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ScienceDirect

Procedia CIRP 69 (2018) 827 – 832

www.elsevier.com/locate/procedia

25th CIRP Life Cycle Engineering (LCE) Conference, 30 April – 2 May 2018, Copenhagen, Denmark

Intermediate bulk containers re-use in the circular economy: an LCA evaluation

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Abstract

The transition towards a circular economy, where the value of products, materials and resources is maintained for as long as possible, is an essential contribution to the European Union's efforts to develop a sustainable economy. Re-use of packaging items plays a key role in the achievement of this goal.
The aim of this study is to assess the environmental impacts associated to the life cycle of Intermediate Bulk Containers (IBCs) as the number of uses (the so-called “rotations”) changes, by using the life cycle assessment (LCA) methodology.
The results of the contribution analysis show that the impacts of the life cycle of IBCs mainly come from the IBCs manufacturing, whereas the reconditioning process accounts for less than 20% of the overall impacts. Moreover, the system where IBCs are reconditioned and re-used has better environmental performance than the system where IBCs are used only once and then sent to recycling/disposal. The advantages of such a system increase with the number of rotations.

Keywords: packaging; re-use; IBC; LCA; circular economy

1. Introduction

The transition towards a circular economy, where the value of products, materials and resources is maintained for as long as possible, and the generation of waste minimized, is an essential contribution to the European Union's efforts to develop a sustainable, low carbon, resource efficient and competitive economy [1]. Re-use plays a central role in the circular economy, as a waste prevention activity. Re-use means, in fact, any operation by which products or components are used again for the same purpose for which they were conceived [2].

Because of their purpose to contain consumable goods, packaging items are particularly prone to re-use.

The intermediate bulk containers (IBCs) are reusable industrial containers designed for the transport and storage of bulk liquid and granulated substances, such as chemicals, food ingredients, solvents, pharmaceuticals, etc.. They consist in a high density polyethylene (HDPE) container (the “bottle”) housed within a tubular steel cage that is attached to a pallet. The pallet may be made of wood, plastic or steel and it is designed to be handled by using a forklift or a pallet jack. In Italy, IBCs re-use is promoted by Conai, the Italian National Packaging Consortium, thanks to a special agreement between Conai and the IBCs reconditioners.

The aim of this study is to assess the environmental impacts associated to the life cycle of IBCs as the number of uses (the so-called “rotations”) changes, by applying the life cycle assessment (LCA) methodology.

doi:10.1016/j.procir.2017.11.010

2. Material and methods

2.1. Goal and scope definition

The LCA has been applied in this study to evaluate the environmental performance of the life cycle of reusable IBCs. IBCs can be re-used after a reconditioning process. Thus, the study has been performed to identify the contribution of this process to the total impacts of the life cycle and to understand if a system based on reusable IBCs performs better than a system based on single-use IBCs.

Two plants situated in the North of Italy were surveyed in order to gather primary information on the reconditioning process. Based on these data, the layout and the mass balance of an average reconditioning plant for IBCs were defined.

In the studied system, the IBCs are manufactured and, after being used, they are sent to a reconditioning plant. Here IBCs that cannot be reconditioned because too damaged are selected prior to the washing stage and sent to material recovery. On average, this flow accounts for 24% of the IBCs sent to the reconditioning process. The remaining 76% of the total IBCs are washed by using hot pressurized water and a mix of chemical products. After washing, IBCs are further checked and the plastic bottles that result not sufficiently cleaned are removed from the structure and replaced by new ones. On average, 25.5% of the bottles are discarded at this stage. The bottles are sent directly to material recovery if they do not contain chemical residues, especially at the solid phase; otherwise the bottom is cut off and washed with high pressured water. If in this way it is possible to separate the bottom from the solid chemical residues, the bottom is sent to material recovery, otherwise it is sent to incineration together with the residues. The wastewater is treated before being discharged in the public drainage system and the sludge produced during the treatment is sent to incineration. On average, the maximum number of rotation in a life span is 5 [3]. At the end of their life, IBCs are sent to material recovery.

