FEFCO

Corrugated Board Boxes
and
Plastic Container Systems:

an analysis of costs and eco-costs

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CONTENTS

Executive Summary

Since there is an ongoing debate on the environmental aspects of re-usable crates versus corrugated board boxes, a calculation is made on the costs and the eco-costs of the transport of fresh fruit and vegetables from a Dutch greenhouse to a German retail shop in Frankfurt (500 km distance).
Two Packaging systems are compared:

- corrugated board boxes
- re-usable plastic containers (rigid as well as foldable)

Extrapolations have been made for longer transport distances, up to 2500 km.

Eco-costs[1] are a measure (a "prevention based single indicator") for the environmental burden as determined in the Life Cycle Analyses of the transport system.
The costs and the eco-costs are determined for the total systems, i.e. including packaging, transport, storage, handling, and in the case of plastic containers the return flow and cleaning.

In total, 8 systems for transport packaging have been analysed:

1a. 600 x 400 x 240 mm corrugated box
1b. 600 x 400 x 240 mm rigid plastic container
1c. 600 x 400 x 240 mm foldable plastic container
2a. 600 x 400 x 110 mm corrugated box
2b. 600 x 400 x 126 mm rigid plastic container
2c. 600 x 400 x 126 mm foldable plastic container
3a. 400 x 300 x 140 mm corrugated box
3b. 400 x 300 x 165 mm foldable plastic container

The costs as well as the eco-costs of the transport system have been calculated per litre of transported goods as a function of the transport distance (from the Dutch auction warehouse to the distribution centre of the retailer). See the Figures below.

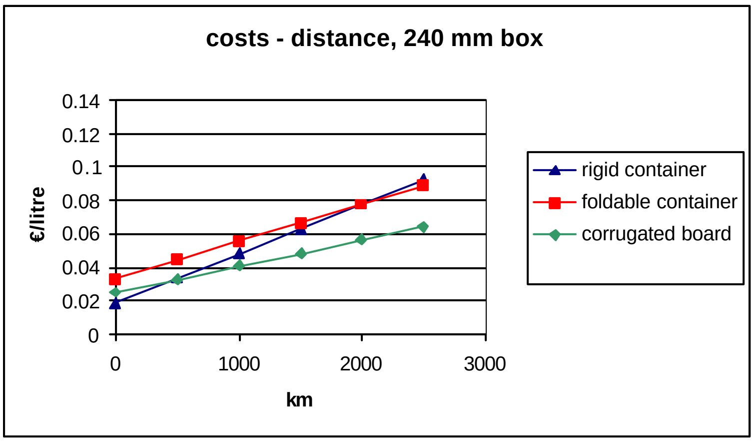

Figure 1. The transport costs per litre for 3 types of transport packaging, as a function of the distance between the auction warehouse and the retailer's distribution centre. Size 600 x 400 x 240 mm.

[1] The so called Eco-costs / Value system has been developed by the Delft University of Technology. It provides a practical and consistent way for "allocation" in LCA, which is indispensable for the analyses of complex technical systems like this transport chain. See for more information Chapter 2.

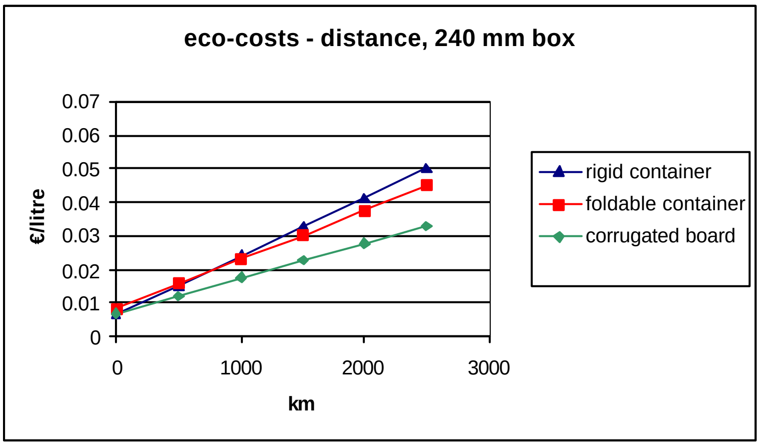

Figure 2. The eco-costs per litre for 3 types of transport packaging, as a function of the distance between the auction warehouse and the retailer's distribution centre. Size 600 x 400 x 240 mm.

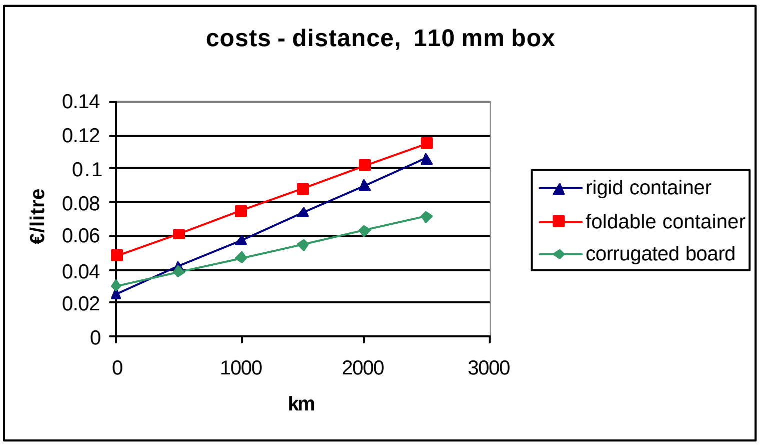

Figure 3. The transport costs per litre for 3 types of transport packaging, as a function of the distance between the auction warehouse and the retailer's distribution centre. Sizes: corrugated board 600 x 400 x 110 mm, plastic containers 600 x 400 x 126 mm.

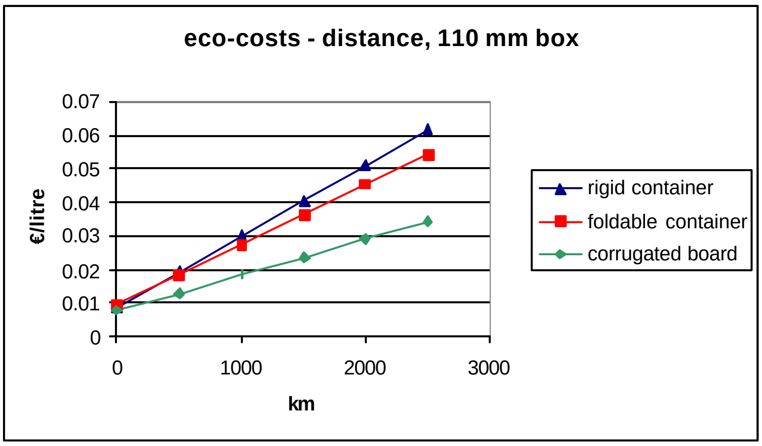

Figure 4. The eco-costs per litre for 3 types of transport packaging, as a function of the distance between the auction warehouse and the retailer's distribution centre. Sizes: corrugated board 600 x 400 x 110 mm, plastic containers 600 x 400 x 126 mm.

