Int J Life Cycle Assess (2012) 17:176–183
DOI 10.1007/s11367-011-0347-x

PULP AND PAPER

Carton for beverage—A decade of process efficiency improvements enhancing its environmental profile

**Anna Lúcia Mourad ·
Henrique Luvison Gomes da Silva ·
Júlio César Batista Nogueira**

Received: 17 May 2011 / Accepted: 28 October 2011 / Published online: 15 November 2011

Abstract

Purpose Chain efficiency is currently a key issue for evaluating the sustainability of products and processes. Thus, the objective of this study was to evaluate how the overall efficiency process improvement carried out in the upstream manufacturing chain of LPB (Liquid Packaging Board) has affected the environmental profile over the last 10 years.

Methods The method employs a life cycle methodology in a *cradle-to-gate* approach as the material can be used for obtaining beverage containers for different purposes. The scope of this study includes data from forest to rolls of finished cartons.

Results and discussion Due to a current slightly larger boundary and more detailed data collection, the following improvements (at the minimum) over the last decade can be observed: a) energy consumption has been reduced by 38% reaching the value of 36,700 MJ/t LPB paperboard; b) water consumption has been reduced by 30% reaching a level of 45.85 m^3/t LPB paperboard; c) wood consumption has been reduced by 40%, mainly as a result of the introduction of high yield CTMP (chemithermomechanical pulp) along with the increased overall efficiency of the production process and d) land use has been reduced by 69% due to increased forest productivity along with greater efficiency in the use of wood. Significant reductions have also been found related to environmental impacts such as global warming (49% less), photochemical ozone creation (14 times less), acidification (10 times less), eutrophication (8 times less) and human toxicity (6 times less).

Conclusions The results have clearly shown how important it is to invest in new technologies and more efficient processes to achieve better sustainable levels. This historical perspective is also a benefit from Life Cycle Assessment (LCA) methodology that allows these types of comparisons and also shows the importance of using new inventories for environmental decisions.

Keywords Cellulose · Efficiency · Environmental impact · Packaging · Paperboard · LCA

Responsible editor: Roland Hischier

A. L. Mourad (✉)
Packaging Technology Center,
Institute of Food Technology (CETEA/ITAL),
Av. Brasil, P.O. Box 139, 13070-178, Campinas, SP, Brazil
e-mail: anna@ital.sp.gov.br

H. L. G. da Silva · J. C. B. Nogueira
Klabin S/A, Fazenda Monte Alegre, S/N,
ZIP 84275-000, Telêmaco Borba, PR, Brazil

1 Introduction

Cellulose packaging materials for more than a century have fulfilled the current requirements to develop sustainable products from renewable sources. Besides this, in more recent times, there is an elevated postconsumer recycling rate of such wood-based products. As a natural consequence, the next step was to enhance the efficiency of the manufacturing processes in order to reduce quantity of raw materials and environmental impact. This target has been by pursued by wood, paper and board sectors around the world as shown by many documents (CEPI 2009a; García et al. 2009; Rivela et al. 2007; White et al., 2005; Das and Houtman, 2004; Ruth, 1998; Seppala et al. 1998, among others).

Klabin is the biggest producer, exporter and recycler of paper in Brazil with 17 industrial plants in Brazil and one in Argentina. Klabin has long been committed to running its business in a sustainable manner and is concerned with the environmental impact of its products. Self-sufficient in wood, it has 224,000 ha of planted forests and 187,000 ha of preserved native woodlands and has been certified by the Forest Stewardship Council (FSC) since 1998.

Paperboard provides strength, structure, a hygienic appearance, and a good printing surface for LPB. The basic construction is multi-ply paperboard made of virgin fibers to ensure a high standard of odor and taint neutrality. The outer layer is always made from bleached pulp. The main difference between LPB and board used for folding cartons is in the type of internal sizing applied at the stock preparation stage. LPB is mainly used to produce aseptic containers for beverage cartons. In general, it is combined with other materials such as polyethylene to provide waterproofing and aluminum to aggregate light and oxygen barriers. The laminate of LPB/polyethylene/aluminum is used to produce aseptic packages mainly used for milk and juices resulting in shelf stable products for over 6 months (Kirwan, 2005 and Hine, 1999). As the unique manufacturer of this material in Brazil, the results presented in this article can be classified as an average of the Brazilian LPB production.