In order to consider the differences that are present among the reconditioning plants, different scenarios were considered in the LCA:

- the IBCs contain chemical residues at the solid state (M scenario) or they do not contain chemical residues at the solid phase (SM scenario);
- two different combination of chemicals are used to wash the bottles (scenarios RE1 and RE2);
- the washing water is heated by using oil or natural gas (scenarios E1 and E2, respectively).

The function of the analyzed system is to provide ready-to-be-used reusable IBCs. The functional unit was assumed as 100 IBCs ready for the n^{th} use, with n included between 1 and 5. This means that, actually, we have five case studies, each with its functional unit and reference flow. For n equal to 1, the new manufactured IBCs are used only once and then sent to recycling/disposal. Thus the reference flow is 100 new manufactured IBCs. For n equal to 2, the new manufactured IBCs, after the first use, are sent to a reconditioning plant. Here, as described before, 24% of the IBCs cannot be reconditioned and are sent to recycling/disposal, whereas the others are cleaned and thus available for the second use. This means that such 24% must be replaced by new manufactured IBCs to have 100 IBCs ready for the second use. The reference flow is, thus, 124 new manufactured IBCs. In wider terms, the reference flow associated with 100 IBCs ready for the n^{th} use is $[100 + 24(n-1)]$ new manufactured IBCs, as can be inferred from Fig. 1.

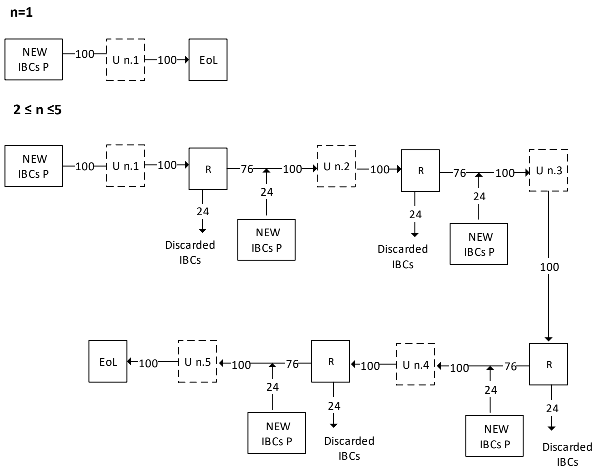

Fig. 1. Simplified chart of the life cycle of 100 IBCs as the number of rotation changes. P= production; U= use; EoL= end of life; R= reconditioning.

The IBCs have the characteristics reported in Table 1 and the pallet can be made of wood, steel or plastic.

Table 1. Characteristics of the IBCs under study.

Type of IBC	Steel (kg)	Plastic (kg)	Wood (kg)
wood pallet	22 (cage)	16 (bottle)	23 (pallet)
plastic pallet	22 (cage)	35 (bottle 16, pallet 19)	-
steel pallet	42 (cage 22, pallet 20)	16 (bottle)	-

The system boundaries (Fig. 2) include:

- the IBCs production and the production of the substituted bottles
- the reconditioning process
- the end of life of the IBCs (after n uses and after being discarded in the reconditioning process) and of the discarded bottles
- the end of life of all the residues generated during the reconditioning process
- the transport of the IBCs to the reconditioning plant and that of the wastes to the disposal/recycling plants.

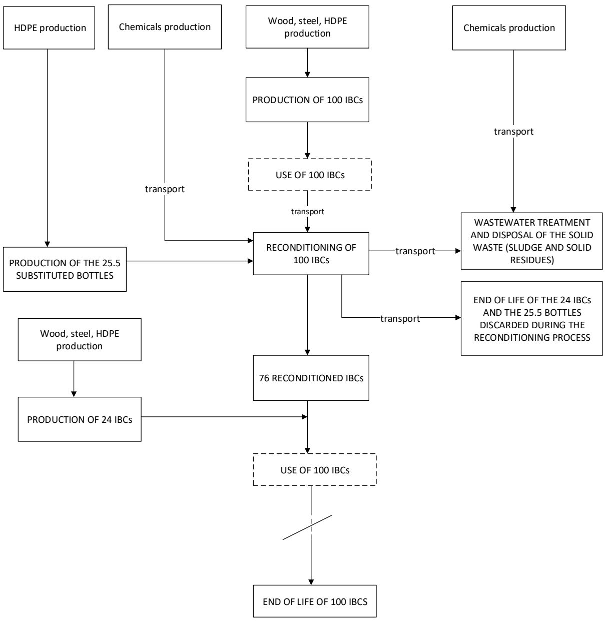

Fig. 2. System boundaries.

