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Environmental indices for the Dutch packaging tax

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Summary

On 1 January 2008 a tax on packaging is to be introduced in the Netherlands. In line with government efforts to 'green' the Dutch fiscal system, tariffs for the new tax are to be indexed to the environmental burden of the packaging material in question. The following materials will be distinguished: paper/board, glass, steel, aluminium, plastics, wood and 'other'. For policymakers, a ranking based on the lifecycle climate impact of the packaging provides a good and workable approximation of the overall environmental burden. For each of the materials covered in this report, an inventory has been drawn up of the greenhouse gas emissions associated with the key steps in the supply chain: raw materials extraction, primary production of the packaging material, package shaping, recycling and final waste disposal. Table 1 reports the calculated environmental burden in kg CO₂ equivalent per tonne of each of the packaging materials.

Table 1 Total score per tonne of material, kg CO₂ equivalent

Material	Score ^(b)	Factor rel. to glass
Paper & board (incl. beverage cartons)	676	1.5
Glass	443	1
Steel	1,095	2.5
Aluminium	5,570	12.6
Plastics	3,453	7.8
Wood	< 0	0
Other ^(a)	475 → 443	1
Average (without wood and other)	1,208	

(a) It is proposed to set the score for the category 'other' equal to that of glass.

(b) NB: Because of the major differences in packaging weight arising in practice, on its own this score per tonne of material cannot be used to class a particular type of packaging as 'environmentally friendlier'.

In dialogue with the Dutch packaging materials industry, the environmental ranking for the new packaging tax has been elaborated in a very short space of time. In the assessment of CE Delft, this has yielded a reasonably robust measure on which a packaging tax for the year 2008 can be based in the short term.

For the 2009 tax year it is recommended to refine the ranking by:

- Incorporating environmental differences in the use phase between different types of packaging (in particular, differences in product spoilage and cooling requirements).
- Incorporating additional environmental themes (particularly land use and biodiversity), especially to improve coverage of paper recycling.
- Incorporating differences between production sites (primary production and shaping) in more detail, as well as environmental differences between sites.
- Further refinement of tariffs for specific submaterials (individual grades of cardboard and plastics) and incorporation of current recycling rates.

After this date, an update every two years would be useful to encourage ongoing innovation.



1 Introduction

On 1 January 2008 a tax on packaging is to be introduced in the Netherlands, covering the packaging on all products marketed domestically. In line with government efforts to 'green' the Dutch fiscal system, tariffs for the new tax are to be indexed to the environmental burden of the packaging material in question, as is the case in Denmark¹.

Earlier, in April 2007, a series of approximate calculations had been carried out by CE Delft for the Ministry of Finance on environmental differentiation of the packaging on a limited number of product groups. Some of the environmental data used in that study for the materials in question were outdated, however.

It has meanwhile been decided to levy the packaging tax on all packaging, rather than restricting it to a limited number of product groups, as in Denmark. At the same time, though, there will be only limited differentiation as to material subcategories, to keep things compatible with the existing Dutch monitoring system for packaging materials (a single, average environmental index for plastics and possibly also for metals (steel + aluminium)). This averaging across material groups requires good estimates of market volumes. The plan is thus to levy the packaging tax as a surcharge per kilo of packaging material.

The principal aim of this study was to provide a robust calculation of the relative environmental burden of the various packaging materials used in the Netherlands, thereby giving due consideration to input from the packaging industry and the industries supplying it.

The result will be used by the Ministry of Finance to set the tax tariffs for the various packaging materials.

¹ Belgium was to do the same, but these tax plans have now been dropped.



2 Calculating the environmental burden

2.1 Lifecycle climate impact as an approximation

In north-west Europe, packaging has been the subject of numerous environmental studies, many of them based on lifecycle assessment (LCA) encompassing all the environmental impacts of the supply chain 'from cradle to grave'. In the Netherlands beverage packaging has been a major focus of LCA studies, a number of them commissioned by the environment ministry, VROM. In some of these analyses full calculations were made for a list of 10 to 20 different environmental impacts. Following experience with different weighting methods, towards the end of the '90s it became clear that the relative performance of the principal packaging materials is determined by only a handful of environmental LCA 'themes'.

In 2001, in an earlier study on the projected impact of an environmental tax on beverage packaging (CE, 2001b) CE Delft focused solely on two such dominant LCA themes: Greenhouse Effect and Final Waste, an approach fully supported by VROM and the Dutch packaging industry (SVM-PACT). A 2004 study by CE Delft and KPMG (CE/KMPG, 2004) at the request of VROM and SVM-PACT on 'a new environmental index for packaging and its integration with products' also concluded that for macro-policy purposes an environmental index based solely on the greenhouse effect and final waste is a good compromise between a complete LCA and the current 'kilogram approach' in which every kind of packaging is taken to be equally environmentally burdensome.

Based on these considerations, the recent heightened interest in climate change as a social and political issue, and the sharp decline in the volume of final waste attributable to packaging following the ban on landfill of burnable waste, it has been decided to take *climate impact as a proxy for the relative environmental burden of the various packaging materials*. Because a decision has already been taken on the aggregate tax income from the measure, all that needs to be done is allocate a charge to each of the materials based on their relative burden.

A rough and ready measure of the environmental impact of packaging that is adequate for policy purposes is thus provided by a ranking based on lifecycle climate impact, encompassing the emissions associated with raw materials extraction, virgin material production, shaping, usage, recycling and waste disposal. The only proviso to be made concerns the difference between biotic and abiotic materials, an issue discussed in sections 3.2 and 4.4.

A similar approach has also been adopted in Denmark², where the scheduled packaging tax is likewise to be based on lifecycle climate impact. The numerical data used differ from ours, however, mainly because of differences in waste

² Belgium was to do the same, but these tax plans have now been dropped.

disposal statistics, recycling percentages and (to a lesser extent) packaging production statistics. In Chapter 4 the systems are compared.

2.2 Use phase

In LCA terms, there is debate about whether and to what extent the use phase of the packaging (the part of the lifecycle in which it is filled with product) should also be included in the analysis. For the industry this is indeed a major issue (see Appendix E). Although packaging does not in itself give rise to any CO₂ emissions during use (there is no plug-in packaging as yet), it does have an influence on the packaged product and, more specifically, on product wastage and spoilage. In addition, certain product/packaging combinations must be kept chilled or frozen.

As rightly pointed out in (GUA, 2005), all packaging is intended (partly) to limit product loss, i.e. spoilage. It is this function that generally determines the minimum thickness/strength and, in part, the choice of packaging material. Long-life milk is packaged in a beverage carton with an aluminium lining, for example.

One of the things learned in the aforementioned study by CE/KMPG on the integration of packaging and product policy (CE/KMPG, 2004) was that for a number of types of packaging the prevention of product spoilage and discard has greater environmental benefits than the negative impact of the packaging in question. In the case of perishable goods with a major environmental footprint such as greenhouse vegetables, dairy produce, fish and meat, this avoidance of product loss is (far) more important for the environment than the impact of the packaging. This issue of perishability is thus relevant when there are different packaging options available for a certain product, as with:

- Products sold both with and without packaging (e.g. a cucumber with and without a sleeve), where the packaging clearly leads to longer shelf life.
- Small 'individual' packs requiring more packaging, but potentially leading to less discard (e.g. mini beverage cartons for fruit or yoghurt drinks, as well as mini bottles of carbonated drinks that lead to less discard of 'flat' drink).
- Resealable forms of packaging that may sometimes have a greater environmental impact (e.g. a plastic cap for milk), but lead to longer shelf life.

The GUA study (2005) provides a calculation of the savings purported to be achieved as a result of reduced food loss through packaging use. It is based entirely on a hypothetical scenario, however, and plastic packaging is assumed to have a greater environmental impact than other types of packaging. Working on these assumptions, GUA derives an approximate figure of 3.5 MJ extra energy savings per kg plastic, or around 3% of the energy saved anyway through packaging use. There is therefore no reason to expect there to be any major differences among packaging materials. The total energy savings cited by GUA for packaging exceed the energy invested in making it, it may be added. If this is to be taken at face value, packaging materials might thus have a *negative* environmental burden, leading to the conclusion that the greater the volume of packaging used, the better it is for the environment. This argument *in extremis*



demonstrates that it would be unreasonable to include these issues in packaging LCAs.

A more relevant reason for not doing so is the fact that packaging choices are product-driven. This holds for chilled and frozen goods, too. Spinach is not stored in a freezer cabinet because of its cardboard packaging, but because consumers find it convenient to have deep-frozen spinach at hand for an 'emergency', or think it tastes better than spinach in a jar, or fresh. If the spinach is going into the freezer anyway, it is reasoned, it might just as well be packaged in cardboard. The same holds for the example of long-life milk cited above.

Finally, different types of packaging material may differ in terms of the amount of transport post-filling. Use of heavy glass versus lighter plastic bottles for a given volume of product will, for example, give differences in total transport tonne-km. If transport is weight-limited, it may well be that glass bottles mean a lower volume load factor and therefore more trips for a given volume of product. In such cases one cannot simply calculate using an additional increment of CO₂/kg that is the same for each and every material. Again, though, it can be queried whether a given transport link is indeed weight-limited by merit of a given type of product, and because transport contributes only minimally to overall carbon emissions, these issues have been ignored here.

Conclusion on use phase

Through differences in product spoilage patterns and freeze/chill requirements there may be substantial variation in the environmental performance of product/packaging combinations. Exactly how much variation is unclear, however, and decisions to adopt a certain type of packaging and whether or not freezing/chilling is required are primarily product-driven. As soon as the packaging and product chain come together, the product becomes the dominant factor. For this reason, these effects have not been included in the analysis as it now stands. This issue might be reconsidered later, particularly for certain types of packaging that do not alter the product but do prevent extra product spoilage (e.g. cucumber 'sleeves'). Still, it would be more logical to deal with these effects via the product rather than the packaging, perhaps by excluding certain product/packaging combinations from the tax.

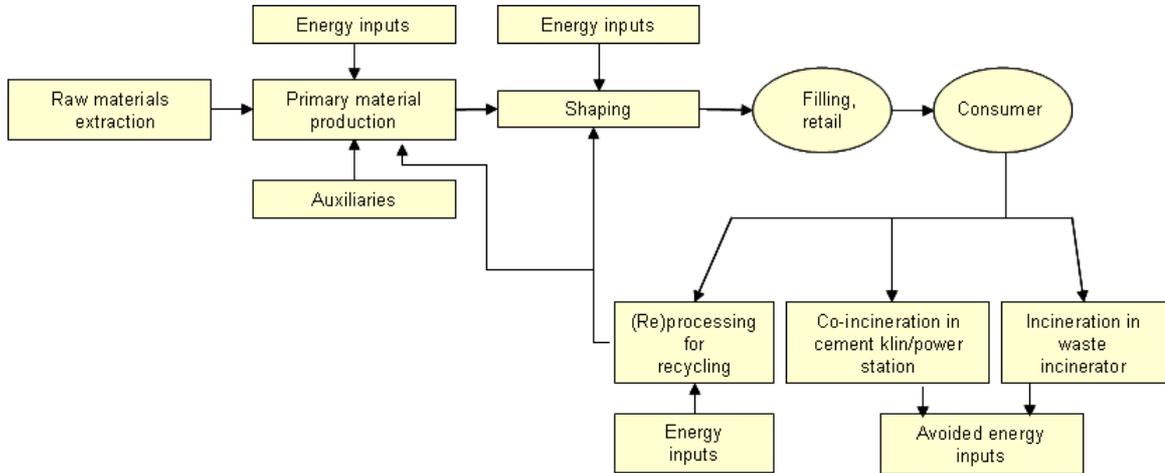
2.3 Links in the packaging chain

For the cited packaging materials, our analysis includes LCA data on the greenhouse gas emissions associated with the following key links in the supply chain:

- Raw materials extraction.
- Primary production of the virgin packaging material.
- The packaging shaping process.
- If the packaging is not recycled, but burned in a (Dutch) waste incinerator: incineration of the material (fossil/combustible plastics only) plus the CO₂ emissions avoided through energy generation at the incineration plant (paper/board and plastics).

- If the packaging is recycled: the production of virgin material avoided through recycling has been deducted in the CO₂ calculations, but the processing steps associated with recycling included.

Figure 1 Links in the packaging supply chain



Differences in environmental impacts in the links disregarded here may obviously still be important, as discussed in section 2.2.

2.4 Sources

For the environmental data we used only standard, reliable databases: for plastics the Ecoprofiles calculated by PlasticsEurope, for steel the database of the global steel industry (IISI), for aluminium the data of the European aluminium industry (EAA, 2005), for glass the data of the Dutch glass industry, for paper/board the data of the European industry (Fefco, 2006; Pro Carton, 2006) and, in addition, the BUWAL database and, occasionally, in-house data compiled by CE Delft (solid board, beverage cartons).



3 Data on individual packaging materials

3.1 General strategy and procedure

The carbon emissions data used in this study have been calculated using the figures and approach discussed with Dutch packaging producers in the framework of the 'Article 14 project' (CE/KPMG, 2004).

The basic dataset for each material comprises the following: process emissions of greenhouse gases (kg emission per tonne of final material) and consumption of auxiliaries (kg per tonne of final material), fuel (GJ final energy use) and electricity (GJ final energy use). In each case these raw data were multiplied by the relevant standard CO₂ conversion factor, as listed in Table 2. As far as possible, the basic data were broken down for each individual link in the production chain (see Figure 1). Certain links are not relevant for some materials. In the case of glass, for example, primary production and shaping are integrated, while burning in a waste incinerator has been ignored because it gives rise to no greenhouse gas emissions.

The accuracy of the 'old data' was discussed with the industry, which led to a number of revisions and improvements to the basic dataset. This new input, and our response, is described in Appendix E.

In this section we discuss some general principles. In the following sections the details of the various individual materials are discussed.

