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Are Cradle to Cradle certified products environmentally preferable? Analysis from an LCA approach

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Abstract

The Cradle to Cradle (C2C) certification has gained popularity amongst companies as a way to distinguish more environmentally friendly products. This article analyzes the C2C certification by determining how successful this eco-labeling scheme is in distinguishing environmentally preferable products in order to probe if the certification informs correctly to the consumer about the environmental performance of products. Furthermore, we identify for which product types the C2C certification really results in environmental impact reduction. First a review is done in order to detect the debilities, if any, of C2C. Secondly, the fact that C2C requirements do not tackle environmental aspects of products from a life cycle approach, and concentrates exclusively on raw materials and end of life phases, is further analyzed in depth. To do so, Life Cycle Assessment (LCA) already published results for different product categories are used to determine if the life-cycle stages considered under the C2C approach coincide with the most relevant stages in terms of life-cycle environmental impacts. This helps ascertain if and when C2C can be considered an appropriate ecolabel.

It is concluded that for products with high-energy consumption during use, C2C does not guarantee relevant environmental improvements, since it does not account for a substantial part of the product's environmental impact. For these reasons, we argue that C2C is not always an appropriate scheme to distinguish environmentally preferable products.

Keywords

cradle to cradle (C2C)
life cycle assessment (LCA)
ecolabelling
product sustainability
recycling

Highlights

►There are many controversies between the Cradle to Cradle concepts and other scientific theories.

►Cradle to Cradle requirements do not tackle environmental aspects of products from a life cycle approach. ►Cradle to Cradle does not guarantee relevant environmental improvements for products with high energy consumption during use. ►Cradle to Cradle does not always distinguish environmentally preferable products.

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1. Introduction

Today's society is more conscious than in the last decades about the Earth's environmental and climate change problems (for example: deforestation, species extinction or increasing CO_2 concentrations). The evidence of the need for a change has influenced our societies' mentality. Consequently, the demand for environmentally friendly products has been increasing (Imkamp, 2000). Accordingly, consumers need to be able to identify and distinguish those products that are more respectful with the environment from those which are not, and producers are motivated to differentiate those environmentally preferable products. In order to be more eco-efficient, the European Commission promotes a Sustainable Consumption and Production (SCP) action plan (European Commission, 2008a). SCP fosters a more sustainable lifestyle, buying behavior and a better product and services use and dispose from consumers. Under the SCP action plan, integrated product policies (IPP) have been promoted to standardize voluntary and mandatory tools to reduce environmental degradation produced by products and services throughout their entire life-cycle. Two of the IPP strategies (European Commission, 2012a) to achieve these objectives, are to promote (1) standardized ecolabelling systems and (2) the use of Life Cycle Assessment (LCA), which is a recognized and standardized method for quantifying environmental impacts supported by the United Nations Environment Program (UNEP, 2010) and the European Commission (European Commission, 2001; 2012b).

Presently there is an important necessity to inform consumers about environmental aspects and one of the possible ways is by using standardized, trusted, objective and credible ecolabel certificates. This article focuses on the Cradle to Cradle (C2C) Certification, which is an ecolabelling scheme whose presence in the market looks set to increase in the coming years (C2C Institute, 2011). The C2C certification is a nongovernmental ecolabel that the MBDC defines as "a multi-attribute, continuous improvement methodology that evaluates products across five categories of human and environmental health (Material health; Material reutilization; Renewable energy and carbon management; water stewardship; Social fairness)" (C2C Institute, 2012a). At first glance, C2C concepts and principles seem to be a solution which may contribute to solve some of the current sustainability problems. However, some literature questioned the feasibility of the ecolabel approaches (Bakker et al., 2009; NL Agency, 2011; Reay et al., 2011; Bjørn and Hauschild, 2012). This literature suggests that C2C certification could not be always distinguishing environmental preferable products.

The general objective of this article is to determine whether C2C certified products can be always trusted to be environmentally friendly and if so, for which product typologies the C2C certification results in environmental impact reduction.

To achieve the objective a bibliography review was realized to detect the limitations of the C2C certification as an ecolabel. Later, in relation with information extracted from the review, LCA results from many different product typologies were used to determine if the C2C certification can always distinguish more environmentally friendly product.

2. Conceptual Framework

This section presents the conceptual framework of the C2C principles and certification scheme and reviews its limitations as an appropriate approach for the promotion and identification of environmentally preferable products. First C2C concept is introduced to the reader and secondly different limitations related to the concept are mentioned and explained.

The aspects concerning life-cycle stages taken into account will be the object of further study throughout the article.