Besides this processes, defined as *foreground processes* and modeled on the basis of primary data, we have included also other processes, such as the production of the chemical products used for the reconditioning, defined as *background processes*. These processes were modeled by using the *ecoinvent 3.3* database (*allocation, recycled content approach*). The use phase of the IBCs is instead not included in the study.

The study refers to the Northern Italian context and the reference year is 2015. Cases of multi-functionality were solved by expanding the system boundaries to include avoided primary productions due to material and energy recovery from waste [4, 5].

The impact assessment includes 12 impact categories with the related indicators recommended by the Product Environmental Footprint (PEF) guide [6]: *climate change, ozone depletion, human toxicity non cancer effect, human toxicity cancer effect, particulate matter, photochemical ozone formation, acidification, terrestrial eutrophication, freshwater eutrophication, marine eutrophication, freshwater ecotoxicity,* and *mineral and fossil resources depletion.* Instead of the *water resource depletion* calculated as included in the PEF, we have decided to simply quantify the net water consumption associated to the whole life cycle of the IBCs considering the results of the life cycle inventory, without calculating the impact associated to that consumption. The reason was that the *water resource depletion* indicator as defined by the PEF guide has still some problems of implementation and thus was not considered completely reliable.

In addition, the *Cumulative Energy Demand* method was chosen to evaluate the energy consumption of the system [7].

2.2. Inventory

This section reports the data and the assumptions for the modeling of the main processes included in the system boundaries.

2.2.1. IBCs production

IBCs consist of a 1 m^3 plastic bottle housed within a tubular steel cage that is attached to a pallet.

The bottle (16 kg of weight) is produced by extrusion blow moulding of HDPE granules with an efficiency of 99.7%.

The cage (22 kg) is made up of low alloyed steel. The production was modelled as pipe drawing, followed by zinc coating (coated surface: 1.32 m^2).

The pallet can be in wood, steel or plastic. Wood pallet production was modelled with the ecoinvent module for the EUR flat pallet. Plastic pallet (19 kg) production was modelled as injection moulding of HDPE granules with efficiency of 99.4%. Steel pallet (20 kg, low-alloyed steel) production was modelled as section bar rolling, followed by zinc coating (coated surface: 2.4 m^2).

2.2.2. Reconditioning process

The distance between the users and the reconditioning plant was assumed equal to 400 km. The IBCs are transported by 16-32 t lorries (80.8% Euro 3, 6.1% Euro 4, 12.7% Euro 5, and 0.4% Euro 6, based on [8]).

As described in Chapter 2.1, several scenarios were introduced to take into account the differences among the reconditioning plants.

The reconditioning of 100 IBCs requires the use of 7 m^3 of water that is heated by a light fuel oil boiler (scenario E1) or by a natural gas one (scenario E2) (assumed consumptions: 35 l of light fuel oil or 35 m_n^3 of natural gas for 100 IBCs sent to reconditioning). Water is mixed with different chemicals to improve the washing operations. The following chemicals are used: in scenario RE1,11.4 kg of detergent, 10.1 kg of pure sodium hydroxide, 4.71 kg of pure sulphuric acid, 1.68 kg of pure sodium hypochlorite, 2.6 kg of acetone, and 6.4 kg of silicone surfactant; in scenario RE2, 4.8 kg of detergent, 10.35 kg of pure sodium hydroxide, and 21.2 kg of silicone surfactant. We assumed that chemicals are bought at a producer located 100 km from the plant and are transported by light commercial vehicle.

The energy consumption of the reconditioning process is equal to 106.7 kWh for 100 IBCs sent to reconditioning.

2.2.3. Wastewater treatment

The treatment of the wastewater resulting from the reconditioning process was modeled as a dedicated physical-chemical treatment plant (located at the reconditioning plant), followed by an average biological sewage treatment plant.

