Introduction

This report presents the life cycle environmental profile of two liquid food packaging systems:

- Tetra Brik Aseptic (TBA) packaging system with apple juice (TBA/juice)
- Tetra Brik (TB) packaging system with milk (TB/milk)

The report is based on an update of two life cycle assessment (LCA) studies performed by Chalmers Industriteknik (Ryberg, 1999; Rydberg et al., 1995). Oestfold Research Foundation performed the update during 1999.

The main objectives of these LCA studies were to:

- Identify and evaluate the relative environmental importance of different process steps in the investigated liquid food packaging systems.
- Provide information on where Tetra Pak should focus to efficiently allocate resources to reduce the environmental impact.

The LCA studies were based on input data that aimed to reflect different geographical regions. The TBA/juice system was based on European average data whereas the Tetra Brik (TB) packaging system with milk (TB/milk) was based on Swedish data sets.

This report is directed towards non-LCA experts and therefore it focuses on a general presentation of the liquid food packaging systems and their environmental profiles rather than to document the complete LCA methodology and calculation process.

Life cycle assessment (LCA): involves a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO, 1997). The life cycle of a product system covers the whole chain from raw material extraction via processing and transport steps to consumption and waste management. LCAs may be useful in giving a systematic overview of the potential environmental impact of a product system and in helping manufacturers identify areas for improvement. LCAs always involves simplifications and assumptions, which must be taken into account when LCA results are used to support a decision making process. For further reading on LCA methodology, see Appendix A.

Description of the packages and packaging systems

The Tetra Brik Aseptic and Tetra Brik packages

The Tetra Brik Aseptic (TBA) and Tetra Brik (TB) packages have a laminate structure (Figure 1). The most apparent difference between the different laminate structures is the presence of aluminium foil in the aseptic TBA package, which efficiently protects the food product from light and oxygen. The weight specifications for the main materials of both packages are shown in Table 1.

Table 1: Material specification of 1-litre TBA and TB packages.

	TBA	TB
Board *g (%)*	19.8 (74)	19.9 (80)
Polyethylene *g (%)*	5.5 (21)	5.0 (20)
Aluminium *g (%)*	1.4 (5)	-
Total weight *g*:	26.7	24.9

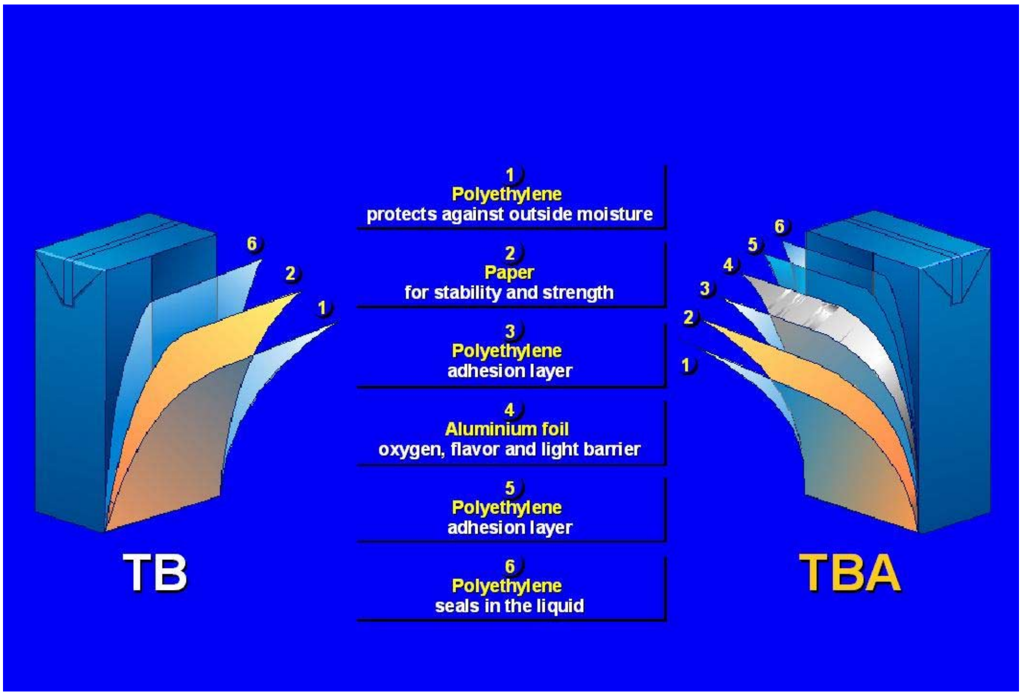

Figure 1: Laminate structure of the TB and TBA packaging materials.

Packaging systems

The scope of the LCAs performed in the TBA/juice and TB/milk case studies is schematically displayed in Figure 2 and 3. The process trees display the main process steps from primary materials, including the food product, to the waste management phase. Transportation between process steps is included, but not displayed in the diagrams.

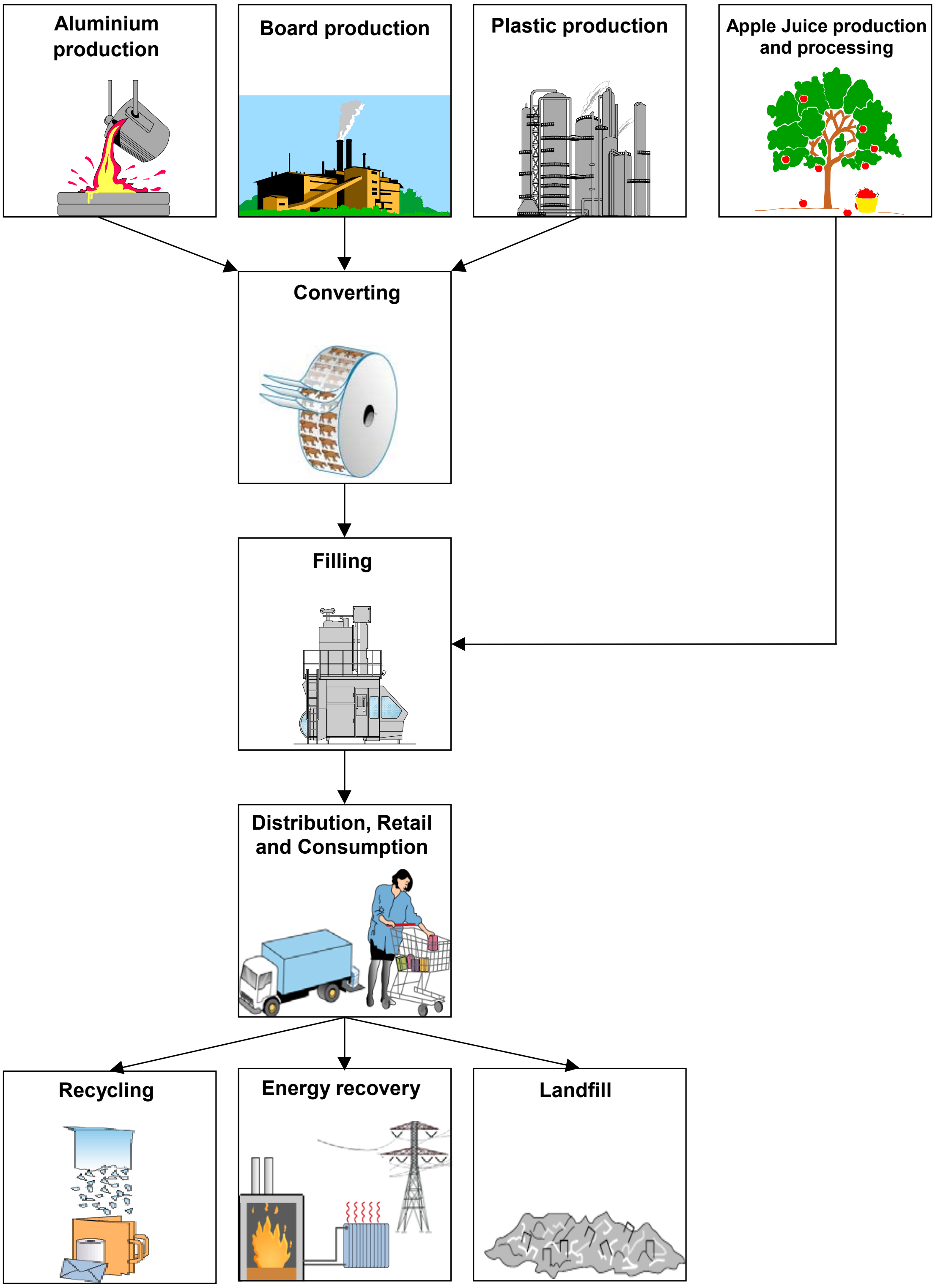

Figure 2: Main process steps of the TBA/juice system. Transport steps are not displayed.