2.1. C2C Concept

Architect William McDonough and chemist Michael Braungart conceived the C2C concept. C2C proposes to replace eco-efficiency by eco-effectiveness (creating solutions that maximize economic value with no adverse ecological effects (Braungart et al., 2007)) to achieve the "state of zero: zero waste emissions, zero resource use and zero toxicity" (Braungart et al., 2007; McDonough and Braungart, 2005).

C2C is focused on three qualitative principles. To achieve zero resource use, the first principle, is based on the idea that “waste equals food”. This concept consists of a system design where waste is considered a nutrient for nature (biological nutrient metabolism) or for other industrial processes (technical nutrient metabolism). The premise is that this closed cycle system does not need to be eco-efficient (reduce resources use and wastes) because the more waste it creates, the more nutrients are available for producing new products (McDonough and Braungart, 2005). The materials which are classified as technological or biological nutrients are defined as upcycling materials. They are designed to close cycles and maintain their status as a source. On the other hand, the waste that is not reused either biologically or industrially is defined as downcycling material. Downcycling "reveals poor design of a life-cycle and the related materials flows" (MBDC, 2012; McDonough and Braungart, 2013). C2C aims to avoid downcycling materials and promote upcycling ones to achieve closed cycles.

The second principle is the use of energy from "current solar income" (McDonough and Braungart, 2005). Consequently, the use of renewable energy makes energy consumption no longer relevant as an environmental impact for the C2C.

Finally, the third principle is to "celebrate diversity" (McDonough and Braungart, 2005). C2C understands diversity as a cultural, economic and environmental issue, existing a strong relation between them. Consequently, designed systems should be respectful with all these aspects. Then, if there is no economic growth and industry is eco-efficient instead of eco-effective nature, societies and cultures stability and survival could be affected negatively (McDonough and Braungart, 2005).

2.2. Limitations of the C2C principles

2.2.1. Nutrients metabolism and the limits to growth

The C2C concept promotes an infinite economic and production growth (MBDC, 2012; McDonough, 2005), however, there are some limitations regarding the biocapacity of the planet.

Historical development shows a relation between direct material consumption per inhabitant and economic growth (EEA, 2010); then probably, even when applying 100% closed material cycles, virgin resources would be required to feed growth (Bjørn and Hauschild, 2012). These virgin resources demand could be compensated by being more efficient and reducing material masses needed for production (as dematerialization concept proposes); nevertheless, being more efficient is not one of the proposed strategies on C2C agenda.

As Nicolas Georgescu-Roegen (1971) stated, "The entropy law is the taproot of economic scarcity". Nowadays economy is a system, which extracts low-entropy resources from nature and throw high-entropy wastes into the environment. These low-entropy resources are the result of high quantity of solar energy absorbed during years (wood) or hundred million years (fossil fuels). Today entropy levels are increasing at a faster level than the natural capacity of ecosystems to absorb wastes and renew stocks of raw materials, which leads to resource scarcity (Ayres, 1998; 2004; Kallis, 2011; Kerschner, 2010). Therefore, biological nutrient cycles may not be compatible with infinite growth because natural regeneration processes are slower than the velocity of resources are consumed.

2.2.2. Biological nutrients metabolism and ecological consequences

C2C biological nutrient metabolism does not seem to be a solution as simple as C2C principles suggest. Some aspects, mentioned below, give the impression that biological nutrient metabolism is not in line with the "Celebrating Biodiversity Principle".

Introducing large quantities of biological nutrients in an ecosystem, could cause negative ecological effects (Reay et al., 2011; Reijnders, 2008). Reijnders (2008) defends that a high concentration of biological nutrients will require a massive local consumption of oxygen, which could affect surrounding organisms. Furthermore, higher concentrations of fixed nitrogen and phosphates could change soil characteristics and cause water eutrophication. These changes cloud be associated with the disappearance of native species (Lal, 2004).

Another potential problem that can result from increased biological nutrients are allelopathic substances. These are substances secreted by organisms that have an inhibiting growing effect on others. These species-specific substances may be detrimental for other organisms (Reijnders, 2008). For example, organic residues coming from the processing of guayule for producing paper pulp, linoleum filler, wallboard or pressed fuel logs, reduce the percentage of germination of crops because of allelopathic substances (Schloman Jr et al., 1991).

Biological nutrients cycles could be a good solution at a small scale with limited flows of biological nutrients introduced in nature; nevertheless, numerous flows and concentrations of biological nutrients may collapse the capacity of ecological systems to assimilate them.