The physical-chemical treatment was modeled on the basis of the data gathered from the field surveys. The treatment of 7 m^3 of wastewater requires 4.86 kg of pure iron (III) chloride, 3.84 kg of pure sodium hydroxide, 34.5 kg of hydrated lime, 3.7 kg of pure sulphuric acid, and 5.92 kg of pure hydrogen peroxide. We assumed that chemicals are bought at a producer located 100 km from the plant and are transported by light commercial vehicle. The electricity consumption is equal to 1.4 kWh for 7 m^3 of wastewater to be treated.

The treatment of 7 m^3 of wastewater produces 151.8 kg of sludge that is incinerated in a municipal solid waste incineration plant located 100 km far from the reconditioning plant, with recovery of thermal energy and electricity (0.15 kWh and 0.29 MJ per kg of sludge). The thermal energy produced by the incineration plant substitutes an equivalent amount of thermal energy produced by a domestic gas boiler with an efficiency of 87%. The avoided electricity was modeled as the Italian electricity mix.

2.2.3. End-of-life

The IBCs after *n* uses and those discarded by the reconditioning process are disassembled and the components are sent to material recovery.

For what concerns bottles, if they do not contain chemical residues at the solid phase (scenario SM), they are sent directly to material recovery, otherwise (scenario M) the bottom is cut off and washed with high pressure water. If it is possible to remove the solid chemical residues, the bottom is sent to material recovery, otherwise it is sent to incineration together with the residues. On average, 25.3% of the bottles (both those of the IBCs discarded prior to the washing, and those discarded after the washing) cannot be recovered and are incinerated with the solid residues in an incineration plant for hazardous waste 300 km far from the reconditioning plant.

The cages and the steel pallets are sent to a sorting plant where they are pressed and crushed (energy consumption: 47.5 kWh per t of input). Due to their purity, we assumed that no waste is generated. Then, the scrap is transported to the recycling plant. The efficiency of the recycling plant is equal to 88.1% [9] and the substitution ratio between the secondary and the primary steel was assumed equal to 1:1. The overall distance reconditioning plant - sorting plant - recycling plant was assumed equal to 100 km.

The bottles and the plastic pallets are directly sent to dedicated recycling plants 200 km away from the reconditioning plant, where they are shredded, grinded and granulated through extrusion. The energy consumption of the plant is 0.21 kWh/kg of plastic [10] and the process efficiency is equal to 97% (personal communication). The substitution ratio between the HDPE granules from mechanical recycling and the virgin HDPE granules is 1:0.81 [9].

The wood pallets are sent to a sorting plant where they are grinded, and then to a recycling plant. Due to the purity of the material, we assumed that no waste is generated during the sorting operations. The recycling process was modelled as described in [9, 11]. The resulting particleboard can be used in replacement of plywood produced from virgin wood. The substitution ratio is 1:0.6 in volume [9]. The overall distance reconditioning plant - sorting plant - recycling plant was assumed equal to 50 km.

3. Results and discussion

This chapter reports the results of the LCA study. They refer to the life cycle of 100 IBCs ready for the n^{th} use and include the impacts of the production of [100 +24*(n-1)] IBCs, of the regeneration of 100*(n-1) IBCs and of the end of life of [100+24*(n-1)] IBCs.

The results will be presented only for the IBCs with wood pallet. Similar results were, in fact, obtained also for the IBCs with plastic pallets and steel pallets.

3.1. Impact assessment

Considering the different scenarios (M and SM scenarios, RE1 and RE2 scenarios, and E1 and E2 scenarios), the results turned out to be mostly influenced by the presence of solid residues in the bottle. When the IBCs contain solid residues that cannot be easily removed during the reconditioning process, the impacts associated with the life cycle of the IBCs in fact increase up to 100% for most of the considered impact categories. The only exceptions are *the human toxicity – non cancer effect* and the *mineral and fossil resources depletion* categories, for which the increase is below 10%. This underlines how it is important that the bottles are completely emptied before the IBCs are sent to reconditioning and before chemicals can solidify, making the cleaning impossible. The other parameters (i.e. the energy used to heat the water and the chemicals used in the reconditioning process) are less important and on average contribute for less than 4% to the differences among the scenarios.

When $n > 1$, the life cycle of the IBCs can be divided in three stages: production, reconditioning and end of life. As shown for example in Fig. 3 for $n = 5$, the major burdens resulted those associated with the production of the IBCs. The contribution of the reconditioning process to the overall impacts increases with the number of uses, but it is in any case modest and below 20% for most of the considered impact indicators. The only exceptions are the *ozone depletion* and the *climate change* impact categories, where the contribution of the reconditioning process reaches a maximum of 40%.

