



## Combining eco-efficiency and eco-effectiveness for continuous loop beverage packaging systems: learnings from the Carlsberg Circular Community

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5 **Combining eco-efficiency and eco-effectiveness for continuous loop beverage**  
6 **packaging systems: learnings from the Carlsberg Circular Community**

7

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16 **Summary**

17 Eco-efficiency, i.e. increasing value while reducing resource use and pollution, can with  
18 advantage be combined with eco-effectiveness, i.e. maximizing the benefits to ecological and  
19 economical systems, to address the challenges posed by the circular economy in the design of  
20 circular industrial systems. We present a framework combining Life Cycle Assessment (LCA) and  
21 the Cradle to Cradle® (C2C) certification program for the development of continuous loop  
22 packaging systems, which was conceived for aluminum cans in the context of the Carlsberg  
23 Circular Community. As a first step, the environmentally optimal beverage packaging life cycle  
24 scenario is identified, both in terms of defined use and re-use. Secondly the limiting factors are  
25 identified for the continuous use of materials in multiple loops, meeting the two requirements in the  
26 C2C certification process that address the material level (i.e. “material health” and “material  
27 reutilization” criteria) and the “renewable energy” criterion. Then, alternative scenarios are built to  
28 meet C2C certification criteria, and LCA is used to quantify the environmental impacts of the  
29 resulting improvement strategies, e.g. change in material composition, in order to guide the  
30 identification of the optimal scenario from an eco-efficiency point of view. Finally, the business  
31 perspective is addressed by assessing the potential for a green value network business model for a  
32 closed-loop supply. The outcome is a list of prioritized actions needed to implement the most  
33 efficient and effective “upcycling” strategy for the beverage packaging, both from an environmental  
34 and economic point of view. In the case of the aluminum cans the main recommendation from both  
35 the LCA and C2C perspective is to ensure a system that enables can-to-can recycling.

36

37 **Keywords: circular economy, life cycle assessment (LCA), cradle-to-cradle, business models,**  
38 **recycling, resource management**

39

40 **<heading level 1>Introduction**

41 Most of the initiatives developed at international level to tackle resource scarcity and  
42 sustainable production and consumption aim at a shift towards a resource-efficient and low-carbon  
43 economy (e.g. UNEP 2011). Their rationale is based on decoupling economic growth from resource  
44 use and reducing the adverse environmental impacts of products and services, while also meeting  
45 human needs and improving well-being (UNEP 2011). The circular economy, defined as a  
46 restorative or regenerative industrial system by intention and design (EMF 2013), has recently been  
47 proposed as a solution for this challenge by the European Commission (EC 2015).

48 High priority in the circular economy agenda is given to the packaging sector (EMF 2013)  
49 and to packaging waste management (EC 2015). Packaging is by its nature transient; most one-way  
50 packaging is discarded after use, entering the waste stream after a use period of typically less than a  
51 year (Hopewell et al. 2009). Companies in the beverage packaging sector were among the pioneers  
52 in the implementation of environmental sustainability strategies in their business. The very first  
53 studies of the direct and indirect use of energy associated with the life cycle of products regarded  
54 indeed the production of beverage containers (Hannon 1972). During the years, many initiatives  
55 have tried to address the issue of sustainability for packaging, e.g. the Australian Sustainable  
56 Packaging Alliance (Sustainable Packaging Alliance 2002) and the Sustainable Packaging Coalition  
57 (Greenblue 2011). As mentioned by Wever and Vogtländer (2013), the traditional approach to  
58 packaging and sustainability has been based on the use of Life Cycle Assessment (LCA). LCA is  
59 the most widespread tool able to quantify improvements in terms of eco-efficiency, i.e. increasing  
60 value while reducing resource use and pollution (Bjørn and Hauschild 2013). Due to its systemic  
61 approach defined by ISO 14040-44 standards (ISO 2006a, 2006b), LCA provides valuable support  
62 in integrating environmental sustainability targets into design, innovation and evaluation of  
63 products (Sala et al. 2012). LCA results provide the background for identification of potential

64 burden shifting and optimization opportunities, thanks to the comprehensive assessment of all  
65 potential environmental impacts connected with a product system. Yet being an eco-efficiency  
66 inspired tool, LCA quantifies the environmental footprint of products or services and identifies  
67 reduction opportunities through comparison of scenarios for product system optimizations with the  
68 current baseline systems (Bjørn and Hauschild, 2013). In the context of the UNEP/SETAC Life  
69 Cycle Initiative a review of LCAs in packaging for food and beverage applications has recently  
70 been conducted, with the aim to provide practical guidance to support decision making in this sector  
71 (UNEP & SETAC 2013). Particularly in the beverage packaging sector, LCA is widely used (von  
72 Falkenstein et al. 2010; Scipioni et al. 2013; Pasqualino et al. 2011; Mourad et al. 2008; Amienyo et  
73 al. 2012; Toniolo et al. 2013). LCA studies generally focus on packaging minimization, i.e. to  
74 reduce material use, leading to reduced environmental impacts, while maintaining the protection  
75 function of the packaging. However, according to Svanes et al. (2010) a long-term sustainability  
76 strategy for packaging should not be based on material minimization, but rather on packaging  
77 optimization, not only in terms of environmental sustainability, but also distribution costs, market  
78 acceptance and user friendliness.

79 Carlsberg Group, the fourth largest global brewery in the world, applies four different  
80 strategies in its sustainable packaging program (Carlsberg Group Annual Report 2016): Reduce  
81 (e.g. the weight of the packaging), Recycle (e.g. influence recycling rates and increase the amount  
82 of recycled content), Reuse (focus on the return and reuse of glass bottles), and Rethink (innovate  
83 within packaging and waste, by optimizing materials and channeling it into other products after its  
84 initial use). The first two approaches follow the eco-efficiency principle, advocating the adoption of  
85 LCA to identify the priority areas for reducing the environmental impacts of the company activities.  
86 According to LCA results, primary and secondary packaging account for approximately 45% of  
87 Carlsberg's total CO<sub>2</sub> emissions (Carlsberg Group 2012), where the former is the packaging in

88 direct contact with the beverage (e.g. an aluminum can) and the latter is the packaging used to  
89 group more units of primary packaging together (e.g. cardboard boxes). This has resulted in  
90 sustainable packaging being a key focus of Carlsberg's work within sustainability. Besides the LCA  
91 methodology, Carlsberg recently adopted a broader approach oriented towards product quality and  
92 innovation, i.e. the Cradle to Cradle® (C2C) design framework. C2C aims to increase the positive  
93 footprint of products by designing "eco-effective" solutions, i.e. maximizing the benefit to  
94 ecological and economical systems. The term "eco-effectiveness" was introduced to characterize an  
95 approach focusing on the development of products and industrial systems that maintain or enhance  
96 the quality and productivity of materials through subsequent use cycles (McDonough and Braungart  
97 2002). The last two principles of Carlsberg's sustainable packaging agenda (reuse and rethink) are  
98 thus based on the eco-effectiveness principle. Moreover, the C2C design framework inspired the  
99 creation in January 2014 of the Carlsberg Circular Community (CCC). This is a cooperation  
100 platform involving Carlsberg and a selection of global partners, aiming at rethinking the design and  
101 production of traditional packaging material, with the ambition to develop packaging products that  
102 are optimized for recycling and reuse, while retaining their quality and their value.