2.2.3. Closing cycles and current paradigms

Implementing the C2C concept in a worldwide scenario requires severe social and infrastructure changes. Furthermore, these changes do not automatically ensure an environmental improvement because of transport and management requirements. Thus, the effectiveness of this concept seems not to be guaranteed.

Applying C2C approaches in an economy requires important logistic changes. For closing cycles, all products' materials must be recovered at the end of their life; nevertheless, under the current paradigm it may be easier for consumers to throw away their wastes. For many reasons, it cannot be expected from all users to give back to the manufacturer all products after their use. Hence, the 100% closed cycle is difficult (or even impossible) to implement.

The full waste recovery would require an extraordinary increase of transport and management of goods that are associated with higher energy consumption. The energy requirements may result in a scenario where materials' management for closing nutrient cycles could represent a higher environmental impact than other waste management solutions.

2.2.4 Current solar income principle

A widespread application of the C2C concept in the current economic system would encounter with some limitations to achieve an energetic system fully based on renewable energies.

The C2C certification demands the use of 100% renewable energy for products manufacturing and materials recycling in the case of the highest standard of certification: Platinum level (C2C Institute, 2012a), which has not been obtained by any product yet. However, C2C certification does not really consider energy not associated with manufacturing (e.g. energy consumed in use).

Nowadays it is feasible to produce one product using 100% renewable energy. However, it is impossible to produce all economy-wide products using renewables as C2C authors suggest. Our society is still far to achieve an energy system based 100% on renewable energies, as in 2008 only the 12.9% of the world's energy demand was supplied by renewable energies (IPCC, 2011a). There is still not clear future for renewable. Best previsions foresee that in 2050 80% of the global energy supply could be based on renewables, however, more pessimistic projections, suggest that only 15% of consumed energy will come from renewable sources in 2050 (IPCC, 2011b).

In addition, it cannot be considered that renewable energies have zero environmental impact, as the C2C eco-effectiveness concept promotes (maximize economic value with no adverse ecological effects). The IPCC (2011b) recognizes that, for example, wind energy have some potential ecological and environmental impacts.

2.2.5. Life Cycle stages considered by C2C

Another limitation is the fact that C2C does not seem to promote environmental improvements in all life-cycle stages (Bjørn and Hauschild, 2012; NL Agency, 2011). As the C2C concept defines, one of its principles is mainly focused on materials, namely their extraction and recycling as technical and biological nutrients, and ignores some life cycle stages of products as shown in figure 1.

For production and transportation, C2C promotes the use of renewables to solve environmental aspects but this requirement has some limitations as it is mentioned in the previous section ("Current Solar Income Principle"). Because of these limitations C2C results in the omission of production, transportation and use stages; therefore, the potential environmental impacts related to these stages are not taken into account under the C2C approach and certification scheme (Figure 1). In consequence, C2C does not always reflect environmental issues of very relevant life-cycle stages.

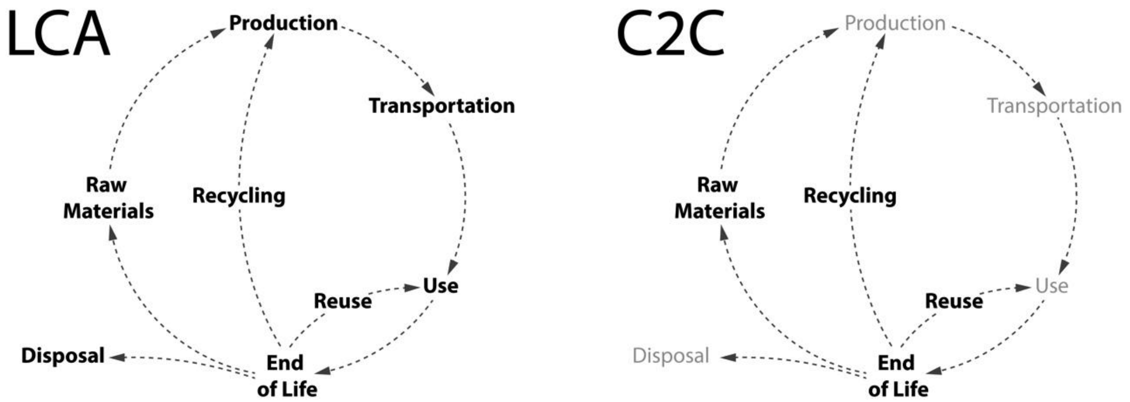

Figure 1: Comparison between stages that LCA and C2C take into account accordingly to a life-cycle approach. Stages taken into account are in bold.