LPB represented 38% of the total volume of products manufactured in 2008 at the Telêmaco Borba plant, one of the company's 17 industrial plants. The expansion of Klabin capacity in 2007/2008 (Project MA-1100) involved a lot of new equipment such as a paper machine of 250 m in length with a wire width of 7 m, the rebuilding of the digester, bleaching, caustifying and evaporation plants, the installation of a new wood preparation line, a new recovery boiler and a lime kiln.

The objective of the overall study was to conduct a *cradle-to-gate* life cycle assessment—in compliance with the requirements of the ISO 14040 standard series—of LPB. In addition, the project had the aim of measuring how the overall technological improvement carried out over the last 10 years has affected the current environmental profile of LPB production.

2 Methods

The present study was structured in accordance with the guidelines and requirements for conducting life cycle assessment studies set forth in ISO Standard 14040—"Environmental management—life cycle assessment—principles and framework" (ISO, 2006). Land use refers to land occupation (m^2a) as used by Hischier et al. (2005). The 1998 inventory of the production of LPB paperboard was developed within the larger framework of the project "Life Cycle Assessment of Packaging Systems for the Brazilian Market" as a building block to develop the inventory of the aseptic laminate (paperboard/aluminum/polyethylene) manufactured by Tetra Pak. Details of the methodology employed to build the 1998 LPB inventory can be accessed in Mourad et al. (2008).

2.1 Functional unit

The LPB investigated in this study were assessed by using a functional unit that consisted of 1,000 kg or 1 t of LPB with 7.5% of moisture content.

2.2 Boundaries of the study

This Life Cycle Assessment (LCA) in 2008 starts with the production of pine and eucalyptus seedlings, which will, at a later stage, be transplanted to the forest and covers the whole manufacturing cycle up to the moment when the rolls of finished LPB carton leaves the Klabin manufacturing facility, an integrated paperboard mill, located in Telêmaco Borba (State of Paraná, Brazil).

The boundaries also include the main chemicals to produce LPB and the transport of raw materials to the factory.

In 1998, Klabin did not have available data with the same degree of detail as now relative to consumption and emissions. In addition, since the objective of that project was to create—with the participation of several companies—a database for several packaging materials, the modeling adopted in 1998 differs from the modeling used in the present project due to the inclusion of the forestry step, with the inputs required for planting such as pesticides, fertilizers and diesel fuel. Figure 1 shows the flowchart of LPB production for both periods, highlighting the technological differences between 1998 and 2008.

2.3 Data collection

Klabin does not produce all the electrical power that it consumes. So, the data relative to the portion of electrical energy purchased from outside sources were based on the inventory of the database of CETEA. In Brazil, electric energy for public utility services is produced by an interconnected system of electric plants, mostly hydroelectric. The data concerning the generation and distribution of Brazilian electric energy refer to the data collected between 1997 and 1998 and updated for the year 2000 (Coltro et al., 2003).

The inventories of fuel oil (burned in the boilers) and diesel oil (used in harvesting operations and truck transportation) were also calculated based on the data contained in the CETEA database (Garcia et al., 2000, CETEA Report P 220/97). These inventories include the main aspects (consumption and emissions) related to the extraction of petroleum and the production of fossil fuels (precombustion).