103 This paper aims at illustrating the opportunities and challenges in combining the use of LCA  
104 and C2C certification in the beverage packaging sector, focusing on the case study of aluminum  
105 cans within the CCC. First, we summarize the outcomes of previous research on the combined use  
106 of eco-efficiency/LCA and eco-effectiveness/C2C in other sectors. Second, the case study of  
107 aluminum cans is introduced, to identify the learnings and limitations from the use of eco-  
108 effectiveness and eco-efficiency approaches separately and to outline how the C2C vision can  
109 inspire LCA. Third, we present a framework to integrate both approaches in the decision support for  
110 beverage packaging companies implementing a continuous loop packaging system. Finally we

111 discuss the challenges for companies that combine the use of LCA and eco-effectiveness  
112 approaches and how LCA can inspire the C2C certification.

113

#### 114 <heading level 1> Case studies of combined eco-efficiency/LCA and eco-effectiveness/C2C

115 The complementarity of eco-efficiency and C2C was previously discussed in more general  
116 terms by Bjørn and Hauschild (2013), and the usability of LCA in a C2C process was addressed by  
117 Bor et al. (2011). In their assessment framework for sustainable product design de Pauw and  
118 colleagues (2014a) propose two new elements to current life-cycle-based product assessment:  
119 assessing against conditions of sustainability, i.e. relative or absolute, and assessing “achievement”,  
120 the extent to which these conditions of sustainability have been achieved. Moreover, the ability of  
121 the C2C certification program to assess the “eco-effectiveness” of a design strategy has been  
122 questioned due to its main focus on the implementation of the C2C strategy within an organization  
123 and support for communication and marketing of products that have already been developed (de  
124 Pauw et al. 2013).

125 The idea of having continuous loops of materials recently inspired Vergheze and colleagues  
126 (2012) to define a more comprehensive packaging sustainability framework. According to their  
127 definition, in order to contribute to sustainable development, packaging needs to be *effective* in  
128 meeting its functional requirements; *efficient* in its use of materials, energy and water throughout its  
129 life cycle; *cyclic* in its use of renewable materials, and recoverability at end-of-life; and finally *safe*  
130 for people and the natural environment (Vergheze et al. 2012). According to Rossi and colleagues  
131 (2006) LCA adopts a “*tool-driven*” approach to addressing environmental problems, i.e. it is a  
132 method to evaluate the environmental performance of a product, which inspires the stakeholders to  
133 make improvements to the product based on the conclusions generated by the LCA study. The C2C  
134 system adopts instead a “*goal-driven*” approach, since first the goals to be achieved are established,

135 and then the tools and metrics needed to measure progress and help achieve those goals are  
136 developed. A goal of the C2C vision is *to generate cyclical, cradle-to-cradle ‘‘metabolisms’’ that*  
137 *enable materials to maintain their status as resources* (upcycling). ‘‘Upcycling’’ refers to re-  
138 designing ingredients or additives so they improve the quality of materials with respect to  
139 maintaining or improving value in continuous loops. In order to identify the best upcycling option  
140 for a product, the so called ‘‘defined use’’ of the product has to be identified, i.e. the use of the  
141 product at each stage of the cascade considering the environment that the product is suited to (Bor  
142 et al. 2011).

143 In spite of the strong historical focus on environmental optimization of packaging systems, no  
144 studies of combined use of eco-efficiency/LCA and eco-effectiveness/C2C on packaging systems  
145 have been identified in literature. The only exception is one LCA study of a cradle-to-cradle cycle  
146 (biogas-to-bioplastic) generating biocompatible beverage packaging materials from methane  
147 emissions (Rostkowski et al. 2012).

148 However, the mutual influence of C2C principles and LCA on each other has been addressed  
149 for other sectors. For the building sector, Silvestre et al. (2014) demonstrated that the eco-efficiency  
150 approach can be an important source of data for decision-making at the end-of-life of building  
151 materials, especially to identify whether the minimization of waste flows, the maximization of their  
152 reuse or recycling operations, or the increase of the recycled content maximizes their C2C  
153 environmental performance. van Dijk and colleagues (2014) focused on three flows in the built  
154 environment, i.e. material, energy and water cycle and concluded that many companies in the  
155 building industry have difficulties to put the C2C theory into practice, because among others the  
156 complexity of building projects. For the household sector, de Pauw and colleagues (2014), in the  
157 case of tableware and cutlery, and coffee machines, showed that C2C can inspire an approach to  
158 product design that is distinct from what an LCA-based methodology would inspire. All previous



159 studies pointed out that further research is needed to support the different industries translating the  
160 C2C theory into practical implementation.

161

## 162 <heading level 1> **The aluminum can case**

163 The following sections will present an overview of the main learnings and limits emerging  
164 from the use of eco-effectiveness and eco-efficiency approaches separately. These learnings are  
165 primarily derived from the experience of Carlsberg with the certification process of the aluminum  
166 cans for beer packaging (size 44, 50, 56.8 cl), which were C2C certified at bronze level in the UK  
167 market in 2015. Moreover, the outcomes of previous studies performed by the authors are also  
168 taken into account (Niero et al. 2016a; Niero and Olsen 2016).