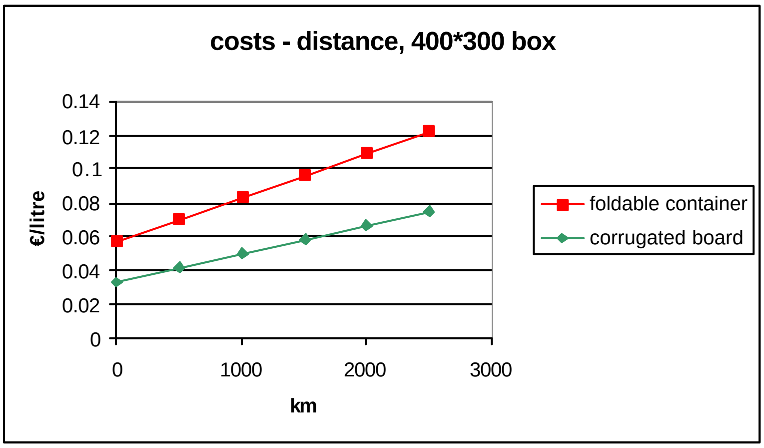

Figure 5. The transport costs per litre for 2 types of transport packaging, as a function of the distance between the auction warehouse and the retailer's distribution centre. Sizes: corrugated board 400 x 300 x 140 mm, plastic containers 400 x 300 x 165 mm.

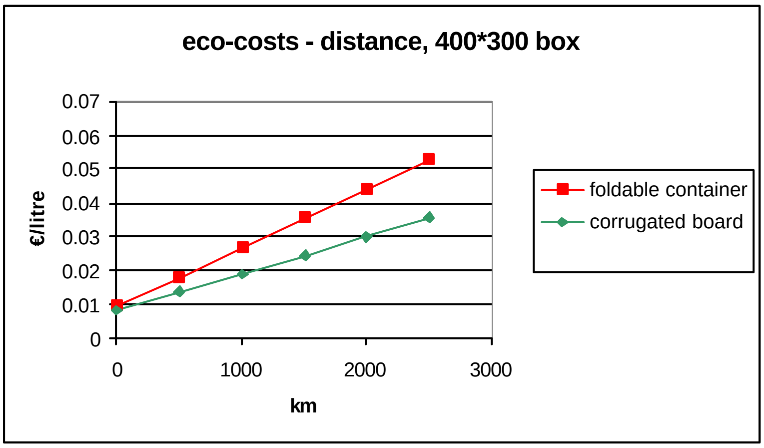

Figure 6. The eco-costs per litre for 2 types of transport packaging, as a function of the distance between the auction warehouse and the retailer's distribution centre. Sizes: corrugated board 400 x 300 x 140 mm, plastic container 400 x 300 x 165 mm.

Analyses show that:

- the corrugated board systems are better in all cases from the environmental point of view
- transport by means of the plastic containers is only cheaper in 600*400 containers for short distances (shorter than 500 km)
- for very long transport distances (longer than 2000 km), the re-packing of vegetables and fruit, from the corrugated box into the containers of the retailers sees the best current system solution (better than transporting the plastic containers over long distances)
- an attempt should be made to introduce re-usable "transfer plates" which are to be used at the retailer's distribution centre, to make the corrugated board box compatible with the retailer's internal transport system; such a solution seems to be attractive for distances longer than 1000 km.

1. Introduction

In The Netherlands as well as in other EC countries, there is, since 1990, an ongoing debate on the environmental aspects of re-usable plastic crates versus solid and corrugated board boxes.
Is a solid or corrugated board box better than a plastic crate or is a plastic crate better since it is re-usable (durable)? How about the transport, handling and cleansing of the empty crates? How about the fact that a crate has a poor net volume versus gross volume? How about the pollution of mills for paper and corrugated board boxes in comparison with the manufacturing of a plastic container?
It is generally accepted that retail companies have lower internal handling costs when they apply crate systems, but it is also known that crate systems tend to be rather expensive at the front end of the chain (filling, storage and transport). Does the environmental burden go hand in hand with the costs?
Within what distance is the crate more attractive from the environmental perspective?
What are the key elements to improve the design of both packaging systems?

Since the transport of fresh fruit and vegetables from the Dutch greenhouses is done in re-usable plastic crates as well as in solid and corrugated board boxes, it was decided to do a case study on these transport systems.
Frankfurt in Germany was selected as a typical distance (500 km) for an important consumers market. The distance from the warehouse of the auction to the distribution centre of the retailer was extrapolated as well to distances up to 2500 km.

Until recently, it was not feasible to make a proper LCA for the required "functional unit", i.e. transport of a litre vegetables from the greenhouse to the retail shop. The reason was that the so called "allocation' in LCA was not sufficiently developed to deal with such a complex transport (service) system.
Most of the elements in such a system are partly used by the goods which are transported: the truck, the warehouses, the crate, the road, etc. This requires a consistent method to allocate the direct and the indirect environmental burden to the functional unit of the specific goods (Bos, 1998). Furthermore, there is the issue of the diesel required for the return trip of the truck in the case that this truck is partly loaded with other freight: this requires allocation to the specific goods as well.
At the Delft University of Technology, a LCA based method has been developed, that can tackle such allocation problems in a practical and consistent way. This method is called the model of the Eco-costs / Value Ratio (EVR). This model is applied to resolve the basic question: "is a transport system with corrugated board boxes better or worse for our environment than a system with re-usable containers?".

2. The model of the Eco-costs / Value Ratio (EVR)

The basic idea of the EVR (Eco-costs/Value Ratio) model is to link the 'value chain' (Porter, 1985) to the ecological 'product chain'. In the value chain, the added value (in terms of money) and the added costs are determined for each step of the product "from cradle to grave". Similarly, the ecological impact of each step in the product chain is expressed in terms of money, the so called eco-costs. See Figure 7.

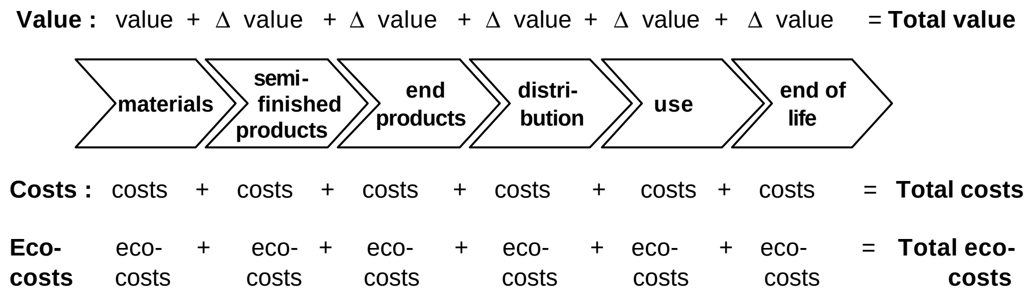

Figure 7. The basic idea of combining the economic and ecological chain: "the EVR chain".

The eco-costs are 'virtual' costs: these costs are related to measures which have to be taken to make (and recycle) a product "*in line with earth's estimated carrying capacity*" [2]. These costs have been estimated on the basis of technical measures to *prevent* pollution and resource depletion to a level which is sufficient to make our society sustainable[3]. For details of these calculations, see (Vogtländer et al., 2002).

Since our society is yet far from sustainable, the eco-costs are 'virtual': they have been estimated on a 'what if' basis. They are not yet fully integrated in the current costs of the product chain (the current Life Cycle Costs).

The ratio of eco-cost and value, the so called Eco-costs / Value Ratio, EVR, is defined in each step in the chain as:

EVR = eco-costs / value

For one step in the production+distribution chain, the eco-costs, the costs and the value[4] are depicted in Figure 8.

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[2] In 1995, the World Business Council for Sustainable Development (www.wbcsd.ch/eurint/eeei.htm) described the role for industry in their definition of eco-efficiency as:
"the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing ecological impacts and resource intensity, through the life cycle, to a level at least in line with earth's carrying capacity."

[3] The eco-costs in the EU are related with the required Best Available Technologies, and are proxies of the tradable emission rights which are required for a sustainable society.

[4] Within the business chain, the value equals the market price. From the consumers point of view the value equals the 'fair price' (Gale, 1994). Note: in the business chain, the cost for the buyer is the value for the seller.