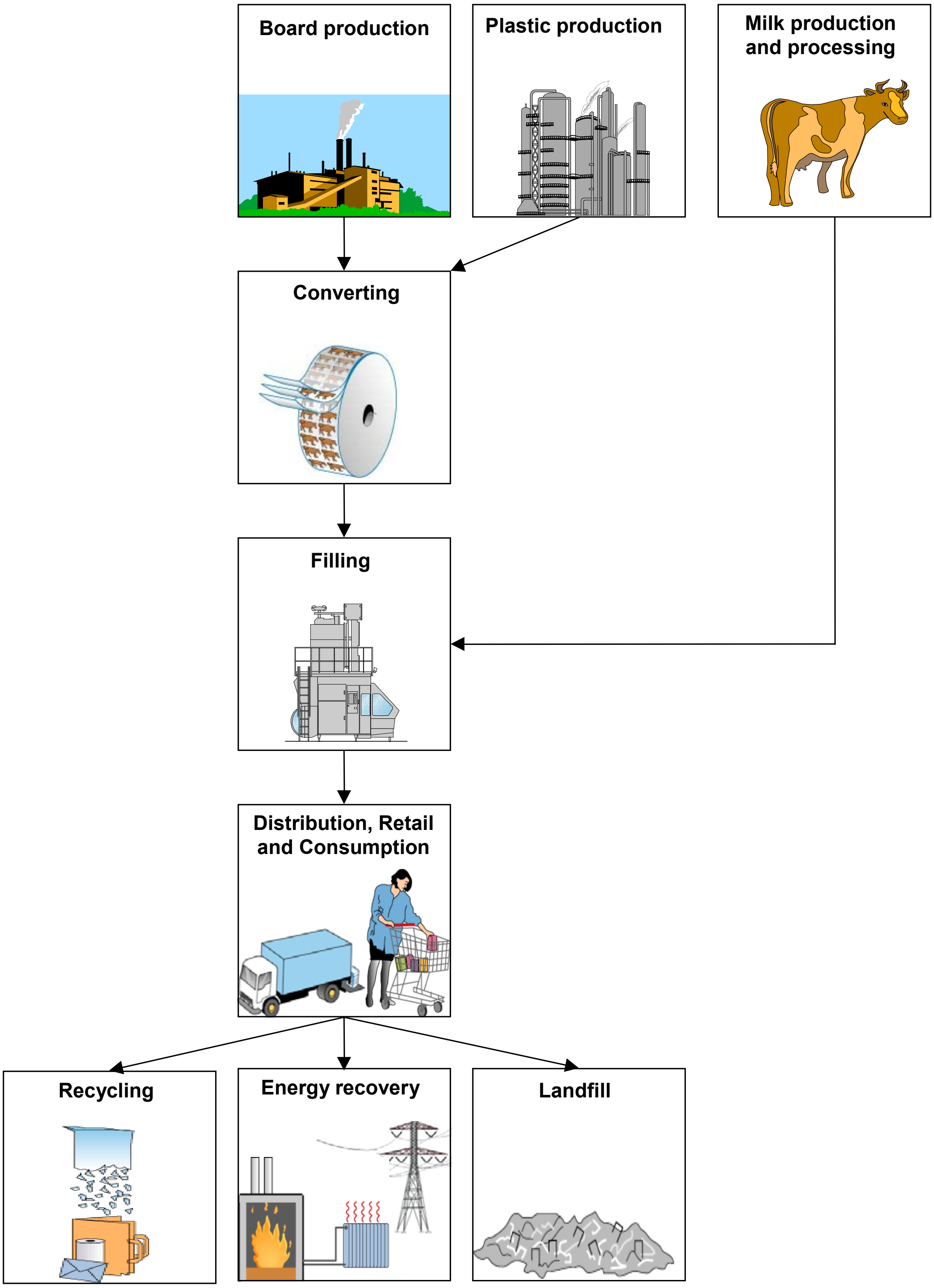

Figure 3: Main process steps of the TB/milk system. Transport steps are not displayed.

Table 2: Description of the TBA/juice and TB/milk systems. The information sources used in each process step are listed in Appendix C.

<table>
<tr><th>TBA/juice[1]</th><th>TB/milk[1]</th></tr>
<tr><td>Aluminium production
The raw material for aluminium is bauxite ore, which is mined and processed to aluminium oxide. Aluminium metal is produced from aluminium oxide by an electrolytic process. Aluminium from the smelters is cast into ingots for rolling of aluminium foil. The aluminium foil is transported to the converting factories by truck.</td><td>NOT APPLICABLE</td></tr>
<tr><td colspan="2">Board production[2]
Wood is processed to pulp which is used to make the paperboard. The board in the TBA/juice system is a clay coated Duplex, which means that it has a bleached outer layer and is coated with clay to improve the printing quality. The board in the TB/milk system is a standard Duplex without clay coating. The board is transported to the converting factories by truck.</td></tr>
<tr><td colspan="2">Plastic production
The raw material for the low-density polyethylene (LDPE) is oil and natural gas. The oil and gas undergo a series of processes (refining, cracking, polymerisation) to produce the LDPE granulate. The LDPE granulate is transported to the converting factories by truck.</td></tr>
<tr><td>Apple Juice production and processing
This step includes growing and harvesting of apples, the production of juice concentrate, dilution, pasteurisation and transport.</td><td>Milk production and processing[3]
This step includes plant husbandry (including fertilisers), animal husbandry, milk processing and transport.</td></tr>
<tr><td colspan="2">Converting[4]
Tetra Pak converting factories use paperboard, aluminium foil (TBA package only), polyethylene (LDPE) and ink to produce the packaging material. The paperboard is printed (production of ink is not included), laminated with LDPE and aluminium foil (TBA package only), and then slit into rolls. The packaging material rolls are delivered to the customer by truck.</td></tr>
<tr><td colspan="2">Filling[4]
At the customer site, Tetra Pak's filling machines make the cartons from the rolls of packaging material and fill the cartons with the juice/milk.</td></tr>
</table>

[1] *The functional unit (ISO, 1997) was set to 100 litres of food product delivered to the consumers in 1 litre packages.*

[2] *Biological resources are assumed not to give a net contribution of CO_2 emissions.*

[3] *85% of the environmental loads of the milk and meat production are allocated to milk production. This is a 'biological allocation', which is based on the relationship between the fodder input and outputs of milk and meat.*

[4] *The wastage rate of packaging material in the converting step was based on an average from 13 Tetra Pak factories in Europe in 1998. The waste of packaging material in the converting and filling step as well as the waste of food product in the filling step yields a need of extra production of these entities. The potential environmental impacts associated with this extra production were allocated to the converting and filling steps respectively and not to the primary production of packaging material and food products. Disposal of the packaging material waste in the converting and filling steps were not included in the study.*

Distribution, Retail and Consumption[5]	**_Distribution, Retail and Consumption_**[5]
The filled TBA packages are packed in cardboard trays and delivered to the retailers by truck. Refrigerating is not required. The retail step was excluded in the assessment. Fibres from secondary packaging are assumed to be recycled used in production of testliners. The packages are transported by car to the consumer for consumption.	The filled TB packages are transported in returnable steel roll containers to the retailers by truck. Refrigerating is required. The retail step was excluded in the assessment. The packages are transported by car to the consumer for consumption.
Recycling[6] Beverage cartons are collected and transported to a paper mill by truck. In a re-pulping process the paperboard fibres are separated from the plastic and aluminium foil (TBA/juice only). The recovered fibres are assumed to replace production of virgin pulp. A fraction of the reject, i.e. residual fibres, plastic and aluminium (TBA/juice only) is assumed to be incinerated thereby replacing other energy sources. The remaining reject is assumed to be landfilled.	
Energy Recovery[6] Beverage cartons are sent to an incineration plant by truck. The incinerator produces heat and power, which is assumed to replace energy and heat that otherwise would have had to be generated by other means.	
Landfill[6] Beverage cartons are sent to a landfill site by truck where they are assumed to partly decompose thereby contributing to the release of methane - a greenhouse gas. A fraction of the methane is assumed to be used for energy generation, thereby replacing other energy sources.	

[5] *Waste of packaging material and food product in the retail and consumption parts of the life cycle were excluded in the LCA studies. The food product, including packaging, is assumed to constitute 2 kg of a total of 20 kg grocery shopping for transport to the household. Thus 10% of the transport is allocated to the liquid packaging systems studied.*

[6] *The waste management was split between recycling, energy recovery and landfill according to:*

- ***TBA/juice**: 33% recycling, 33% energy recovery and 33% landfill*
- ***TB/milk**: 30% recycling, 40% energy recovery and 30% landfill*

***TBA/juice.** The split was chosen mainly to facilitate comparison of different waste management options but also because the total recovery rate approximately corresponds to the maximum target set in the European Parliament and Council Directive 94/62 on Packaging and Packaging Waste (The European Parliament and the Council of the European Union, 1994). In 1998 the actual rates of material recycling and energy recovery for beverage cartons in Europe were 21% and 18% respectively (ACE, 1999).*

In the TBA/juice system the 50% of the reject from the recycling process was assumed to be incinerated in a cement kiln thereby replacing hard coal, which was set to be the normal energy source. The energy recovery process of beverage cartons was assumed to replace energy sources based on natural gas and oil. In the landfill, 8.5% of generated methane was assumed to be used for energy generation, which was assumed to replace European average electricity.

***TB/milk.** The split approximately mirrors the Swedish situation in 1996 (Almgren, 1996).*
In the TB/milk system the energy released from incinerating 20% of the reject was assumed to replace Swedish district heat. The energy recovery process of beverage cartons was assumed to replace Swedish district heat. In the landfill, 28% of generated methane was assumed to be used for energy generation which was assumed to replace Swedish district heat.

Environmental profiles

The environmental profiles of the liquid food packaging systems studied are displayed graphically in Figure 4-7. The figures show the relative contribution of each main process steps to a number of impact categories. These impact categories represents *potential* environmental impacts and not the *actual* impacts, which take place in the ecosystems. The impact categories are:

- Global Warming Potential (GWP)
- Acidification Potential (AP)
- Total renewable and non-renewable energy use (Energy)
- Abiotic resource depletion (Resources)
- Eutrophication Potential (EP)
- Photochemical Ozone Creation Potential (POCP)
- Non-hazardous waste (Waste)

The 'Waste' impact category does not represent a potential environmental impact per se but is an indicator of the amount (weight) of material sent to landfill. A more detailed explanation of the different impact categories is available in Appendix B.