169

## 170 <heading level 2> **Learnings from eco-effectiveness**

171 The eco-effectiveness concept of C2C encompasses a series of strategies for generating  
172 healthy defined material flow metabolisms (Braungart et al. 2007). The components of a product,  
173 consisting of one or more materials, should be designed by intention to fit either within a biological  
174 or a technical cycle. Materials in the biological cycle are meant to be returned to the soil by  
175 composting or anaerobic digestion, while materials in the technical cycle are designed to be  
176 recovered and upgraded (Braungart and Engelfried 1992). The C2C vision with its three key  
177 principles “waste equals food”, “use current solar income” and “celebrate diversity” (McDonough  
178 and Braungart 2002) aims to maximize the benefit to the ecological and economic systems through  
179 a shift towards a resource-effective economy, rather than just reduce the negative impacts of  
180 existing solutions. In such an economy humans are part of the ecological systems, and resources are  
181 retained within the economy when a product has reached the end of its use, so that they remain in

182 productive use and create further value. C2C has demonstrated to be a powerful framing for  
183 communicating and mobilizing societal and political action (Potting and Kroeze 2010), driving the  
184 circular economy.

185 With regard to C2C, a distinction should be made between Cradle to Cradle® as a vision  
186 oriented towards product quality and innovation based on the three abovementioned design  
187 principles, and the Cradle to Cradle Certified™ Product standard (hereafter C2C certification  
188 program), which is a certification standard developed to document the degree of implementation of  
189 the C2C concept within product manufacturing. The certification program, operating with five  
190 levels of accomplishment (basic, bronze, silver, gold, platinum), was conceived to allow companies  
191 to document their progress in applying the C2C vision (Cradle to Cradle Products Innovation  
192 Institute 2016). Only platinum certified products are fully C2C compliant, but so far only one C2C  
193 certified product worldwide has reached the platinum level. The only example of C2C certification  
194 within the beverage packaging area hitherto concerns aluminum used for the manufacturing of  
195 beverage bottles and aluminum cans (<http://www.c2ccertified.org/products/registry>).

196 According to the C2C terminology, aluminum is a “technical nutrient”, i.e. a material that has  
197 the potential to remain safely in a closed-loop system of manufacture, recovery, and reuse (the  
198 technical metabolism), maintaining its highest value through many product life cycles (Braungart et  
199 al. 2007). Technical nutrients are used as “products of service”, which are durable goods that  
200 provide a service to customers, such as the aluminum can does. Opposed to products of service are  
201 the so-called “products of consumption”, i.e. made of biological nutrients.

202 Figure 1 presents the life cycle of an aluminum can, which is made of two components, the  
203 body, obtained typically from the 3004 alloy with a higher manganese content, and an upper part,  
204 including the lid and the pull tab, made by the 5182 alloy with a higher magnesium content and  
205 referred hereafter as “lid” (The University of Liverpool 2015). The lid is typically made from

206 primary aluminum alloy while the body is made from secondary aluminum alloy, adjusted with  
207 primary aluminum. Secondary aluminum is obtained from recycling operations, which include pre-  
208 processing, remelting and a final step of alloy adjustment, where the desired alloy composition is  
209 obtained (Niero and Olsen 2016).

210 Applying the five certification criteria (described in Table 1 and presented in Figure 1 with  
211 the exception of the social fairness criterion) several lessons were learned from the C2C  
212 certification of the aluminum can. For material health (MH) the ultimate goal is for all products to  
213 be manufactured using only those materials that have been optimized and do not contain any X or  
214 Grey assessed materials (i.e. toxic materials according to the C2C certification). From the rating of  
215 the materials composing the can (i.e. body, lid, external varnishes and internal coatings) it turned  
216 out that substances even at ppm (i.e. part per million) level have an impact on value and  
217 recyclability. These substances often originate from additives or alloying elements giving the  
218 desired functional properties to the base material, as in the case of the lacquer. The material  
219 reutilization (MR) criterion is quantified by the so-called Material Reutilization Score (MRS). In the  
220 case of a material belonging to the technical cycle the MRS (see Equation 1) includes two variables:  
221 the % of the product considered recyclable (i.e. a material that can be recycled at least once after its  
222 initial use stage), and the % of recycled content (RC) in the product (Cradle to Cradle Products  
223 Innovation Institute 2016):

$$224 \quad MRS = [2 \cdot (\% \text{ of the product considered recyclable}) + (\% \text{ RC})] / 3 \cdot 100 \quad (1)$$

225 In the case of the aluminum can a prerequisite for a high MRS is to ensure recyclability, e.g.  
226 in the case of closed loop through the optimization of the lacquer. The ease of removal of the  
227 lacquer indeed increases the recyclability of the Al scrap, whose value is directly dependent on its  
228 contamination level. However, the traditional de-lacquering is based on an energy intensive thermal  
229 process: the direct combustion of the paints results in the oxidation loss of aluminum as well as the

230 generation of toxic gas containing dioxin and furan (Li and Qiu 2013). The current MRS formula  
231 only takes into account the possibility to recycle the material at least once after its initial use stage  
232 and to a lesser extent the recycled content.

233 The last three certification criteria are at process level and concern renewable energy use and  
234 carbon management (RE&CM), water stewardship (WS) and social fairness (SF) and to meet them,  
235 performance at production and organization levels need to be included in the optimization strategy.  
236 The learnings listed above are generic, and in the case of the Carlsberg's C2C certified aluminum  
237 can, most of the learnings came from MH and MR criteria: the in-depth knowledge of its material  
238 composition (in terms of alloys) and the identification of optimized components (i.e. the lacquer)  
239 suggested the potential for a closed loop recycling.

240

## 241 <heading level 2>Learnings from eco-efficiency

242 The eco-efficiency concept is based on “adding maximum value with minimum resource use  
243 and minimum pollution” (Huesemann, 2004). The focus in LCA is on reducing the environmental  
244 impacts of product/service and recycling is addressed only as one issue amongst several others.  
245 Reduction in environmental impacts has often been pursued through material efficiency either at the  
246 end-of-life of the product's first life, through product life extension (longer product life,  
247 refurbishment and remanufacturing, components reuse), or at the product design stage, e.g. reducing  
248 the amount of material in product manufacturing (Allwood et al. 2011). For beverage packaging,  
249 due to the short duration of its use stage, product life extension is not a viable option (except for  
250 returnable packaging) whereas focusing on the material use extension certainly is. A relevant aspect  
251 in this sector is the recyclability of the packaging material, which depends on both its technical  
252 recyclability, i.e. the ease with which it can be reprocessed and used to manufacture new products,  
253 and on the availability of facilities to collect, sort and reprocess the material (Verghese et al. 2012).