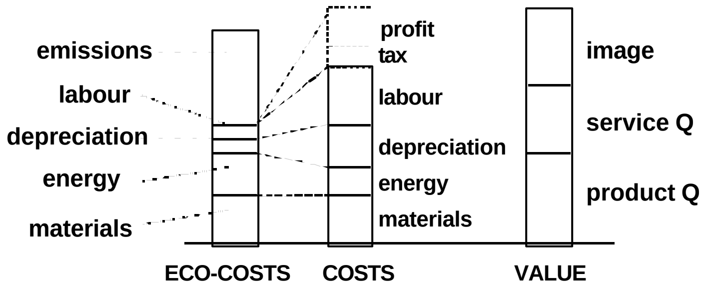

Figure 8. The decomposition of "virtual eco-costs", costs and value of a product

The five components of the eco-costs have been defined as 3 'direct' components plus 2 'indirect' components:

- ✓ virtual pollution prevention costs, being the costs required to reduce the *emissions* of the production processes to a sustainable level
- ✓ eco-costs of *energy*, being the price for renewable energy sources
- ✓ *materials* depletion costs for metals, being (costs of raw materials)x(1-á), where á is the recycled fraction
- ✓ eco-costs of *depreciation*, being the eco-costs related to the use of equipment, buildings, etc.
- ✓ eco-costs of *labour*, being the eco-costs related to labour, such as commuting and the use of the office (building, heating, lighting, electricity for computers, paper, office products, etc.).

The eco-costs of physical products are calculated by means of the LCA method. In complex cases and in case of services (like transport), allocation is done by means of so called "economic allocation", i.e. *"…..environmental input and output data are allocated between co-products in proportion to the economic value of the products."* (quoted from ISO 14041).

A consequence of the consistent economic allocation system in the EVR model is that the costs calculation of a Product Service System is running strictly parallel to the calculation of eco-costs, see Figure 7.
This enables a powerful feature of the EVR model: based on a detailed cost-structure of the product, the eco-costs can be calculated by multiplying each cost element with its specific Eco-costs / Value Ratio, the EVR. These specific EVRs have been calculated on the bases of LCAs. Tables are provided for materials, energy and industrial activities (Vogtländer et al., 2002).

For the calculation of eco-costs, the following marginal prevention costs are applied:

- prevention of acidification:	6.40	€/kg (SOx equivalent)
- prevention of eutrophication:	3.05	€/kg (phosphate equivalent)
- prevention of heavy metals:	680	€/kg (calculation based on Zn)
- prevention of carciogenics:	12.3	€/kg (PAH equivalent)
- prevention of summer smog:	3.0	€/kg (calculation based on VOC equivalent)
- prevention of winter smog:	12.3	€/kg (calculation based on fine dust)
- prevention of global warming:	0.114	€/kg (CO2 equivalent).

The European database 2003 of FEFCO (FEFCO, 2003) is applied to calculate the eco-costs of corrugated board.

3. Data on the corrugated board boxes and plastic containers

The total transport costs and eco-costs have been calculated for 8 systems of transport packaging,
See Table 1.

	240 mm height			110 mm / 126 mm height			400 x 300 mm	
type	**CB**	**RC**	**FC**	**CB**	**RC**	**FC**	**CB**	**FC**
ext. dimensions:								
Length (mm)	0.6	0.6	0.6	0.6	0.6	0.6	0.4	0.4
Width (mm)	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3
Height (mm)	0.24	0.241	0.241	0.11	0.126	0.126	0.14	0.165
int. dimensions								
Length (mm)	0.587	0.566	0.566	0.585	0.575	0.574	0.385	0.364
Width (mm)	0.399	0.366	0.366	0.387	0.38	0.378	0.285	0.263
Height (mm)	0.228	0.212	0.212	0.105	0.097	0.097	0.135	0.146
Volume (litres)	53.40	43.92	43.92	23.77	21.19	21.05	14.81	13.98
Weight (kg)	1.086	1.95	1.95	0.61	1.3	1.3	0.4	0.76
Costs of tray (€)	0.98	-	-	0.58	-	-	0.39	-
Rent per trip (€)	-	0.28	0.86	-	0.2	0.6	-	0.46
Deposit (€)	-	3.86	3.86	-	3.86	3.86	-	3.86
Nr. of trips	-	30	20	-	30	20	-	20
Ecocosts tray (€)	0.159	-	-	0.0895	-	-	0.0587	-
Ecocosts cont.(€)	-	0.0645	0.0967	-	0.0430	0.0645	-	0.0377
Costs (€/litre)	0.0184	0.0093	0.0240	0.0244	0.0155	0.0377	0.0263	0.0467
Ecocosts (€/litre)	0.0030	0.0015	0.0022	0.0038	0.0020	0.0031	0.0040	0.0027
Nr. per pallet	50	50	50	110	95	95	170	140
Total height (m)	2.4	2.41	2.41	2.42	2.394	2.394	2.38	2.31
Litres per pallet	2670	2196	2196	2615	2013	1999	2518	1957
Nr. per returnpall.	-	50	190	-	95	190	-	380

Table 1. Data on the systems for transport packaging as applied in the calculations.
CB = corrugated board tray
RC = rigid plastic container
FC = foldable plastic container

Information on the number of trips of re-usable containers is provided by The Greenery. The pallets which are used in the calculations are 1.2 x 1.0 m.
Although it is common practice to apply inserts and labels for plastic containers, these inserts and labels are *not* taken into account in the calculations, since they differ from case to case.

4. Description of the transport chain

The transport and distribution chain for Dutch fresh fruit and vegetables is a so called "hub-and-spokes" system:

- in the first leg the goods are transported from the greenhouse to the warehouse of the auction or export company in Holland ("Hub 1"), where all fruit and/or vegetables of that day are stored
- in the second leg the goods are transported to the distribution centre of the retailer in Germany
- in the third leg the goods are distributed from the distribution centre ("Hub 2") to the retail shops

This system is depicted in Figure 9. It also shows the how the re-usable containers (and pallets) are returned in the chain.