The relative potential environmental impacts of each process step are expressed as the percentage contribution to the total environmental impact. Most process steps give a positive contribution to the total environmental impact whereas the waste management steps *may* yield net credits for some impact categories, i.e. reduce the total environmental impact. These credits show as negative contribution in the figures. However, the sum of the results for each impact category adds up to the total environmental impact for the life cycle, i.e. 100%. As a result, the relationships between process steps are *only comparable within* each figure.

The results are presented both with and without the potential environmental impacts of the food product. This facilitates:

- Comparison of the relative environmental importance of the production of the food product with the rest of the liquid food packaging system.
- Identification of environmental improvement areas within the packaging part of the systems.

The results where the potential environmental impacts from the production of the food product are included are presented in Figure 4 (TBA/juice) and Figure 6 (TB/milk). In addition to its production and processing the food product also affects the potential environmental impacts in the 'Filling' and 'Distribution, Retail and Consumption' steps.

The results where the food product is excluded are presented in Figure 5 (TBA/juice) and Figure 7 (TB/milk). However, the 'Filling' step *includes* potential environmental impacts associated with the wastage of the food product during this step, i.e. both the production of the extra food product needed and the treatment of the wasted food product are included in Figure 5 and 7.

It is important to acknowledge the fact that LCA results are completely dependent on how the investigated system is modelled. The results are dependent on the objective and scope of the study, the current level of understanding of the system, and availability of appropriate input data. Consequently it is possible that different LCA studies of the same liquid food packaging system yield results which are different and not comparable. It can therefore be hazardous to draw general conclusions from individual LCA studies.

Tetra Brik Aseptic including juice (TBA/Juice)

The production and processing of apple juice is the most important individual process step throughout the life cycle for a majority of impact categories (Figure 4). The importance of the apple juice is mainly explained by the fact that it constitutes approximately 97% of the combined weight of the package and food product.

Other important process steps are the manufacturing of the raw materials: aluminium foil, board and LDPE granulate. When added together the raw materials become the most important part of the life cycle for most impact categories.

'Distribution, Retail and Consumption' is as important as each individual raw material, particularly for the 'POCP' impact category.

The filling and the waste management steps are generally of less importance compared to the apple juice production and processing. However, both energy recovery and landfill of used beverage cartons are important to the 'Waste' impact category.

A more detailed analysis shows that the contribution of transport is generally less than 5% for all of the life cycle steps, except for distribution, retail and consumption where transport constitute more than 90% of the potential environmental impacts. The only other exception is transport from the converting factory to the juice filling plant, which contributes with approximately 8% to the eutrophication potential through emission of nitrogen oxide gases. Note, however, that there are transport steps included in the production of raw materials, which can not be identified from the information available.

The contribution of transport in the waste management steps varies considerably and is difficult to assess in a clear and consistent manner. This is due to the fact that the waste management steps include both processes that contribute to potential environmental impacts as well as processes which result in credits to the system.

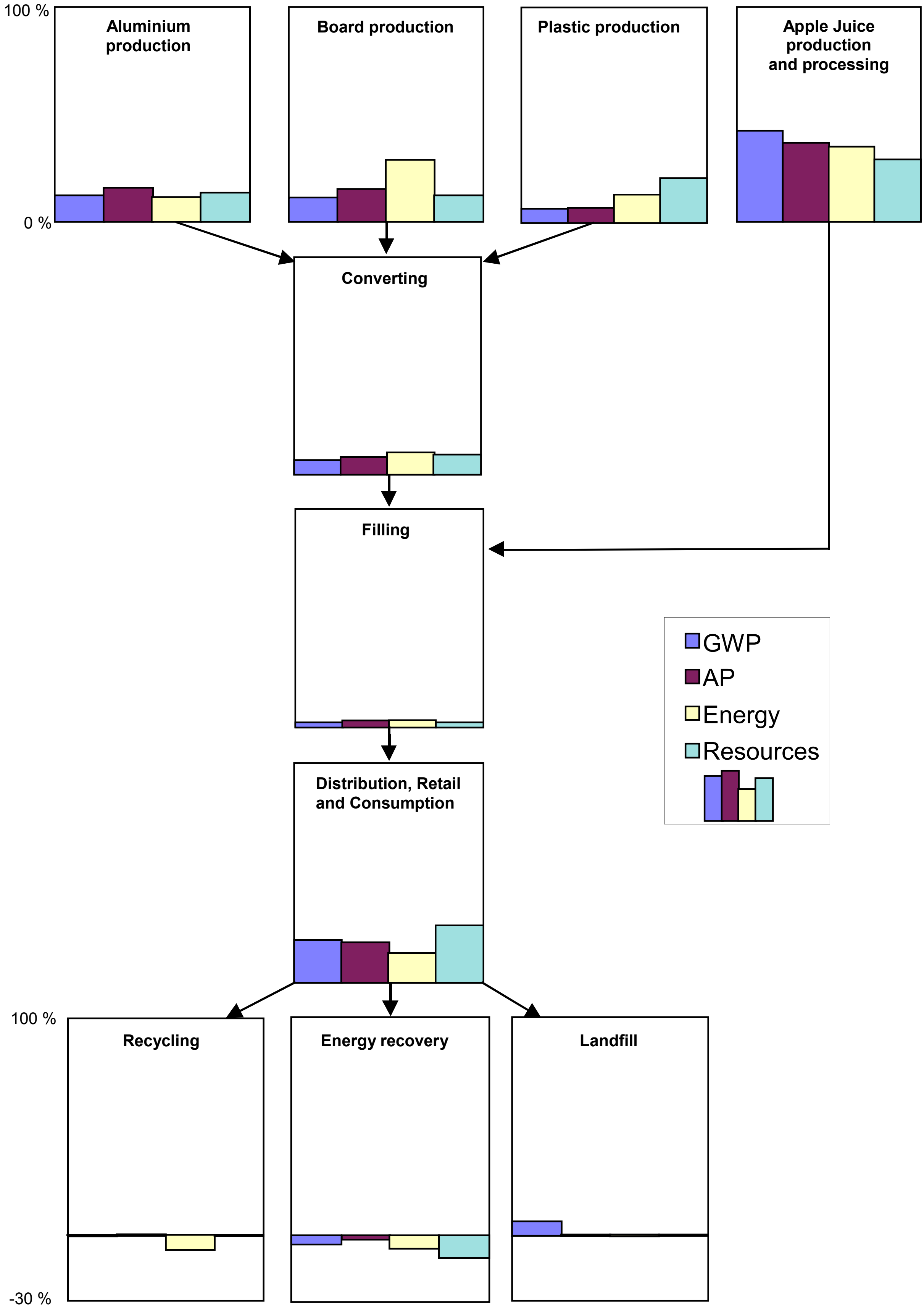

Figure 4a: Relative environmental contribution of process steps, apple juice included.

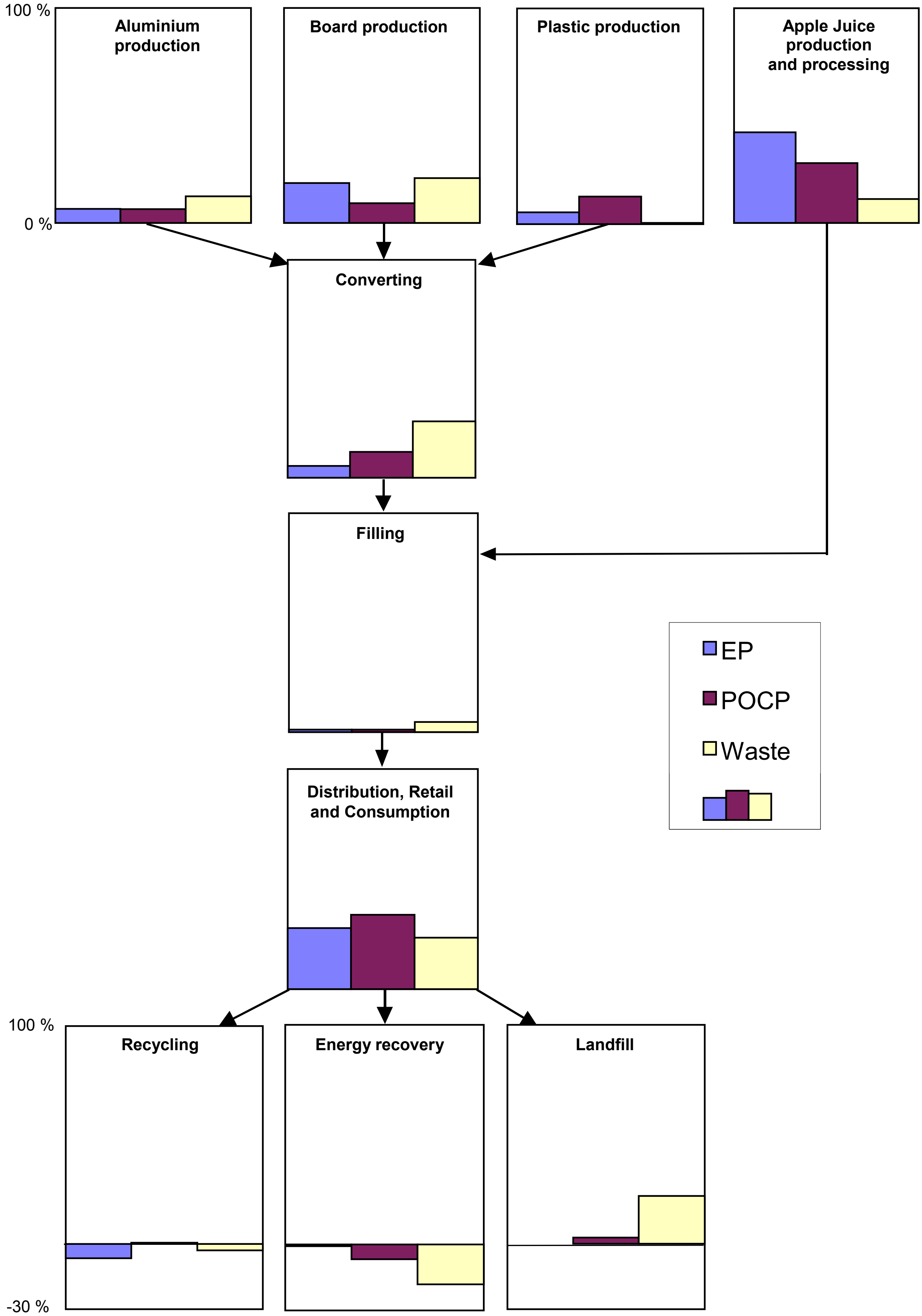

Figure 4b: Relative environmental contribution of process steps, apple juice included.