254 This double dependence calls for a closer collaboration between product designers and waste  
255 management as a prerequisite to close the material loop (Ordoñez and Rahe 2013). According to  
256 Bakker and colleagues (2014), the first item of a future research agenda for products in a circular  
257 economy is to establish the optimal product life scenario. But which is the optimal beverage  
258 packaging life scenario?

259 In a previous publication (Niero et al., 2016a), we considered the case of a 33 cl aluminum  
260 can in the UK market and compared the climate change impacts and cumulative energy demand  
261 associated with achieving different levels of two C2C certification requirements (MR and RE). The  
262 functional unit considered was the containment of 1 hl of beer (where 1 hectolitre = 100 litres). In  
263 the calculation of the MRS we assumed that the % of the product considered recyclable is constant  
264 and equal to the total weight of the can minus the lacquer, i.e. 96.8% (Niero and colleagues 2016a),  
265 and varied the % of RC (50%, 65%, 100%) corresponding to a MRS value of 81.2, 86.2 and 97.9,  
266 respectively. The LCA modelling was based on a pure Al flow (EAA 2013), using the default  
267 ecoinvent v3.1 datasets for primary and secondary aluminum production (Moreno Ruiz et al. 2014).  
268 The latter dataset is based on two sources: the European Aluminium Association 2005 LCI data and  
269 the ecoinvent v2.2 dataset for the same activity (Moreno Ruiz et al. 2014). We concluded that,  
270 limited to MR and RE, performance to a higher C2C certification level does not necessarily lead to  
271 a reduction in the system's climate change impact (Niero et al. 2016a).

272 Figure 2 summarizes the results of the Life Cycle Impact Assessment (LCIA) of the  
273 progressions in the C2C certification level from bronze (B) to gold (G) for the combinations of MR  
274 and RE criteria considered in the abovementioned study of the 33cl aluminum can (Niero and  
275 colleagues 2016a). Results are shown for four impact categories: climate change (IPCC 2013),  
276 freshwater ecotoxicity (USEtox, Rosenbaum et al. 2008), metal depletion and fossil depletion  
277 (ReCiPe 2008, Goedkoop et al. 2009), in relative terms, i.e. normalized to the highest score for each

278 impact category. Only the combinations relevant for the progressions of the bronze certified  
279 aluminum can towards higher certification levels are considered, i.e. gold and above for MR (where  
280 the can already meets the silver level requirements) and bronze and above for RE.

281 As the relative LCA results show (Figure 2) increasing the % of renewable energy and the  
282 MRS result in a decrease of the potential environmental impacts in terms of climate change and  
283 fossil depletion. At the same time an increase in recycled content, which implies an intensification  
284 of recycling activities, seems to increase the metal depletion and freshwater ecotoxicity potentials,  
285 so there appears to be a trade-off. The increase in ecotoxicity is primarily due to the emissions of  
286 metals (mainly Cu) during aluminum recycling, which dominate the freshwater toxicity impact  
287 (applying both recommended and interim characterization factors to cover as many emissions as  
288 possible) (Hauschild et al. 2013). The increase in metal depletion at increasing recycling rate is  
289 linked to the increase in the use of secondary aluminum, whose production is modelled by the  
290 default ecoinvent v3.1 dataset considering the extraction of copper and silicon as proxy alloying  
291 elements. These side-effects are not relevant in the case of aluminum recycling for cans and the  
292 observation points out the limitation of modelling aluminum processes with the default datasets  
293 based on average aluminum alloy composition, since the contribution to metal depletion of Cu is  
294 three orders of magnitude higher than the contribution of Al. When the actual alloy contribution is  
295 considered in the Life Cycle Inventory (LCI) modelling, results show that an increase of the  
296 recycling rate leads to lower impacts for climate change, resource depletion and human toxicity  
297 impacts (Niero and Olsen 2016).

298

299 **<heading level 2> Limits of a standalone use of eco-effectiveness and eco-efficiency**  
300 **approaches**

301 The standalone use of eco-effectiveness and eco-efficiency approaches provides limited inputs to  
302 improve the design of the aluminum can system. The learnings provided by the C2C certification  
303 mainly suggest improving the composition of the can with a focus at the material level. There is no  
304 clear indication on which actions should be prioritized to reach higher certification levels. On the  
305 other side, if LCA is used without a vision of continuous loop packaging system, i.e. focusing  
306 solely on the primary function of containment of the aluminum can, there is a risk of overlooking  
307 conceptually different design options for the packaging systems. This calls for a combination of  
308 both approaches in a systematic framework, able to provide decision makers in the packaging  
309 industry with a tool to prioritize actions towards the development of the most eco-efficient and eco-  
310 effective packaging solutions.

311

## 312 <heading level 2>How can a C2C vision inspire LCA

313 Table 2 summarizes how the C2C vision can provide inspiration to each of the four  
314 methodological phases of the LCA (ISO 2006a, 2006b) in packaging optimization for the technical  
315 cycle.

316 The most relevant insights from the C2C vision to LCA modelling are in the goal and scope  
317 definition and LCI modeling. The functional unit for an LCA on a beverage container is  
318 traditionally based on the service provided by the beverage container (e.g. to facilitate containment,  
319 distribution and storage of the beverage from the production site via retailers to consumers). This is  
320 valid when the scope of the study refers to only one life cycle, but in a circular economy perspective  
321 materials are meant to be used in continuous loops. We showed that to model multiple loops the  
322 functional unit should be defined including multiple co-functions, as introduced in the ILCD  
323 Handbook, Annex C (EC-JRC-IES 2011). Therefore, the functional unit should be “the containment  
324 of 1 hl of beer and supply of resource after its use stage for 30 loops” (Niero and Olsen 2016).

325 The actual material composition needs to be taken into account while addressing the use of  
326 aluminum in continuous loops. We challenged the prevailing LCI modelling of aluminum products,  
327 based on a pure aluminum flow, and performed the LCA considering both the components of an  
328 aluminum can, i.e. body and lid/tab, and their actual alloy compositions, showing that a closed  
329 product loop recycling, i.e. a can-to-can recycling is the best option from an environmental point of  
330 view, at least considering climate change impacts (Niero and Olsen 2016).