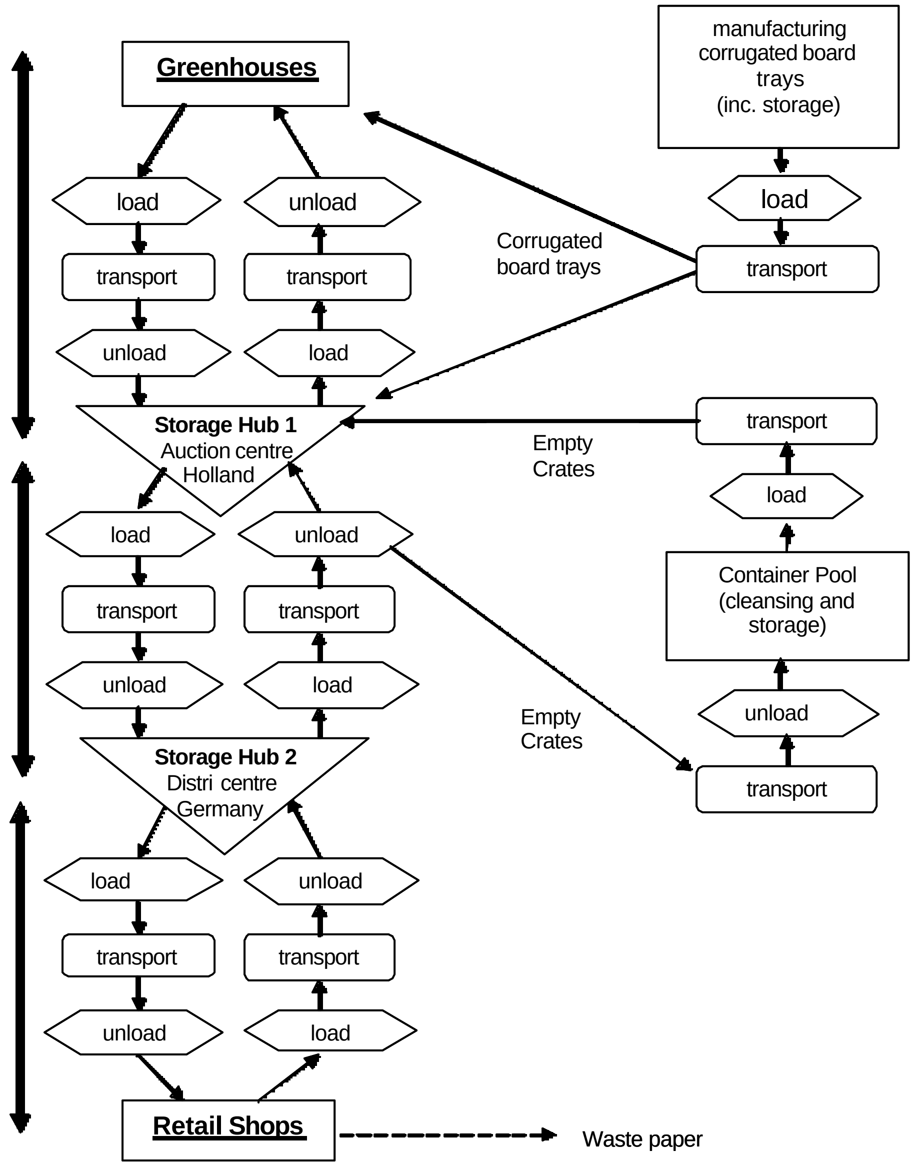

Figure 9. Structure of the transport and distribution system

Such a hub-and-spokes system is also common for goods other than fresh food. The logistic idea behind it is that in such a system the truckload for the long distance (in

this case Holland-Germany) can be maximized. ("hub-and-spokes" refers to a wheel: freight is collected - the "spokes" - and temporarily stored in a warehouse - the "hub" - , transported at a high frequency and optimum efficiency to the other hub, stored, and distributed there over the adjacent area - the "spokes" -).
Most of the international transport companies operate in this way to minimize costs. They run their own warehouses in the hubs: in a well designed logistic system the extra costs of intermediate storage is less than the savings of having a better utilization of the total truck fleet. Since the EVR of transport is higher than the EVR of storage and its related handling, optimization of costs go here hand in hand with minimization of environmental burden (see Chapter 6).

There are many hubs (auctions and export companies) in Holland and many in Germany (every Retail Company has its own distribution centres). The trucks from Holland to Germany are basically operating as shuttles: the trip back to Holland is either filled with empty re-usable containers or, in the case of a corrugated board tray the transport companies try to transport other commercial goods on the trip back to Holland. However, in such a fast and frequent operation it is hardly feasible to arrange 100% payload for the trip back. In the calculations it is assumed that 70% of the available empty pace can be used for other commercial goods.

In order to analyse the logistic system, the structure of one link (leg) in the chain has to be detailed on the level of activities:

1. pallets with full crates have to be transported from the storage or filling area to the dispatch area by forklift trucks
2. pallets have to be loaded by forklift trucks
3. the truck is driving from place A to place B
4. pallets are unloaded by forklift trucks
5. pallets with empty crates are loaded with forklift trucks
6. the truck is driving from place B to place A
7. pallets with empty crates are unloaded with forklift trucks
8. pallets with empty crates are transported to storage

This process is depicted in Figure 10.

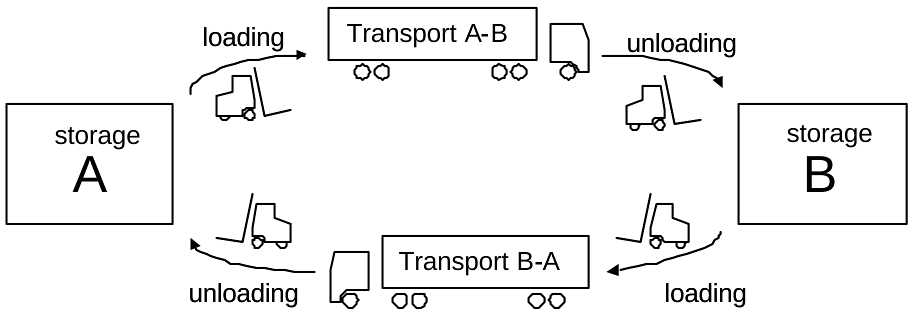

Figure 10. The structure of one link (leg) in the chain

So there are three main activity groups:

I. transport
II. loading and unloading
III. storage

The main elements of this link of the chain are:

A. the truck
B. the forklift truck
C. the warehouse for storage
D. the road infrastructure

Each of these elements comprises (the so called “attributes”):

- The costs and the eco-costs of the object
- the “direct” energy requirements (i.e. fuel, electricity)
- the related “direct” labour (e.g. the forklift truck driver)
- “indirect costs” like insurance, interest, etc.

Each object has its own life cycle (“value chain”):

- the materials required
- the manufacturing
- the distribution (of the truck and the forklift truck)
- the use and the maintenance
- the “end-of-life”

According to this structure, a spreadsheet program has been made to facilitate the calculations. In the input of the spreadsheet program, the activity is defined per “main element”, the output gives the costs and the eco-costs of the sum of all activities.
In the chapter 5 the general data on the costs and the eco-costs for each main element are summarized. In chapter 6 it is shown how the costs and the eco-costs of activities in the transport cycle and in the transport chain are calculated from the general data of the main elements.

5. General data on the main elements of the transport chain

<u>Trucks</u>

General financial data on trucks are provided in Table 2.

Figure 11. A truck + trailer as normally used in the EC for transport of fresh food

All prices excl. VAT; diesel 0,67 Euro/litre	Truck+trailer net 24 tons
(1) Purchase price (Euro)	135.000
(2) Total distance in life time (km)	1.000.000
(3) Diesel fuel (litres/km)	0,33
(4) Max. distance one set tyres (km)	100.000
Eurovignet (Euro/annum)	1255
Tax (Euro/annum)	910
Insurance (Euro/annum)	6850
Interest (Euro/annum)	2720
(5) Subtotal yearly costs (Euro/annum)	11735
(6) Total distance per year (km/annum)	140.000
(7) Max. pallets (1,00 x 1,25m) per trip	26
Costs per distance (Euro/km):	
Depreciation =(1)/(2) (Euro/km)	0,135
Diesel =(3)*0,67 (Euro/km)	0,221
Lube oil (Euro/km)	0,004
Maintenance (Euro/km)	0,070
Tyres (Euro/km)	0,047
Yearly costs =(5)/(6) (Euro/km)	0,084
Total (Euro/km)	**0,561**

Table 2. Financial data of trucks. (EVO, 2002) (Kuipers, 1998)

The costs of the driver is about 18 Euro/hour (Kuipers, 1998). This is based on approx. 2000 driving hours per annum (by Dutch law there is a maximum of 110 driving hours per 2 weeks).

The eco-costs of trucks are calculated according to the scheme of Figure 12. The results of the calculations are given in Table 2. Detailed data are provided in Annex I.