More in detail, the main burdens of the “production” stage are associated with the production of the steel cage.

For the “reconditioning” (which includes the transport of the IBCs to the reconditioning plant, their washing, the recycling/disposal of the discarded bottles, the manufacturing of an equivalent number of new bottles and the wastewater treatment), the main burdens are associated with the handling of the discarded bottles (disposal of the solid residues and production of the new bottles) and with the transport of the IBCs to the reconditioning plant. Indeed, these processes are not directly under the control of the reconditioning plant. It is thus very important the behavior of the users that should remove any chemical residues from the bottles before sending the IBCs to reconditioning. Moreover, a widespread distribution of the reconditioning plants in the national territory could reduce the burdens associated with the transports. The washing process, instead, contributes for less than 20% to the burdens of this stage, with the exceptions in the *ozone depletion* impact category (maximum contribution = 36%, depending of the scenario) and in the *human toxicity - non cancer effect* impact category (average contribution = 25%). The burdens are mainly associated with the wastewater treatment and with the sludge incineration. Other non-negligible burdens are related to the consumption of surfactant (especially for the impact category *ozone depletion*) and to the heating of the water. The benefits are associated with the recycling of the discarded bottles (deprived of the non-recoverable bottoms).

For what concerns the "end of life", the burdens are associated with the incineration of the solid residues and of the non-recoverable bottoms (only for scenario M) and are usually compensated by the benefits associated with material recovery (especially steel). The only exceptions are the *human toxicity - cancer effect*, the *climate change* and *ozone depletion* impact categories (the last two only for the scenarios M).

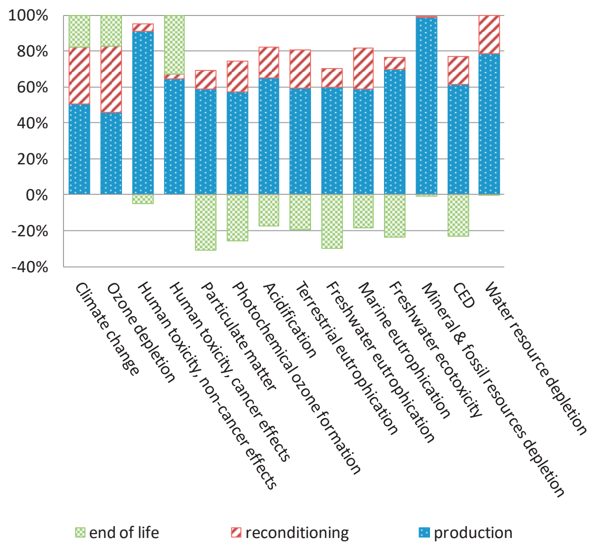

Fig. 3. Percentage contribution of the life stages "production", "reconditioning" and "end of life" to the value of the indicators for 100 IBCs with wood pallet ready for the 5th use. The results refer to the scenario with maximum burdens (i.e. scenario M-RE2-E1).

3.2. Reconditioning vs. single use

Fig. 4 compares the situation under study (i.e. the IBCs, after use, are sent to the reconditioning process) to an alternative situation where the IBCs are used just once and then sent to recycling/disposal and substituted with new ones. The comparison is showed only for three of the considered impact categories (the ones which showed the minimum and maximum difference between the two situations and one with an intermediate behavior), but similar results were found for the others.

It is evident that a situation where the IBCs are reconditioned is preferable. When the IBCs bottles contain solid residues, the environmental burdens of a system based on re-use are about 62-76% of those of a system based on the single use if n=2, 49-69% if n=3, 43-64% if n=4, 39-62% if n=5, depending of the considered impact category. If the IBCs do not contain solid residues, the burdens of a system based on re-use are 62-74% of those of a system based on the single-use if n=2, 49-65% if n= 3, 43-60% if n=4 and 39-58% if n=5, depending on the considered impact category. The benefits of the re-use increase with the number of uses. It is, thus, important to improve the reconditioning process in order to reduce the percentage of discarded IBCs.

