LCA Case Studies

Life Cycle Assessment of a Basic Lager Beer *

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Abstract. The current case study was performed to determine and evaluate the environmental impacts, and to look for possible improvements in the production and distribution of a basic lager beer that is packed into multi-packs of glass bottles. The life cycle investigated includes the stages from agricultural production up to the delivering of products to the shops, the consumption phase has been excluded. Raw water treatment and energy production and use have been included, and the contribution of different sub-systems inside of the life cycle to climate change, acidification, eutrophication, oxygen depletion and summer smog were assessed. The investigation resulted with several suggestions for improving the product and environmental performance of brewery.

Keywords: Beer; case studies; DAIA 1998; food; KCL-ECO; LCA; Life Cycle Assessment; LCA in foods; product LCA

Introduction

In the design stage of a new brewery, it is useful to study the old unit with respect to the sustainability and effectiveness of different internal part-processes and also to study the history of consumption of auxiliary materials. The LCA method is amenable for such a study. Although additional buildings have been added to the production unit (brewery) of the investigated beer from time-to-time, the physical location has remained constant. The decision for relocating and building a new remote complex has recently been made.

Since beer production uses grains as its main raw material, it is considered to be a food product. Food production and the environment have always been strongly connected to each other. In a life cycle assessment (LCA) of a product in the food industry, a study of agricultural production should be included. Agricultural production depends to a large extent on the natural environment. To design an LCA for an agricultural product, one must address special problems, for example defining the boundaries of the functional unit and the allocation procedures. Public LCI (life cycle inventory) quality databases are also non-existent. Food production and consumption systems consume both energy and natural resources [1], and an LCA analysis of the new brewery should therefore include both energy and natural resource needs and effects on the environment.

The investigated brewery belongs to a larger company, which also produces soft drinks and other sort of beers at the same facility. Parallel to the LCA study of the brewery, another production unit of the enterprise is preparing an application for ISO 14000 certification. For establishing a sustainable Environment Management System at a brewery, the United Nations Environment Program has produced useful guidelines that are readily available [2].

Brewing was one of the first commercial scale food processing industries. The modern brewery can produce a stable product even though raw materials, plant types and the scale of operation are changing.

The studied beer – a medium strength basic lager – is representative of the largest volume of beers generally sold. The beer recipe is confidential and hence is not presented here, but the recipe was used for identifying the inputs and outputs for the brewery. The beer making process is described in detail below.

Beer is a dilute solution of ethanol, obtaining its characteristic flavour from the use of malt, which is the predominant source of fermentable carbohydrates and other yeast nutrients. Hops are the source of bitter components [3]. The important production stages within the brewery are mashing and fermentation. The malting is done at a different site in this case. Malting and mashing produce wort, an aqueous extract of malted barley. Yeast is added to the wort and subsequently fermentation occurs. The yeast cells convert the nutrients in the wort predominantly into ethanol and carbon dioxide. After removal of the yeast, the product beer remains. The uniqueness of a given beer is achieved by an appropriate degree of metabolism; it will contain a certain mixture of by-products, which contribute to its unique flavour and taste. It is also important to achieve the final product in a reasonable amount of time.

1 Goal and Scope Definition

The overall objective of this LCA study was to assess the potential environmental effects of the different stages of the beer life cycle and to also obtain new and updated information for establishing the new facility.

One goal was to define and assess the life cycle of a certain sort of beer packed into multi-packs of refillable glass bottles from cultivation of barley to selling the beer in shops with respect to production resource conservation and improvement of the environmental performance at the brewery. Another

* The critical review according to ISO 14040 of this study has not been performed.

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goal was to compare the relative environmental effects/impact of each stage of the life cycle, and hence identify the part of the system, which most affects the environment.