331 In the LCI modelling the main challenge is to model recycling over multiple life cycles. C2C  
332 advocates for continuous material loop, which is different from closed material/product loop. In the  
333 ISO standards (ISO 2006b) recycling is methodologically a case of multi-functionality and it is  
334 modelled according to two factors: i) the next use of the material, distinguishing between closed-  
335 loop recycling (material recycled in the same product system) and open-loop recycling (material  
336 recycled in a different product system), and ii) the changes in the inherent properties of materials,  
337 meaning that if the recycled material is used in another product system, then the closed loop  
338 approach can also be used for open-loop systems, as long as the inherent properties of the material  
339 are not changed. Both closed loop and open loop recycling approaches are potentially in accordance  
340 with circular economy principles. However, in the LCA community there is still no agreement on  
341 the way recycling processes should be modelled and different approaches are available (Allacker et  
342 al. 2014). The choice of the method to include recycling in LCA for aluminum cans does influence  
343 the results (van der Harst et al. 2016). An overestimated grade of the recovered materials can  
344 significantly inflate the perceived benefits gained from recycling. Nonetheless, most waste  
345 management LCA studies assume a 1:1 substitution ratio and/or quality similar to the substituted  
346 product, i.e. that 1 kg of secondary material substitutes 1 kg of primary material (Laurent et al.  
347 2014b). However, even for metals this assumption might not be valid if the actual alloy composition  
348 is taken into account. The key aspect is to take into account the benefits of recovery of material not



349 only from a quantitative, but also qualitative point of view. Further investigation is needed to  
350 identify how to quantify the downgrading of metals, even though some general guidance is  
351 provided, e.g. in the ILCD handbook (Annex C) (EC-JRC-IES 2010) in terms of quantification of  
352 the inherent technical properties of the secondary good or by the inclusion of a ratio between the  
353 quality of the secondary material and the quality of the primary material (Allacker et al. 2014).

354

### 355 <heading level 1>Framework to combine eco-efficiency and eco-effectiveness for continuous 356 loop packaging systems

357 Our framework to combine eco-efficiency and eco-effectiveness (see Figure 3) is based on a  
358 stepwise procedure aiming to assess the potentials for establishing continuous loop beverage  
359 packaging systems.

360 As a first step the optimal environmental life cycle scenario for beverage packaging is  
361 identified, both in terms of defined use and re-use. The distinction between the technical cycle and  
362 biological cycle can help in identifying the best use of the packaging. Inspired by the C2C vision,  
363 the defined re-use of the packaging should be addressed in the functional unit definition. Apart from  
364 its primary function of containment, the function of an aluminum can is also to provide the  
365 aluminum scrap as secondary resource for subsequent product systems (Niero and Olsen 2016). The  
366 question is then “for how long should the co-function be provided”? The answer depends on the  
367 number of uses allowed for that material, which is linked to the definition of the best next use, i.e.  
368 identifying what “upcycling” means for packaging. When including the alloying elements in the  
369 LCA of the aluminum can, the closed product loop option emerged to be the best in terms of  
370 climate change performances (Niero and Olsen 2016).

371 Secondly, the two requirements at material level of the C2C certification process, i.e. MH and  
372 MR, and the RE criterion are used to identify the limiting factors for the continuous use of materials

373 in multiple loops. For the aluminum can, can-to-can recycling is nowadays limited by the can  
374 composition in terms of lacquer and by recycling operations, considering that aluminum scraps are  
375 mixed (Cullen and Allwood 2013) and recycled aluminum is used for body production. Options to  
376 separate body and lids in order to increase the recyclability of the can in multiple closed product  
377 loops should be explored.

378 As a third step, alternative LCA scenarios of C2C certification are built to quantify the  
379 environmental impacts of different options for the improvement of the packaging, encompassing  
380 different improvement strategies, such as change in material composition (e.g. using a different  
381 lacquer), use of renewable energy in product manufacturing and supply chain (see Niero et al.  
382 2016a), increase of recycled content and recycling rate.

383 Finally, since circular economy is not only about resource scarcity and environmental impact,  
384 but also economic benefit (Lieder and Rashid 2016), the business model of a closed loop supply has  
385 to be included in the procedure. Our suggestion is to apply a green value network business model,  
386 which supports a business model proposition formulated on a value network perspective,  
387 incorporating both the economic and environmental perspectives, e.g. the framework developed by  
388 Stewart et al. (in prep.). Such framework for green value network business model is built on the  
389 archetype “create value from waste” proposed by Bocken et al. (2014) including insights from  
390 literature about closed loop supply chain, value network business models and green business  
391 models, where “green” refers to the environmental aspect of sustainability.

392 The outcome of the stepwise procedure is a list of prioritized actions relating to e.g.  
393 technology, logistics, waste management, consumer and customer relationships, needed to  
394 implement the most efficient and effective “upcycling” strategy for the beverage packaging  
395 considered, both from an environmental and economic point of view, as shown in Figure 3.

396 Our framework aims to connect upstream and downstream decisions in the value chain,  
397 providing coherent incentives between producers, distributors, consumers and recyclers, and  
398 ensuring a fair distribution of costs and benefits, through the definition of the green value network  
399 business model, in accordance with the circular economy political agenda (EC 2014) . The C2C  
400 vision with the identification of a defined use scenario indeed allows aligning the interest of all  
401 stakeholders towards a common goal. The inclusion of the defined use and re-use in the functional  
402 unit definition of the LCA allows the alignment of eco-effectiveness principles and eco-efficiency  
403 tools (see step 1 in Figure 3).

404 The need for interconnection is not only at the upstream level (e.g. coordination between can  
405 producers and beverage producers to optimize lacquer composition), but also downstream, for  
406 managing and controlling used materials and products for reuse by the firm, e.g. through reverse  
407 logistics systems (van der Wiel et al. 2012). The development of reverse logistics systems for  
408 packaging is constrained by the existing waste management system, which in some countries, e.g.  
409 the UK, prevents the separate collection of used beverage cans (UBCs). Therefore, a systems  
410 approach is required, with connections among all the stakeholders in the value chain, from suppliers  
411 to recyclers, and with repercussions at different levels, from technology (e.g. recycling technology)  
412 to logistics and waste management, as well as for different actors, i.e. customers and consumers, as  
413 summarized in Figure 3. The aim of joint actions such as the CCC, is indeed to engage suppliers  
414 and customers in initiatives with shared values, as well as consumers and new partnerships with  
415 relevant actors for a continuous loop product chain. On the top of the priority action list for the  
416 CCC is to design packaging for “zero contamination”, since high quality recycling can only happen  
417 when the materials are not contaminated, either by other materials or through contamination by the  
418 content. For packaging belonging to the “technical cycle”, such as the aluminum can, the ambition  
419 is to develop packaging solutions that are optimized for recycling and retain their quality and their

420 value throughout multiple loops. Four types of actions form the backbones of the CCC (Carlsberg  
421 Group Annual Report 2016): i) *assessment and optimization* which is targeting suppliers such as the  
422 aluminum can producers; ii) *communication and information* oriented towards customers, e.g. using  
423 the C2C certification scheme; iii) *behavior change* for consumers, e.g. through the participation to  
424 campaigns for UBC collection in events like festivals (see the “Every Can Counts initiative” in the  
425 UK) to educate end-users to dispose the packaging material in the appropriate collection bin and iv)  
426 involvement of *partners* aiming at packaging upcycling.