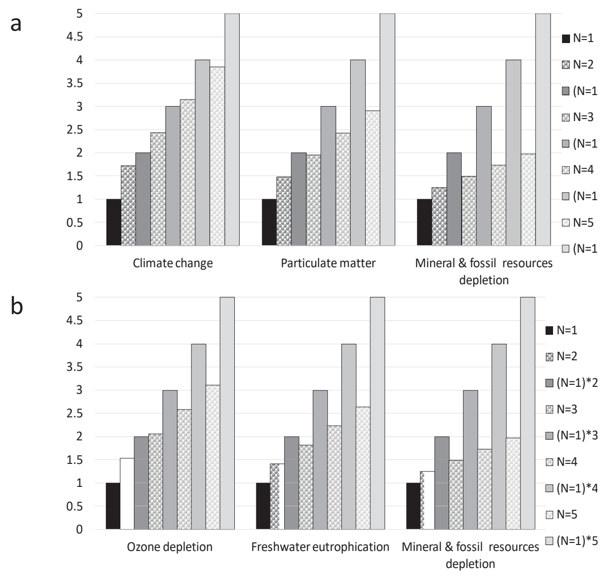

Fig. 4. Comparison between a system where the IBCs are reconditioned (N=2, N=3, N=4, N=5) and a system based on single-use IBCs ((N=1)*2, (N=1)*3, (N=1)*4, (N=1)*5). The indicators are normalized on the basis of the results obtained for a single use (N=1). (a) scenario SM: IBCs do not contain solid residues; (b) scenario M: IBCs contain solid residues.

3.3. Sensitivity analysis

Since the main contribution to the overall environmental benefits associated with the life cycle of the IBCs is given by the recovery of the steel components, we have decided to perform a sensitivity analysis by changing the value assumed for the substitution ratio between secondary steel and primary steel. In the baseline LCA we have assumed a substitution ratio equal to 1:1. A 1:1 substitution ratio is however possible only if the properties of the secondary product are exactly the same of the primary product and if, during the recycling process, it is not necessary to add other virgin materials to meet the minimum technical specifications [12]. During the melting in the electric arc furnace, alloying elements cannot be separated and accumulate in the secondary material, thus limiting the application of secondary steel or requiring the addition of high-quality scraps or even of pure primary steel [13]. For such a reason, a substitution ratio of 1:1 for steel is not usually representative of the real situation.

On average, the steel recycling process requires the addition of 300 kg of primary steel, 16 kg of coal and 64 kg of gypsum for 880 kg of scrap [14]. The percentage of scrap is thus equal to 70% of the total materials required by the process. Despite not being possible to exclude the possibility to reach higher percentage of scrap in the furnace inlet, in absence of other data we have decided to assume in the sensitivity analysis a substitution ratio of 1:0.7, as reported in [15].

The reduction of the substitution ratio determines a global increase of the value of the impact indicators. However, the overall LCA results do not change: the re-use of IBCs is still preferable to a situation where IBCs are used once and then sent to recycling/disposal.

4. Conclusions

The impacts associated with the life cycle of reusable IBCs were assessed as the number of rotation changes.

Results showed that the impact of the reconditioning process is modest compared to that associated with the IBCs production. Its contribution to the overall impacts increases with the number of rotations, but it is always below 20% for most of the considered indicators. The only exceptions are in the *ozone depletion* and *climate change* impact categories, where the reconditioning process contributes for a maximum of 40%. Reconditioning and reusing IBCs is thus preferable to a situation where IBCs are used only once and then sent to recycling/disposal. In addition, the benefits associated with the practice of re-use increase with the number of rotations.

Focusing on the reconditioning process, the main burdens are associated with the transport of the IBCs from the users to the plant and with the disposal of the solid residues contained in the bottles and of the non-recoverable bottoms. These processes are not directly under the control of the reconditioning plant. It is thus important the behavior of the users, that should remove any chemical residues from the bottles before sending the IBCs to reconditioning. Moreover, a widespread distribution of the reconditioning plants in the national territory could reduce the burdens associated with the transports. The influence of the chemicals used for the washing and of the fuel used for the water heating is negligible.

Acknowledgements

The study was financed by Conai. We wish to thank all the plant operators who have supplied primary data for the LCA.

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