2 Functional Unit

The multi-pack of bottles packing type was chosen as it was assumed to be the most complicated product of the unit. Glass bottles of beer are packaged into packs of six and these multi-packs are subsequently placed onto pallets; empty crates are also distributed to the shops for use in returning bottles. The crates with the empty bottles are taken back to the distribution station by the same distribution trucks that deliver the beer. The production system also includes the environmental impact of multi-pack board making and has a larger transport impact than the usual crate beer (due to the separate transport of crates for returning bottles). The bottle recycling rate is very high – 98%.

The functional unit was defined as 505 multi-packs of bottled beer (10 hl of beer) in the shop. The study started with the agricultural production and ended with delivery of the product to the shop because the goal was to investigate and compare the environmental effects of different production processes (cultivation of barley, raw and auxiliary material production, beer production), transportation and energy consumption.

3 System Definition

The inputs and outputs which arise from agricultural processes (irrigation, fertilisation, erosion, etc.), cultivation and harvesting of the barley, malting, beer and auxiliary material production, packaging (including washing of refillable glass bottles) and transportation were investigated. It should be further noted that the production of heat, electricity and pre-treatment of raw water were also included in this analysis.

The following systems were excluded:

1. Consumption of product
2. Shopping (transportation from retailer to household)
3. Capital costs (manufacture, maintenance and decommissioning of capital equipment)
4. Recycling of glass, board and plastic
5. Dumping of wastes (transport of wastes was included)
6. Production of crates and bottles (bottle production and recycling of glass were investigated using LCA some years ago [4])
7. General infrastructures, accidents, immaterial commodities and human resource

The model system for the whole life cycle consists of subsystems such as the cultivation of barley; malt production; production of other raw materials; production of auxiliary materials; transport of raw materials, beer production, transport of residues and beer; and transport of auxiliary materials. The system is presented on **Fig. 1**. Two stages – production of beer and production of auxiliary materials – were looked at as more detailed subsystems, but these schemes are not presented here due to confidentiality.

The main data sources for different sub-systems are provided in **Table 1**. The most varying data quality was in the sub-systems production of raw materials and the production of auxiliary materials, the data we obtained depended on willingness of different enterprises in Europe and the USA to make their data available to us.

4 Methods

The LCA computer tool KCL – ECO was used for all calculations. This tool was originally designed for performing the LCA on wood and forest products. This study could be looked at as an adoption of this tool to study a food production system. The producer of this tool (KCL [5]) also provides Life Cycle Inventory (LCI) level databases for some modules (paper products, chemicals, transportation and energy systems). Inside the brewery, the data for the whole brewery (available from bookkeeping system) were allocated by volume between the different products produced.