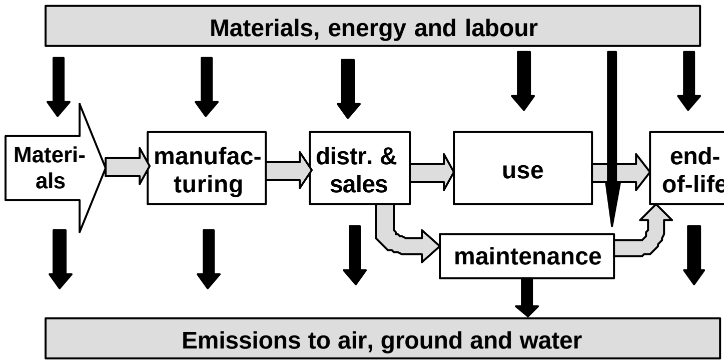

Figure 12. The LCA calculation structure

All values in Euro/km *Note: all tyres in eco-costs of vehicle*	Truck+trailer net 24 tons
Pollution prevention costs materials (Annex I)	0,012
Eco-costs of materials depletion (Annex I)	0,005
Eco-costs of manufacturing (Annex I)	0,011
Eco-costs of distribution (Annex I)	0,007
Eco-costs of end-of life (Annex I)	-
Sub total eco-costs of vehicle	**0,035**
Eco-costs of maintenance (EVR=0,2)	0,014
Eco-costs of diesel fuel (1,1 Euro/litre)	0,363
Sub total eco-costs of use	**0,377**
Total eco-costs (Euro/km)	**0,412**

Table 3. Eco-cost data of trucks

The Table above is excluding **eco-costs of the driver**. The costs of the driver are estimated at 18 Euro/hour. This is based on approx. 2000 driving hours per annum (by Dutch law there is a maximum of 110 driving hours per 2 weeks). The EVR is in this case estimated at 0,05 , so the eco-costs of the driver are estimated at 0,9 Euro/hour.

Forklift trucks

All prices excl. VAT; electricity 0,094 Euro/kWh	Forklift Truck
(1) Purchase price (Euro)	21.000
(2) Total life time (years)	15
(3) Total life time (hours)	25.000
(4) Average operating hours per day	10
(5) Occupancy rate	70%
(6) Power cons. during oper. (kWh/hour)	51
(7) Battery life (hours)	6.250
(8) Tyre life (hours)	8.300
(9) Maintenance costs per annum (Euro)	1050
Costs per hour (Euro):	
Depreciation =(1)/(3) (Euro/hour)	0,84
Electrical power =(6)*0,094 (Euro/hour)	4,79
Maintenance (Euro/hour)	0,63
Total (Euro/hour)	**6,26**

Table 4. Financial data of Forklift Trucks (Caterpillar, 1999), (Brantjes, 1999)

The eco-costs of forklift trucks are calculated in the same way as in the previous chapter, according the scheme of Figure 12, the data are summarized in Table 5.

All values in Euro/hour *Note: all tyres in eco-costs of vehicle*	Forklift Truck
Pollution prevention costs materials (Annex II)	0,18
Eco-costs of materials depletion (Annex II)	0,06
Eco-costs of manufacturing (Annex II)	0,10
Eco-costs of distribution (Annex II)	0,04
Eco-costs of end-of life (Annex II)	-
Sub total eco-costs of the forklift truck	**0,38**
Eco-costs of maintenance (EVR=0,2)	0,12
Eco-costs of electrical power (0,118 Euro/kWh)	6,02
Sub total eco-costs of use	**6,14**
Total eco-costs (Euro/hour)	**6,52**

Table 5. eco-cost data of forklift trucks

The Table above is excluding **eco-costs of the driver**. The costs of the driver are estimated at 16 Euro/hour. The EVR is in this case estimated at 0,05 , so the eco-costs of the driver are estimated at 0,8 Euro/hour.

<u>Warehouse</u>

General financial data on a warehouse of 920 pallets (conventional storage in racks, 4 high) are provided in Table 6.

All prices excl. VAT; electricity 0,094 Euro/kWh	Warehouse (unconditioned)
(1) Investment on building (Euro)	400.000
(2) Total life time (years)	25
(3) Nr of storage positions for pallets	920
(4) Maintenance (Euro/year)	7.050
(5) Energy consumption (kWh/year)	21.000
(6) Energy costs per year (Euro/year)	1974
(7) Interest (Euro/year)	12.000
(8) Insurance (Euro/year)	4.000
Costs per pallet per year (Euro):	
Depreciation =(1)/(2*3) (Euro/pallet.year)	17,4
Electricity =(6)/(3)*0,094 (Euro/pallet.year)	2,1
Maintenance (Euro/pallet.year)	7,7
Interest and insurance (Euro/pallet.year)	17,4
Total (Euro/pallet.year)	**44,6**

Table 6. Financial data of a warehouse

The eco-costs of the warehouse are calculated in Annex III, the data are summarized in Table 7.

All values in Euro per pallet.year	Warehouse (unconditioned)
Pollution prevention costs materials (Annex III)	5,2
Eco-costs of materials depletion (Annex III)	1,2
Eco-costs of manuf. and construction (Annex III)	3,1
Eco-costs of end-of life (Annex III)	-
Sub total eco-costs of the warehouse	**9,5**
Eco-costs of maintenance (EVR=0,2) **)	1,5
Eco-costs of electrical power (0,118 Euro/kWh) *)	2,7
Sub total eco-costs of use	**4,2**
Total eco-costs (Euro/pallet.year)	**13,7**

Table 7. eco-cost data of a warehouse

Road infrastructure

The "embodied energy" of road infrastructure in The Netherlands has been studied at IVEM of the University of Groningen (Bos, 1998). This study has been based on the following macro-economic data for the year 1990 in The Netherlands:

1. total vehicle "distance x load" by trucks: $47{,}12\ 10^9$ tonkm/year
2. load factor of utilization of the total truck fleet for "long distance" 0,5
3. total embodied energy in road infra. (incl. maintenance) [5]: 888 PJ
4. depreciation of (3.) over 50 years 17,8 PJ/year

The above data result in an embedded energy in road infrastructure of: 0,38 MJ/tonkm

Since the majority of the "embodied energy" stems from the energy used by road transport during the construction phase, and since the major part of that is the use of diesel, the "embodied energy" is directly converted to eco-costs by the price for sustainable energy for diesel: 29,55 Euro/GJ (revised data).
So the eco-costs of road infrastructure [6] can be estimated as:
'maximum load' x 'load factor' x 'embedded energy in roads' x 'eco-costs of sustainable energy'
Which results in the following data of eco-costs of road infrastructure for a truck + trailer:

24 (ton) x 0,5 x 0,38 (MJ/tonkm) x 0,0295 (Euro/MJ) = 0,13 (Euro/km)

[5] The total embedded energy in roads in The Netherlands is estimated at 3471 PJ, of which 888 PJ has been allocated to trucks (Bos, 1998)
[6] Note that the eco-costs of the embodied energy is the major part of the total eco-costs of infrastructure.

6. Results of the calculation and Conclusions

A computer spreadsheet program has been developed at the Delft University of technology to calculate the costs and eco-costs of transport, based on the data of the previous chapters and based on de following input per transport leg for transport, loading and unloading, and for storage respectively:

- type of vehicle (truck+trailer, light lorry, van)
- number of pallets in the vehicle
- number of pallets return
- percentage of freight in vehicle (other freight might be transported at the same time)
- percentage of freight in vehicle return (when there is no other return freight 100%)
- distance in km
- waiting time for vehicle at docks for loading and unloading
- loading and unloading time per pallet for forklift truck
- time for forklift truck for storage in the warehouse (per pallet)
- type of storage (conditioned or unconditioned)
- storage time of pallets

The above set of input data enables an "Activity Based Costing" calculation for the costs as well as the eco-costs.