Some of the CO₂ conversion factors used here differ from those used in the 'Article 14 project'. These new values derive partly from Ecoinvent version 1.3 (auxiliaries) and partly from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy (calorific values and CO₂ emissions³ for fuel combustion). The characterisation factors for greenhouse gases are all according to IPCC 2001 (Third Assessment Report). While not yet employed for the National Inventory Reports under the terms of the Kyoto protocol, these values are used in virtually all other climate policy settings, being scientifically the most reliable.

The standard conversion factors used in the present study are shown in Table 2 and Table 3, below.

³ Non-CO₂-emissions contribute less than 1% to the climate impact of fuel combustion.

Table 2 CO₂ conversion factors

		Article 14 'old data' (kg CO ₂ eq.)	New values (kg CO ₂ eq.)	Source of new values
Emissions to air (per kg emission)	CO ₂	1		
	N ₂ O	296		
	CH ₄	23		
	CF ₄	6,500	5,700	IPCC 2001
	C ₂ F ₆	9,200	11,900	IPCC 2001
Auxiliaries + standard raw materials (per tonne)	Na ₂ CO ₃ (synthetic)	770		
	Na ₂ CO ₃ (natural)		100	EPA 2007
	NH ₃	2,239	2,080	Ecoinvent v1.3
	NaOH (50%)	1,499	1,010	Ecoinvent v1.3
	NaCl	216	167	Ecoinvent v1.3
	CaO	1,265	944	Ecoinvent v1.3
	CaCO ₃	10	23	Ecoinvent v1.3
	AlF ₃	1,754	1,160	Ecoinvent v1.3
	Al(OH) ₃		66	Ecoinvent v1.3
	CaF ₂	95		
	Anodes (alum. prod.)		983	Ecoinvent v1.3
	Petrol coke		507	Ecoinvent v1.3
	Pitch (at plant)		1,040	Ecoinvent v1.3
	H ₂ SO ₄	115	119	Ecoinvent v1.3
	Cathode carbon		2,410	Ecoinvent v1.3
	Fe		17	Ecoinvent v1.3
	Dolomite		27	Ecoinvent v1.3
Oxygen	216	373	Ecoinvent v1.3	
Precombustion (per GJ final use)	Natural gas	12	12.4	Ecoinvent v1.3, IPCC calorific value
	Petroleum	19	17	Ecoinvent v1.3, IPCC calorific value
	Soft coal		33	Ecoinvent v1.3, IPCC calorific value
	Hard coal	16	10	Ecoinvent v1.3, IPCC calorific value
Combustion + heat (per GJ final use)	Natural gas	67	56	IPCC, 2006
	Fuel oil, light	85	77	IPCC, 2006
	Fuel oil, heavy	97		IPCC, 2006
	Diesel oil		74	IPCC, 2006
	Soft coal		101	IPCC, 2006
	Hard coal	106	95	IPCC, 2006
Electricity (GJ)	Mix NL	188	145	CE, 2007
	Mix EU	120		
	Mix EAA	94	103	EAA update 2002; Sept. 2005
Transport (tonne/km)	Maritime	0.00028		
	Inland shipping	0.034		
	Rail	0.034		
	Road	0.078		

The calorific values taken for the relevant primary energy sources are shown in Table 3.



Table 3 Calorific value of primary energy sources

	Calorific value MJ/kg	Source
Natural gas	48	IPCC, 2006
Diesel oil	43	IPCC 2006
Petroleum	40.4	IPCC, 2006
Soft coal	11.9	IPCC, 2006
Hard coal	28.2	IPCC, 2006

Transport

Transport distances were estimated according to the philosophy set out in (MERLAP, 2002), with the distance becoming shorter the more deliveries of packaged goods there are along the transport route. The following distances were adopted:

Transport to incinerator plant	40 km
Transport to pelleting plant	150 km
Transport to cement kiln	150 km
Transport to a single location in the Netherlands	150 km
Transport to 2 locations in the Netherlands	100 km
Transport to 3 locations in the Netherlands	75 km
Transport to 4/5 locations in the Netherlands	50 km

In the case of transport from other countries (mainly raw materials and semi-finished product) we have used actual distances as far as possible, taken partly from relevant industry databases, and otherwise the maximum distance of 150 km (MERLAP, 2002).

Processing of final waste and assumptions on incineration

For used packaging material that is not recycled there are in principle three disposal options:

- Incineration in a municipal waste incinerator with energy recovery.
- Co-incineration in a cement kiln or power plant (replacing coal).
- Landfill.

It has been assumed that there is no land filling of packaging waste. A minor percentage of waste cardboard and plastics will be co-incinerated as a secondary fuel (see sections 3.2 and 3.5), but the vast bulk of packaging waste will be burned along with other household refuse in a waste incineration plant. The 'carbon credits' embodied in the generated power have been allocated to the materials in proportion to their calorific value. In doing so we have based ourselves on the average efficiency of Dutch municipal incinerators: 22% electrical and 7% thermal. The electricity output is taken to replace an equal output from the average of Dutch installed capacity ('mix NL' in Table 2). The heat output replaces an equal amount of heat produced using a gas boiler. In the case of co-incineration in a cement kiln or power station, savings on coal have been based on the calorific value of that fuel (see values in Table 2 and 3; see also Appendices A and D).

In both types of incineration the burning of cardboard (produced from wood) leads to CO₂ emissions. This 'short-cycle' CO₂ was absorbed from the atmosphere at the beginning of the chain (forestry), which means that up to the moment of combustion these materials have a 'negative' CO₂ content. The net lifecycle emission of (short-cycle) CO₂ is thus zero.

No allowance has been made for the fact that materials with a high/low calorific value may have a favourable/unfavourable impact on incineration efficiency, nor for secondary effects of the Paper/Plastic Fraction (PPF) being removed. The average composition of the waste burned in incinerators is a given and will be scarcely influenced, moreover, by minor variations in the recycling percentages of packaging materials.

In principle, it is only cardboard and plastics that contribute to power generation at incinerator plants. Metal and glass packaging are assumed to be inert. In the case of aluminium this is not entirely true, as the aluminium does partially oxidize and thus contribute to combustion. When it comes to metal packaging, however, this is only a small fraction, which leads to a minor loss of material in the recovery phase (see below). In the case of the aluminium in beverage cartons, complete combustion with energy recovery has been assumed, because the layer in the laminate is exceptionally thin and therefore consumed by fire.

Pre-treatment and slag reprocessing

At a number of Dutch incinerators there is preliminary mechanical separation of metals, paper and/or plastics. Experience shows that cardboard packaging does not generally end up in the PPF, because of its relatively high weight per m². This is indeed the case at the GAVI and VAGRON facilities, where beverage cartons remain in the residual waste fraction. In the case of paper as well as beverage cartons, then, secondary fuel production has been left out of consideration. With plastics, there is a certain amount of prior separation; see Appendix D. With metals, a total recycling percentage has been determined for the fraction ending up in the residual waste; much of this is reclaimed during slag reprocessing (Appendix C).

Recycling

Whether or not packaging materials are recycled has an impact on the average greenhouse gas emissions to which they give rise. There are basically two ways in which recycling can be factored in, which in the case of a closed cycle give the same final result:

- Via 'recycled content': glass, paper (except for surpluses of secondary material, for which the following holds).
- Via 'recycling percentage': other materials. Although the data used are for production from primary feedstocks, use of secondary material means there are savings on these (albeit after the necessary upgrading steps). In the case of plastics being recycled within a different supply chain, there is not always 1:1 substitution; in such cases we used a quality factor, as with PET re-used in a fibre application like fleece (see section 3.5).



In the case of steel this approach is somewhat formalistic, because as a rule steel production is never based on 100% primary raw materials. This issue is dealt with in section 3.4.

For recycling percentages and total volumes we based ourselves on the data reported in the (Dutch) Packaging Commission's latest annual report (2005). In the case of glass, cardboard and plastics there is separate waste collection, while for metals there is both separate collection and recovery from incinerator slag (see above). The split for aluminium and steel is described in Appendix C.

For each individual packaging material we now provide the precise details of the calculations.

3.2 Paper/board

In the case of paper and cardboard packaging, five 'submaterial' groups can be distinguished:

- Corrugated board.
- Folding boxboard.
- Solid board.
- Beverage cartons.
- Other (wrappings, from gift paper to cement bags).

This is the subdivision used by the industry, based on product characteristics and production methods. Within each of these submaterial groups there are all kinds of further subdivisions, which may share characteristics with other submaterial groups. A case in point are the laminates used for deep-frozen products. These are produced in much the same way as folding boxboard, but with an additional step in which a thin PE lining is applied. The production method thus differs from that used for beverage cartons. These laminates have therefore been categorised under folding boxboard. The extra step of applying a layer of PE involves so little additional environmental impact that it is not recommended to introduce a separate category.

The volumes of the various submaterials are reported in Table 4.

Table 4 Paper/board packaging: volumes of submaterials (kt) and percentage secondary input

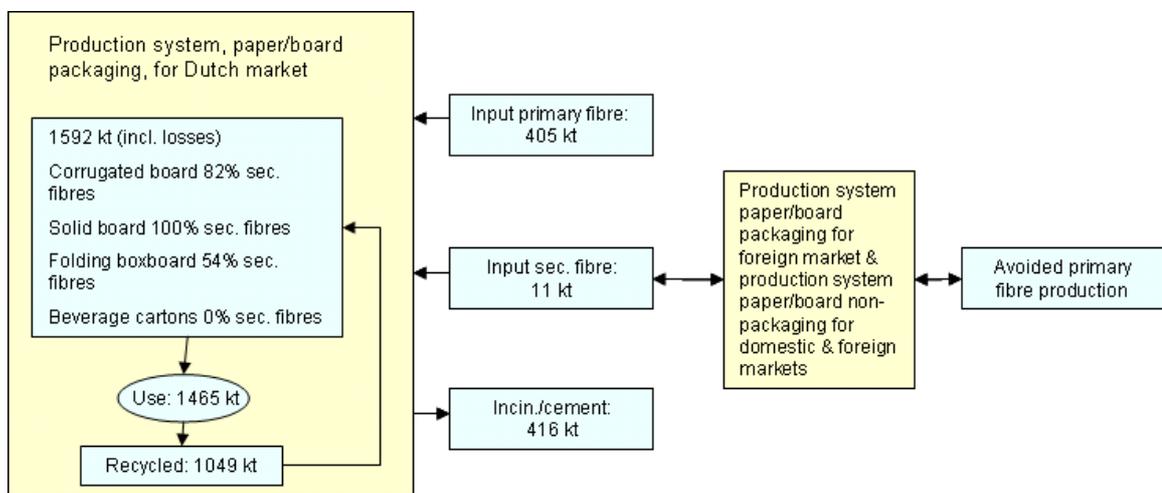
	Volume, 2005 (kt)	Share	Allocation of 'other'	Adjusted volume (kt)	Adjusted share	Percentage secondary input
Solid board	180	12%	14%	190.2	13%	100%
Folding boxboard	305	21%	23%	322.3	22%	54%
Corrugated board	840	57%	63%	887.5	61%	82%
Beverage cartons	65	4%		65	4%	0%
Other	75	5%				
Total	1,465			1,465		

Source: VNP.

Most of the solid board for the Dutch market is produced domestically, but production of the other submaterials is mainly foreign. Average use of secondary fibre is 100%, 82%, 54% and 0%, respectively, for the production of solid board, folding boxboard, corrugated board and beverage cartons (VNP, 2002).

The supply chain for cardboard packaging starts with pulp production and processing of the pulp to board, delivered to packaging producers on reels or in sheets. This semi-finished material is then cut and printed to create the box or package, which is then sent to the filler and subsequently marketed. Some of these steps are integrated and take place at one and the same facility. In that case the data have not been broken down. For all the submaterials, average losses amount to 8%.

Figure 2 Mass balance for paper/board packaging for Dutch consumption



NB: The figure shows how the system has been analysed in this project. In reality it is rather more complex, of course, as the production industry serving the Dutch packaging market uses a relatively high percentage of secondary fibre and processes a substantial amount of separately collected graphic paper along with ditto packaging materials. In addition, some of the packaging paper collected is re-used in other paper/board applications (e.g. aseptic grades).

A major fraction of the discarded packaging is separately collected and recycled. This yields rejects, consisting mainly of non-paper-related materials like sand and plastics. The remainder comprises paper-related materials like staples, labels and so on. The fibre fraction lost with these rejects is 0.5% (industry data). It is only this fibre fraction in the rejects that has been considered a secondary fuel for co-incineration in cement kilns.

Short-cycle CO₂ has not been disregarded, but included at the back end of the chain and then taken to be emitted at the front end, during incineration. A value of 1,643 kg CO₂ per tonne board has been taken, derived from a carbon content of 44.8% (by weight). Removal of the CO₂ from the atmosphere and subsequent CO₂ emissions have thus been based solely on carbon content. Emissions associated with land use, land use changes and forestry ('LULUCF') as a result



of primary raw materials use have not been included. The same holds for the indirect effects of resource depletion.

Because average use of secondary fibre in packaging board is slightly greater than the waste paper recycling rate, on balance there is a 'shortfall' of 11 kt secondary fibre (after correction for cutting losses). This is made up for from different supply chains from those for domestically consumed packaging. Here we have assumed that sulphate pulp (kraft pulp) is used; see Appendix A.2.

In the following paragraphs the carbon emissions data for the four submaterials are discussed individually.

Solid board

As solid board is produced mainly in the Netherlands, Dutch output can be said to be representative of the material sold on the Dutch market⁴. Dutch production is based entirely on waste paper and takes place at Smurfit Kappa Solid Board.

Emission factors and data on auxiliaries consumption and energy inputs for solid board production were provided by the (then) main Dutch producers in 2004, based largely on BUWAL 250. With respect to the shaping stage, new energy data on two producers were provided by the industry: 0.24 and 0.29 GJ_e per tonne. These figures are considerably lower than the older data. In this study the higher value of 0.29 GJ_e per tonne has consequently been taken; a more general update of these data would be desirable.