3. Methodology

This section presents the methodology in order to determine whether C2C certified products can be trusted to be environmentally friendly and for which product categories.

The methodology of analysis used is divided into three steps (figure 2):

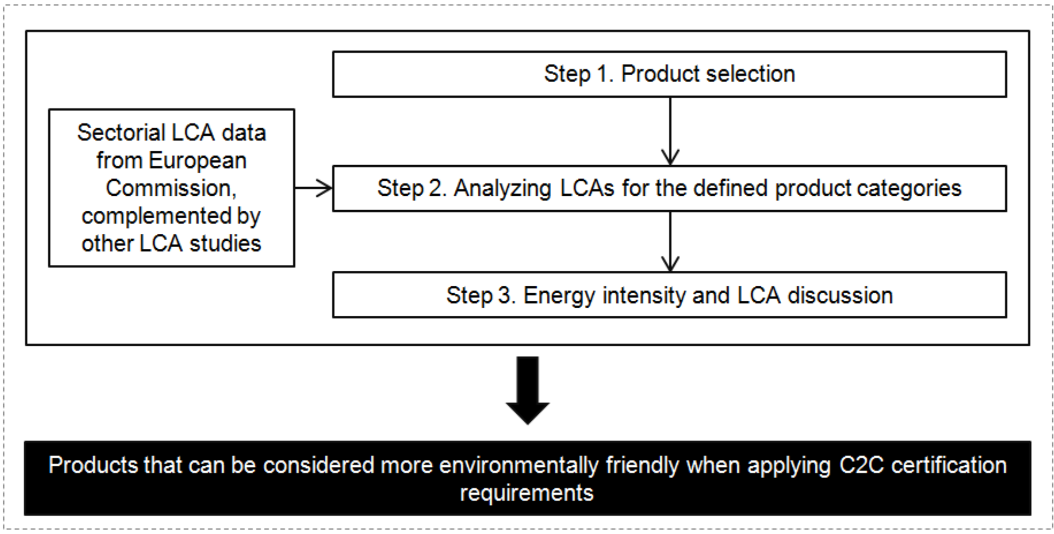

Figure 2: Methodology scheme

3.1. Step 1. Product selection

A set of Product Categories (mattresses, furniture, paper, footwear, paints, buildings, textiles, cleaning products, televisions, portable computers, mobile phones and light bulbs) were identified. These product categories had to satisfy the following requirements: (1) they should be of everyday use, and (2) they should be included both in the C2C certification scheme (C2C Institute, 2012b) and in the EU Ecolabel system (European Commission, 2013).

The last criterion was included because the EU Ecolabel is a reference label and uses LCA studies as a base. Later, the identified Products Categories were classified according to their energy intensity (figure 3). Finally, five Product Categories with varying energy intensity were selected for the study, trying to cover all energy intensity ranges: furniture, office buildings, cleaning products, textiles and TV & Lamps.

Energy intensity is defined as the ratio between the product's energy consumption during use per year (KJ) and the product's mass (kg). The parameter was used as the selection parameter because it was predicted that if the use stage is not taken into account by C2C certification schemes, there could be an interesting difference between those products with and without energy consumption at use, as it is suggested that energy consumption during use is responsible for most of the life-cycle impacts of energy related products. This selection parameter was also interesting because it contrasts the relation between energy consumption at use stage (not taken into account by C2C certification schemes) and the amount of material used to produce a product (the main aspect that C2C tackles).

Data used for this classification was based on technical specifications of products (e.g. TVs and light bulbs technical sheets) or on existing sectorial-wide reports as it is the case of EU Ecolabel product categories' bases and preliminary reports (European Commission, 2013). The collected data was basically the products' mass and energy consumption during use stage.

Furniture, Mattress, Footwear, Paper and Paints Product Categories were considered to have an energy intensity equal to 0 as they do not have energy consumption. For the other groups specific references were used to define their energy intensity: office buildings (European Commission, 2011a); cleaning products (European Commission, 2011b; Procter &Gamble et al,. 2006; Dewaele et l., 2004); textiles (Beton et al., 2010); TVs(Sony, 2013; Samsung, 2013a; Philips, 2013a); portable computers (ASUS, 2013; Apple, 2013a; Hp, 2013); mobiles (Samsung, 2013b; Apple, 2013b; htc, 2013); and light bulbs (EuropeanCommission. 2011c; Philips, 2013b).