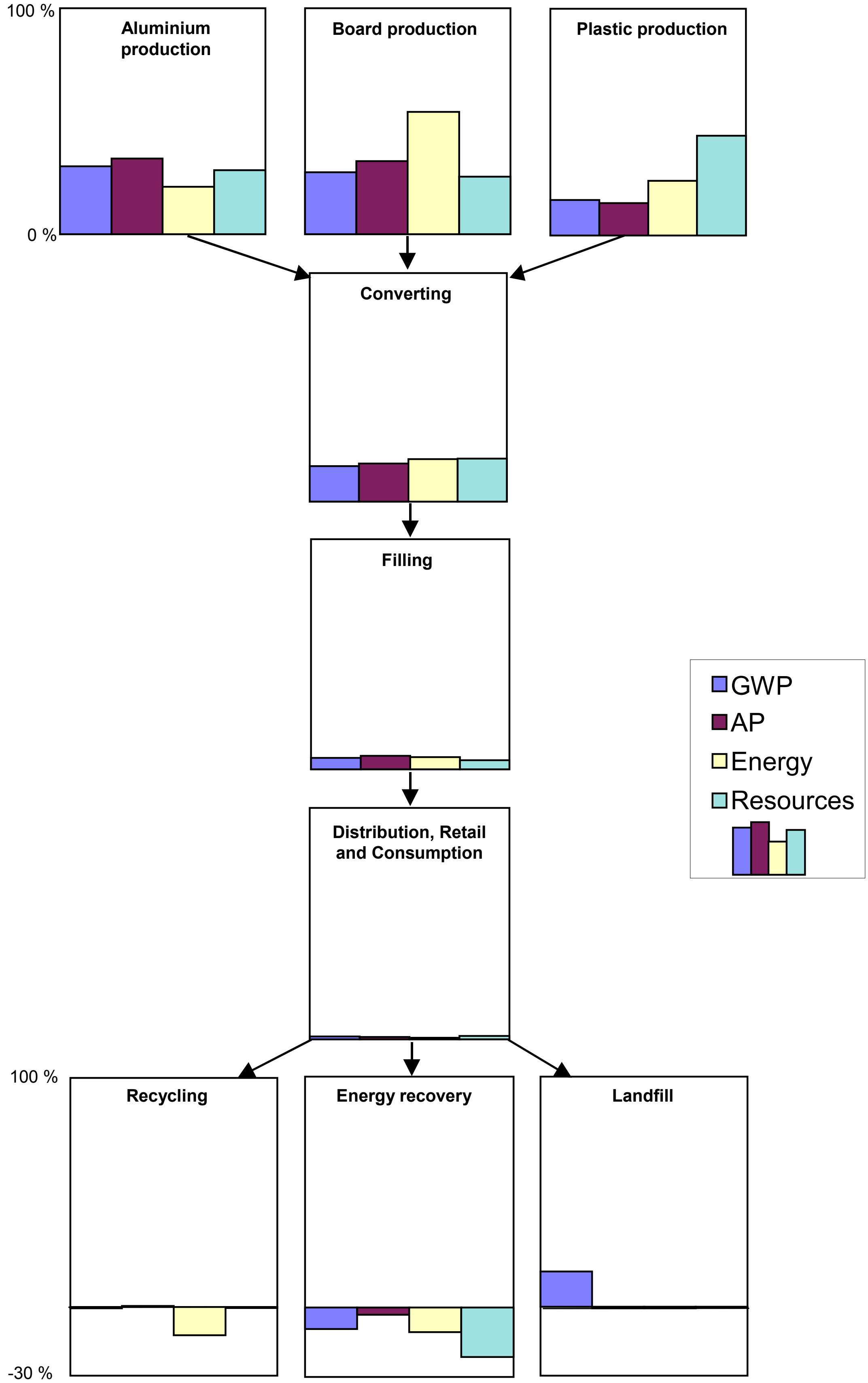

Figure 5a: Relative environmental contribution of process steps, apple juice excluded.

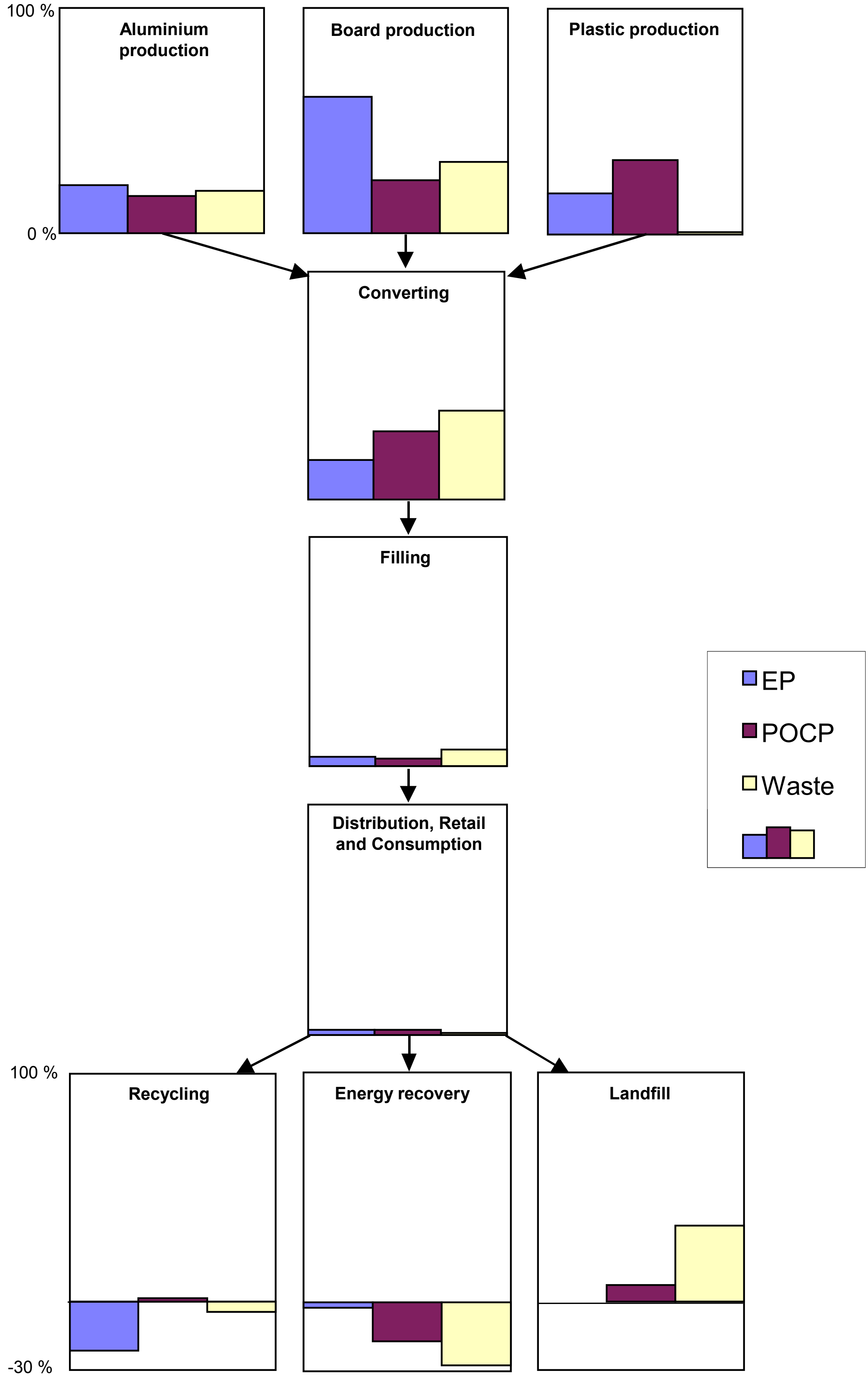

Figure 5b: Relative environmental contribution of process steps, apple juice excluded.

Tetra Brik Aseptic excluding juice production (TBA/juice)

Production of raw materials is the most important contributor to the potential environmental impacts in the life cycle (Figure 5). Despite it's relatively low weight, ca. 5% of the total package weight (Table 1), aluminium contributes significantly to the overall environmental impact. The board production is particularly important for the 'Energy' impact category and the potential eutrophication – the 'EP' impact category. However, more than 50% of the energy consumption in the board production is based on renewable fuels – derived from wood. Plastic production is particularly important for the 'Resource' impact category due to the consumption of fossil reserves (e.g. oil, coal, natural gas etc.). The importance of plastic production for the 'POCP' impact category is due to the release of hydrocarbons. Consequently it is important to consider both the amount and type of packaging material to reduce the net potential environmental impact in the raw material steps.