Recycling has been included via recycled content.

The full dataset for solid board is provided in Appendix A. The final score for solid board (908.5 kg CO₂ eq./t) is subsumed in the total figure for cardboard.

Corrugated board

As most of the corrugated board packaging for the Dutch market is imported, for production of this packaging we have taken average European production data. Emissions for corrugated cardboard are thus based on the data reported in (FEFCO, 2006). Pulp produced from fresh wood or waste paper is processed to reels of paper. The share of virgin material is 18% and packaging production is integrated. The transport distances in Appendix A have been 'corrected' for this as necessary (i.e. transport of virgin raw materials over 1,000 km gives an effective distance of 180 km).

For cutting losses, rejects, recycling and disposal the same general procedure was followed as for paper/board as whole.

The full dataset for corrugated board is given in Appendix A. The total score for corrugated board (750.3 kg CO₂ eq./t) is subsumed in the total figure for board.

⁴ 65% of the solid board produced in the CEPI countries is from the Netherlands.

Folding boxboard

Production of pulp and semi-finished product, i.e. reels or sheets of folding boxboard, takes place at integrated production centres. During processing of the primary pulp, commodity pulp produced elsewhere is sometimes also purchased to cover requirements. The remainder is produced in-house. The total share of primary raw material in production is 46%. The data in Appendix A are from the Pro Carton database (www.procarton.com).

For cutting losses, rejects, recycling and disposal the same general procedure was followed as for paper/board as whole (see also Appendix A).

The full dataset for folding boxboard is given in Appendix A. The total score for folding boxboard (282.1 kg CO₂ eq./t) is subsumed in the total figure for board.

Beverage cartons

There are two types of beverage carton⁵:

- Septic cartons, consisting of a combination of about 11% PE and 89% board and used for packaging dairy products.
- Aseptic cartons, consisting of a combination of about 5% aluminium, 20% PE and 75% board and used for packaging longer-life products.

The cardboard (liquid packaging board, LPB) is produced from 100% primary raw materials in Scandinavia. Lamination, which takes place in the Netherlands, involves applying a PE coating to both sides the board (by extrusion). In the case of aseptic beverage cartons, there is a thin layer (7-8 µm) of aluminium on the inside, between the board and the PE. The laminate is sent to the packager on reels for filling and subsequent marketing.

In 2005 a figure of 2 kt was reported for 'useful application' of recycled beverage cartons, in the form of secondary fuel (PPF). This has been ignored, partly because it has only a negligible effect on the total figure for paper/board.

Emission factors and data on auxiliaries consumption and energy inputs for production of the LPB used in beverage cartons and ditto for laminate production have been taken from (BUWAL 250). The environmental data for the PE film and for primary aluminium were calculated specially for the present study.

When aseptic beverage cartons are incinerated, the aluminium they contain will burn (in contrast to solid aluminium packaging) and contributes to power and heat generation. In the Netherlands 100% of beverage cartons are burnt in incinerators; for details, see Appendix A.2.

⁵ Based on information from Hedra.



The full dataset for beverage cartons is given in Appendix A. The total score van beverage cartons (1,182.8 kg CO₂ eq./t) is subsumed in the total figure for board.

Paper/board, total

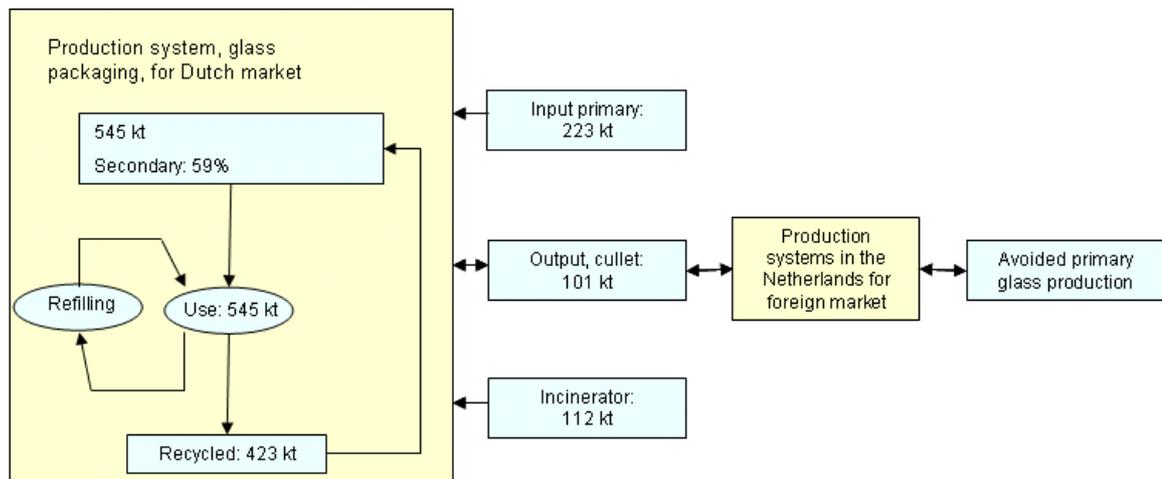
The total score for paper/board is 676 kg CO₂ eq./tonne.

3.3 Glass

Dutch glass production capacity exceeds domestic consumption by a factor of over two. In 2006 Dutch recycling of broken glass (cullet) was up to 59%. This figure is a weighted average for the Dutch glass packaging industry as a whole (Ardagh Glass Benelux and O-I Manufacturing Netherlands B.V.).

For the portion consumed domestically (545 kt) the recycling percentage is even greater (78%), giving rise to a surplus of cullet (101 kt). This surplus is also used at domestic production facilities, but for the production of packaging for foreign consumption. Figure 3 shows the mass balance for Dutch consumption.

Figure 3 Mass balance for glass packaging for Dutch consumption



For the environmental data, we took the emissions of the Dutch glass industry. Plenty of glass packaging is imported; around 50% of consumption consists of wine bottles from wine-producing countries. As Dutch production of glass packaging is over double domestic consumption, though, more Dutch glass is exported than foreign glass imported. On top of that, some of the exported glass will return to the Netherlands after being filled with product.

The primary raw materials used in glass production are soda (Na₂CO₃), limestone (CaCO₃) and sand. Much of the soda used in Europe is produced from rock salt (NaCl) and limestone or calcium chloride (CaCl₂). Some soda is imported from North America, where it occurs naturally. According to the Dutch industry's own data, one-third of the soda used is of natural origin. Most process emissions relate to the use of soda.

Data on cullet processing have been taken from (BUWAL 250; p.500/501). Losses in this part of the chain are around 4%, but this has already been corrected for in the recycling percentage of 78%.

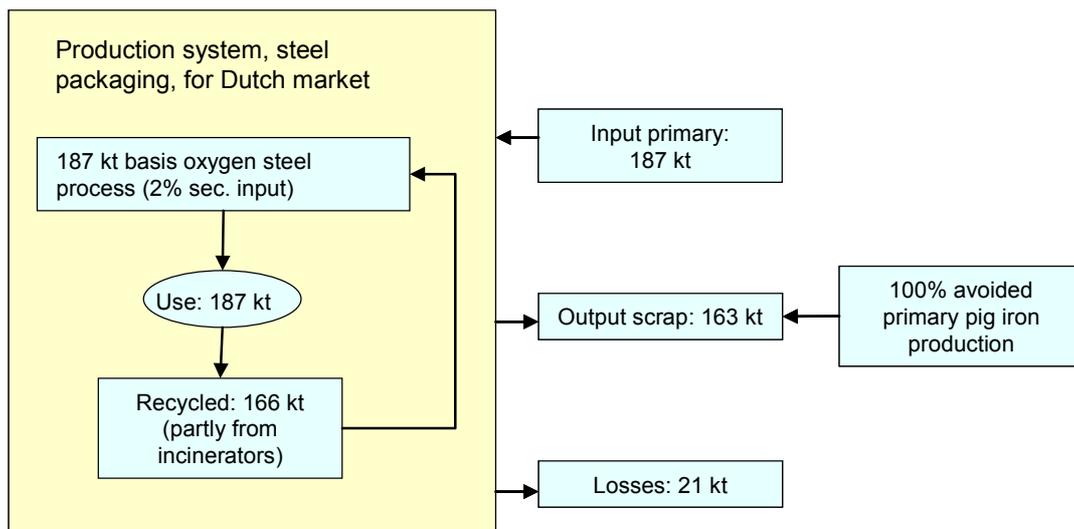
The full dataset for glass is given in Appendix B. The total score is 443 kg CO₂ eq./t glass.

3.4 Metals

3.4.1 Steel

In Europe steel is produced from imported raw materials and then processed regionally to, among other things, packaging. Following discard, steel packaging is segregated and recycled: part of the steel packaging used by households is collected separately, while part is separated in waste separation plants (Wijster, VAGRON, OMRIN). Most of the steel remaining in the slag left after incineration of the integrally collected residual domestic waste fraction is recovered (see Appendix C).

Figure 4 Mass balance for steel packaging for Dutch consumption



It has been assumed that the packaging is made exclusively of tin-plated steel (cf. Boulonois, 2003). For primary production we based ourselves on the IISI 'cradle-to-gate' European environmental profiles for tin-plated coil (IISI, 2002). These data allow for only very little use of scrap (2%). Rolled sheet is the semi-finished product from which the packaging is made. The IISI environmental profile cites all the main raw material and energy inputs. These were converted to CO₂ emissions using the standard conversion factors. In the IISI data the transport steps are included in the energy data.



Cans are assumed to be the most common form of steel packaging and these have therefore been taken as approximately representative of the whole spectrum of such packaging. Data on the energy input involved in producing cans from rolled sheet were adopted from (BUWAL 250).

Again there is separate collection of discards; in this case 36% of steel packaging is recovered this way. In addition, the steel ending up at incineration plants is largely recovered, via mechanical separation and reprocessing of the bottom ash. The details of the calculation are provided in Appendix C; the effective percentage is 82% of the steel in the residual waste fraction. For the energy consumption of slag reprocessing we have taken a figure of 0.64 kWh/t (Appendix C). For both types of scrap, collection and reprocessing have been calculated according to Ecoinvent; the transportation involved in this step has been included in the standard manner (see section 3.1).

Recycling and avoided primary production

There are limits to the amount of scrap that can be fed back into the oxygen steel process. Although the theoretical maximum is about 30%, in practice only about 20% is used, partly for quality considerations (Boulonois, 2003)⁶.

To all intents and purposes, though, all the scrap deriving from the steel packaging used in the Netherlands does end up in the oxygen steel process, as this flow represents only a very small fraction of total steel production. Once more, then, the recycled content is lower than the percentage recycled and a surplus of secondary material arises, allowing for savings on primary production (of pig iron), similar to the situation for glass.

In tackling these issues there are two practical problems:

- In the IISI data used, no production steps are cited; the share of pig iron (primary raw materials chain) in the total figure for the oxygen steel process is therefore unknown.
- The IISI data assume use of only 2% scrap.

We have therefore assumed that 2% of the steel is in a closed loop. For the other recycled material we have used a factor for the share of pig iron production in the total CO₂ emissions of steel production based on Ecoinvent data (version 1.3). This factor is 80%⁷. So with respect to use of tin-plated coil (our basic point of departure), on balance 2% of the discarded product can be re-used in a 'closed loop', as it were. The rest has been factored in as avoided pig iron production.

The full dataset for steel is given in Appendix C. The total score is 1,095 kg CO₂ eq./t steel.

⁶ In Europe the average is probably lower.

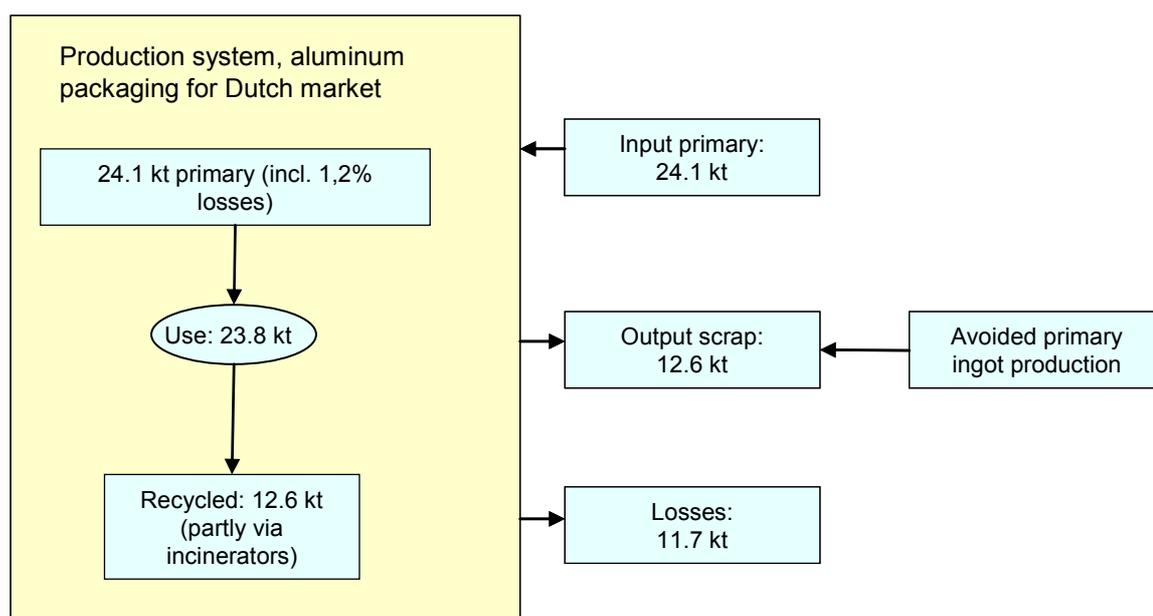
⁷ The precise value obviously depends on all kinds of factors impinging on the basic oxygen steel process and there is no way to verify whether the same factor holds for the IISI data. An alternative method for quantifying the savings in the primary chain is to proceed from the volume of scrap used in electric furnace steel. This yields a similar figure of around 80% savings. It is unrealistic to allocate zero energy use to the use of scrap in the process, even though it is used to cool the hot steel, because it is an intrinsic part of the overall process.