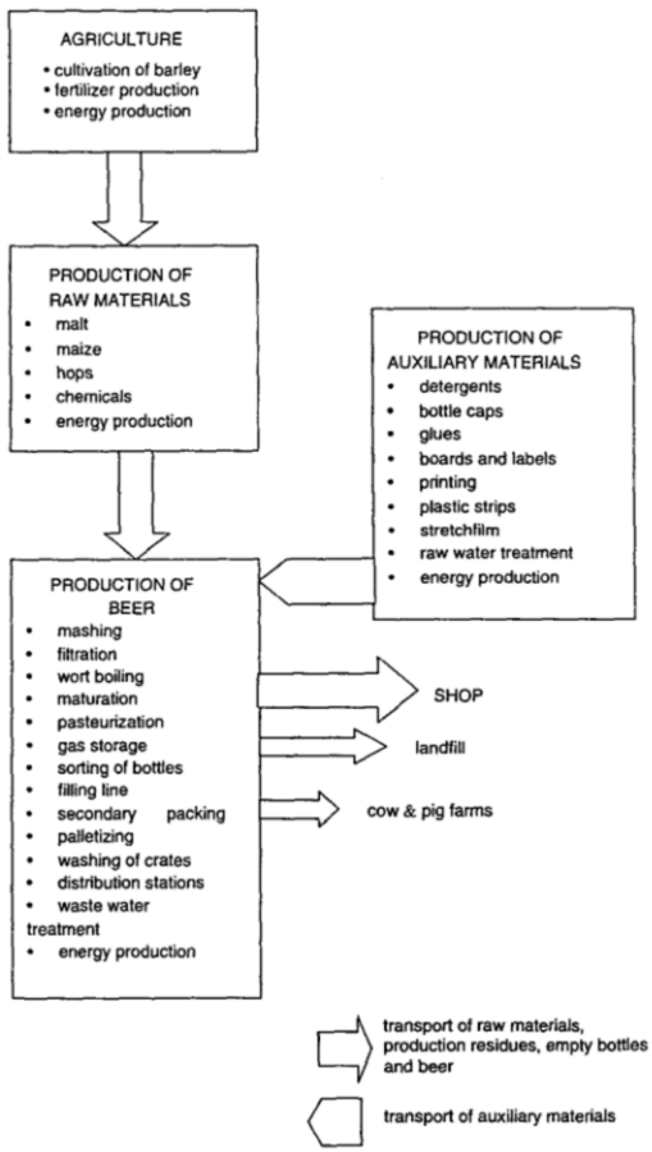

Fig. 1: Scheme of investigated life cycle

Table 1: Data sources

Sub-system	Data source	Data quality
Agriculture (barley from cradle to farmer's warehouse)	Company Kemira Agro	LCI quality data from year 1997
Production of other raw materials than barley	Producers / suppliers	LCI level data not delivered referring to confidentiality, partly incomplete data
Beer production	Production unit	Recipe – based data for inputs and outputs into beer. Need for packaging materials and waste glass generation – experiment was conducted. Usage of heat and wash water consumption data are based on estimations of experts from unit. For determination of electricity use and beer losses in the production process, the average data from 1999 was used.
Production of auxiliary materials	Producers / suppliers, KCL database	LCI quality data is missing, data quality varies, where available KCL LCI quality data was used.
Raw and wastewater treatment	Local water / wastewater treatment unit	LCI quality data.
Transport emissions and beer delivering profiles from distribution stations to shops	Beer production unit, transport emission database [8] (1999 data), producers / suppliers, KCL database	Transport profiles of beer are based on conducted experiment. According to the official database, different truck emission modules were specially generated. Producers / suppliers give quality data about truck transport, for sea transport (ship types), partial estimations were used. Ship emission data _ KCL database (LCI quality).
Energy production	KCL database	LCI quality Average state profile was used

For impact assessment, the KCL-ECO program has both the Ecoindicator 95 and DAIA (Decision Analysis Impact Assessment) 1998 methods. As DAIA 1998 is considered to be a more suitable impact assessment method for Nordic conditions [6], it was chosen and used. In the environmental impact assessment, climate change, acidification, eutrophication, oxygen depletion and summer smog were included.

5 Results

5.1 Resource consumption and waste generation

An important task of this study was to determine the resource consumption within the brewery. Because it was possible to monitor the electrical consumption at all key-points within the production system, it was investigated in fine detail. The largest percentage of electricity (**Fig. 2**) was used for cooling purposes. The storage electricity consumption includes the loading and transport inside of storage facility. The filling line consumption also includes the bottle-washing system.

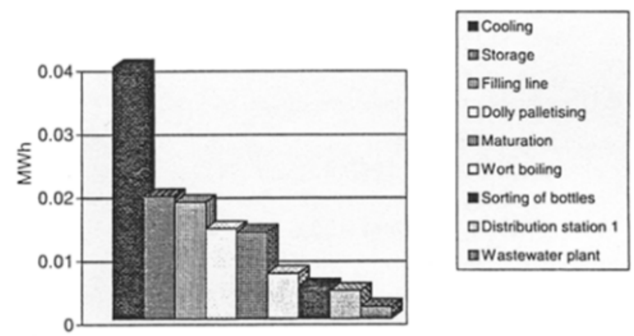

Fig. 2: Electricity consumption in brewery, (MWh/ref.unit)

The water usage in the brewery per functional unit of the system was less than 40 hl. The largest water consumer was the agriculture sub-system, which uses about 17 m³ of water per functional unit.