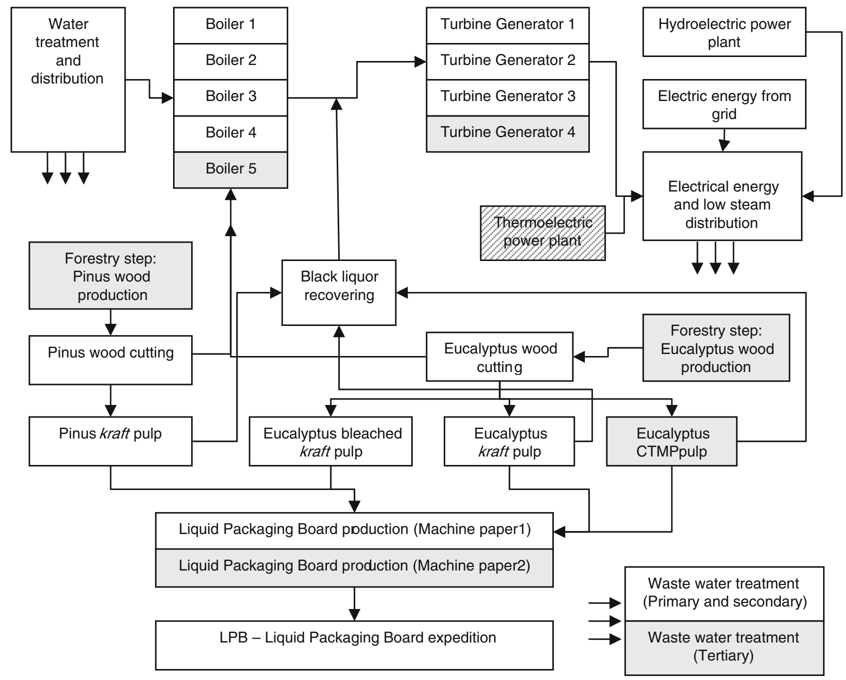

Fig. 1 Flowchart of LPB production system showing steps included in inventory calculation: *empty blocks* represent process steps considered in both periods, *grooved block* represents step existing only in 1998 and *grey blocks* represent steps existing only in 2008

The process data were collected through 22 questionnaires prepared by CETEA and completed by the person(s) responsible for each production area within Klabin. The inputs and emissions were quantified on a per process per year basis. The data sent in to CETEA were analyzed, modeled and discussed throughout the entire development of the project with the Klabin team for complete validation of the data.

2.4 LPB production system

The system was modeled including all the steps showed in Fig. 1. The system was modeled using the GABI 4.2 software program.

2.4.1 Forestry and pulping processes

Klabin produces cellulose from pine (*Pinus taeda* and *Pinus elliottii*) and eucalyptus (*Eucalyptus grandis*, *Eucalyptus saligna* and *Eucalyptus dunnii*) trees. Pine and eucalyptus trees for cellulose production have life cycles of 14 and 7 years, respectively. Reforesting follows the mosaic plantation concept, with pine and eucalyptus stands intermingled with areas of native forest, thereby preserving biodiversity. Detailed information on forest management can be found in the brochure “Forest Management Plan” (Klabin 2009).

Wood, pine and eucalyptus with 55% and 47% of humidity on average, respectively, is separated from the bark and chips that will be routed to the biomass boilers. Bark is removed by abrasion. After having passed through a log washer, the debarked logs are then fed into the chipping unit. Wood chips graded by size and thickness are sieved and moved to outside storage areas.

The digestion processes of pine and eucalyptus woods are performed separately. Four types of pulp in various combinations are used to produce LPB paperboard: pine kraft pulp, eucalyptus CTMP (chemithermomechanical pulp), Eucalyptus kraft pulp and bleached eucalyptus kraft pulp.

The kraft pulp is obtained by digestion with caustic soda, low pressure steam and white liquor recovered from black liquor. The chemithermomechanical pulp is preheated with steam and treated with chemical agents before refining and washing. Eucalyptus bleaching pulp starts with oxygen delignification. After the delignification stage, the actual bleaching process is initiated. The pulp is bleached using the Elementary Chlorine Free (ECF) process using a sequence of chlorine dioxide (ClO_2), hydrogen peroxide and chlorine dioxide.