3.4.2 Aluminium

The aluminium supply chain starts with bauxite extraction. The aluminium leaves the aluminium smelter as a semi-finished product, being converted to finished product elsewhere by rolling or other means.

As with steel, aluminium is recovered both via separate waste collection and via reprocessing of incinerator slag. Recycled aluminium can be reused, thus saving on the primary aluminium production chain.

Figure 5 Mass balance for aluminium packaging for Dutch consumption



For the production of rolled sheet we have based ourselves on the data in the Environmental profile report for the Aluminium Industry: 'Primary Aluminium' and for scrap remelting on ditto, 'Semi-finished aluminium products and recycling' (EAA, 2005a,b).

It has been assumed that cans are the most common form of aluminium packaging and that these can be taken to be roughly representative for the whole spectrum of such packaging. Data on the environmental burden of can production from rolled sheet have been taken from (BUWAL, 250); there proved to be no other data available.

Again, there is separate collection; in this way, 30% of aluminium packaging is recovered. Following (Werner, 2002), we have assumed aluminium losses of 1.5% during processing and re-use of this fraction. In addition, some of the aluminium sent to incinerators is recovered via bottom ash reprocessing. The details of the calculation are given in Appendix C; the effective percentage is 30-33% of the (pure) aluminium in the residual waste fraction. For the energy consumption of slag reprocessing, 9 kWh/t has been allocated. We have



assumed, furthermore, that recycling takes place in the Netherlands and that the Dutch generating mix can therefore be taken for energy use.

The full data set for aluminium is given in Appendix C. The total score is 5,570.5 kg CO₂ eq./t aluminium.

3.5 Plastics

The following types of plastics have been distinguished:

- LDPE.
- HDPE.
- PP.
- (E)PS.
- PET.

This accounts for 97.5% of post-consumer plastics packaging waste (European average, AJI 2004). The proportions of the various materials in this waste⁸ have been taken from (AJI, 2004), but adjusted in the case of PET. Although the European average for the share of PET is apparently 14%, this is too high for the Netherlands. We have taken a figure of 6% from (VAOP, 2007), a percentage in line with our own estimate. The shares of the other submaterials have been increased proportionally. The percentages used are shown in Table 5.

Table 5 Plastics: volume shares, recycling rates and useful applications of submaterials

	Share	Recycling (%)	Recycling (kt)	Useful application and substitution ratio	Co-firing (PPF)
PET	6%	20%	7	Bottles (100%), fleece (50%)	12%
LPDE	39%	37%	86	Refuse bags, agricultural film (62%)	12%
HDPE	23%	18%	24	Boxes & crates (100%)	12%
PP	21%	6%	7	Boxes & crates (100%)	12%
(E)PS	11%	9%	6	Insulation, trays, flowerpots, etc. (100%)	12%
Total kt	592		131		72

For PET it has been assumed that 25% of recycling is 'bottle-to-bottle' (BTB), i.e. 1.7 kt. The other 75% of the recycled material is 'bottle-to-fleece' (BTF).

In some cases the recyclate is inferior to virgin material, which means that in a given application more recyclate is, or would be, needed than virgin material. The substitution ratios for the various plastics cited in Table 5, based on data from the Dutch Association for Environmental Management of Plastics Packaging, VMK (VMK, 2004), proceed from the following assumptions.

- Approximately half the EPS collected (the clean fraction) is ground up and re-used as an insulation material. This is 1-to-1 substitution, i.e. 1 kg of clean secondary foam replaces 1 kg of virgin EPS.

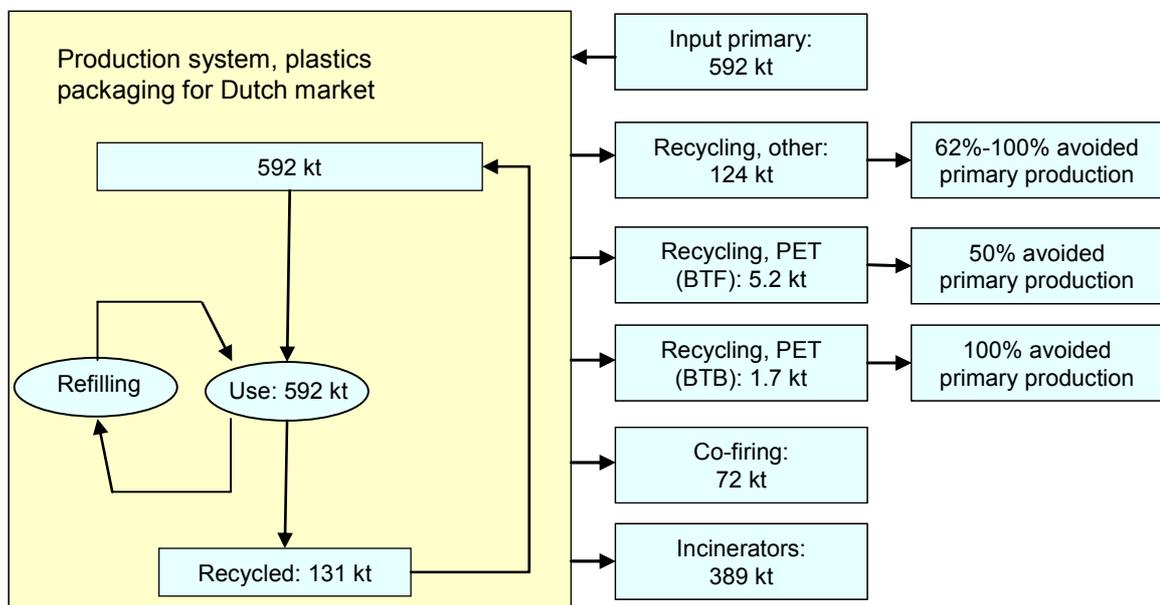
⁸ Domestic refuse and commercial waste.

- The other half of the EPS is degassed and re-used in all PS applications, provided they are black or grey. The PS derived from degassed EPS is brittle, so between 20% and 50% high-impact virgin PS has to be added. This is also the case with 100% virgin PS, it should be added. Products made of pure virgin PS or partly of secondary PS are equally thick, so 1 kg of fouled secondary foam replaces 1 kg of virgin PS.
- Crates and boxes made of HDPE and PP are shredded and granulated, with 1 kg of secondary material replacing 1 kg virgin.
- One Belgian producer makes refuse bags from both virgin and secondary LDPE. The ratio of the thicknesses of the respective bags is 40:65 (virgin:secondary), which means secondary PE replaces 62% virgin.

System

From the data of Table 5 the mass balance shown in Figure 6 can be derived.

Figure 6 Mass balance for plastics packaging for Dutch consumption



For primary production, data on auxiliaries and (final) energy use have been taken from the Plastics Europe Ecoprofiles (March 2005 versions). During shaping of the packaging (injection moulding, extrusion, etc.) there are very minor losses of material; these have been integrally adopted from the Ecoprofiles. The associated CO₂ emissions data were calculated using the standard conversion factors listed in section 3.1. Transport data were based on the standard distances given in the same section.

A certain amount of plastic packaging is segregated during mechanical separation of domestic refuse and dry business, shop and office waste, as part of the Paper/Plastic Fraction (PPF), which is generally processed to yield a secondary fuel ('subcoal'). It has been assumed that 12% of each of the submaterials is co-incinerated as a secondary fuel via this route (see Table 5).



The details of the incineration and recycling routes are provided in Appendix D. The avoided emissions due to recycling were calculated using the substitution ratios reported in Table 5. This means that for LDPE the avoided emissions per tonne are 0.62 times the emissions per tonne associated with primary production.

The full dataset for plastics is given in Appendix D. The total score is 3,084.6 kg CO₂ eq./t plastics.

3.6 Wood

Because the combustion of waste wood yields CO₂ neutral electricity that displaces fossil based output, wooden packaging has a negative climate impact. This is in line with the way emission credits are calculated in Dutch and European sustainable energy policy, as laid down in the Dutch Protocol on the Monitoring of Renewable Energy (SenterNovem, 2006).

This emission credit exceeds the emissions associated with processing of the wood. According to Ecoinvent, the cumulative lifecycle CO₂ emissions of a wooden pallet amount to minus 35 kg CO₂ per 0.05 m³ wood. Assuming a typical density of around 500 kg/m³, this means minus 1,400 kg CO₂ per tonne. Taking a net CO₂ emission for incineration roughly the same as for paper still makes the lifecycle emissions markedly negative.

The basic assumptions here are that production forests are replanted as prescribed by regulation and that there is no landfilling of wood waste in the Netherlands. As the wooden packaging used in this country is generally made of Scandinavian softwood, the assumption of proper replanting would seem warranted.

Obviously the same considerations as for paper/board hold here with respect to the fact that the primary material has a negative CO₂ content. Even though there may be net CO₂ removal, use of this packaging material is not to be encouraged. It is therefore recommended to use a factor of zero for wood.

3.7 Other

Among 'other packaging', earthenware pots are likely to constitute the largest single category. There has been no detailed study of the lifecycle CO₂ emissions associated with production of these items. Table 6 shows the emission factors for several standard categories, as available in public databases.

Table 6 CO₂ emission factors of 'other packaging' from public databases

Ceramic tiles (Ecoinvent)	763 kg CO ₂ /t
Porcelain (Idemat 2001)	371 kg CO ₂ /t
Stoneware (Idemat, 2001)	291 kg CO ₂ /t

The average of these values is 475 kg CO₂ per tonne. This is close to the figure for glass. So as not to have unduly many different tariffs, it is proposed to use the same emission factor for 'other packaging' as for glass (443 kg CO₂ eq./t) as a charge base for the tax.



4 Results: emissions of individual packaging materials

4.1 Carbon emissions per tonne

Table 7 provides a synopsis of the CO₂ emission factors per tonne of packaging material for all the submaterials considered in this study.

Table 7 Total scores in kg CO₂-equivalent per tonne of submaterial

Solid board	909 ^(a)
Corrugated board	750 ^(a)
Folding boxboard	282 ^(a)
Beverage cartons	1,183
Glass	443
Steel	1,095
Aluminium	5,570
LDPE	2,341
HDPE	3,478
PP	4,622
PET	3,872
(E)PS	4,895

(a) These figures do not include shortfalls of secondary material.

Note that, on its own, a lower CO₂ rating per tonne does not mean a packaging material is necessarily 'environmentally friendlier'. In practical reviews of the environmental impact of packaging (when comparing an aluminium drinks can with a PET bottle, say, or a beverage carton with a small glass bottle) it is the actual weight of the competing forms of packaging that counts, and these may be very different. In practice, the environmental performance of a given type of packaging can be estimated by multiplying these figures by the weight of the packaging.

Initially, the new Dutch packaging tax will not distinguish all the varieties of packaging materials listed above. Using statistics on market volumes, two groups of submaterials (Paper/board and Plastics) were aggregated to an average, yielding the figures shown in Table 8.

Table 8 Total scores in kg CO₂ equivalent per tonne of material

<i>Material</i>	<i>Score</i>	<i>Factor relative to glass</i>
Paper & board (incl. beverage cartons)	676	1.5
Glass	443	1
Steel	1,095	2.5
Aluminium	5,570	12.6
Plastics	3,453	7.8
Wood	< 0	0
Other ^(a)	475 → 443	1
Average (without wood and other)	1,208	

(a) It is proposed to set the score for the category 'other' equal to that of glass.

4.2 Packaging volumes

Under the 1st, 2nd and 3rd Packaging Agreements with the Dutch packaging industry an extensive packaging monitoring system has been established, including correction mechanisms and audits by accountants. While fairly accurate data are available for certain submaterials, however, there is as yet no reliable overall picture. In addition, the government intends to organize the new tax around the same monitoring system. The best basis for calculating tariffs would therefore appear to be the volumes of packaging materials reported in 2005.

Table 9 Marketed volumes of packaging materials (2005), as reported under the Packaging Agreement

	kt marketed (2005)
Glass	545
Steel	187
Aluminium	24
Cardboard (incl. beverage cartons)	1,465
Plastics	592
Wood	533
Other	-
Total	3,346 (without wood 2,813)

4.3 Comparison with Denmark and Belgium

It is interesting to compare the relative environmental performance of the various packaging materials reflected in the data of Table 8 with the figures used in Denmark and Belgium. In Belgium it was recently decided *not* to introduce a packaging tax (see textbox).

In **Belgium** a new tax on packaging was to be introduced on 1 July 2007, as announced by Prime Minister Guy Verhofstadt on 17 October 2006.

The tariffs were to be indexed to the CO₂ emissions associated with production of each packaging material. Thus, for each material the charge was to be calculated by multiplying a basic figure of 0.35 euro per kilo by the following coefficients:

- 0 for paper (0 Euro).
- 1 for glass (0.35 Euro).
- 5 for steel (1.75 Euro).
- 11 for polystyrene and PVC (3.85 Euro).
- 18 for aluminium (6.3 Euro).

The new tax would have created 300 million Euro revenue for the Belgian Treasury. However, it was subsequently decided to abandon the plans for this general packaging tax because of administrative problems.

To an extent, these data are similar to those used for the Danish packaging tax (see textbox).



Danish packaging tax tariffs		
Charges based on weight of packaging material, by (sub)material		
	DKR/kg	EUR/kg
Paper & board: virgin materials, incl. textiles	0.95	0.13
Paper & board: recycled materials	0.55	0.07
Plastics (excl. EPS & PVC): virgin materials	12.95	1.71
Plastics (excl. EPS & PVC): recycled materials	7.75	1.02
Plastics (excl. EPS & PVC): with filler	7.75	1.02
Plastics (excl. EPS & PVC): UN-approved	10.35	1.36
EPS & PVC	20.35	2.68
Aluminium	33.30	4.39
Steel	9.25	1.22
Steel packaging: UN-approved	7.40	0.98
Glass and ceramics	1.85	0.24
Wood	0.55	0.07

Source: Danish Ministry of Taxation, February 2003.