According to the special interest of the brewery, the balance of biogenic CO_2 was determined during the investigation. The biogenic CO_2 does not contribute to GWP. The barley in the agricultural phase bound twice as much CO_2 than is emitted during the following beer production and packaging processes. The main sources of biogenic CO_2 from the current life cycle are presented in **Fig. 3**.

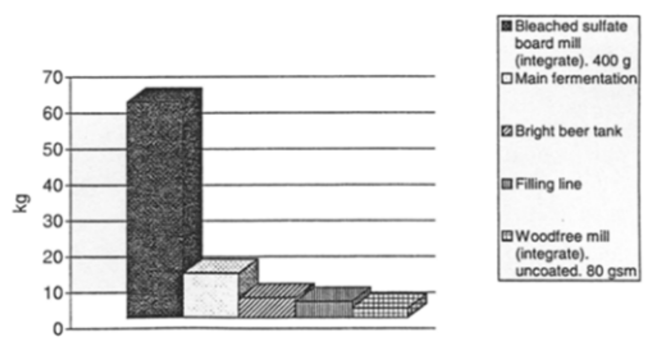

Fig. 3: Emission sources of biogenic CO_2 from investigated system, (kg)

During the investigation, all the waste flows from the unit were investigated. A special wastewater analysis was performed, and the levels analysed were reduced according to the purification rates of the local wastewater treatment plant (the co-treatment of brewery and municipal wastewater is ongoing). The filtration residue from the beer producing process is composted. Bottles and part of the waste glass, plastic packages and used cardboard are recycled. It was assumed that all used bottle caps; labels (removed from recycled bottles on a line before reusing the bottles), glues, plastic strips and stretch film end up in the landfill as solid waste. The largest part of the dumped solid waste from the production unit is the waste glass. There is a need for improving the procedure for returning the reuseable bottles on crates returned from the shops; currently many stacked bottles end up in the landfill along with garbage in these crates. The crates should only have useable recycled bottles, and not garbage and unuseable bottles. This separation should be done at the shops. Only transport to landfill is included in the system (in the sub-system for the transport of raw material, beer and residues). In the whole brewery sub-system, about 16 kg of solid waste per functional unit was generated.

The trub and yeast are reused as feed for cows (235 kg per functional unit) and pigs (0.16 hl per functional unit). Farming (handling of trub and yeast) is excluded from investigation, and transport of spent raw material is included in the sub-system transport of raw material, beer and residues. Filtration residues (3.62 kg per functional unit) are composted.

5.2 Results of Impact Assessment

For the impact assessment (characterisation, normalisation, weighting), the DAIA 1998 method [7] was used. It is designed in Finland and is more relevant than the Ecoindicator 95 for using in the current study.

In the DAIA 1998 method for accounting COD to water, oxygen depletion is a separate category. The results for oxygen depletion are presented in **Fig. 4**. In the sub-system production of auxiliary materials, the main COD emission sources are package board and paper production, followed by detergent production. Brewery COD emissions are not high due to the effective municipal wastewater treatment plant that treats the brewery's wastewater.

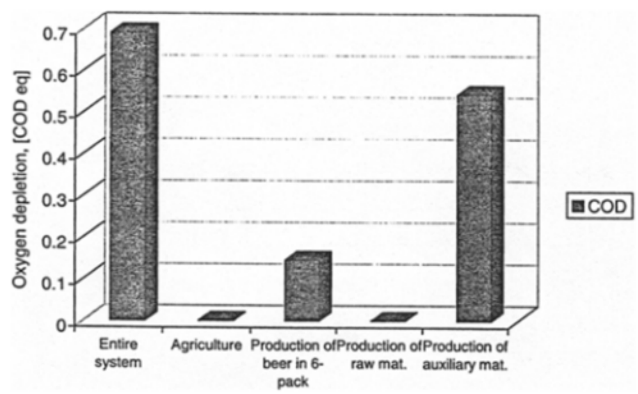

Fig. 4: Contribution of different sub-systems to oxygen depletion, (COD eq)