The black liquor produced during the wood digestion processes passes through a series of evaporators until it reaches a solids level of 80%. The concentrated black liquor is sprayed into the recovery boilers and burned, generating high pressure steam. The solid mass remaining is recovered in many stages recreating the white liquor used in the wood-cooking process.

2.4.2 LPB sheet formation

LPB paperboard is produced on large paper machines. The first step in the manufacture of paper, called the preparation of the mass, consists in refining the cellulose pulps by dispersing the fibers as a dilute suspension in water with the aid of chemicals. The fibers are filtered from the suspension through a sieve or screen in a way as to make a uniform layer of drained pulp, that is, a wet sheet of paper. Next, this sheet is passed to the pressing section of the paper machine where it is placed in contact with a felt and pressed to remove excess water. Final drying is accomplished by evaporation of the water contained in the wet sheet by contact with high temperature steam rolls to reduce the moisture level to within specification.

The sheet then passes onto the coater where couchê ink and starch are applied to the surface of the carton. At the end of the production process, the paperboard is rolled onto spools. The spools or rolls are cut to the width and diameter specified by the customer.

2.4.3 Energy and steam supply

The process of steam generation consists in transforming fuels and water (demineralized) into high pressure steam in power boilers. In this process, three fuels are used: a) biomass from bark and wood trimmings, b) black liquor from the wood digestion process, and c) fuel oil purchased from outside sources. The boilers operate at temperatures between 400 and 500°C and produce high pressure steams of 46 and 100 bar (kgf/cm^2). In the turbine generators, these high pressure steams are converted to low and medium pressure steams (12 and 4 bar) and electrical energy that are consumed in the cellulose production process and by the paper machines.

Klabin operates the Presidente Vargas—Mauá hydroelectrical plant, located downstream the facility on the Tibagi river. The plant normally operates at full capacity of 23 MW with a flow rate of approximately 80 m^3 water/s. The dam is 246 m wide and 20 m high. In 2008, the plant supplied about 20% of the total electrical power consumed by the facility.

Approximately 40% of the total electrical energy consumed is bought from the Brazilian grid. In Brazil, electric energy for public utility services is produced by an interconnected system of electric plants, mostly hydroelectric.

2.5 Environmental impact

The inventories obtained were evaluated according to the CML 2001 methodology developed by the Centre of Environmental Science at Leiden University (Guinée et al., 2001) and in accordance with the principles of ISO Standard 14044. The significant environmental impact categories were: abiotic depletion (ADP), global warming potential (GWP), acidification (AP), eutrophication (EP), human toxicity (HTP) and photochemical ozone creation potentials (POCP).

The consequence of the differences in the boundaries is that the numbers related to 1998 are probably greater than those presented for all impact categories considered.

3 Results and discussion

Energy, water, wood consumption and land use can be considered as some of the main macroindicators of a paperboard life cycle inventory and they have been selected to present the main results of this project. The comparison of the results found with similar studies is always important to locate the environmental profile of our particular case in a global vision. On the other hand, this comparison needs to be done with extreme caution because, in general, the differences in boundaries and methodological approaches turn this task quite impossible. So, the comparisons done in this article give only an idea of worldwide spread of results found.

3.1 Macroindicators—energy, water, wood and land use consumption

By 2008, the total energy consumption had decreased by 38% over the previous 10 years reaching the value of 36,700 MJ/t LPB paperboard (Fig. 2). Subtracting the feedstock energy contained in the wood from this figure, only 25% of the total energy comes from external sources.

It can be observed that the profile of the primary energy supply has substantially changed over the years, with increasing substitution of fossil fuels by renewable energy sources. The thermoelectric plant that operated with mineral coal in 1998 was substituted by more efficient boilers and turbine generators in 2008. As a result, in addition to the reduction of the total amount of energy consumed, only 9% of that energy comes from fossil fuels, a fact that makes its primary energy supply predominantly renewable.