The 'Converting' step is also an important process step (Figure 5). The most important factor in the converting step is the converting waste of packaging material, which contributes more than 50% to each impact category. Thus reducing the wastage of packaging material is important in order to reduce the environmental impact from the converting process. However, the LCA calculation does not address the fact that the majority of the converting waste is recycled - a matter that may reduce the net environmental impact.

In the 'Filling' step energy consumption, primarily in the form of electricity, contributes the most to the potential environmental impacts. The waste of packaging material is also important in the filling step and contributes on average with 25% of the potential environmental impacts. For a given waste rate, the waste of apple juice is almost as important as the waste of packaging material. Thus reducing wastage of both packaging material and food product is important in order to reduce the environmental impact from the filling process.

The importance of the 'Distribution, Retail and Consumption' step has been significantly reduced compared with the results in Figure 4. This is because transport is the dominating factor in the 'Distribution, Retail and Consumption' step and the burdens associated with transport have been allocated on a weight basis. Thus the packaging material is responsible for less than 3% of the total environmental burdens in the 'Distribution, Retail and Consumption' step.

Both recycling and energy recovery of packaging material generally results in a net environmental credit to the system (Figure 5). This result is largely dependent on the assumptions regarding which material and energy type will be replaced by recycling and energy recovery respectively. The relatively large credit from recycling to the 'Energy' impact category is due to the fact that the half of the reject (polyethylene, aluminium and residual fibres) from the recycling process was assumed to replace hard coal and the associated environmental burdens from coal burning. The relatively large credit from recycling to the 'EP' impact category is due to the fact that the recycled fibres were assumed to replace production of virgin softwood pulp, which exhibits a relatively high eutrophication potential. The relatively large credits in the 'Energy Recovery' step are mainly due to the assumed replacement of European average electricity, which is partly based on fossil fuels.

Landfilling of used beverage cartons is important for the 'GWP' impact category. The contribution to the global warming potential is due to the amount of methane, which is assumed to be released when parts of the packaging material decompose. Of course, the mass of unrecovered cartons is reflected in the 'Waste' impact category in the 'Landfill' step.

Tetra Brik including milk (TB/milk)

The 'Milk Production and Processing' step dominates most impact categories (Figure 6). The dominance of the milk production and processing is partly explained by the fact that the milk constitutes 97% of the combined weight of the package and food product.

The importance of the 'Milk Production and Processing' step for the global warming, acidification and eutrophication potential is to a large extent due to the cattle and the cattle feed production. Processing of milk requires significant amounts of energy, which explains the relatively large importance of the 'Energy' impact category.

The 'Waste' impact category is dominated by landfill of beverage cartons and by waste of raw materials from the converting process. In reality, however, the major part of the converting waste is recycled, a matter which may reduce the potential environmental impact from the converting step. The life cycle inventory data for the 'Milk Production and Processing' step does not include data on solid waste.

A more detailed analysis shows that the contribution of transport to the impact categories studied is less than 4% for board and plastic production, and less than 7% for the production and processing of milk. Note, however, that there are transport steps included in the production of raw materials, which can not be identified from the information available. The contribution of transport in the converting step is generally less than 10% except for the global warming, acidification and eutrophication potential where transport contributes with 20-25% of the potential environmental impact. Transport contributes with 99% of the potential environmental impacts in the 'Distribution, Retail and Consumption' step.

The contribution of transport in the waste management steps varies considerably and is difficult to assess in a clear and consistent manner. This is due to the fact that the waste management steps include processes that contribute to potential environmental impacts as well as processes which result in credits to the system.

Tetra Brik excluding milk production (TB/milk)

The production of raw materials constitutes important steps for many impact categories (Figure 7). Board production dominates the 'Energy' impact category, but is to a large extent utilising renewable energy sources - mainly biomass. The utilisation of biomass as an energy source results in a relatively low contribution to the 'GWP' impact category. The board production also contributes significantly to the eutrophication potential. This is mainly due to emissions to surface waters during the production of pulp.

Despite polyethylene only constituting some 20% of the package weight (Table 1) the importance of the plastic production yields similar potential environmental impact as the board production for many impact categories. The production of polyethylene dominates the 'Resources' impact category because of the usage of fossil reserves. Polyethylene production also yields a significant contribution to 'POCP' impact category due to emissions of hydrocarbons.

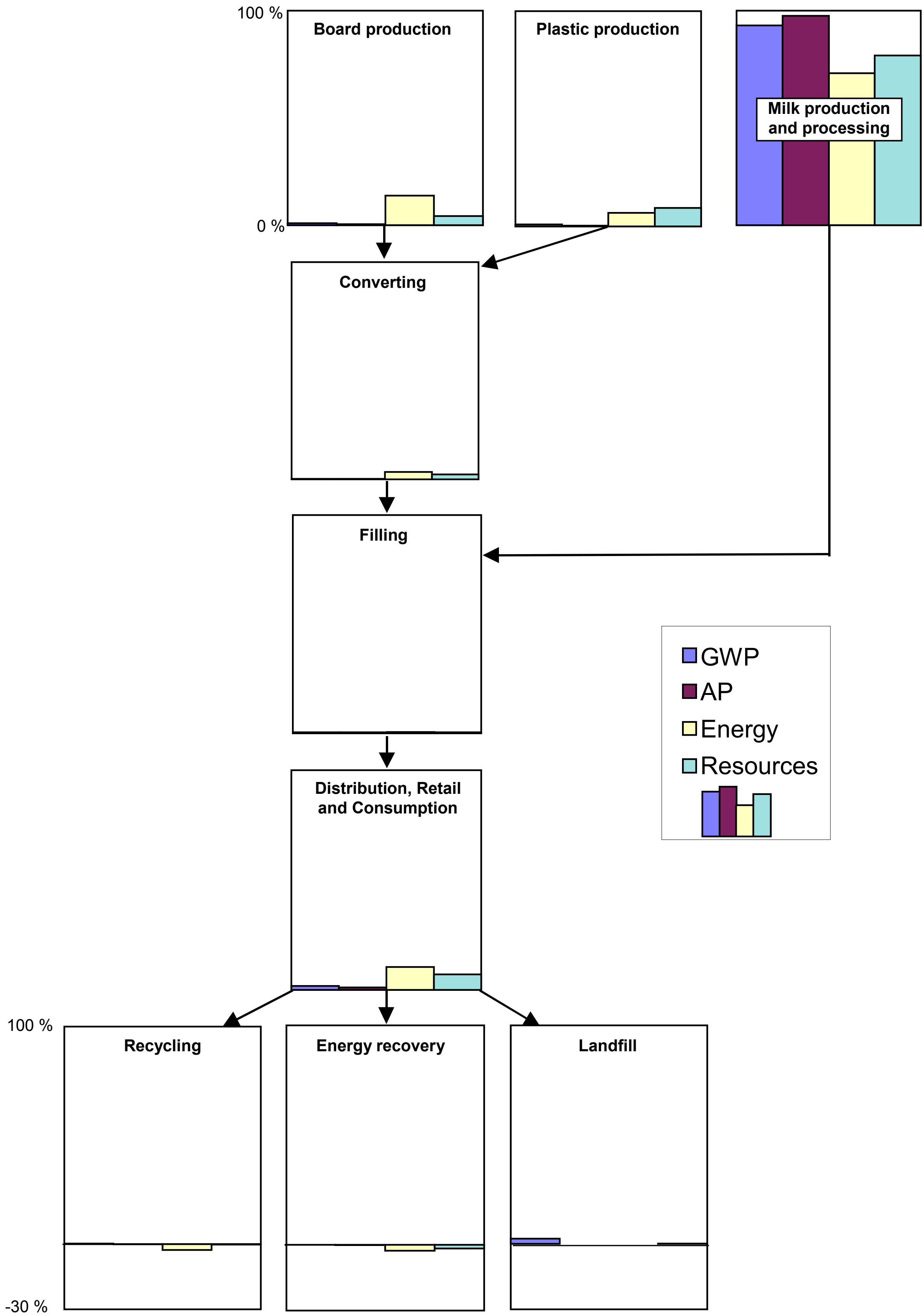

Figure 6a: Relative environmental contribution of process steps, milk included.