Such a calculation has been made for transport of vegetables from the Dutch greenhouses to the retailer shops in Germany (Frankfurt).
The main characteristics are:

- for the first transport leg (greenhouse - auction): truck+trailer, distance 50 km at a speed of 40 km/hour, number of pallets 26 (full truck load)
- for the second transport leg (Holland - Frankfurt): truck+trailer, distance 500 km at a speed of 70 km/hour, number of pallets 26 (full truck load)
- for the third transport leg (distri centre - retail shop): truck+trailer, distance 40 km at a speed of 40 km/hour, average number of pallets 21 (80% truck load)[7]
- distance from the container pool centre to the auction warehouse 50 km, full truck loads
- distance from the manufacturer of corrugated board trays to the auction warehouse 50 km, full truck loads (empty on return trip)
- operational storage within the transport chain 7 days (unconditioned storage)
- operational buffer (unconditioned storage) of empty transport packaging: 30 days for corrugated board trays, 60 days for the re-usable containers
- 1 litre water, 60 ^{0}C, for cleansing of 1 re-usable container

The results of the calculations are depicted in Figure 13, 14 and 15.

[7] for the third leg it is obvious that in reality the truck is loaded with a full range of products and not with peppers or tomatoes alone; for the calculation however this does not make any difference

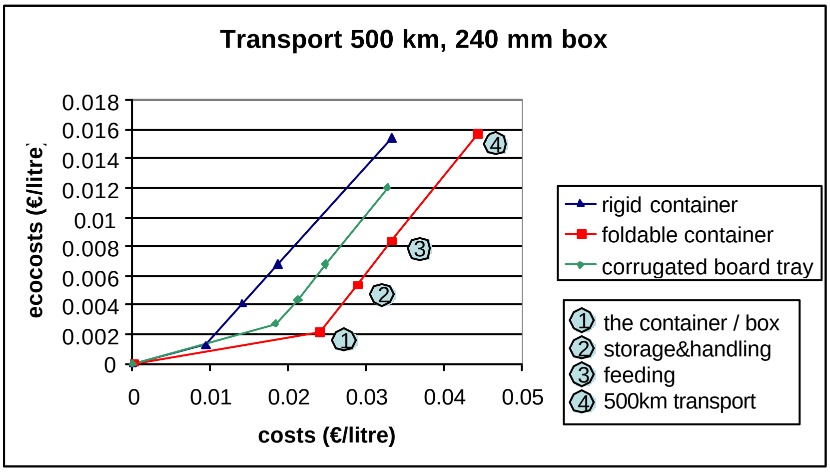

Figure 13. The costs and the eco-costs per litre for 3 types of transport packaging from the Dutch warehouse to the retail shop in Frankfurt (500 km).
Size 600 x 400 x 240 mm.

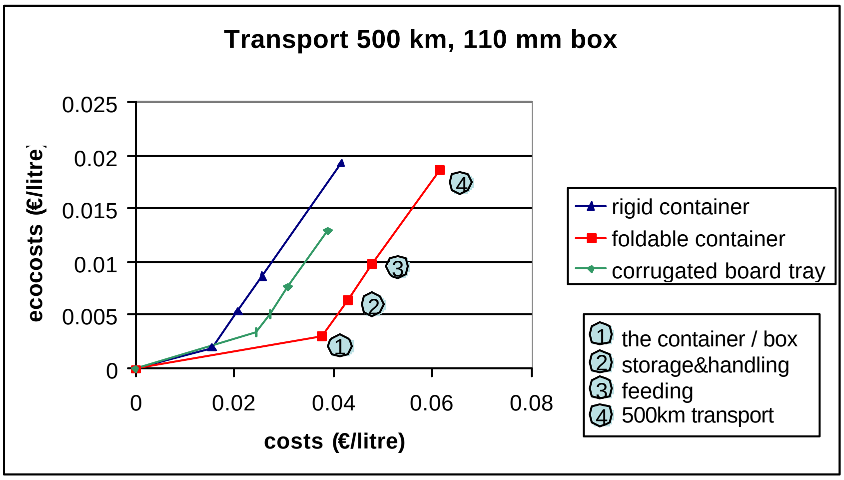

Figure 14. The costs and the eco-costs per litre for 3 types of transport packaging from the Dutch warehouse to the retail shop in Frankfurt (500 km).
Sizes: corrugated board 600 x 400 x 110 mm, plastic containers 600 x 400 x 126 mm.

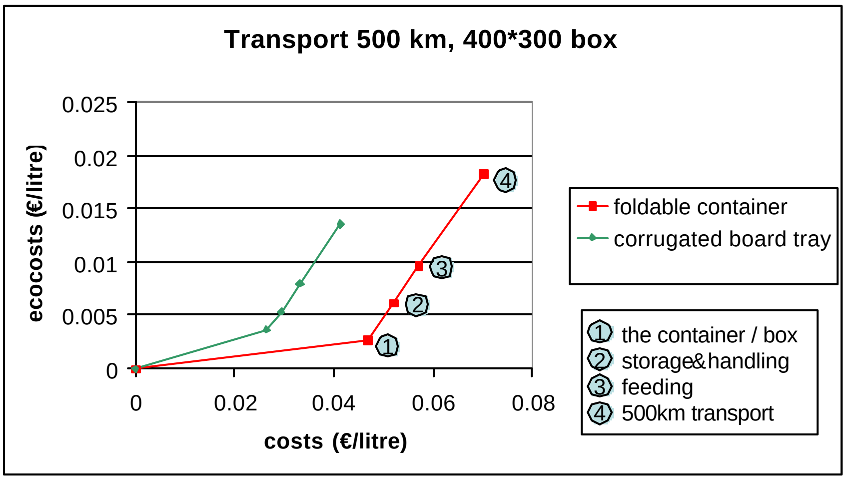

Figure 15. The costs and the eco-costs per litre for 2 types of transport packaging from the Dutch warehouse to the retail shop in Frankfurt (500 km).
Sizes: corrugated board 400 x 300 x 140 mm, plastic container 400 x 300 x 165 mm.

The conclusions of the calculations are:

a. the rigid container system and the corrugated board tray system have the same total costs per litre for 500 km distance
b. the foldable container system is more expensive for 500 km distance
c. From the environmental point of view, the corrugated board trays score the best, since the eco-costs are lower in all cases

The calculations have been extrapolated for longer distances up to 2500 km. See Figure 1 through 8 of the Executive Summary.
From these Figures it is clear that neither foldable containers, nor rigid containers are good solutions for longer distances.

It is generally accepted that retail companies have lower internal handling costs when they apply plastic crate systems, but it can be concluded from the calculations that crate systems are more than 0,01 €/litre more expensive for distances over 1000 km.
An attempt should be made to introduce re-usable "transfer plates" which are to be used at the retailer's distribution centre, to make the corrugated board box compatible with the retailer's internal transport system. In such a way separate internal handling systems or re-packing can be avoided.
From the technical point of view it seams feasible to make such transfer plates for less than 0,01 €/litre.