427

## 428 <heading level 1>Recommendations and perspectives

429 Eco-efficiency and eco-effectiveness approaches can be made operational by combining LCA  
430 and the C2C certification program. The C2C as a vision has a long term perspective and the C2C  
431 certification scheme is the way to address the transient period towards a world of “platinum” C2C  
432 products, where the C2C certification levels represent different level of achievement of eco-  
433 effectiveness. Our framework is based on a four step procedure to combine two tools, LCA and the  
434 C2C certification program, in order to identify which actions should be prioritized for reducing the  
435 impacts or even increasing the (positive) effect of the company activities on society.

436 The framework was developed based on a case study of aluminum cans and the experience of  
437 Carlsberg with adopting both LCA and the C2C certification program to produce both eco-efficient  
438 and eco-effective packaging. The main learnings from the CCC experience are that, to achieve an  
439 eco-efficient and eco-effective packaging, the can should be optimized by improving the  
440 composition of the lacquer, increasing the recycled content of the can, separating body and lids in  
441 order to increase the recyclability of the can in multiple closed product loops, and improving  
442 transparency in the materials composition, which is essential for high quality recycling. For  
443 aluminum cans the main recommendation from the developed framework is to ensure a system that

444 enables can-to-can recycling and to design packaging for “zero contamination”. This is valid for the  
445 packaging system under study, characterized by high volumes, short use life, and existence of  
446 infrastructures for material collection. The suggested framework can be applied and adapted by any  
447 other company, familiar with both LCA and C2C certification program, to assure that the decision  
448 making process considers both eco-efficiency and eco-effectiveness.

449

## 450 <heading level 2> Challenges in combining eco-effectiveness and eco-efficiency

451 One of the main challenges in the implementation of the C2C certification scheme is the need  
452 for a closer cooperation with suppliers in order to gather the necessary data for the classification in  
453 the ABC-X assessment (see Table 1) and following optimization of substances as part of the MH  
454 certification. The shift to eco-effective industrial systems indeed requires to provide customers with  
455 information on how to deal with the product after its use period, as well as recyclers with  
456 information on appropriate material composition and dismantling processes (Braungart et al. 2007).

457 Among all challenges for the implementation of circular economy strategies from a business  
458 perspective, product design plays a key role. This is especially true for packaging, which has to fit  
459 both product and its use environment and to take into account the increasingly complex packaging  
460 technology. A further complication is due to the increasing web of material producers, packaging  
461 component manufacturers, packaging equipment suppliers, users, retailers and waste recovery  
462 facilities and reprocessors that might have different priorities and interests. The C2C certification is  
463 performed on the product level, e.g. in the case of aluminum cans for the primary packaging, i.e. the  
464 materials in direct contact with the product, so neglecting the secondary and tertiary packaging.  
465 Combining the C2C certification with LCA provides a further option to avoid the risk of sub-  
466 optimization of the primary packaging at the expense of secondary or tertiary packaging.

467           However, we are aware that in coupling LCA with the eco-effectiveness approach there are  
468 data limitations, e.g. on specification of materials and recycling operations, which may lead to  
469 simplification. In the ideal case we would have time and data to go much deeper in terms of what is  
470 the real material composition including additives, how it can be recycled, what is the composition  
471 of the recycled material and what are its potential and real applications, but in practice there is  
472 always a trade-off between the wish for precision and simplification (Zamagni et al. 2012).

473

## 474 <heading level 2>How can LCA inspire C2C certification

475           Elements for improving the C2C certification program can be found for most of the  
476 certification requirements. For MR, efforts should be put on increasing the recycling rate to increase  
477 the availability of recycled aluminum. The current formula to calculate the MRS only takes into  
478 account the possibility to recycle the material at least once after its initial use stage, which might not  
479 reflect the actual recycling routine for the considered material. Efforts to improve the separate  
480 collection of materials should be rewarded and accounted for in this requirement.

481           As suggested by Bjørn and Hauschild (2013) in cases where there is a trade-off between the  
482 C2C requirements for energy and material consumption, the environmental impacts associated with  
483 the energy consumption should also be considered. We recently provided an overview of the  
484 limitations of the current RE&CM requirement, mainly focusing on use of energy in the  
485 manufacturing stage. We considered the introduction of a broader RE perspective covering the life  
486 cycle, and our results showed that increasing the share of RE in the primary aluminum production  
487 from a full life cycle perspective can greatly increase the environmental benefits brought up by the  
488 C2C certification, not only for climate change, but for the broader range of impact categories (Niero  
489 et al. 2016b).

490 A last suggestion for improvement of the C2C certification program refers to the water  
491 stewardship (WS) criterion, which provides information on the quantitative and qualitative aspects  
492 of water, but could benefit from being integrated with an impact assessment method considering the  
493 scarcity aspect, e.g. through a water scarcity footprint assessment, see e.g. Boulay et al. (2013).

