manual in China than in the UK, hence the CO_2 emissions associated with this phase may be lower. Second, energy generation in China is more carbon intensive than in the UK so any energy savings that arise from using recovered materials will translate into higher emissions savings. Finally, virgin alternatives – either pulp or virgin polymers – used in China may need to be sourced from further afield than those used in the UK, which may mean that the use of recovered materials would be associated with some additional transport savings.

8. Conclusions

This study suggests that there are CO_2 savings to be made from recycling relative to the alternative of landfill and using virgin materials, even if the recovered materials have to be transported to China. That is, the emissions associated with exporting material to China do not outweigh the CO_2 benefits of recycling.

The CO_2 emissions associated with transporting one tonne of recovered paper from the UK to China are estimated to lie between 154kg and 213kg of CO_2. The emissions associated with transporting one tonne of recovered plastic bottles range between 158kg and 230kg of CO_2. These CO_2 emissions levels represent less than a third of the carbon savings from recycling identified by a majority of the life cycle assessments (LCAs) reviewed in the study.

This conclusion becomes even more compelling if the reverse haulage nature of recovered materials export is taken into account. If only the marginal shipping emissions are calculated, the CO_2 emissions associated with transporting recovered materials to China drop to below 10 per cent of the benchmark carbon savings for the vast majority of the scenarios considered.

This study forms a *necessary* part of the evidence base to demonstrate that exporting recovered material for export is environmentally sustainable. However, it is not *sufficient* to demonstrate that exporting is a desirable outcome. In particular, it makes no assessment of the relative benefits of recycling domestically versus recycling in China. Moreover, it does not tackle a wide range of other relevant factors including wider environmental and social impacts.

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