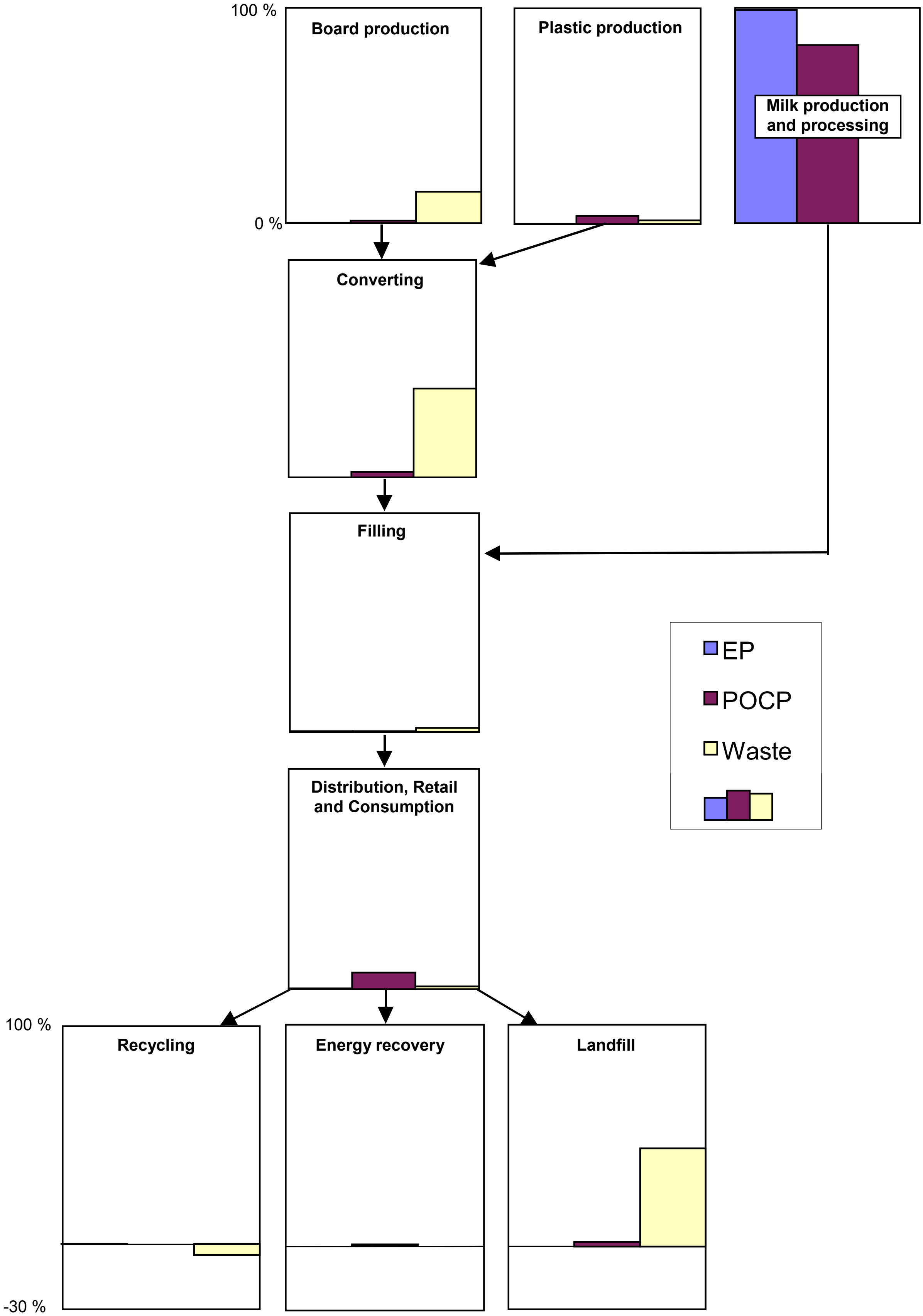

Figure 6b: Relative environmental contribution of process steps, milk included.

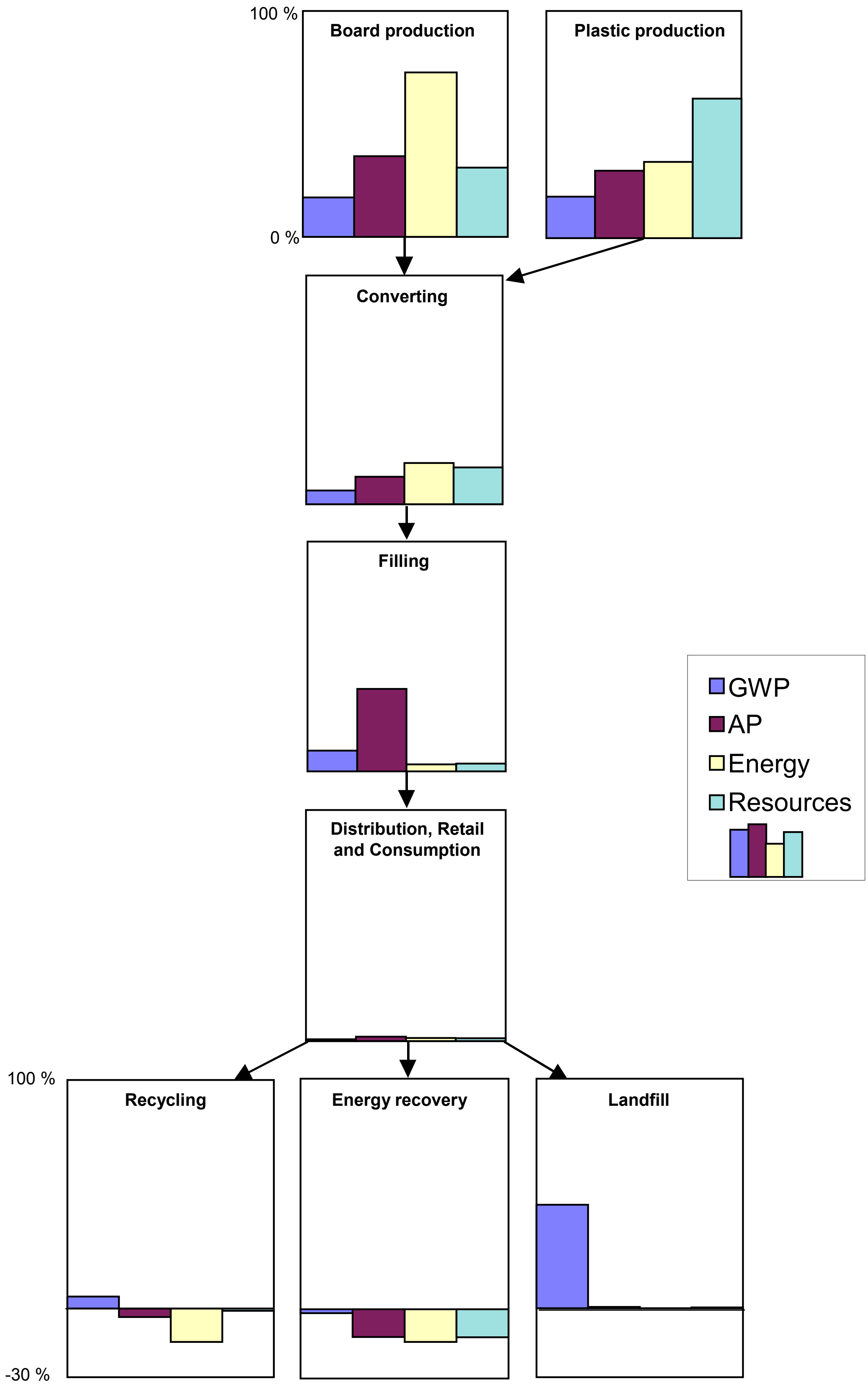

Figure 7a: Relative environmental contribution of process steps, milk excluded.

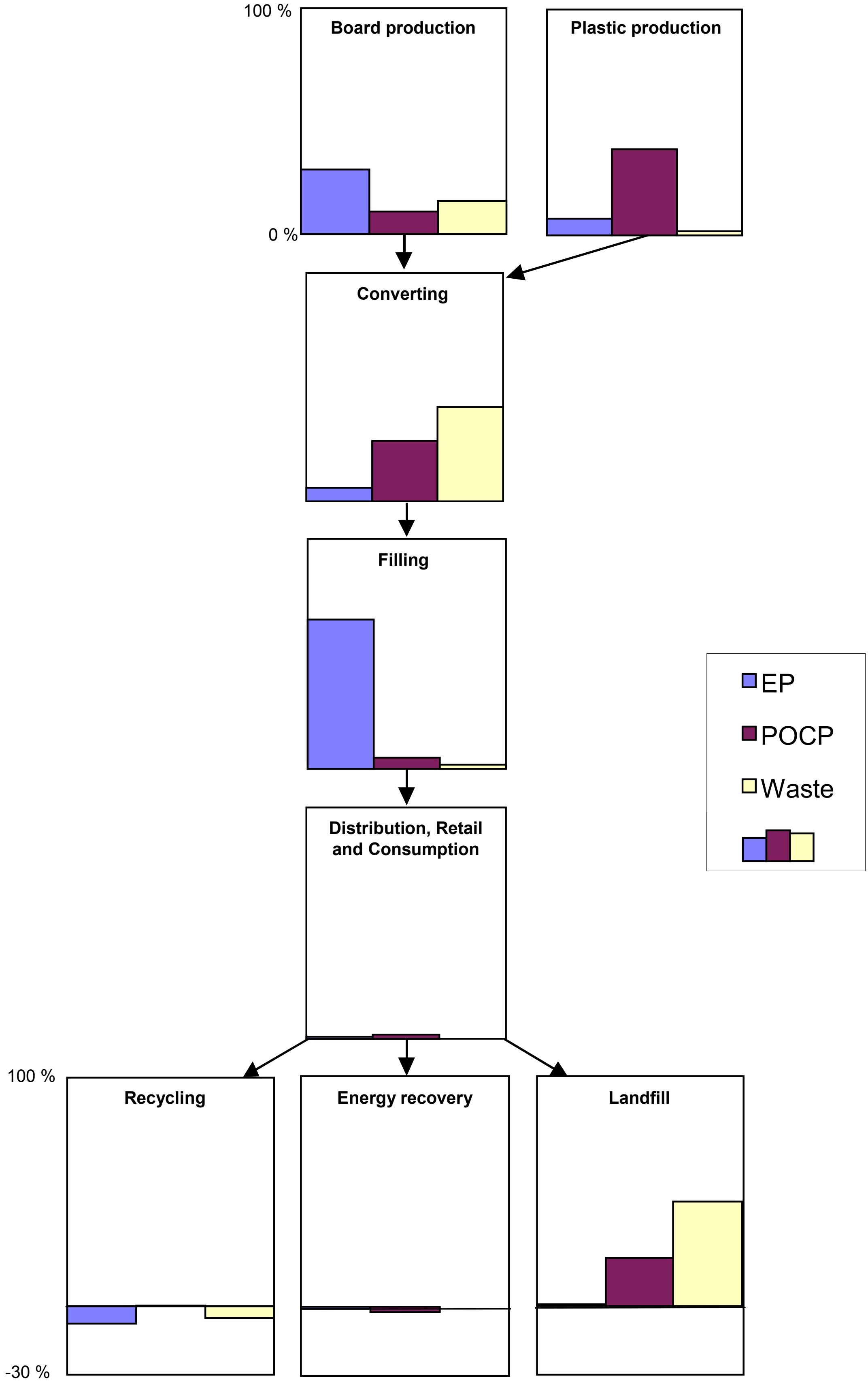

Figure 7b: Relative environmental contribution of process steps, milk excluded.