494

495

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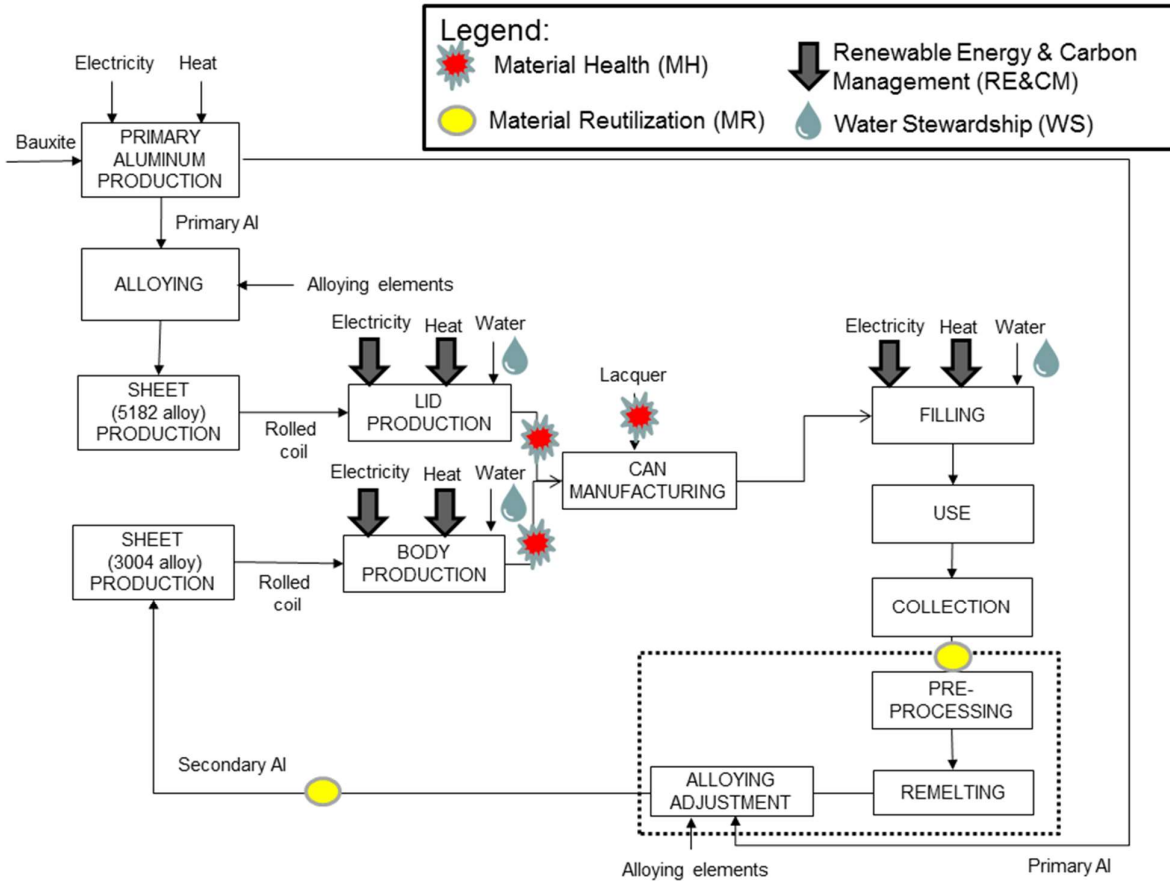
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699 **About the authors**

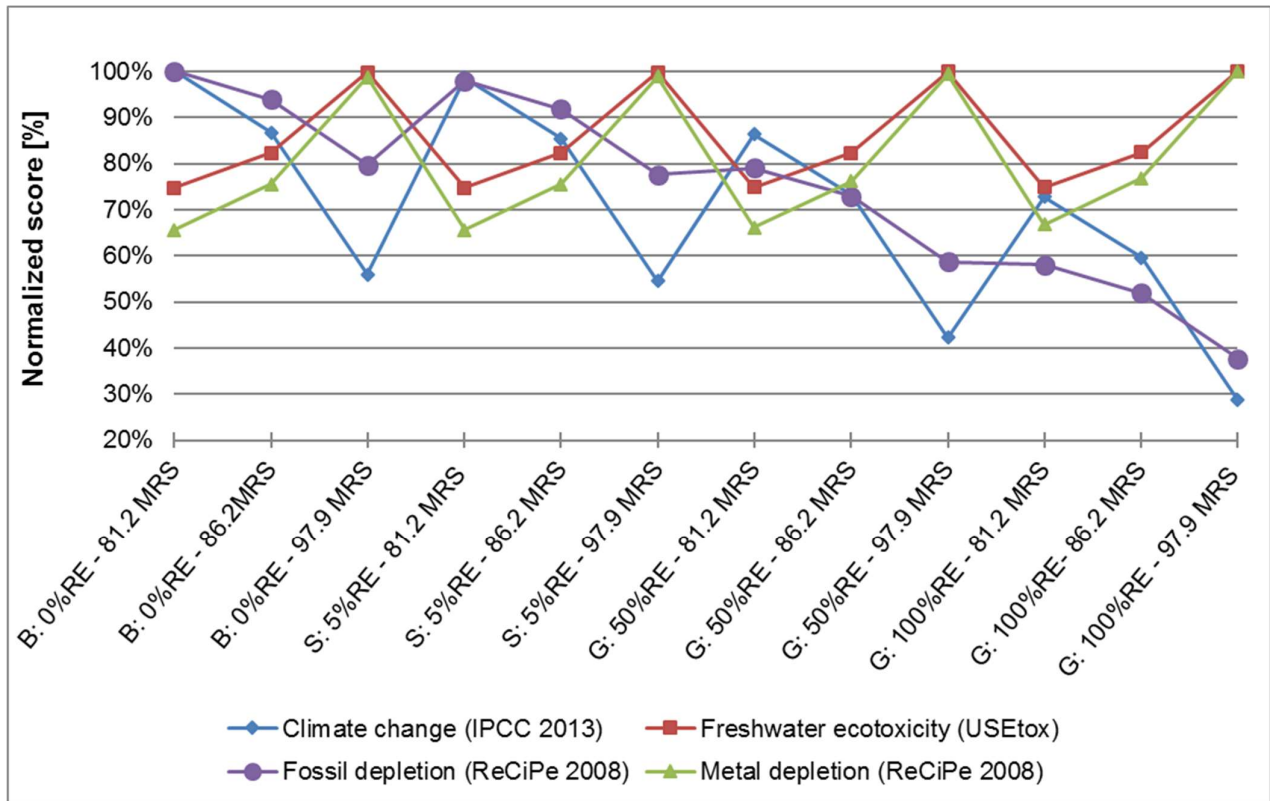
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709 **Figure 1 System boundaries of the life cycle of aluminum can, from raw material extraction**  
 710 **(i.e. primary aluminum production) to the end of life, including recycling (represented by the**  
 711 **dashed line including pre-processing, remelting and alloying adjustment). The consideration**  
 712 **of 4 out of the 5 Cradle-to-Cradle (C2C) certification criteria is indicated at the relevant**  
 713 **points in the life cycle - material health (MH), material reutilization (MR), renewable energy**  
 714 **and carbon management (RE&CM), and water stewardship (WS).**