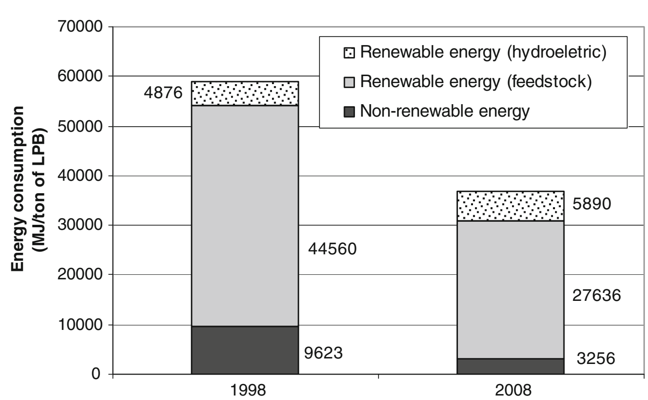

Fig. 2 Energy consumption per ton of LPB for 1998 and 2008

The 4th CEPI Sustainability Report showed that European countries had an increase of 1.5% since 2007 in the use of renewable energy achieving 54.4% of biomass-based 'green' energy in 2008 (CEPI 2009b).

A Canadian benchmarking report (Francis et al., 2002) that surveyed 23 bleached kraft pulp mills showed a consumption of energy, considering steam and electricity, varies from 17,000 to 32,000 MJ/air dried ton. Comparing these values with the same inputs in 2008 of energy consumption in the Klabin plant of 18,740 MJ/t LPB (this number was extracted from Klabin mill modeling and cannot be directly compared to other LCA results), it can be observed that the Brazilian facility can be classified among the most energy efficient mills. A Chinese study shows another result: 23 GJ/t of coated white board. (Cui et al., 2011). Another LCA study for Portuguese printing and writing paper (Lopes et al., 2003) showed an energy consumption between 27 and 29 MJ/t, but paper and board are different products and these numbers cannot be directly compared.

Reducing water consumption has been one of the major goals of Klabin, and this translated into a pronounced reduction in the use of this natural resource. In comparison to the year 1998, the amount of water consumed was reduced by 30% reaching the level of 45.85 m^3 per ton of paperboard (Fig. 3). The Chinese process states that it consumes 70 m^3 per ton of white-coated board in a similar process (Cui et al., 2011).

The introduction of CTMP, which has a higher pulp yield than the kraft process, increased the overall efficiency of wood use, which, along with all the other improvements incorporated into the process, reduced the consumption of wood by 40%.

Continued intensive research on genetic improvement of the species planted in the reforested areas significantly increased forestry productivity, thereby optimizing land use. Between 1998 and 2008, the productivity of eucalyptus increased by 11% and reached 315 t per hectare, whereas the productivity of pine increased by 3%, reaching 519 t per hectare (Fig. 4).

The introduction of CTMP pulp also reduced the consumption of wood and, consequently, land use. The increase in forest productivity, associated to the increase in the efficiency of wood use, resulted in a reduction by 65% of continued land use (Fig. 5).