In Table 10 the *relative* tariff levels under the various tax schemes are compared.

Table 10 Relative environmental scores of packaging materials in Belgium, Denmark and the Netherlands (proposed), per kilogram and with glass set to 1

Material	Belgium	Denmark	Dutch proposal
Paper & board	0	0.3 recycling 0.5 no recycling	1.5
Glass	1	1	1
Steel	5	5	2.5
Aluminium	18	18	12.6
Plastics	7 PS & PVC	4-7 11 EPS & PVC	7.8

With respect to the Danish tax, one striking feature is that the factors used for steel and aluminium are based on LCA calculations assuming 100% virgin material, with zero recycling. In the case of paper, the Danish calculations for 100% virgin material with no recycling yield a negative result (on balance, a negative CO₂ emission); if 90% recycling is assumed, the outcome is positive to roughly the same degree. It was decided to take a factor of 0.3 for secondary and 0.5 for virgin board.

4.4 Using the calculated values

The data calculated here can be used for proportional allocation of an indexed packaging tax to the various materials. In the analysis, the packaging volumes used in the Netherlands have been considered as closed systems as far as possible. This is a simplification, because a fair amount of material switches from one supply chain to another in the recycling phase. Within this project there was no scope for performing a sensitivity analysis on this or other assumptions, however.

On the basis of the data used, nothing can therefore be said about the impact of major changes in recycling percentages or other substantial shifts in the overall situation. The CO₂ data give no more than a rough impression of the current situation. To compare two different situations - a high versus low recycling rate for paper, for example - a larger system would have to be analysed and indirect effects also factored in.

This is not an arbitrary example. The figures for paper/board (see Appendix A) show that, in contrast to all the 'abiotic' supply chains, use of secondary materials is associated with higher emissions than use of virgin raw materials. This is due to a number of factors:

- The primary paper production chain is energy efficient, with most energy inputs biomass-based.
- Raw materials extraction (i.e. harvesting) leads to CO₂ removal rather than CO₂ emissions.
- Dutch waste incinerators are highly efficient, so that incineration of paper/board (and plastics) saves a considerable amount of fossil fuels.

For the same reasons, the net lifecycle CO₂ emissions of wood (see section 3.6) are less than zero, without any recycling (though with a degree of re-use).

There are good reasons for continuing to recycle paper, nonetheless, including land use. Especially with the current demand for biomass-based fuels, land use and competition for land are major issues that impinge directly on climate policy. Although there are various methodological procedures for dealing with these matters, most of them are still hotly debated⁹. One option for policymakers would be to *not* link the tax rate for paper/board 1-to-1 to the CO₂ emissions per tonne of material calculated in this study. The Danish packaging tax, based on similar results, also has a slightly adjusted tariff for paper (see section 4.3).

In the case of wood, it is recommended to set the tax rate at zero (see section 3.6).

The category 'other packaging' comprises mainly earthenware pots. An indicative figure for the CO₂ emissions per tonne of material in this category is close to that for glass. One option would therefore be to use the same tariff as for glass. As this category may include materials with a far greater impact per kilo, however, an alternative would be to take the average of the other categories of packaging.

In this study we did not examine lids, caps and composite materials (laminates), except in the case of beverage cartons, which are very much in a category of their own. Although the calculations were for the principal packaging element (a steel can, for example), the results can in principle also be used for steel lids on other types of packaging. No separate calculations were made for laminated films like metallic plastics, on the assumption that these materials will be reported as plastics.

⁹ One could include LULUCF emissions for the use of primary resources or include 'biotic depletion': the material is unavailable for other purposes like bio-energy (cf. section 3.2).



This was also the point of departure for beverage cartons, as these have always been reported under 'Paper & board' (cf. Packaging agreement). Although separate calculations were made for these cartons (see Appendix A), in Table 8 the results have been subsumed under the same combined heading. The actual tariff for this type of packaging will be based on the relative shares of cardboard, plastics and aluminium, however, with their attendant CO₂ emissions, as calculated. This approach is perhaps debatable, because the type of cardboard used (LPB) is not the same as the other varieties (no secondary fibre, for example), the aluminium in the laminate is, by way of exception, fully consumed in incinerators, and the packaging shaping process is very different.

4.5 Recommended follow-up on underpinning of a packaging tax

In dialogue with the Dutch packaging materials industry, and in a very short space of time, an environmental ranking of packaging materials has been elaborated to provide numerical underpinning for the forthcoming Dutch packaging tax. In the assessment of CE Delft, this has yielded a reasonably robust measure on which a packaging tax for the year 2008 can be based in the short term.

Nonetheless, there are a number of issues which CE Delft recommends should be the subject of further study, so the results can be included in an more refined update for the 2009 tax year. These issues can be summarised as follows:

- Incorporation of environmental differences between different types of packaging in the use phase, in particular how to score additional prevention of product spoilage and possibly differences in energy consumption for cooling.
- Incorporation of other environmental themes besides the greenhouse effect (in particular, land use and biodiversity), to achieve a more precise ranking of materials and especially to improve coverage of the effects of paper recycling.
- Incorporation of differences between production sites (primary production and shaping) in more detail, as well as environmental differences between sites.
- Updates of a number of statistics that the industry sought to compile this summer, but was unable to do in the short space of a few weeks. Updates on certain aspects of several materials are expected towards the end of 2007.
- Further refinement of tariffs for specific submaterials (individual grades of cardboard and plastics) and incorporation of current recycling rates.

After this update in 2008 for the tax year 2009, an update every two years is recommended. This will allow improvements in material supply chains to be incorporated relatively quickly, creating a constant incentive for the industry to improve the environmental performance of the packaging chain.



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Environmental indices for for the Dutch packaging tax

Appendices

Report

Delft, November 2007

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A Data, paper & board

A.1 Basic dataset

In this appendix the datasets for the various kinds of cardboard packaging are presented (cf. section 3.2).

Table 11 Dataset, solid board (SC = short-cycle)

		Emission or consumption (1)			(2)	Product (1)*(2)		
		Production of solid board in the Netherlands	Packaging production: cutting and printing	Transport to filler and market	Characterisation factor, or contribution per unit	Production of solid board in the Netherlands	Packaging production: cutting and printing	Transport to filler and market
SC	CO ₂				1,0			
Emissions to air (per kg emission)	CO ₂				1			
	N ₂ O				296			
	CH ₄				23			
	CF ₄				5.700			
	C ₂ F ₆				11.900			
Auxiliaries + standard raw materials (kg)	Na ₂ CO ₃ (synthetic)				0,77			
	Na ₂ CO ₃ (natural)				0,10			
	NH ₃				2,08			
	NaOH (50%)				1,01			
	NaCl				0,17			
	CaO				0,94			
	CaCO ₃				0,02			
	AlF ₃				1,16			
	Al(OH) ₃				0,07			
	CaF ₂				0,10			
	Anode (alu prod)				0,98			
	Petrol coke				0,51			
	Pitch (at plant)				1,04			
	H ₂ SO ₄				0,12			
	Cathode carbon				2,41			
	Fe				0,02			
	Dolomite				0,03			
Oxygen				0,37				
Scrap								

		Emission or consumption (1)			(2)	Product (1)*(2)		
		Production of solid board in the Netherlands	Packaging production: cutting and printing	Transport to filler and market	Characterisation factor, or contribution per unit	Production of solid board in the Netherlands	Packaging production: cutting and printing	Transport to filler and market
Precombustion (GJ)	Natural gas	7,5			12,4	93,6	0,0	
	Petroleum				17,0			
	Soft coal				33,0			
	Hard coal				10,0			
Combustion + heat (GJ)	Natural gas	7,5			56,0	420,0	0,0	
	Fuel oil light				77,0			
	Fuel oil heavy				97,3			
	Soft coal				101,0			
	Hard coal				95,0			
Electricity (GJ)	mix NL	0,02	0,29		145,0	2,6	42,1	
	mix EU				119,8			
	mix EAA				94,0			
Transport (tonne/km)	Maritime				0,00028			
	Inland shipping							
	Rail				0,034			
	Road		100,0	100,0	0,078		7,8	7,8
Aggregate score (kg CO₂ eq/tonne solid board)						516,1	49,8	7,8



Table 12 Dataset, folding boxboard

		Emission or consumption (1)		(2)	Product (1)*(2)	
		Production folding boxboard and packaging	Transport to filler and market	Characterisation factor, or contribution per unit	Production folding boxboard and packaging	Transport to filler and market
SC	CO ₂	-755,8		1,0	-755,8	
Emissions to air (per kg emission)	CO ₂			1		
	N ₂ O			296		
	CH ₄			23		
	CF ₄			5.700		
	C ₂ F ₆			11.900		
Auxiliaries + standard raw materials (kg)	Na ₂ CO ₃ (synthetic)			0,77		
	Na ₂ CO ₃ (natural)			0,10		
	NH ₃			2,08		
	NaOH (50%)	5,0		1,01	5,1	
	NaCl			0,17		
	CaO			0,94		
	CaCO ₃	23,6		0,02	0,5	
	AlF ₃			1,16		
	Al(OH) ₃			0,07		
	CaF ₂			0,10		
	Anodes (alum. prod.)			0,98		
	Petrol coke			0,51		
	Pitch (at plant)			1,04		
	H ₂ SO ₄	5,0		0,12	0,6	
	Cathode carbon			2,41		
	Fe			0,02		
Dolomite			0,03			
Oxygen			0,37			
Scrap						
Precombustion (GJ)	Natural gas	4,33		12,4	53,7	
	Petroleum	0,55		17,0	9,4	
	Soft coal	0,0007		33,0	0,02	
	Hard coal	0,46		10,0	4,6	
Combustion + heat (GJ)	Natural gas	4,33		56,0	242,5	
	Fuel oil light			77,0		
	Fuel oil heavy	0,55		97,3	53,5	
	Soft coal	0,0007		101,0	0,1	
	Hard coal	0,46		95,0	43,7	
Electricity (GJ)	mix NL			145,0		
	mix EU	2,61		119,8	312,6	
	mix EAA			94,0		
Transport (tonne/km)	Maritime	281		0,00028	0,079	
	Inland shipping					
	Rail	46		0,034	1,6	
	Road	179	100	0,078	13,9	7,8
Aggregate score (kg CO₂ eq/tonne folding boxboard)					-14,1	7,8

Table 13 Dataset, corrugated board

		Emission or consumption (1)		(2)	Product (1)*(2)	
		Pulp production, board production & packaging production	Transport to filler and market	Characterisation factor, or contribution per unit	Pulp production, board production & packaging production	Transport to filler and market
SC	CO ₂	-295,7		1,0	-295,7	
Emissions to air (per kg emission)	CO ₂			1		
	N ₂ O			296		
	CH ₄			23		
	CF ₄			5.700		
	C ₂ F ₆			11.900		
Auxiliaries + standard raw materials (kg)	Na ₂ CO ₃ (synthetic)	0,4		0,77	0,3	
	Na ₂ CO ₃ (natural)			0,10		
	NH ₃	0,8		2,08	1,7	
	NaOH (50%)	4,1		1,01	4,1	
	NaCl			0,17		
	CaO	0,625		0,94	0,6	
	CaCO ₃			0,02	0,0	
	AlF ₃			1,16		
	Al(OH) ₃			0,07		
	CaF ₂			0,10		
	Anodes (alum. prod.)			0,98		
	Petrol coke			0,51		
	Pitch (at plant)			1,04		
	H ₂ SO ₄	2,7		0,12	0,3	
	Cathode carbon			2,41		
	Fe			0,02		
	Dolomite			0,03		
Oxygen			0,37			
Scrap	0,3			0,0		
Precombustion (GJ)	Natural gas	6,5		12,4	80,6	
	Petroleum	0,63		17,0	10,7	
	Soft coal	0,28		33,0		
	Hard coal	0,49		10,0	4,9	
Combustion + heat (GJ)	Natural gas	6,3		56,0	352,8	
	Fuel oil light			77,0		
	Fuel oil heavy	0,63		97,3	61,3	
	Soft coal	0,28		101,0	28,3	
	Hard coal	0,49		95,0	46,6	
Electricity (GJ)	mix NL			145,0		
	mix EU	0,76		119,8	91,0	
	mix EAA			94,0		
Transport (tonne/km)	Maritime	142		0,00028	0,0	
	Inland shipping					
	Rail	68		0,034	2,3	
	Road	381	100	0,078	29,6	7,8
Aggregate score (kg CO₂ eq/tonne corrugated board)					419,4	7,8



	Petrol coke									0,51									
	Pitch (at plant)									1,04									
	H ₂ SO ₄	8,0								0,12	1,0								
	Cathode carbon									2,41									
	Fe									0,02									
	Dolomite									0,03									
	Oxygen	5,0								0,37	1,9								
	Scrap																		
Precombustion (GJ)	Natural gas						-1,2	-2,3	-3,0	12,4							-15,3	-28,3	-37,5
	Petroleum									17,0									
	Soft coal									33,0									
	Hard coal									10,0									
Combustion + heat (GJ)	Natural gas	1,3		0,1	0,6		-1,2	-2,3	-3,0	56,0	72,9		3,3	31,8			-69,3	-127,9	-169,6
	Fuel oil light	0,7								77,0	57,6								
	Fuel oil heavy	1,4								97,3	140,1								
	Soft coal									101,0									
	Hard coal									95,0									
Electricity (GJ)	mix NL						-3,7	-9,0	-6,8	145,0							-535,9	-1311,1	-988,9
	mix EU	5,2		0,0	1,0					119,8	624,0		5,6	124,6					
	mix EAA									94,0									
Transport (tonne/km)	Maritime	2000								0,00028	0,6								
	Inland shipping																		
	Rail									0,034									
	Road	100					50,0	40,0	40,0	40,0	0,078	7,8				3,9	3,1	3,1	3,1
Aggregate score (kg CO₂ eq/tonne beverage cartons)											-694,4	2105,3	10224,3	8,9	156,4	3,9	1032,8	1678,6	-1192,9

A.2 Paper and board : incinerator/cement kiln and sulphate pulp

The data cited in this paragraph do not apply to beverage cartons,

Rejects

For secondary fuel production from rejects, 2.56 GJ natural gas consumption and 0.45 GJ_e power production per tonne rejects was assumed. These data are from an engineering study for a pelleting plant by DSM Research and are based on a moisture content of 45%, the figure cited in (FEFCO).