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Annex I

Detailed environmental data on the LCA of truck+trailer, net 24 tons.

all data in kg	greenhouse	acidification	eutroph.	hv metals	carcin.	s. smog	w.smog
Truck:	kg CO2 equ	kg SO4 equ	kg PO4 eq	kg Pb equ	kg B(a)P equ	kg ethene eq	kg SPM equ
Steel, 6000kg	6263	30.43	1.861	0.003212	0.0035351	71.70884	27.49697
PVC, 500kg	1050	18.28	1.271	0.003	0	4.179	2.95
Glas, 50kg	37	0.22	0.016	0.002292	9.25E-06	0.03455	0
SBR I*, 2000kg	2528	48.97	3.366	0	0	12.23304	5.6615
Aluminium, 200kg	2460	25.55	0.565	4.30E-05	4.46E-07	0.79628	29.68666
Copper, 100kg	753	108.16	0.331	1.41E-05	9.48E-08	0.03350	106.3847
Machining, 4500kg steel	249	1.60	0.073	0.001809	1.25E-04	0.05671	1.20175
Castwork, 1500 steel	2493	12.35	0.633	1.064076	0.0007485	3.61045	13.71558
Kopper (wire), 100kg	154	0.47	0.031	0.000371	2.57E-05	0.34752	0.305106
Aluminium extrusion,200kg	249	1.60	0.073	0.001814	0.000125	0.05687	1.205174
total:	13965	203.59	5.194	1.07663	0.004569	82.04704	183.5121
Trailer:							
Steel, 4800kg	5011	24.34	1.488	0.002569	0.002828	57.36707	21.99757
Aluminium, 653kg	8031	83.43	1.845	0.00014	1.45671E-06	2.59986	96.92694
Wood, 306kg	89	0.67	0.086	2.29E-05	1.78E-07	0.50473	0.267025
SBR I, 2300kg	2907	56.32	3.871	0	0	14.06799	6.51073
Machining, 4800kg steel	265	1.70	0.078	0.001929	1.33E-04	0.06049	1.281866
total	13689	115.79	3.886	0.00466	0.002963	61.93897	121.1245
TOTAL Truck+ Trailer	32546	414.16	15.595	1.08129	0.007532	167.6569	315.5916

Multiplier (Euro/kg)	0,114	6,4	3,05	680	12,3	3/0,398	12,3
Poll.Prev.costs (Euro)	3710	2650	48	735	0	1264	3881
Total pollution prevention costs: 12289 (Euro) or 0,012 (Euro/km)							

Table I.a. Pollution prevention costs for the materials of a truck+trailer, net 24 tons.
Weight of materials in the first column are derived from (Kuhndt, 1999), (Bos, 1998) and (Brantjes, 1999).The classification/characterization results derived from Simapro.

	Weight	Raw material (Euro/kg)	Eco-costs of materials depletion (Euro)
Aluminium	300 + 653kg	1.40	1334
Copper	100kg	1.90	190
Steel	6000 + 4800kg	0.30	3240
PVC	500kg	0.60	300
Wood	306kg	0	0
Total Eco-costs of materials depletion: 5064 (Euro) or 0.005 (Euro/km)			

Table I.b. Eco-costs of materials depletion of a truck+trailer, net 24 tons.

	added value	EVR	eco-costs	eco-costs
assembling	80,000 Euro	0.14	11,200 Euro	0.011 (Euro/km).
distribution(dealer network)	45,000 Euro	0.15	7,000 Euro	0.007 (Euro/km)
End-of-life	<1,000 Euro	<1	<1,000 Euro	negligible

Table I.c. Eco-costs of assembling, distribution and EoL of a truck+trailer, net 24 tons.

Annex II

Detailed environmental data on the LCA of a forklift truck.

all data in kg	greenhouse kg CO2 equ.	acidification kg SO4 eq.	eutroph. kg PO4 eq	hv. metals. kg Pb equ.	Carcin. kg B(a)P eq	s. smog kg ethene eq	w.smog kg SPM eq
steel, 2250kg	2348	11.4	0.697878	0.001204	0.001326	26.89	10.31
lead, 1200kg	2463	56.6	0.724112	0.000431	4.48E-06	0.43	49.56
Sulfuric acid,2800kg	251	73.5	0.448669	0.004903	0.000822	0.24	0
SBR I, 90kg	113	2.2	0.151509	0	0	0.55	0.25
Copper, 50kg	376	54.0	0.165524	7.07E-06	4.74E-08	0.01	53.19
castwork, 1000kg	1662	8.2	0.422291	0.709384	0.000499	2.40	9.14
machining, 1250kg	69	0.4	0.020457	0.000502	3.48E-05	0.01	0.33
copperwire, 50kg	77	0.2	0.015651	0.000185	1.28E-05	0.17	0.15
total:	7363	206.8	2.646091	0.716618	0.002699	30.73	122.95

Multiplier (Euro/kg)	0,114	6,4	3,05	680	12,3	3/0,398	12,3
Poll.Prev.costs (Euro)	839	1323	8	487	0	232	1512
Total pollution prevention costs '99: 4403 (Euro) or 0,18 (Euro/hour)							

Table II.a. Pollution prevention costs for the materials of a forklift truck.

Weight of materials in the first column are derived from (Brantjes, 1999).

The classification/characterization results derived from Simapro.

	Mass	Eco-costs (Euro/kg)	Eco-costs of materials depletion (Euro)
Steel	2250 kg	0.30	675
Copper	50 kg	1.90	95
Lead	1200 kg	0.55	660
Plastic	40 kg	0.60	24
Total Eco-costs of materials depletion: 1454(Euro) or 0.058 (Euro/hour)			

Table II.b. Eco-costs of materials depletion of a forklift truck.

	added value	EVR	eco-costs	eco-costs
assembling	13,000 Euro	0.2	2,600 Euro	0.10 (Euro/hour)
distribution(dealer network)	7,000 Euro	0.15	1,000 Euro	0.04 (Euro/hour).
End-of-life costs	<500 Euro	<1	<500 Euro	negligible

Table II.c. Eco-costs of assembling, distribution and EoL of a forklift truck.

Annex III

Detailed environmental data on the LCA of a warehouse of 920 pallets.

all data in kg	greenhouse kg CO2 equ	acidification kg SO4 equ	eutroph. kg PO4 eq	hv. metals kg Pb equ	carcin kg B(a)P eq	s. smog kg ethene eq	w.smog kg SPM eq
Concrete, reinforced, 551200kg	59629	484.6	51.0744	0.4563	0.015109	21.37	6489.65
Fe360, 51000kg	58271	708.1	63.6528	1.0514	0.034922	31.61	427.33
steel sheet, 22000kg	38585	214.4	12.0904	0.1228	0.020775	266.56	175.94
PS, 40kg	164	0.2	0.03811	0	2.16E-07	0.2013	0.15
PS foaming, 40kg	222	3.3	0.07492	0.0043	0.000722	0.82	0
steel transforming, 22000kg	1449	9.6	0.44312	0.0108	0.000753	0.34	7.23
steel transforming, 51000kg	3475	22.3	1.02724	0.0252	0.001745	0.79	16.76
Total:	161798	1442.9	128.40	1.6711	0.074026	321.71	7117.08

Multiplier (Euro/kg)	0.114	6.4	3.05	680	12.3	3/0.398	12.3
Poll.Prev.costs (Euro)	18445	9235	392	1136	1	2425	87540
Total pollution prevention costs '99: 119173 (Euro) or 5.18 (Euro/pallet per year)							

Table III.a. Pollution prevention costs for the materials of an unconditioned warehouse, 920 pallets.

Weight of materials in the first column are derived from (Brantjes, 1999).

The classification/characterization results derived from Simapro.

Warehouse (920 pallets)	Weight (kg)	Eco-costs (Euro/kg)	Eco-costs of materials depletion (Euro)
Steel for structure	51000	0.30	15300
PS-foam	40	0.60	24
Steel in concrete	22000	0.30	6600
Steel for cladding	22000	0.30	6600
Total Eco-costs of materials depletion: 28524 (Euro) or 1.2 (Euro/pallet per year)			

Table III.b. Eco-costs of materials depletion of an unconditioned warehouse, 920 pallets.

	added value	EVR	eco-costs	eco-costs
Construction (unconditioned wh)	360,000 Euro	0.2	72,000 Euro	3.1 (Euro/pallet per year).
End-of-life	negligible	<1	negligible	negligible

Table II.c. Eco-costs of the construction and EoL of an unconditioned warehouse, 920 pallets.