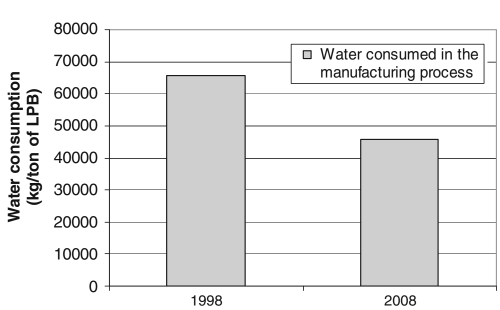

Fig. 3 Water consumption per ton of LPB for 1998 and 2008

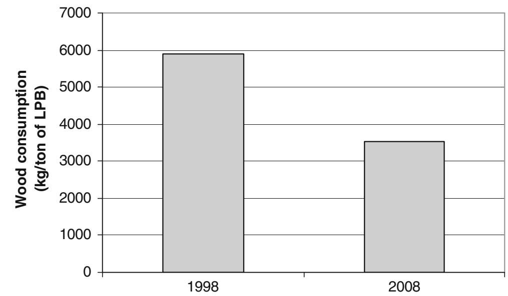

Fig. 4 Wood consumption per ton of LPB for 1998 and 2008

3.1.1 Land use—a fundamental issue

LCA studies distinguish two aspects of land use: transformation and occupation. Transformation of the land is associated with changes in its quality, typically expressed in terms of biodiversity and/or life support functions. Klabin forests have been planted since 1934 and practically 100% of them have FSC certification, annually renewed (Klabin, 2008), which attests to the fact that the company adheres to the criteria for responsible forestry (Forest Stewardship Council 2002) conserving biological diversity, water resources, soils, unique and fragile ecosystems and landscapes respecting the rights of indigenous people; planning the use of land and forest for the long-term; and maintaining the social and economic well-being of forest workers and local communities, among others aspects.

Occupation is the length of time for which the land is used and refers to the time period during which the land is unavailable for other uses (the unit is normally m^2a). The drastic reduction (65%) in continued land use shows that the occupation of land by forests to produce paperboard has been significantly reduced. This is a very important factor when considering the continuous growth of the cellulose market and the high price of new land.

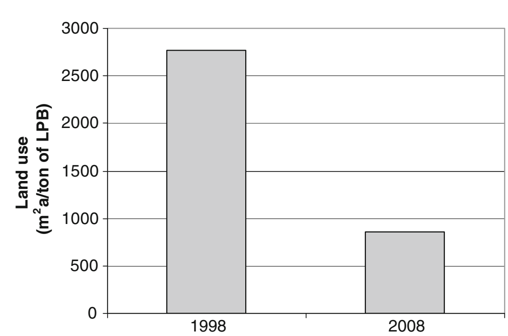

Fig. 5 Land use per ton of LPB for 1998 and 2008

3.2 Other environmental impact categories

Table 1 shows the main environmental impact indicators of the systems evaluated, calculated based on the CML 2001 methodology (Guinée et al. 2001). Over the past few years, depletion of natural resources associated with the manufacture of carton has been reduced as a direct result of increased overall efficiency of the production process. In this project, the most significant abiotic resources are petroleum and natural gas. Abiotic depletion has decreased by 18% in this window of time. The reduction presented is smaller than the real amount because in the previous study, the forestry step was not considered. In 2008, this step represented 17% of the total abiotic depletion.

A reduction of 49% (at minimum) in fossil greenhouse gas emissions was observed between 1998 and 2008 period, reaching a 512 kg of fossil CO_2 eq/LPB. This reduction is probably due to the partial substitution of fossil fuels by wood biomass fuel and the introduction of modern boilers and turbine generators.

Pro Carton (European Association of Carton and Cartonboard Manufacturers) has demonstrated its environmental commitment related to GHG emissions. Using production data provided by a large number of carton and carton board manufacturers across Europe, *cradle to gate* studies—from the forest to the exit gate of the manufacturing plants—have been carried out in accordance with the standards and procedures laid down in the document PAS 2050—Publicity Available Specification (BSI, 2008). The average European Cardboard emitted 1,004 kg of fossil CO_2 eq. per ton of material produced in 2005 (Pro Carton, 2008). This study was updated and shows that the European Industry average carbon footprint was reduced by 7% in 2008, emitting 964 kg of fossil CO_2 eq. per ton of carton produced (Pro Carton, 2010). The study also covered the companies that use recovered fibers. The European study includes the use of recycled fiber and also uses a different methodology (Erikson et al. 2010) to perform these calculations.

Acidification is associated with the emission of gases that, when in contact with rain clouds, may contribute to acid rain formation. The dramatic reduction in the emission of these gases, along with the increased overall efficiency of the production process resulted in an about 10 times lower acidification potential in 2008 as compared to 1998. The acidification potential of a Spanish Eucalyptus bleached pulp is 2.83 kg SO_2 equiv by ton air dried using CML 2000 (González-García et al. 2009). This same impact category calculated by Impact 2002+ methodology is 2.96 kg SO_2 equiv by LPB ton and for the Chinese study is 13.2 kg SO_2 equiv by ton of white board (Cui et al., 2011).