The summer smog formation circumstances in North and Central Europe are different [7]. In Northern Europe the limiting emission is NO_x, not VOC (volatile organic compounds) as in Central Europe. The summer smog characterisation chart (**Fig. 5**) is based on CO, NO_x and VOC emissions over the whole system. The largest source of smog here was due to the distribution of the product (beer) to shops.

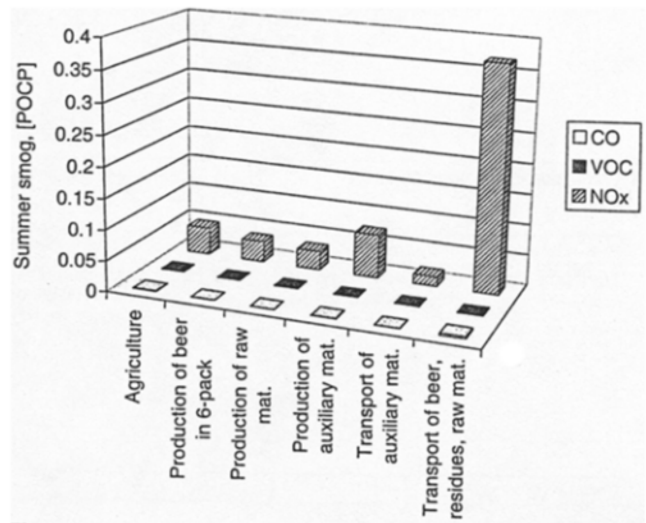

Fig. 5: Contribution of different sub-systems to summer smog, (POCP)

The maximum potential contributions to eutrophication are shown in **Fig. 6**. Major sources in this category are the phosphorus and nitrogen emissions from agriculture – leakage from fields, production of fertilisers, etc.

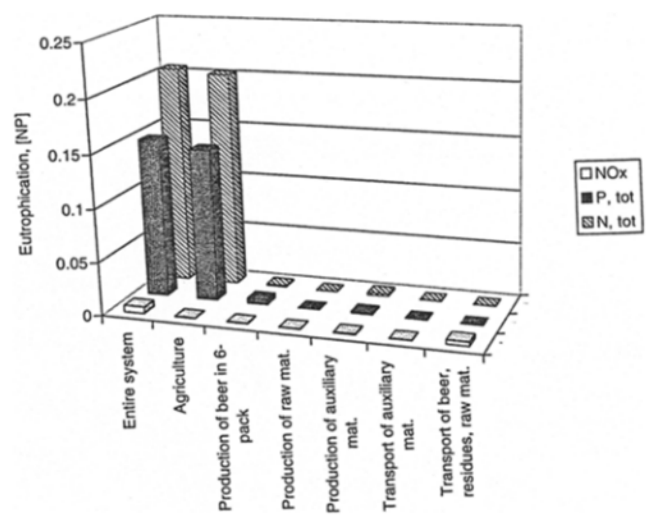

Fig. 6: Contribution of different sub-systems to eutrophication, (NP)

Emissions of sulphur dioxide and nitrogen oxides are the key parameters contributing to acidification. The largest impact score (**Fig. 7**) belongs to the sub-system transport of beer, residues and raw materials, and within the sub-system to transport the multi-packed beer to shops.