The CO₂ emissions assumed for co-firing of this secondary fuel were calculated on the basis of the Environmental Impact Assessment for the National Waste Management Plan (MERLAP, 2002), in particular the relevant Appendix (see background documents 2003-A01 and 2003-A28). The calculations were based on the chemical composition given in Table 15, which was also used in (MERLAP, 2002).

Table 15 Assumed chemical composition of waste paper

Component	Percentage
- ash	6.6%
- C	44.8%
- H	6.2%
- O	41.7%
- N	0.3%
- S	0.2%
- Cl	0.3%

In the CO₂ emissions of co-firing the rejects, due allowance was made for savings on coal use: with 1 tonne of rejects (dried) about 1 tonne of coal can be saved. The net impacts are given in Table 17.

Incineration

The CO₂ emissions assumed for incinerator combustion were calculated according to the methodology used in the National Waste Management Plan EIA. Background document A2 explains how to calculate a mass balance for an incinerator from the chemical composition of the waste as well as the inputs of auxiliaries for flue-gas treatment and the resultant quantities of residues, such as flue-gas treatment residues and fly ash. The net impacts are shown in Table 17.

Sulphate pulp to balance secondary fibre surplus/shortfall

In 2005 the total volume of secondary fibre used in the packaging consumed in the Netherlands was greater than the volume yielded by domestic recycling. This meant that secondary fibre from other production chains was used: 10.6 kt in all, as shown in Table 16. As a result, extra primary fibre had to be used elsewhere.

Table 16 Mass balance for consumption of 1,465 kt cardboard packaging based on percentage recycled content of individual materials

	Input	Output	Surplus
Primary	405		
Secondary, cutting losses	0.0	127.4	127.4
Secondary, packaging rejects	1,187	1,049	-138.0
AVI, rejects		416	
	1,592.4	1,592.4	-10.6

Environmental data for the production of commodity pulp were derived from the annual environmental report of the Finnish paper industry (FFIF), which gives the emissions to water and air of a number of individual pulp/paper mills. The data are for a mixture of bleached and unbleached pulp and for softwood as well as hardwood pulp. The data are for the following pulp/paper mills:

- the Oy Metsä-Botnia AB plants at Joutseno, Kaskinen and Kemi;
- the Sora Enso OYJ plants at Enocell and Kemijärvi;
- the Sunila Oy plant.

Table 17 gives the full dataset for use of waste paper/board as a secondary fuel in incinerators and cement kilns as well as for sulphate pulp production.



Table 17 Use of waste paper/board as an energy source and production of sulphate commodity pulp, for 1 tonne input

		Emission or consumption (1)				(2)	Product (1) * (2)			
		To incineration	Production subcoal	Production commodity pulp (chemical pulp, sulphate pulp)	Displaced use hard coal as result of subcoal in cement kilns	b) Characterisation factor or contribution per unit	To incineration	Production subcoal	Production commodity pulp (chemical pulp, sulphate pulp)	Displaced use hard coal as result of subcoal in cement kilns
SC	CO ₂	1643,0			1643,0	1,0	1643,0		-1643,0	1643,0
Emissions to air (per kg emission)	CO ₂			210,5		1			210,5	
	N ₂ O					296				
	CH ₄					23				
	CF ₄					5.700				
	C ₂ F ₆					11.900				
Auxiliaries + standard raw materials (kg)	Na ₂ CO ₃ (synthetic)					0,77				
	Na ₂ CO ₃ (natural)					0,10				
	NH ₃	2,0				2,08	4,2			
	NaOH (50%)	1,8				1,01	1,8			
	NaCl					0,17				
	CaO	1,4				0,94	1,4			
	CaCO ₃					0,02				
	AlF ₃					1,16				
	Al(OH) ₃					0,07				
	CaF ₂					0,10				
	Anodes (alum. prod.)					0,98				
	Petrol coke					0,51				
	Pitch (at plant)					1,04				

	H ₂ SO ₄					0,12				
	Cathode carbon					2,41				
	Fe					0,02				
	Dolomite					0,03				
	Oxygen					0,37				
	Scrap									
Precombustion (GJ)	Natural gas	-1,2	2,6			12,4	-15,4	31,7		
	Petroleum					17,0				
	Soft coal					33,0				
	Hard coal				-16,8	10,0				-168,0
Combustion + heat (GJ)	Natural gas	-1,2	2,6			56,0	-69,4	143,6		
	Fuel oil light					77,0				
	Fuel oil heavy					97,3				
	Soft coal					101,0				
	Hard coal				-16,8	95,0				-1596,0
Electricity (GJ)	mix NL	-3,7	0,4			145,0	-536,5	65,1		
	mix EU					119,8				
	mix EAA					94,0				
Transport (tonne/km)	Maritime					0,00028				
	Inland shipping					0,034				
	Rail			100,0		0,034			3,4	
	Road	40,0	150,0	100,0	150,0	0,078	3,1	11,7	7,8	11,7
Aggregate score (kg CO₂ eq/tonne paper/cartons)							1032,2	252,0	-1421,3	-109,3

For the incineration of beverage cartons separate data were used (Figure 7).

Figure 7 Calculation basis for displaced emissions due to beverage carton incineration

Combined Cycle Gas Turbine efficiency	95%
Incinerator, electrical efficiency	22%
Incinerator, thermal efficiency	7%
CO ₂ emission, Dutch generating mix (g/MJ)	145
CO ₂ emission, gas boiler (g/MJ)	66.8

	Calorific value (MJ/kg)	Electricity production (GJ)	Heat production (GJ)	Natural gas consumption (GJ)	Avoided CO ₂ emissions (g.kg)
LPB	16.8	3.70	1.18	1.24	614
Alum.	41.1	9.04	2.88	3.03	1,503
PE	31	6.82	2.17	2.28	1,134

A.3 Final score for paper/board

The aggregate scores for each of the submaterials and the final score for paper/board as a whole are shown in Table 18.

Table 18 Aggregate scores for cardboard

Solid board, aggregate score (kg CO ₂ eq./t)	908.5
percentage mass	13%
Folding boxboard, aggregate score (kg CO ₂ eq./t)	282.1
percentage mass	22%
Corrugated board, aggregate score (kg CO ₂ eq./t)	750.3
percentage mass	61%
Beverage cartons, aggregate score (kg CO ₂ eq./t)	1,182.8
percentage mass	4.4%
Total paper/board (kg CO₂-eq./t solid, corrugated, folding boxboard)	635
Corrected for commodity pulp production	624
Total paper/board, final score (kg CO₂-eq./t)	676



B Data, glass

B.1 Basic dataset

In this appendix the datasets for glass packaging are presented (cf. section 3.3)

.

Table 19 Dataset, glass

		Emission or consumption (1)					(2)	Product (1) * (2)				
		Primary raw materials	Secondary materials	Transport to filler and market	Treatment for recycling	To incinerator, associated displaced emission	b) Characterisation factor or contribution per unit	Primary raw materials	Secondary materials	Transport to filler and market	Treatment for recycling	To incinerator, associated displaced emission
Emissions to air (per kg emission)	CO ₂	83					1	83				
	N ₂ O						296					
	CH ₄						23					
	CF ₄						5.700					
	C ₂ F ₆						11.900					
Auxiliaries + standard raw materials (kg)	Na ₂ CO ₃ (synthetic)	155,3					0,77	119,1				
	Na ₂ CO ₃ (natural)	51,8					0,10	5,0				
	NH ₃						2,08					
	NaOH (50%)						1,01					
	NaCl						0,17					
	CaO						0,94					
	CaCO ₃	155,0					0,02	3,6				
	AlF ₃						1,16					
	Al(OH) ₃						0,07					
	CaF ₂						0,10					
	Anodes (alum. prod.)						0,98					
	Petrol coke						0,51					
	Pitch (at plant)						1,04					
	H ₂ SO ₄						0,12					
	Cathode carbon						2,41					
	Fe						0,02					
Dolomite						0,03						

	Oxygen						0,37					
	Scrap											
Precombustion (GJ)	Natural gas	5,3	3,9				12,4	65,5	48,6			
	Petroleum						17					
	Soft coal						33					
	Hard coal						10					
Combustion + heat (GJ)	Natural gas	5,3	3,9				56	297	218			
	Fuel oil light				0,33		77				25	
	Fuel oil heavy						97					
	Soft coal						101					
	Hard coal						95					
Electricity (GJ)	mix NL	0,48	0,48		0,01		145	70	70		1	
	mix EU						120					
	mix EAA						94					
Transport (tonne/km)	Maritime	466					0,00028	0,13				
	Inland shipping						0,034					
	Rail						0,034					
	Road	150	75	50	75	40	0,078	12	6	4	6	3
Aggregate score (kg CO₂ eq/tonne glass)								Road	342	4	33	3

B.2 Final score for glass

The recycling percentage is 78%, the recycled content 59%. The surplus leads to savings on the difference between the use of primary and secondary material. This gives a final score for glass of 443 kg CO₂/tonne.



C Data, metals

C.1 Basic data

In this appendix the datasets for metal packaging are presented (cf. section 3.4), distinguishing between steel and aluminium (sections 3.4.1 and 3.4.2, respectively).

	Fe									0,03									
	Dolomite									0,37									
	Oxygen																		
Precombustion (GJ)	Scrap	2,4		3,9		3,6			4,0	12,40	29,2		48,6		44,6				50,0
	Natural gas	20,3		1,5		0,1			0,0	17,00	344,9		25,6		2,2				0,2
	Petroleum								0,07	33,00									2,2
	Soft coal	0,02		0,13						10,00	0,2		1,3						
Combustion + heat (GJ)	Hard coal	2,4		3,9		3,6			4,0	56,00	131,9		219,5		201,6				225,8
	Natural gas	20,3		1,5		0,1			0,01	77,00	1562,1		116,2		10,0				0,9
	Fuel oil light								0,07	97,32									6,5
	Fuel oil heavy									101,00									
	Soft coal	0,02		0,13						95,00	2,2		11,9						
Electricity (GJ)	Hard coal							0,03		145									4,70
	mix NL						0,5 1			120					61,1				
	mix EU			54,6						94			5135,0						
	mix EAA	2,2		0,4		2,0			0,64	120	262,4		42,5		242,6				77,3
Transport (tonne/km)	Maritime		7191		3782					0,00028		2,0		1,1					
	Inland shipping		2		206					0,034		0,1		7,1					
	Rail		11		43					0,034		0,4		1,4					
	Road		338		15		150	50	40	150	0,078		26,3		1,2		11,7	3,9	3,1
Aggregate score (kg CO₂ eq/tonne aluminum)											2668,3	28,7	7516,4	10,8	501,0	72,7	3,9	7,8	374,6

Table 21 Dataset, steel

		Prod. tinned coil	Can production	Transport to filler and market	Incineration, reprocessing slag	Processing for recycling oxygen steel	Avoided primary prod.	Characterisation factor or contribution per unit	Prod. tinned coil	Can production	Transport to filler and market	Incineration, reprocessing slag	Processing for recycling oxygen steel	Avoided primary prod.
Emissions to air (per kg emission)	CO ₂						-2940	1						-2940
	CO ₂	0,11						296	32,56					
	N ₂ O	1,23						23	28,29					
	CH ₄							5.700						
	CF ₄							11.900						
Auxiliaries + standard raw materials (kg)	C ₂ F ₆							0,77						
	Na ₂ CO ₃ (synthetic)							0,10						
	Na ₂ CO ₃ (natural)							2,08						
	NH ₃							1,01						
	NaOH (50%)							0,17						
	NaCl							0,94						
	CaO	106						0,02	2,44					
	CaCO ₃							1,16						
	AlF ₃							0,07						
	Al(OH) ₃							0,10						
	CaF ₂							0,98						
	Anodes (alum. prod.)							0,51						
	Petrol coke							1,04						
	Pitch (at plant)							0,12						
	H ₂ SO ₄							2,41						
	Cathode carbon	1897						0,02	32,25					
	Fe	12						0,03	0,32					
Dolomite							0,37							

	Oxygen	2,02													
Precombustion (GJ)	Scrap	4,83	1,93					12,40	59,9	23,9					
	Natural gas	1,23						17,00	20,9						
	Petroleum							33,00							
	Soft coal	22,84						10,00	228,42						
Combustion + heat (GJ)	Hard coal	4,83	1,93					56,00	270,41	108,1					
	Natural gas	1,23						77,00	94,57						
	Fuel oil light							97,32							
	Fuel oil heavy							101,00							
	Soft coal	22,84						95,00	2169,99						
Electricity (GJ)	Hard coal				0,0023	0,003		145				0,33	0,40		
	mix NL		0,29					120		34,7					
	mix EU							94							
	mix EAA							120							
Transport (tonne/km)	Maritime							0,00028							
	Inland shipping							0,034							
	Rail							0,034							
	Road			50	40	150		0,078			3,89	3,89	3,11		
Aggregate score (kg CO₂ eq/tonne steel)									2940	167	4	4	4	-2940	

C.2 Waste metals collection and recovery

A certain amount of metal packaging is separately collected (36% steel, 30% aluminium). Some is additionally recovered before or after incineration/power generation. Under the Packaging Agreement, respective percentages of 82% and 30% were assumed for recovery at this stage. For the aggregate figures reported in the Dutch Packaging Commission's latest report (CV III), this gives the values shown in Table 22.