In the ‘Converting’ step the waste of raw materials is the most important contributor to the impact categories displayed. As previously stated, material losses in converting are, in reality, recycled to a large extent. Still, reducing material wastage is important in order to reduce the potential environmental impact from the converting step.

The ‘Filling’ step is particularly important for the acidification and eutrophication potential. This is due to the waste of milk in the filling line and the fact that the production and processing of milk completely dominates these two impact categories. The loss of milk in the filling line contributes with almost 99% of the acidification potential and with 65% of the eutrophication potential. In general, the waste milk is by far the most contributing factor to the potential environmental impact from the filling step. As a consequence, changes in the wastage rate of milk may have significant effects for the potential environmental impact from the filling step. Energy consumption and waste of packaging material are less important than the wasted milk, but still important for the overall potential environmental impact of the filling step.

The results for the waste management steps in this study show that both recycling and energy recovery generally result in net credits to the system, i.e. these steps reduce the total potential environmental impact of the system (Figure 7). Despite the fact that the energy content in a fraction of the released methane from the landfill is used to replace Swedish district heat, landfill of beverage cartons does not result in net credits to the life cycle.

The recycling option results in a net contribution to the ‘GWP’ impact category. The reason for this is that the used beverage cartons must be transported and processed, which require fossil based energy. Thus, despite the fact that fibres from the beverage carton were assumed to replace virgin softwood pulp, recycling does not result in a reduction of the global warming potential. Recycling would have been a more beneficial option for reducing global warming if incineration of the reject was replacing more fossil fuel intensive energy sources. The net credit in the energy impact category also indicates that the replacement of energy yields a net gain but does not affect the global warming potential to the same extent. Furthermore, recycling results in a net credit for the eutrophication potential. This is due to the assumed replacement of the production of virgin softwood pulp.

The difference in net credits between the ‘Recycling’ and ‘Energy Recovery’ steps for the ‘Resources’ impact category is mainly due to differences in the amount of fossil fuels replaced by the recycling and energy process respectively. Softwood pulp, and the associated usage of fossil fuel, is assumed to be replaced in the ‘Recycling’ step and Swedish district heat, partly based on fossil fuels, is assumed to replaced in the ‘Energy Recovery’ step. This suggests that the underlying assumptions and data regarding the replaced material and energy mix determine the outcome when comparing ‘Recycling’ and ‘Energy recovery’ options in terms of potential environmental impacts.

Landfilling of beverage cartons is the most important contributor to the global warming potential. This is due to the assumed level of methane emissions released from the landfill site as a result of decomposition of part of the packaging material. The importance of the ‘POCP’ impact category is also a result of these methane emissions. Consequently, the importance of the ‘Landfill’ step is to a large extent dependent on the assumptions regarding the decomposition of the packaging material and the collection efficiency of the released methane.

Conclusions from this study

The presented results of the potential environmental impacts for the TBA/juice and TB/milk liquid food packaging systems show that:

- The potential environmental impact of different food products varies, but dominates the environmental profile in the TB/milk system and contributes significantly in the TBA/juice system.
- Inclusion or exclusion of the food product in LCA studies of liquid food packaging systems is an important consideration as it may change the relative environmental importance of the process steps.
- The production of the raw materials, i.e. board, polyethylene and aluminium, is an important contributor to the potential environmental impact for the investigated systems.
- The waste of raw and packaging materials is the most important contributor to the potential environmental impacts from the converting process.
- The waste of both food product and packaging material in the filling step may, depending on waste rate and type of food product, dominate the environmental impacts associated with the filling process.
- Distribution of filled packages is the most significant transport step in the life cycles of the studied systems.
- The waste management processes are generally not the most significant contributors to the overall potential environmental impacts of the systems studied.
- Both material recycling and energy recovery yield environmental credits for many impact categories, which are not achieved by the landfill option.
- For the waste management scenarios studied neither the ‘Recycling’ nor the ‘Energy recovery’ options score better on all impact categories. Therefore, for these specific cases, neither option can be said to be categorically better than the other.
- For a given environmental impact category, the ranking between ‘Recycling’ and ‘Energy recovery’ is to a large extent governed by the underlying assumptions and data bases with regard to the displaced material and energy.

General recommendations

Consideration of this study, other internal Tetra Pak LCA-studies as well as a number of publicly available studies indicate areas Tetra Pak should focus on in order to reduce the potential environmental impact of liquid food packaging systems. Recommendations of actions for Tetra Pak within these areas of priority are listed below:

Food product (e.g. Andersson, 1998; Kooijman, 1996)
- Reduce loss of food product in the processing and filling processes as well as in the distribution chain.

Raw materials and energy (e.g. Bez and Goldhan, 1999; Suhr Wesnæs, 1996; Tillman et al., 1992).
- Minimise the amount of packaging material required to protect and preserve the food product.
- Reduce the waste of packaging materials in the converting and filling processes.
- Encourage reduction of environmental impacts from raw material production.
- Encourage development of packaging materials with reduced environmental impact.
- Improve the energy efficiency in the converting and filling processes.

Waste management options (e.g. Caevel De, 1997; Finnveden and Ekvall, 1998; IIED, 1996b)
- Encourage recycling and energy recovery of used beverage cartons where these provide net environmental benefits given the specific conditions applicable.
- Encourage and support development of environmentally favourable recycling and energy recovery techniques.

Transports (e.g. IIED, 1996a).
- Encourage reduction of environmental impacts from transport.

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Appendix A: Life cycle assessment – framework and methodology

Definition of Life cycle assessment (LCA)

Life cycle assessment (LCA) is a process that evaluates the environmental burdens associated with a product system, or activity. This is done by identifying and quantitatively, or qualitatively, describing the energy and material uses and releases into the environment. An LCA includes the entire life cycle of the product, or activity from 'cradle to grave' (i.e. from raw material extraction and processing, through to manufacture, distribution, use, re-use, recycling and final disposal). All transportation involved in the life cycle is also considered. LCA assesses the environmental impacts of the system in the areas of ecological systems, human health and resource depletion. It does not address economic, or social effects (Lindfors et al., 1995, Consoli, 1993).

Phases of an LCA

According to the ISO 14040 standard (ISO, 1997) life cycle assessments shall include definition of goal and scope, inventory analysis, impact assessment and interpretation of results (Figure A.1).

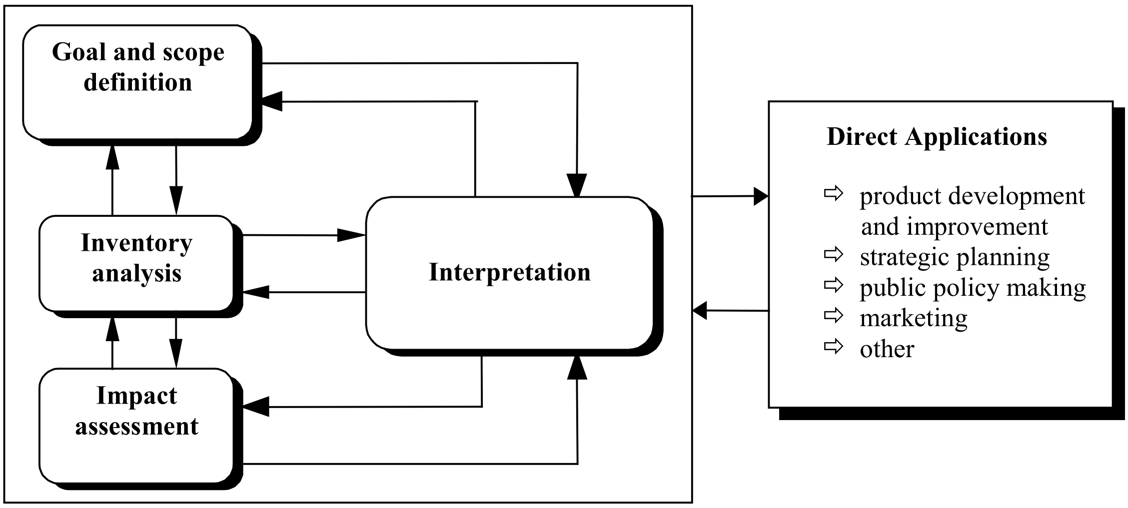

Figure A.1: The phases involved in an LCA (adopted from ISO (1997)).

Goal and scope
The goal and scope of the study should be unambiguously and clearly described. The scope shall cover the functional unit, system boundaries, allocation procedures, assumptions and limitations etc. The functional unit is defined as a "quantified performance of a product system for use as a reference unit in a life cycle assessment study" (ISO, 1997).

Inventory analysis
Inventory analysis involves data collection and calculations procedures to quantify relevant inputs and outputs of a product system (ISO, 1997). Thus inventory analysis aims to quantify all energy and raw material requirements, emissions to air, discharges to water, solid waste and other releases for each process step of a product system (Figure A.2).