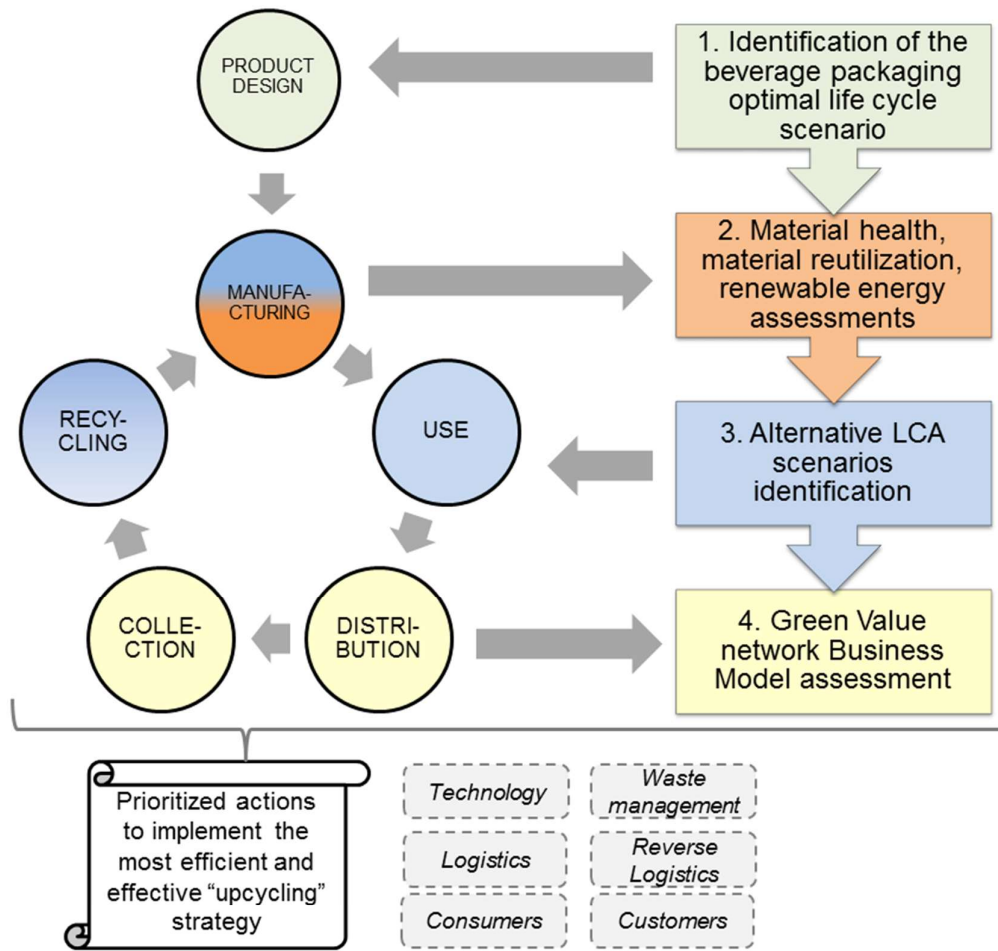


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716 **Figure 2: Normalized Life Cycle Impact Assessment (LCIA) scores of progression in Cradle-**  
 717 **to-Cradle (C2C) certification from bronze (B) to silver (S) to gold (G) based on the Life Cycle**  
 718 **Inventory (LCI) modelling presented in (Niero et al. 2016a) for climate change, freshwater**  
 719 **ecotoxicity metal depletion and fossil depletion. The LCIA scores are normalized using**  
 720 **normalization by maximum approach (Laurent and Hauschild 2015), where each impact scores**  
 721 **is divided by the maximum value of the different scenarios (as %). Scenarios were built varying**  
 722 **two parameters, % RE (renewable energy) and the material reutilization score (MRS),**  
 723 **calculated according to Equation 1 with constant % of material considered recycled and**  
 724 **increasing % recycled content (RC, i.e. 50%, 65%, 100%) corresponding to a MRS value of**  
 725 **81.2, 86.2 and 97.9, respectively.**

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729 **Figure 3: Framework combining eco-efficiency and eco-effectiveness for optimization of**  
 730 **closed loop packaging systems, based on a 4-step procedure, where LCA refers to the Life**  
 731 **Cycle Assessment methodology.**



732 **Table 1: Description of C2C certification criteria and main learnings gained by the Carlsberg Circular**  
 733 **Community (CCC) during the C2C certification process for the aluminum can. In brackets under each**  
 734 **criterion the level reached by the aluminum can considered in the case study.**

<b>C2C certification criterion</b>	<b>Description (Cradle to Cradle Products Innovation Institute 2016)</b>	<b>Learnings from CCC</b>
MH: Material Health (Bronze)	Provide material assessment ratings (ABC-X assessment) based on the hazards of chemicals in products and their relative routes of exposure during the intended (and highly likely unintended) use and end-of-use product phases.	Substances even at ppm level, such as the lacquer, have an impact on value and recyclability
MR: Material Reutilization (Silver)	Provide quantitative measure of the product's design for recyclability (technical cycle) and/or compostability (biological cycle)	Ensuring recyclability, e.g. through the optimization of the lacquer, is a prerequisite for high recycled content
RE&CM: Renewable Energy & Carbon Management (Bronze)	Provide quantitative measure of the share of renewable energy utilized in the manufacture of the product	Performance at production level needs to be included in the optimization strategy
WS: Water Stewardship (Bronze)	Provide quantitative and qualitative measure of water usage and water effluent related directly to manufacture of the certified product	Performance at production level needs to be included in the optimization strategy
SF: Social Fairness (Bronze)	Provide qualitative measure of impact of product manufacture on people and communities	Performance at organization level needs to be included in the optimization strategy

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738 **Table 2: Main challenges and opportunities for including the C2C vision in each step of LCA**  
 739 **methodology in the case of “products of service” belonging to the technical metabolism.**

<b>Step</b>	<b>Challenge</b>	<b>Opportunity</b>
<b>1. Goal and scope definition</b>	- Include secondary function of the packaging in the functional unit definition	- Identification of the least environmentally impacting option considering multiple loops - Use scenario analysis to test the influence of possible design choices
<b>2. Life Cycle Inventory (LCI)</b>	- Identify how much primary secondary is substituted by secondary material - Data availability	- Take into account the benefit of recovery of material not only from a quantitative, but also qualitative point of view
<b>3. Life Cycle Impact Assessment (LCIA)</b>	- Avoid burden shifting	- Include all relevant impact categories
<b>4. Life Cycle Interpretation</b>	- Include the learnings from LCA not only ex-post, but also ex-ante, i.e. at the early design phase	- Add further elements to support the decision making process, e.g. implications for the supply chain, business models

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