Table 22 Recovery/recycling of metals according to CV III (2005)

	Sales volume (kt)	Recovery (kt)			
		Incinerator	Separate coll.	Total	Recycling %
Steel	187	98	68	166	88.6%
Aluminium	23.8	4.9	7.2	12.1	50.8%
Total metals	211	103	75	178	84.3%

Recovery of steel (ferrous fraction) from incinerator bottom ash is carried out at slag reprocessing plants using magnetic separators. The non-ferrous fraction (incl. aluminium) is salvaged using eddy-current separators (ECS). Most slag reprocessing plants have two ECS, which means the smallest fragments are not recovered. Two Dutch plants (Twence, Feniks Alkmaar) have three such units, however, and here the aluminium recovery percentage is higher. According to (TNO, 2006) the Twence plant achieves a 48% recovery rate¹⁰. We have assumed the same figure holds for Alkmaar, too, and that each plant processes 18% of total Dutch incinerator residues.

This yields a figure for aluminium recovery about 10% higher than that in the CV III report. Compared with the overall volumes of metals, though, the difference is minimal (Table 23).

Table 23 Recovery/recycling of metals with higher incinerator recovery rate for aluminium

	Sales volume (kt)	Recovery (kt)			
		Incinerator	Separate coll.	Total	Recycling %
Steel	187	98	68	166	88.6%
Aluminium	23.8	5.4	7.2	12.6	53.1%
Total metals	211	103	75	178	84.6%

¹⁰ This is pure aluminium, implying no extra losses during resmelting ('dross'). There may still possibly be losses during separation of the various metals from the non-ferrous fraction (pers. comm. Peter Rem, TU Delft) but there are no data on this issue. Here we have assumed 0% further losses.



We have taken the higher percentages as the best estimate.

Only part of the energy consumption at slag reprocessing plants can be allocated to metals recovery: besides the magnetic separators and ECS with their vibrating screens, there are also jaw crushers, shakers and conveyor belts. After suitable treatment, the bottom ash can be used in road building and other applications, although if the metals are not (largely) removed it must be landfilled. There are therefore economic motives for improving the quality of this ash and, equally, motives for recovering the metals, especially given today's high market prices. Reprocessing is thus driven by both factors, as stated in the BREF document on waste incineration.

According to the ISO standards for LCA, allocation should preferably be based on physical considerations. In this case the obvious choice would be to allocate the energy use of the magnetic separators to the ferrous fraction and that for the ECS to the non-ferrous fraction. In the case of the energy deployed in crushing and shaking - the lion's share - things are rather less clear, but we decided that this energy was best allocated to the reprocessed slag.

Table 24 Data for Feniks Alkmaar slag reprocessing plant (pers. comm. Feniks; average values)

	Weight	Share	Energy use	
Total waste input	680 kt			
Bottom ash input	150 kt		750 MWh (total)	
Ferrous output	18.8 kt	12.5%	2 x 6 = 12 MWh	
Non-ferrous output	2.6 kt	1.75%	3 x 10 = 30 MWh	65% aluminium in this fraction (TNO, 2006)
Bottom ash output	129 kt	86%	708 MWh	

For steel, this gives a figure of 0.64 kWh/t energy use for reprocessing. For aluminium, an allocation step is required because the non-ferrous fraction also contains other high-value metals. In particular, the energy consumption of the ECS (30 MWh for 2.6 kt in total) must be allocated; we did so on the basis of economic allocation (Table 25). This yields a figure of 9 kWh/t for the energy use of aluminium recovery.

Table 25 Allocation of ECS to aluminium

	kt	Euro/t	kWh/t
Non-ferrous fraction	2.6		11
<i>Aluminium</i>	1.7	1,460	9
<i>Other</i>	0.9	2,900	16

C.3 Final scores for metals

Table 26 Final score for steel

Substitution ratio	100%
Losses in reprocessing and re-use	1%
Aggregate score (kg CO ₂ -eq./t steel)	3,115.9
Displaced primary production (88.6% recycling)	2,021.1
Steel, final score (kg CO₂-eq./t)	1,095

Table 27 Final score for aluminium

Substitution ratio	100%
Losses in reprocessing and re-use	1.5%
Aggregate score (kg CO ₂ -eq./t aluminium)	11,005.0
Displaced primary production (53.1% recycling)	5,352.5
Aluminium, final score (kg CO₂-eq./t)	5,653



D Data, plastics

D.1 Basic data

In this Appendix the datasets for plastic packaging materials are presented, distinguishing between LPDE, HPDE, PP, PET and EPS (cf. section 3.5).

Table 28 Dataset, LPDE

		Emission or consumption (1)						(2)	Product (1) * (2)							
		1 tonne LDPE resin	1 tonne LDPE film from resin	Transport to filler and market	Processing for recycling	Incineration	Processing of PPF to 'subcoal'	Combustion of 'subcoal' in cement kiln	b) Characterisation factor or contribution per unit	1 tonne LDPE resin	1 tonne LDPE film from resin	Transport to filler and market	Processing for recycling	Incineration	Processing of PPF to 'subcoal'	Combustion of 'subcoal' in cement kiln
Emissions to air (per kg emission)	CO ₂	140,0				2977,0	-1338,5	1	140,0				2977,0		-1338,5	
	CO ₂							296								
	N ₂ O	3,6	1,4					23	82,8	32,2						
	CH ₄							5.700								
	CF ₄							11.900								
Auxiliaries + standard raw materials (kg)	C ₂ F ₆							0,77								
	Na ₂ CO ₃ (synthetic)							0,10								
	Na ₂ CO ₃ (natural)							2,08								
	NH ₃							1,01								
	NaOH (50%)							0,17								
	NaCl							0,94								
	CaO							0,02								
	CaCO ₃							1,16								
	AlF ₃							0,07								
	Al(OH) ₃							0,10								
	CaF ₂							0,98								
	Anodes (alum. prod.)							0,51								
	Petrol coke							1,04								
	Pitch (at plant)							0,12								
	H ₂ SO ₄							2,41								

	Cathode carbon								0,02							
	Fe								0,03							
	Dolomite								0,37							
	Oxygen															
Precombustion (GJ)	Scrap	5,67	0,22			-3,03	0,68		12,4	70,3	2,7			-37,5	8,4	
	Natural gas	7,03	0,82						17,0	119,5	13,9					
	Petroleum								33,0							
	Soft coal								10,0							
Combustion + heat (GJ)	Hard coal	5,67	0,22			-3,03	0,68		56,0	317,5	12,3			-169,6	38,1	
	Natural gas	7,03	0,82						77,0	541,3	63,1					
	Fuel oil light								97,3							
	Fuel oil heavy								101,0							
	Soft coal								95,0							
Electricity (GJ)	Hard coal					-9,0	0,35		145,0					-1311,1	50,8	
	mix NL	3,94	1,92		2,86				119,8	471,8	229,9		342,5			
	mix EU								94,0							
Transport (tonne/km)	mix EAA								0,00028							
	Maritime								0,034							
	Inland shipping								0,034							
	Rail		100	100	75	40	150	150	0,078		7,8	7,8	5,8	3,1	11,7	11,7
(Aggregate score (kg CO₂ eq/tonne LDPE))										Road	362,0	7,8	348,3	1461,9	108,9	-1326,8

Table 29 Dataset, HPDE

		Emission or consumption (1)						(2)	Product (1) * (2)							
		1 tonne HPDE resin	1 tonne HPDE to bottle resin	Transport to filler and market	Processing for recycling	Incinerator	Processing of PPF to 'subcoal'	Combustion of 'subcoal' in cement kiln	b) Characterisation factor or contribution per unit	1 tonne HPDE resin	1 tonne HPDE to bottle resin	Transport to filler and market	Processing for recycling	Incinerator	Processing of PPF to 'subcoal'	Combustion of 'subcoal' in cement kiln
Emissions to air (per kg emission)	CO ₂	190,0				3049,0		-1371,5	1	190,0				3049,0		-1371,5
	CO ₂								296							
	N ₂ O	4,1	0,2						23	94,3	4,6					
	CH ₄								5.700							
	CF ₄								11.900							
Auxiliaries + standard raw materials (kg)	C ₂ F ₆								0,77							
	Na ₂ CO ₃ (synthetic)								0,10							
	Na ₂ CO ₃ (natural)								2,08							
	NH ₃								1,01							
	NaOH (50%)								0,17							
	NaCl								0,94							
	CaO								0,02							
	CaCO ₃								1,16							
	AlF ₃								0,07							
	Al(OH) ₃								0,10							
	CaF ₂								0,98							
	Anodes (alum. prod.)								0,51							
	Petrol coke								1,04							
	Pitch (at plant)								0,12							
H ₂ SO ₄								2,41								

	Cathode carbon								0,02							
	Fe								0,03							
	Dolomite								0,37							
	Oxygen															
Precombustion (GJ)	Scrap	5,39	0,18				-3,10	0,68		12,4	66,8	2,2			-38,5	8,4
	Natural gas	7,39	0,62							17,0	125,6	10,5				
	Petroleum									33,0						
	Soft coal									10,0						
Combustion + heat (GJ)	Hard coal	5,39	0,18				-3,10	0,68		56,0	301,8	10,1			-173,7	38,1
	Natural gas	7,39	0,62							77,0	569,0	47,7				
	Fuel oil light									97,3						
	Fuel oil heavy									101,0						
Electricity (GJ)	Hard coal						-9,3	0,35		145,0					-1343,0	50,8
	mix NL	2,45	6,73			2,16				119,8	293,4	805,9		258,7		
	mix EU									94,0						
Transport (tonne/km)	mix EAA									0,00028						
	Maritime															
	Inland shipping									0,034						
	Rail		100	100	75	40	150	150		0,078		7,8	7,8	5,8	3,1	11,7
(Aggregate score (kg CO₂ eq/tonne HDPE))										1641,0	888,9	7,8	264,5	1496,9	108,9	-1359,8

Table 30 Dataset, PP

		Emission or consumption (1)							(2)	Product (1) * (2)							
		1 tonne PP resin	1 tonne injection-moulded PP	Transport to filler and market	Processing for recycling	Incinerator	Processing of PPF to 'subcoal'	Combustion of 'subcoal' in cement kiln	b) Characterisation factor or contribution per unit	1 tonne PP resin	1 tonne injection-moulded PP	Transport to filler and market	Processing for recycling	Incinerator	Processing of PPF to 'subcoal'	Combustion of 'subcoal' in cement kiln	
Emissions to air (per kg emission)	CO ₂	400,0	10,0			2977,0		-1338,5	1	400,0	10,0			2977,0		-1338,5	
	CO ₂								296								
	N ₂ O	3,3	0,6						23	75,9	13,8						
	CH ₄								5.700								
	CF ₄								11.900								
Auxiliaries + standard raw materials (kg)	C ₂ F ₆								0,77								
	Na ₂ CO ₃ (synthetic)								0,10								
	Na ₂ CO ₃ (natural)								2,08								
	NH ₃								1,01								
	NaOH (50%)								0,17								
	NaCl								0,94								
	CaO								0,02								
	CaCO ₃								1,16								
	AlF ₃								0,07								
	Al(OH) ₃								0,10								
	CaF ₂								0,98								
	Anodes (alum. prod.)								0,51								
	Petrol coke								1,04								
	Pitch (at plant)								0,12								
	H ₂ SO ₄								2,41								
Cathode carbon								0,02									
Fe								0,03									
Dolomite								0,37									

	Oxygen																
Precombusti on (GJ)	Scrap	4,37	12,80			-3,03	0,68		12,4	54,2	158,7				-37,5	8,4	
	Natural gas	8,51	1,60						17,0	144,7	27,2						
	Petroleum								33,0								
	Soft coal								10,0								
Combustion + heat (GJ)	Hard coal	4,37	12,80			-3,03	0,68		56,0	244,7	716,8				-169,6	38,1	
	Natural gas	8,51	1,60						77,0	655,3	123,2						
	Fuel oil light								97,3								
	Fuel oil heavy								101,0								
	Soft coal								95,0								
Electricit y (GJ)	Hard coal					-9,0	0,35		145,0						-1311,1	50,8	
	mix NL	1,85	7,64		2,16				119,8	221,5	914,9		258,7				
	mix EU								94,0								
Transport (tonne/km)	mix EAA								0,00028								
	Maritime																
	Inland shipping Rail								0,034								
			100	100	75	40	150	150	0,078		7,8	7,8	5,8	3,1	11,7	11,7	
(Aggregate score (kg CO₂ eq/tonne PP)										1796,3	1972,4	7,8	264,5	1461,9	108,9	-1326,8	

	Dolomite									0,37								
	Oxygen																	
Precombustion (GJ)	Scrap	13,94	0				-1,61	0,68		12,4	172,8	0,0					-20,0	8,4
	Natural gas	9,64	0							17,0	163,9	0,0						
	Petroleum									33,0								
	Soft coal									10,0								
	Hard coal	13,94	0				-1,61	0,68		56,0	780,6	0,0					-90,4	38,1
Combustion + heat (GJ)	Natural gas	9,64	0							77,0	742,3	0,0						
	Fuel oil light									97,3								
	Fuel oil heavy									101,0								
	Soft coal									95,0								
	Hard coal						-4,8	0,35		145,0							-698,6	50,8
Electricity (GJ)	mix NL	5,23	6,52		2,16	2,97				119,8	626,3	780,8		258,7	355,7			
	mix EU									94,0								
	mix EAA									0,00028								
Transport (tonne/km)	Maritime																	
	Inland shipping									0,034								
	Rail		100	100	75	75	40	150	150	0,078		7,8	7,8	5,8	5,8	3,1	11,7	11,7
	(Aggregate score (kg CO₂ eq/tonne PET))											2683,4	788,6	7,8	264,5	361,5	1382,1	108,9

Precombustion (GJ)	Oxygen															
	Scrap	18,48	2,00			-2,92	0,68		12,4	229,1	24,8			-36,2	8,4	
	Natural gas	15,61	1,41						17,0	265,4	24,0					
	Petroleum								33,0							
	Soft coal								10,0							
Combustion + heat (GJ)	Hard coal	18,48	2,00			-2,92	0,68		56,0	1034,9	112,0			-163,4	38,1	
	Natural gas	15,61	1,41						77,0	1202,0	108,6					
	Fuel oil light								97,3							
	Fuel oil heavy								101,0							
	Soft coal								95,0							
Electricity (GJ)	Hard coal					-8,7	0,35		145,0					-1263,2	50,8	
	mix NL	1,74	4,32		1,10				119,8	208,4	517,3		131,7			
	mix EU								94,0							
Transport (tonne/km)	mix EAA								0,00028							
	Maritime															
	Inland shipping								0,034							
	Rail		100	100	75	40	150	150	0,078		7,8	7,8	5,8	3,1	11,7	12
(Aggregate score (kg CO₂ eq/tonne EPS))										3182,6	811,3	7,8	137,6	1734,3	108,9	-952,3

D.2 Plastics: incineration and recycling

The environmental burden associated with incineration was calculated from the carbon content of the plastic and its calorific value. The CO₂ emission factors used for the various plastics are given in Table 33.