Eutrophication is associated with emissions of gases and compounds that contribute to increasing the amounts of nutrients in water. The striking reduction in the emissions of mainly gases, along with the increased overall efficiency of the production process resulted in 8 times reduction between 1998 and 2008. Nitrogen oxides were reduced from 91% to 86% of EP in the last decade, mainly due to the use of more efficient boilers, removal of the coal thermoelectric unit and the significant reduction of heavy fuel oil usage to a minimum level enough to start up the black liquor recovery unit. The waste water treatment was also completely remodeled with the introduction of a more efficient oxygenation process and a new tertiary treatment unit for ultrafiltration. This modernization also reduced the chemical (7% EP in 2008) and biological (1.4% EP in 2008) oxygen demands. The result of 1998 is underestimated, since most of the water emissions had not yet been quantified at the time. Comparing the eutrophication impact with a Chinese study (Cui et al., 2011) that used the Impact 2002+ methodology, the Brazilian result is 0.017 kg PO_4 equiv by ton and the Chinese study is 0.83 kg PO_4 equiv by ton of white board. Eutrophication due to Spanish Eucalyptus bleached pulp (González-García et al., 2009) of 0.698 kg PO_4 equiv. by ton air dried using CML 2000 is similar to the level found for LPB of 0.68 kg PO_4 equiv by LPB ton using CML 2001.

The environmental impact indicator human toxicity also showed a very significant reduction between 1998 and 2008: 6 times. This reduction was achieved mainly as a result of improvements introduced in the effluent treatment system and with the implementation of the ultrafiltration

Table 1 Indicators of the main environmental impact categories evaluated for the inventories of 1998, and 2008. Functional unit: 1,000 kg of LPB—Liquid Packaging Board

Environmental impact indicator	1998 CML 2001[a]	2008 CML 2001	2008 Impact 2002+
Abiotic resource depletion (kg Sb equiv.)	3.62	2.98	NC
Global warming potential (kg CO_2 equiv.)	999	512	NC
Acidification potential (kg SO_2 equiv.)	64.7	6.1	2.96
Euthrophication potential (kg phosphate equiv.)	5.36	0.68	0.017
Human toxicity (kg de DCB equiv.)	50.1	7.9	NC
Photochemical ozone creation potential (kg ethylene equiv.)	6.80	0.49	0.28

NC not calculated

[a]Underestimated value since the boundary is much different

unit in 2008 along with the increased overall efficiency of the production process. The value in 1998 is underestimated, since most of the water emissions had not yet been quantified at the time and the boundary was much different.

Human toxicity from Spanish Eucalyptus bleached pulp (González-García et al., 2009) is 39.19 kg DCB equiv. using CML 2000 and the Brazilian materials is 7.9 kg DCB equiv of LPB ton using CML 2001.

The photochemical ozone creation potential underwent a very significant reduction between 1998 and 2008: 14 times. This drop is associated with the reduction of several air emissions such as methane, nitrogen oxides, among others, along with the increased overall efficiency of the production process.

It is important to note that the reduction in nitrogen oxide emissions had a great influence on the reductions shown. In 2008, nitrogen oxides represented 52% of AP, 86% of EP, 69% of HTP and 26% of POCP. The reduction of this emission is due to the removal of the thermoelectrical power plant fired by mineral coal and the use of more efficient boilers. Currently, some boilers employ a Circulating Fluidized Bed (CFB) technology, which reduces the temperature of combustion from 1,100°C to 900–950°C, eliminating the dissociation of N_2 and the subsequent formation of thermonitrogen oxides.

3.3 Opportunities for improvements

Analysis of Fig. 6 shows the contribution analysis of the main manufacturing steps for the environmental impact categories analyzed (which contribute to more than 98% of each category impact).

The main environmental impacts are distributed among the forestry, electric energy from the Brazilian grid, bleaching and black liquor recovering stages. The minimization of nitrogen oxides and sulfur dioxide emissions can be among the future guidelines for the company since these emissions have a great contribution in many environmental impact categories.