Data: (Brantjes, 1999, (De Jonge, 2004)

Annex IV

Environmental data on Kraftliner (from European Database FEFCO, 2003)

Name	Kraftliner FEFCO 2003			**eco-costs (€)**		
Time period	2000-2004					
Geography	Europe, Western					
Technology	Average technology					
Date	16/03/2004					
Record	A de Beaufort					
Products						
FEFCO Kraftliner 2003	1	kg	100 % Cardboard Paper+ Board\FEFCO			
Avoided products						
Heat oil (S,EU) B250	0.59	MJ	Represents thermal energy as a sold byproduct	0.004838		
Electricity UCPTE B250	0.007	MJ		0.000137		
subtotal					-0.00497	
Resources (ecocosts of fossil fuels included in ecocosts of CO2)						
biomass (fuel)	0.68	MJ	biofuel			
Materials/fuels						
Natural gas B300	0.01967	kg	0,9(MJ)*0,8(kg/m3)/36,6(MJ/m3)			
Oil heavy B300	0.0425	kg	1,7(MJ)/40(MJ/kg)			
Oil light B300	0.0006	kg	0,027(MJ)/42,7(MJ/kg)			
Diesel B300	0.000187	kg	0,008(MJ)/42,7(MJ/kg)			
Starch	9.5	g			0.002184	
Electricity/heat/transport						
Truck 40t B250	0.257	tkm		0.01028		
Train (diesel & electric) B250	0.167	tkm		0.00167		
Sea ship B250	0.309	tkm		0.00309		
Truck 40t B250	0.015	tkm		0.0006		
Train (diesel & electric) B250	0.112	tkm		0.00112		
Sea ship B250	0.024	tkm		0.00024		
Electricity UCPTE B250	2.3	MJ		0.044965		
subtotal					0.061965	
Emissions to air						
dust	0.45	g	unknown particle size	0.005535		
CO2	201	g	fossile	0.022914		
SOx (as SO2)	0.58	g		0.003712		
S	0.05	g	TRS (H2S as S)	0.000569		
NOx (as NO2)	1.3	g		0.005824		
Emissions to water						
N-tot	0.13	g		0.000167		
P-tot	0.016	g		0.000149		
Solid emissions						
slags/ash	6.6	g	inorganic ashes			
organic waste	1.1	g	organic sludges other			
anorganic waste	5.7	g	inorganic sludges			
rejects	0	g	paper related landfill			
rejects	9.5	g	other landfill			
wood	12.8	g	bark, wood			
steel packaging	0	g	steel and iron			
inorganic general	2.3	g	calcium carbonate			
total solid emissions	25.2	g		0.00252		
subtotal emisssions					0.04139	
TOTAL ECO-COSTS (€)						**0.100564**

Annex V

Environmental data on Semichemical Fluting (from European Database FEFCO, 2003)

Name	Semichemical Fluting 2003 FEFCO			eco-costs (€)		
Time period	2000-2004					
Geography	Europe, Western					
Technology	Average technology					
Date	16/03/2004					
Record	A de Beaufort					
Products						
FEFCO SemichemFluting	1	kg	100 % Cardboard Paper+ Board\FEFCO			
Avoided products						
Electricity UCPTE B250	0.083	MJ		0.001623		
Heat oil (S,EU) B250	0.59	MJ	a sold byproduct	0.004838		
subtotal					-0.00646	
Resources (ecocosts of fossil fuels included in ecocosts of CO2)						
biomass (fuel)	0.66	MJ	bark, biofuel, wood chips			
unspecified energy	2.5	MJ	peat			
Materials/fuels						
Natural gas B300	0.031	kg	1,4(MJ)*0,8(kg/m3)/36,6(MJ/m3)			
Oil heavy B300	0.0425	kg	1,7(MJ)/40(MJ/kg)			
Oil light B300	2.34E-05	kg	0,001(MJ)/42,7(MJ/kg)			
Coal B300	0.044	kg	1,3 (MJ)/29,3 (MJ/kg)			
Crude lignite	0.047	kg	0,38 (MJ)/8,1 (MJ/kg)			
Diesel B300	0.0004	kg	0,018(MJ)/42,7(MJ/kg)			
Sulfur	12.9	g			0.012	
Electricity/heat/transport						
Truck 40t B250	0.116	tkm		0.00464		
Train (diesel & electric) B250	0.182	tkm		0.00182		
Sea ship B250	0.156	tkm		0.00156		
Truck 40t B250	0.009	tkm		0.00036		
Train (diesel & electric) B250	0.018	tkm		0.00018		
Sea ship B250	0	tkm		0		
Electricity UCPTE B250	1.7	MJ		0.033235		
subtotal					0.041795	
Emissions to air						
dust	0.55	g	unknown particle size	0.006765		
CO2	518	g	fossile	0.059052		
CO2 (non-fossil)	563	g	biomass			
CO	0.78	g				
SOx (as SO2)	2.9	g		0.01856		
S	0.12	g	TRS (H2S as S)	0.001365		
NOx (as NO2)	1.6	g		0.007168		
Emissions to water						
N-tot	1.3	g		0.001665		
P-tot	0.028	g		0.000261		
NH4+	1.3	g		0.001308		
Solid emissions						
wood	58	g	bark, wood			
slags/ash	23.2	g	inorganic ashes			
organic waste	17.5	g	organic sludges other			
anorganic waste	3	g	inorganic sludges			
rejects	5	g	paper related landfill			
rejects	8.2	g	other landfill			
subtotal solid emissions	56.9	g		0.00569		
subtotal emissions					0.101835	
TOTAL ECO-COSTS (€)						**0.14917**

Annex VI

Environmental data on Converting (from European Database FEFCO, 2003)

Name	Corrugated Board FEFCO		**eco-costs (€)**		
Time period	2000-2004				
Geography	Europe, Western				
Technology	Average technology				
Date	16/03/2004				
Record	A de Beaufort				
Products					
FEFCO Corrugated Board	1 kg	100 % Cardboard Paper+ Board\FEFCO			
Resources (ecocosts of fossil fuels included in ecocosts of CO2)					
Materials/fuels					
Heat gas B250	0.038 MJ	bought steam			
Natural gas B300	0.0179 kg	0,82(MJ)*0,8(kg/m3)/36,6(MJ/m3)			
Oil heavy B300	0.00375 kg	0,15(MJ)/40(MJ/kg)			
Oil light B300	0.0017 kg	0,073MJ)/42,7(MJ/kg)			
Diesel B300	0.000375 kg	0,016(MJ)/42,7(MJ/kg)			
Crude LPG	0.00137 kg	0,063(MJ)/46(MJ/kg)			
Starch	26.1 g			0.006	
Electricity/heat/transport					
Electricity UCPTE B250	0.42 MJ		0.008211		
Heat gas B250	0.038 MJ		0.00019		
subtotal				0.008401	
Emissions to air					
dust	0.011 g	unknown particle size	0.0001353		
CO2	66 g	fossile	0.007524		
CO2 (non-fossil)	0 g	biomass			
SOx (as SO2)	0.19 g		0.001216		
NOx (as NO2)	0.27 g		0.0012096		
Emissions to water					
N-tot	0.02 g	data 2000 (2003 na)	0.00002562		
Cu	0.00052 g				
Zn	0.00052 g				
	0.00104		0.0007072		
Solid emissions					
wood	0.91 g	bark, wood			
organic waste	5.5 g	organic sludges other			
chemical waste	0.92 g	ink residue, data 2000, 2003: 0			
steel scrap	0.4 g	steel and iron			
plastics packaging	0.56 g	plastics			
other waste	1.8 g	starch, glue (wet weight)			
subtotal solid emissions	10.09 g		0.001009		
subtotal emissions				0.011827	
TOTAL ECO-COSTS (€)					**0.026228**

Note: in the calculations the following materials have been applied for corrugated board trays:

- kraftliner 58.6 %
- semichemical fluting 41.4%