Table 33 Emission factors for plastics incineration

Material	kg CO ₂ /t
LDPE, PP	2,977
HDPE	3,049
PS	3,194
PET	2,188

Source: In-house calculation by CE Delft.

Figure 8 reports the figures used for displaced emissions.

Figure 8 Calculation basis for displaced emissions due to plastics incineration

Combined Cycle Gas Turbine efficiency	95%
Incinerator, electrical efficiency	22%
Incinerator, thermal efficiency	7%
CO ₂ emission, Dutch generating mix (g/MJ)	145
CO ₂ emission, gas boiler (g/MJ)	66.8

	Calorific value (MJ/kg)	Electricity production (GJ)	Heat production (GJ)	Natural gas consumption (GJ)	Avoided CO ₂ emissions (g.kg)
LDPE	41.1	9.04	2.88	3.03	1,503
HDPE	42.1	9.26	2.95	3.10	1,540
PP	41.1	9.04	2.88	3.03	1,503
PET	21.9	4.82	1.53	1.61	801
(E)PS	39.6	8.71	2.77	2.92	1,448

The processing of plastics waste as an integral part of PPF comprises the following steps:

- Transport of raw waste to processing facility.
- Production of PPF (drying, pelletization to 'subcoal').
- Transport of pellets to combustor.
- Combustion of pellets in cement kiln or coal-fired power station.
- Displacement of coal production and use in the same cement kiln or power station.

The climate impact of transportation and the environmental burden/credits associated with use of PPF pellets and displaced coal were calculated using the methodology described in (MERLAP, 2002). For the transport distance we took 100 km, as assumed there. By using this relatively high figure, we effectively accounted for the fact that there are only a limited number of PPF producers in the Netherlands and, especially, very few buyers.



Emissions to air and displaced emissions due to coal substitution were calculated using the same mass balances for cement kilns as in (MERLAP, 2002). Coal was assumed to be displaced 1-to-1 based on calorific value.

Only in the case of PPF pellet production was a different source used to calculate the associated environmental burden. For the processing of plastics to secondary fuel by this route we took figures of 0.35 GJ_e and 0.68 GJ_{gas} per tonne, as reported in a DSM engineering study for a pelletization plant for residual household waste.

Figure 9 Calculation basis for displaced emissions due to co-incineration of 'subcoal'

Calorific value of coal (MJ/kg)		28.2	
kg CO ₂ /t coal		2,961	

	Calorific value (MJ/kg)	kg coal/kg plastic	kg CO ₂ /t plastic
LDPE	41.1	1.46	4,315.5
HDPE	42.1	1.49	4,420.5
PP	41.1	1.46	4,315.5
PET	21.9	0.78	2,299.5
(E)PS	39.6	1.40	4,158.0

The net emissions from incinerator combustion or co-incineration in a cement kiln are shown for each of the submaterials in Appendix D.1.

Recycling

For all products except for EPS foam it was assumed that recycling consists of four steps: grinding, washing, drying and regranulation. The associated electricity consumption data were taken from (Eggels, 2001). According to this source, reprocessing of plastics film requires 2.86 GJ_e on average and recycling of rigids 2.16 GJ_e, in both cases per ton of recyclate. No allowance was made for any plastics losses occurring during recycling (e.g. screening residues during regranulation).

In the case of EPS a different approach was adopted. According to the Dutch Association for Environmental Management of Plastics Packaging, VMK, roughly half of all separately collected EPS foam is ground up and re-used in foam applications. As the grinding process generally requires little energy (see, for example, Michaeli, 1993) we ignored the energy consumption of this recycling route. The other half is regranulated. To keep calculations on EPS foam recycling to manageable proportions, we used a single figure for electricity consumption, the average of the two routes. As one route has virtually zero energy inputs and the other 2.16 GJ_e/t regranulate and roughly the same amounts are processed by each (VMK, 2004) we took the average value of 50% x 2.16 ≈ 1.1 GJ_e/ton.

D.3 Final score for plastics

Using the total market volumes of the five submaterials distinguished, the data were aggregated to a single figure for plastics.

Table 34 Aggregate score for plastics

LDPE	Substitution ratio	62%
	Displaced virgin production	488.6
	Aggregate score (kg CO ₂ -eq./t LPDE)	2,341.4
	Percentage mass	23%
HDPE	Substitution ratio	100%
	Displaced virgin production	451.2
	Aggregate score (kg CO ₂ -eq./t HPDE)	3,478.4
	Percentage mass	23%
PP	Substitution ratio	100%
	Displaced virgin production	218.9
	Aggregate score (kg CO ₂ -eq./t PP)	4,621.8
	Percentage mass	21%
PET	Substitution ratio to fleece	50%
	Substitution ratio to bottle	100%
	Displaced virgin production	434.0
	Aggregate score (kg CO ₂ -eq./t PET)	3,871.9
	Percentage mass	6%
(E)PS	Substitution ratio	100%
	Displaced virgin production	375.3
	Aggregate score (kg CO ₂ -eq./t (E)PS)	4,895.0
	Percentage mass	11%
Total plastics, final score (kg CO₂-eq./t)		3,454



E Synopsis of input from industry and CE Delft response

E.1 Introduction

In the short period permitted by this project, the packaging industry had three weeks to respond to the draft methodology and basic datasets presented on 16 July. Both written and oral input could be submitted to CE Delft. The following organisations were sent a written notice to this effect by the Environment ministry, VROM:

- VNO-NCW¹¹ (general).
- SKB (cans, steel & aluminium).
- Dutch Aluminium Centre.
- VMK (plastics).
- SKG (glass).
- PRN (paper & board).
- Nedvang (general packaging).

This opportunity was taken up by a range of parties, identified below. In each case a brief synopsis of their input is accompanied by the response of CE Delft and a statement as to whether the input led to changes to the originally proposed data.

E.2 Paper/board

On 1 August 2007 there were talks with:

- Ms A.S.H. de Beaufort, independent consultant.
- Mr B. Van Konijnenburg, Koninklijke VNP.
- Mr G. van Oosterum, PRN.

As a follow-up, a (corrected) written response was received from Mr Van Konijnenburg on 6 August.

New data were forthcoming:

- *Shares of the 4 submaterials in the sum total: adopted (see Appendix A).*
- *Solid board: energy use of packaging production should be electricity only; data on two producers cited as 0.24 and 0.29 GJ_e/t. Higher value adopted.*
- *Folding boxboard: new ProCarton database (www.procarton.com) recently up and running, though not yet public. These data adopted.*
- *Corrugated board: updated FEFCO data adopted.*
- *Beverage cartons: aggregated CO₂ data provided. Not adopted, for lack of transparency. Data used by CE Delft have slightly lower emissions than aggregate data.*
- *Cutting losses reported to be 8% on average (three types of board): adopted.*

¹¹ VNO-NCW is the Confederation of Dutch Industry; the other organisations cited are the trade associations for the respective packaging materials.

- *Rejects reported to be 0.5% of paper fibre: adopted.*
- *Improvements to wording: largely adopted.*

A major issue in these discussions was the fact that in the current methodology the recycling of cardboard does not lead to lower CO₂ emissions per kg. This ties in with a wider debate on assigning an appropriate value to the recycling of biotic resources in Life Cycle Assessment exercises, and more particularly on the omission of 'land use' in most LCAs. The industry made several proposals on how to tackle this issue and CE Delft also sees scope for including land use in future analyses. Unfortunately, though, it was not possible in the short time available to examine an essentially new issue like land use and incorporate it in the present study. We recommend that consideration be given, prior to the first update of the indices for the packaging tax, to including land use as an environmental factor, so that the recycling of paper and cardboard are duly accredited. This issue is discussed in sections 4.4 and 4.5.

E.3 Glass

On 12 July 2007 there were talks with:

- Mr A.P. van Notten and Mr Schalken, Stichting Duurzaam Verpakkingsglas.
- Mr van Dalen, Ardagh Glass Benelux.

At this meeting discussions focused on the overall strategy and the data to be used for glass. The main issues were the increased use of cullet in production and the appropriate CO₂ emission factor for soda use. No new data on cullet reprocessing were provided. Reprocessing losses amount to 4%, but this has already been accounted for in the recycling rates reported by the Packaging Commission (2005).

In an email dated 31 July Mr Van Notten provided the following additional input:

- *Improvements to wording: adopted.*
- *Use of secondary glass 59%: adopted.*
- *Use of natural soda versus synthetic soda: CO₂ data corrected.*

Other industries were not happy with the fact that Dutch data had been used for glass, even though 50% of Dutch glass consumption consists of imports. In section 3.3 we report our reasons for sticking to the Dutch data.

E.4 Metals

There was discussions with the following people, some repeated, and some per email:

- Mr Bruinsma, Aluminium Centre.
- Mr Ubbens, Stichting Kringloop Blik.
- Mr Von Keitz, Corus.
- Mr Schaefer, European Aluminium Association.

On 6 August a letter was also received from Stichting Kringloop Blik.



Main issues:

- *New data on aluminium production: adopted.*
- *New data on can production: failure to provide more recent data.*
- *Recovery of aluminium from incinerator bottom ash: based on industry information, Peter Rem (TU Delft) and several incinerator and scrap reprocessing plant operators, recovery percentages were adjusted and energy data recalculated (see Appendix C.2). Industry argument that separation of metal fractions should be allocated to reprocessed bottom ash not adopted.*
- *No difference in quality between steel from the basic oxygen and electric furnace steel processes in score for recycling. In addition, recycled packaging steel is used entirely in the basic oxygen process. Adopted (as explained in 3.4), but with a correction for the IISI data not being broken down.*
- *No difference in quality between wrought and cast aluminium: adopted.*
- *Allocation of recycling percentages to steel and aluminium: adopted (see Appendix C).*

E.5 Plastics

On 27 July there were talks with:

- Mr Lucas, VMK.
- Mr Marechal, BCF consultants.

The industry proved to have major objections to the omission of the use phase of packaging in the analysis. They are adamant that certain aspects of the use phase (in particular, reduced product spoilage/loss) should be included, and that exclusion puts plastics at a disadvantage; as evidence a study (GUA, 2005) was presented.

Response by CE Delft: The aspects alluded to may certainly be relevant, but in policy terms the question is whether these should be approached via the packaging or the product. There is also very little quantitative information available on inter-packaging differences in the use phase. We have included a qualitative discussion of this issue (see section 2.2). Before the first update of the environmental indices, we recommend assessing whether it is worthwhile and feasible to include the use phase of certain types of packaging with a marked impact on product spoilage in the calculations. It then also makes sense to include differences in energy use associated with chilling and freezing.

There are no data available on Dutch consumption of the individual submaterials. The industry presented a study (AJI, 2004) reporting European averages for the shares of various types of plastics in packaging materials. These data were all adopted, with the exception of those for PET, because in this case the data are very different from previous Dutch estimates (see section 3.5).

The monitoring data for 2005 were markedly different from those for previous years. The industry reported that this is due to a major influx of German products onto the Dutch market that year. The data for 2005 have nonetheless been taken as the point of departure, because market trends in 2006 are still unclear.

The Ecoprofiles data compiled by Plastics Europe are by no means representative when it comes to the processing of primary materials to packaging. CE Delft is well aware of this fact, but there are no better data available. TNO is currently looking into this issue, but at the time of writing the results were not yet available. The Ecoprofiles figures were therefore used.

The industry drew attention to the fact that the presence of non-combustible materials in residual household waste sent to incinerators can reduce the efficiency of combustion. This would put glass and metals at an apparent advantage and plastics and paper at a disadvantage.

Response by CE Delft: While this is true, the effect is minimal. Incinerator combustion efficiency is determined above all by the amount of 'green waste' in the residual waste fraction. The energy losses embodied in the slag amount to around 0.25 GJ/t slag. The impact of mechanical separation of PPF has likewise been ignored.

E.6 Wood

There were no responses relating to wood.

E.7 Other

On 26 July CE Delft was one of the parties at a general discussion of the draft report hosted by VNO-NCW, together with representatives of all the parties cited in E.1. A letter dated 2 August 2007 was received from MKB Nederland¹² and VNO-NCW.

The main issues discussed were as follows:

- There are major import and export flows of packaging and (primary/secondary) materials; using Dutch or even European data may give a skewed picture. *Response: While this is true, the differences will be minimal, particularly as the scores are relative.*
- Non-inclusion of the use phase, with attendant consequences for calculated environmental burden. *Response: see section 2.2.*
- Assumptions have been made that may possibly have major consequences for the outcome; the industry would have liked a sensitivity analysis. As a result, there is no clear picture of the uncertainties embodied in the indices that are to be used for setting the tariffs of the new Dutch packaging tax. *Response: In the time available for the present study there was no scope for a sensitivity analysis. We have done our best to make our assumptions explicit, so that there are clear 'entry points' for improving the data.*

¹² Dutch Association of Small and Medium-sized Businesses.