Special attention needs to be paid to the external suppliers of hydrogen peroxide, electric energy and heavy fuel oil since these inputs have a meaningful impact on the LPB profile.

4 Conclusions

Significant environmental improvements have been introduced over the past years in the Life Cycle Inventory of LPB paperboard, which goes from the planting of tree seedlings in the forest up to the moment when the finished product leaves the exit gate of the Klabin manufacturing facility in Telêmaco Borba. Despite the current slightly larger boundary and more detailed data collection than the previous work, it can be concluded that (at the minimum) the following improvements were observed between 1998 and 2008:

—Energy consumption was reduced by 38%, reaching the value of 36,700 MJ/ton LPB paperboard in 2008. In addition to the lower energy consumption, there was an important and increasing change in the composition of the total primary energy supply. In 2008, only 9% of the total energy consumed came from fossil fuels.

—Water consumption was reduced by 30%, reaching a level of 45.85 m^3/ton of LPB.

—Wood consumption was reduced by 40%, mainly as a result of the introduction of high yield CTMP pulp along with the increased overall efficiency of the production process.

—Land use was reduced by 69% due to increased forest productivity along with greater efficiency in the use of wood.

—The global warming potential was reduced by 49%, reaching 512 kg of fossil CO_2 eq/LPB.

—The acidification potential was reduced by 10 times.

—The photochemical ozone creation potential was reduced by 14 times. This drop is associated with the reduction of several emissions such as methane, nitrogen oxides, among others, along with the increased overall efficiency of the production process.

—The eutrophication potential was reduced by 8 times and the human toxicity indicator by 6 times. This improved performance was achieved mainly through improvements introduced into effluent treatment activities along with the increased overall efficiency of the production process as a whole.

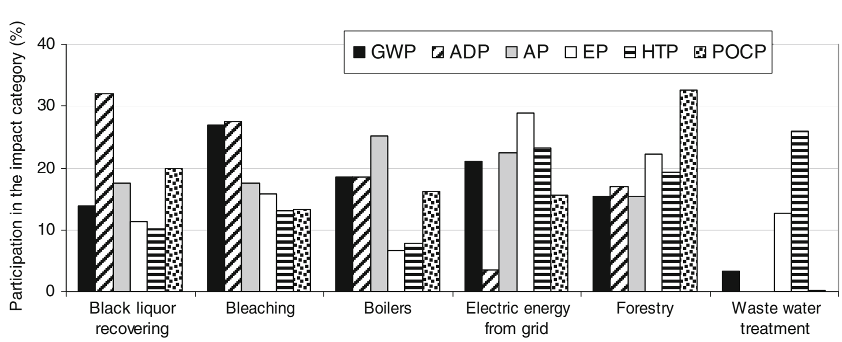

Fig. 6 Relative contribution of the main steps of LPB manufacturing (2008) in the environmental impact categories evaluated using CML 2001 method

—Abiotic resources depletion was reduced by 18%, mainly due to reduced use of fossil fuels.

These results summarize 10 years of technological improvements that were introduced in this period, when a significant part of the equipment was optimized or replaced by more efficient and modern equipment such as new digestors, refiners, boilers, turbine generators, paper machines, etc.

One lesson learned from this project is how important it is to invest to increase the efficiency of all the productive chain in order to achieve better sustainable patterns. The better environmental profile of LPB was reached by a combination of technological improvements applied in all manufacturing steps. Another lesson from this study is the importance of measuring the results using a LCA tool in a historical perspective: when it exists, it is easy to evaluate the effectiveness of each initiative and also it is possible to communicate these results to employees and clients. The other important lesson learned from this study is the importance of having updated inventories to make environmental decisions.

Acknowledgments The authors are grateful to Klabin S/A that scommissioned this project to CETEA and also to FAPESP (The State of São Paulo Research Foundation) for supplying the financial support that allowed CETEA to establish its expertise in the field of life cycle assessment in 1998.

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