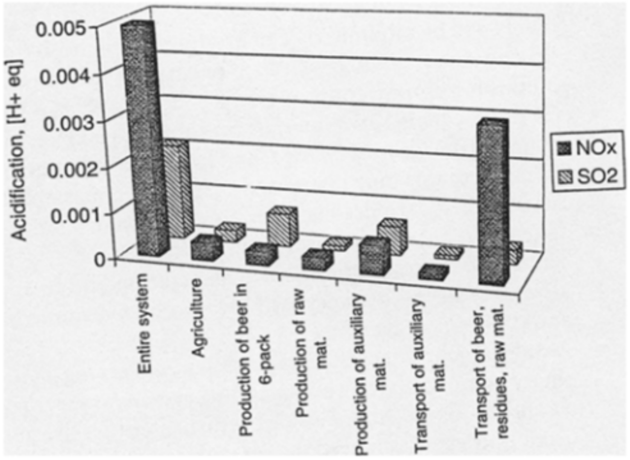

Fig. 7: Contribution of different sub-systems to acidification, (H^+ eq)

Results for climate change are shown in **Fig. 8**. This impact category depends mostly on the use of energy (emissions of CH_4, N_2O and CO_2). Different types of fuels followed the electricity profile used in the current investigation as shown in **Table 2**. As the brewery was the largest electricity consumer in the system, its share is also the biggest in climate change.

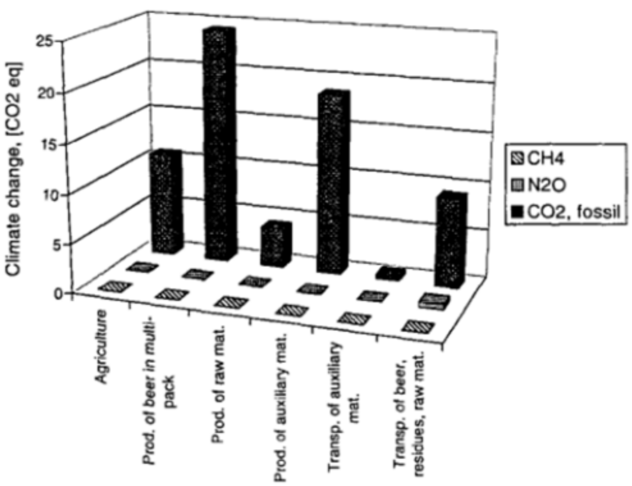

Fig. 8: Contribution of different sub-systems to climate change, (CO_2 eq)

Table 2: The share of different fuels in electricity profile

Type of fuel	Share %
Natural gas	10.2
Hard coal	17.5
Heavy oil	2.9
Hydro power	24.9
Nuclear power	36.5
Peat	8.0

As mentioned in other food industry LCA studies [8], agriculture is a remarkable hot spot over the whole food processing systems. This tendency is seen to be similar in the current results (see weighting results in **Table 3**). The weighting results provide a possibility to compare the share of different subsystems to the global environmental effect categories.

6 Discussion

During the LCA investigation at the enterprise, not only did the environmental awareness of the administration grow, but also all people participating in the data collection at the different production sites gained new knowledge, perspectives and point of views with respect to resource conservation and waste generation. This demonstrated the value of co-operation and sharing of data to all participants.

The idea to ask suppliers of auxiliary materials to the brewery to supply Life Cycle Inventory quality data about their products was suggested. Subsequently, it would be easy to update the previous LCA and then choose between various offers from suppliers. The main problem while conducting this study was the varying data quality from enterprises other than the brewery engaged in the life cycle of the beer. Especially hard and sometimes impossible was to get data from central Europe and the USA enterprises, even when asked by the brewery (i.e. the client) itself. To ensure a thorough LCA for any product, cooperation should be obtained between the different enterprises within the life cycle of the product.