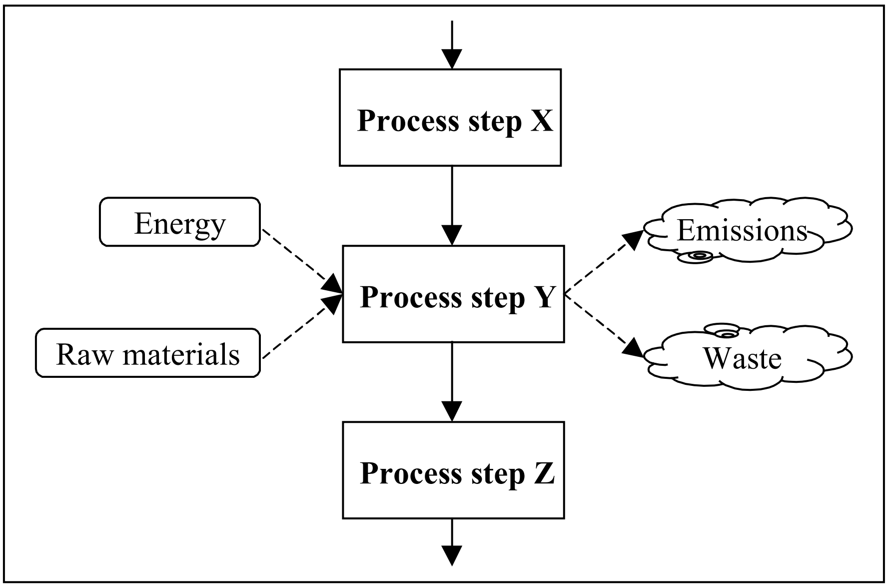

Figure A.2: The inventory analysis process.

Impact Assessment
The impact assessment phase of an LCA is aimed at evaluating the significance of potential environmental impacts using the results of the life cycle inventory analysis and includes the phases shown in Figure A.3 (ISO, 1997).

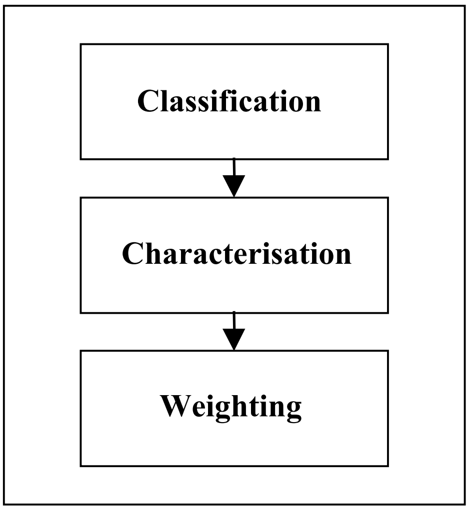

Figure A.3: The impact assessment process.

In the classification phase, inventory data are assigned to different impact categories based on the expected kind of potential impacts on the environment. The characterisation phase involves modelling of the inventory data within impact categories accounting for the relative contribution within each impact category. The weighting phase is an optional phase (ISO, 1999) where the results for each impact category are weighted into an overall quantitative statement of the potential environmental impact for the product system.

Appendix B: Environmental impact categories

Global Warming Potential (GWP)

Gases that contribute to global warming all have properties that enable them to absorb energy and emit thermal infra red radiation. Increased concentrations of these, so-called, greenhouse gases may lead to changes in climatic patterns and increased global temperatures. The global warming potential of the greenhouse gases considers both the life time and absorption characteristics of the gas. The characterisation factors used in this study are those presented by (IPCC, 1994). The characterisation factors also consider secondary effects such as the global warming potentials of breakdown products and indirect effects such as the negative effect of the destruction of ozone, which itself is a greenhouse gas. Global warming potentials use CO_2 as a reference substance, i.e. global warming potential is expressed in CO_2 equivalents.

Acidification Potential (AP)

Acidification results from the atmospheric depositions of acidifying compounds, which is a result of emissions of air pollutants such as ammonia, sulphur oxides and nitrogen oxides. Acidification of terrestrial ecosystem leads, among other changes, to a decrease of pH in the soil solution (pH is a measure of the concentration of hydrogen ions in a solution). Acidification of surface water systems leads to decreased pH, which in turn may lead to disturbances in the ecosystem. However, the effect of acid deposition is site specific, i.e. the sensitivity to acidifying deposition varies between ecosystem. In this study the potential to cause acidification is calculated on the basis of the number of hydrogen ions that can be released per mole of the acidifying substances, using sulphur dioxide (SO_2) as the reference substance. The characterisation factors used are those given in Lindfors *et al.* (1995).

Total renewable and non-renewable energy use (Energy)

The results for the energy impact category represents extracted energy. Extracted energy includes all of the energy that is used to extract the raw materials, the energy content of the material, and the efficiency of the energy production process. For example, in order to deliver 1 MJ of electricity from a coal based power plant, 4.3 MJ of energy is required when the extraction of raw materials, the efficiency of the power plant and delivery system are accounted for.

Abiotic resources depletion (Resources)

This is a measure of fossil (e.g. oil, gas, coal etc.) and mineral reserve depletion (e.g. bauxite ore). Use of fossil fuel reserves is most heavily weighted using this method. The characterisation factors used are those given in Heijungs *et al.* (1992).

Eutrophication Potential (EP)

Eutrophication of an ecosystem involves a transformation from a nutrient poor towards a more nutrient rich state through an excessive input of nutrients, e.g. phosphorous and nitrogen compounds. Eutrophication leads to a change of the chemical conditions which in turn may change the structure and function of the ecosystem, e.g. in surface water systems eutrophication often increases the biomass of some species which lead to an increased oxygen demand when it is decomposed. In this study the substances which have the potential to contribute to eutrophication are weighted according to their capacity to support the formation of biomass, using phosphate as reference. The characterisation factors used are those given in Goedkoop (1995) and Lindfors *et al.* (1995).

Photochemical Ozone Creation Potential (POCP)

The formation of photochemical oxidant smog is the result of complex reactions between nitrogen oxides and volatile organic compounds (VOCs) in the presence of ultraviolet radiation (present in sunlight) which leads to the formation of ground level ozone. Photochemical ozone creation potentials of VOCs are defined as the ratio between the change in ozone concentration caused by a change in the emission of a particular VOC and the change in ozone concentration due to a change in the emission of ethene (i.e. in ethene equivalents). The ethene equivalent values used come from Lindfors *et al.* (1995).

Non-hazardous waste (Waste)

This impact category addresses non-hazardous solid waste, measured in mass units. No characterisation factors for different types of waste are used within this category.

Appendix C: Process steps – used information sources

Table C.1: Information sources used in the LCA-calculations for the TBA/juice system.

Life Cycle Step	Geographical Region	Reference
Aluminium production	Europe[7]	(EAA, 1996)
Board production	Sweden	(Hulteberg, 1999) (Rydberg et al., 1995) (Svending, 1999)
Plastic production	Europe[7]	(Boustead, 1999)
Apple Juice production and processing	Poland/Sweden[8]	(Barkman, 1999) (Lundholm, 1999) (Stadig, 1997)
Converting	Europe[7]	(Lundahl, 1999)
Filling	Sweden[7]	(Barkman, 1999) (Lundahl, 1999) (Lundholm, 1999)
Distribution, Retail and Consumption	Europe[7]	(Finnveden et al., 1994b)
Recycling	Europe[7]	(Finnveden et al., 1994a) (Jaako Pöyry Consulting AB, 1995) (Hedenberg et al., 1997) (Heyde and Kremer, 1997)
Energy recovery	Europe[7]	(CORINAIR, 1996) (Eurostat, 1997a) (Eurostat, 1997b) (Eurostat, 1997c) (Frees and Weidema, 1998a) (Frees and Pedersen, 1996) (Frischknecht, 1996) (SAEFL, 1998) (SK Energi, 1994) (OECD, 1997) (Tillman et al., 1992)
Landfill	Europe[7]	(Söremark, 1999) (Tillman et al., 1992)
Transport (explicitly included)[9]	Generic	(CIT, 1994b)

[7] The electricity in the LCA-calculations corresponds to an average of the European Union (EU-15) base load in 1994-95 and the corresponding emissions reflect 1995-96 estimates.
[8] The production of pesticides and fertilisers for the apple productions is based on average electricity production in Sweden, Switzerland, Germany, Belgium and France (CIT, 1994a).
[9] There are transport steps included in the production of raw materials, e.g. production of LDPE, for which the underlying information sources can not be identified.

Table C.2: Information sources used in the LCA-calculations for the TB/milk system.

Life Cycle Step	Geographical Region	Reference
Board production	Sweden[10]	(Hulteberg, 1999).
Plastic production	Europe[7]	(Boustead, 1999)
Milk production and processing	Sweden/Norway[10]	(Cederberg, 1998) (Høgaas, 1998)
Converting	Sweden[10]	(Lundahl, 1999)
Filling	Sweden[10]	(Høgaas, 1998)
Distribution, Retail and Consumption	Swedish/ Norwegian	(Blinge et al., 1995) (Høgaas, 1998)
Recycling	Sweden[10]	(Finnveden et al., 1994b) (Hedenberg et al., 1997) (Jaako Pöyry Consulting AB, 1995)
Energy recovery	European[7]	(CIT, 1994a) (Frees and Pedersen, 1996) (SAEFL, 1998) (SK Energi, 1994)
Landfill	Sweden[10]	(Finnveden et al., 1995) (Heyde and Kremer, 1997) (Lundahl, 1999)
Transport (explicitly included)[9]	Generic	(CIT, 1994b)

[10] The electricity mix corresponds to the Swedish average production in 1991 (Lundgren, 1992).