Table 3: Results of weighting (by sub-system codes)

	Agriculture	**Production of beer in 6-pack**	**Production of raw material**	**Production of auxiliary material**	**Transport of auxiliary material**	**Transport of beer, residues, raw materials**	**SUM**
Climate change	$4.86367 \cdot 10^{-5}$	0.000109131	$1.86072 \cdot 10^{-5}$	$8.3566 \cdot 10^{-5}$	$2.12496 \cdot 10^{-6}$	$4.36212 \cdot 10^{-5}$	0.000305687
Acidification	$4.17206 \cdot 10^{-5}$	$6.45632 \cdot 10^{-5}$	$2.34101 \cdot 10^{-5}$	$7.90852 \cdot 10^{-5}$	$1.3988 \cdot 10^{-5}$	0.000224097	0.000446864
Eutrophication	0.00485077	$9.06973 \cdot 10^{-5}$	$4.68067 \cdot 10^{-6}$	$6.73895 \cdot 10^{-5}$	$2.32477 \cdot 10^{-6}$	$5.55919 \cdot 10^{-5}$	0.00507145
Summer smog	$2.23751 \cdot 10^{-5}$	$1.66233 \cdot 10^{-5}$	$1.49201 \cdot 10^{-5}$	$3.4885 \cdot 10^{-5}$	$7.48503 \cdot 10^{-6}$	0.000179012	0.0002753
Oxygen depletion (COD)	$1.55339 \cdot 10^{-7}$	$2.83154 \cdot 10^{-5}$	$3.31389 \cdot 10^{-8}$	0.000105277	0	0	0.000133781
SUM	0.00496365	0.00030933	$6.16512 \cdot 10^{-5}$	0.000370203	$2.59227 \cdot 10^{-5}$	0.000502322	

Also, it is important that the LCA data from the various scientists and LCA practitioners not only be collected, but assembled and then made available to all of the scientists. The central repository must also be periodically updated and quality controlled. Unless the data is up-to-date and readily available to all scientists, it is not of much use.

The generated data can also be considered in designing new beer production units and for forming platforms for future environmental work at the company.

Furthermore, investigations of consumer consumption behaviour analyses could be performed for completing the full LCA of the beer, that is a study of the consumption habits, i.e. shopping (transportation of beer from retailer to homes) and storage of beer in refrigerators.

The computer tool KCL-ECO is used here for the first time to study the life cycle of a food product. It appeared to be easily adaptable to this area and was useful for explaining and graphically presenting results to the companies. This was due to the nice feature that allowed one to present the whole scheme of the life cycle on one figure along with numerical data flows on the same figure.

7 Conclusions and Recommendations

The main recommendations which resulted from this study on how to improve the environmental performance of the brewery are as follows:

- To establish an environment management system. To achieve this goal, one must collect all existing and any new environmental information in one place (database) so that it will be useable. This will make it easier to determine whether any information is lacking, and, if so, which, information or data. Currently, the information and knowledge is spread between different specialists and not in one central location, hence everybody thinks or assumes that someone else has the required/important data, but, in reality, some important data could be missing.
- In the new brewery, the data on energy, natural resources (water!) and emissions needs to be recorded both at the plant level and for each individual specific production line. By monitoring and analysing the resource consumption and waste generation of the actual process, possible environmental and economical improvements can be suggested.
- In the product itself – beer in multi-packs shipped on pallets– the largest environmental load is caused by the production of cluster board. The multi-pack cluster package could be redesigned.
- Remarkable environmental impact is caused by distribution of the beer. The multi-pack pallets should be designed so that empty returned bottles can be placed on them for return to the brewery so the transport of empty crates will be minimised. The product distribution truck driving routes could be checked once more to find possibilities for optimisation.
- One of the main raw materials for the beer production is bought from Central Europe, and hence the environmental effect of this long distance transport is remarkable. A search for local possible alternatives should be undertaken to reduce the environmental effect.
- Finding ways to diminish waste generation and to save electricity in the brewery will give both environmental and economical benefits.
- An agreement with retail companies concerning better empty bottles collecting and recycling systems at the shops should be made. About 9% of returned bottles are soft drink bottles, which need to be separated at the brewery on a special line. It could be more sensible to separate them at the shops while putting the bottles into the crates. Soft drink bottles are easy to detect, as the colour of these bottles is different.

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