3.2. Step 2. Analyzing LCAs for the defined product categories

The purpose of this step is to identify which life-cycle stages concentrate the most relevant environmental impacts for each of the selected product categories (*furniture, office buildings, cleaning products, textiles and TV & Lamps*) by using LCA studies as reference. LCA studies available for each Product Category are analyzed to determine how their environmental impact is distributed throughout their entire life-cycle, which is considered to be divided into 5 life cycle stages: *material resources, transportation, production, use and end of life*.

This step aims to analyze if the stages with the highest environmental impact from each Product Category are or not the same that C2C requirements tackle: raw materials and end of life (figure 1). If the majority of the environmental impact from one group category is not focused on these stages, it will be considered that C2C does not approach correctly the environmental concerns of this type of products.

The selected impact categories for the study are: abiotic depletion potential (ADP), acidification potential (AP) eutrophication potential (EP), global warming potential (GWP), ozone layer depletion potential (ODP) and human toxicity potential (HTP).

The arithmetic mean of the percentage contribution of the different impact categories was done to calculate the environmental impact for each product life cycle stage. For example, to calculate the use stage percentage of environmental impact, the contribution, of the different impact categories used during the analysis, was added and divided by the number of impact categories used. This process was repeated for each product within each product category and their 5 life-cycle stages. In case that any of the selected indicators was not available; the arithmetic mean was calculated without taking it into account. However, at least 5 indicators are required for calculating the mean.

Most of LCA results used were available from the European Ecolabel product categories' bases (European Commission, 2013) that include sectorial wide LCA data (Table 1). This database is considered trustful and reliable as it comes from public sources and it is supported by the European Commission (European Commission, 2012c). Some of the available sectorial LCA studies analyze different subgroups of products for each EU Ecolabel product category.

For the case of TV & Lamps, European Commission reports does not present specific LCA results but directly the environmental impact distribution for each life cycle stage, which is automatically taken for this assessment.

For furniture and Cleaning products categories, LCA results provide packaging environmental impact as a separated impact. (González-García et al., 2012; Procter &Gamble et al., 2006; Dewaele et al., 2004). To study the most favorable case for C2C, packaging impacts are allocated to the raw material stage, as is where C2C requirements focus on.

The LCA results for office buildings, cleaning products and TV& Lamps categories were available from the European Ecolabel product categories' bases (European Commission, 2013). For defining the distribution of environmental impacts for the furniture Product Category, information coming from the EU Ecolabel background report (European Commission, 2008b) does not provide LCA results; therefore, other case studies were used to support results (Table 1). To determine the environemntal impact for the different impact categories, information was extracted from a specific case study based on wooden childhood furniture (González-García et al., 2012). For Textiles group there was a similar situation, consequently another document from the Danish Ministry of The Environment was used (Møller Kristensen et al., 2007).

Table 1. References used to determine the environmental impact for each Product Category and the impact categories analyzed from each document.

LCA references for each selected Product Category and related impact category		
Product Category	**Reference**	**Impact Category**
Furniture	González-García et al., 2012	ADP; GWP; AP; EP;ODP; HTP
Office buildings	European Commission, 2011a	ADP; AP; EP; GWP;ODP
Cleaning Products	Procter &Gamble et al., 2006	AP; EP; GWP;ODP; HTP
	Dewaele et al., 2004	AP; EP; GWP;ODP; HTP
Textiles	Beton et al., 2010	GWP, HTP and Freshwater Ecotoxicity for Raw materials category & other support information
	Møller Kristensen et al., 2007	AP; EP; GWP;ODP; HTP
TV & Lamps	EuropeanCommission. 2011c	Tv's general environmental impact information.
	European Commission, 2008c	Lamps' general environmental impact information
	European Lamp Companies Federation, 2005	Direct percentage of the environmental impact distribution for the different phases
	European Lamp Companies Federation, 2009	
**For those impact categories with more than one reference, the arithmetic mean from the several LCA studies was done. If more than one product is analyzed in these references, mean values are used too.*		

3.3. Step 3. Energy intensity and LCA results discussion

This step aims to determine for which products applying C2C concepts will represent an environmental improvement under a life cycle approach. It is discussed if C2C can be considered a correct certification for all product typologies. Finally, we propose a new approach to adequate the use of the C2C certification and avoid transmitting misleading or confusing information to consumers in order to protect them.

4. Results & Discussion

This section is divided into three steps according to the methodology:

4.1. Step 1. Product selection

As figure 3 shows, five different groups, with differences in material use and energy consumption are considered for this study: furniture; office buildings; cleaning products; textiles; and TV & Lamps. The selected Product categories try to cover most of energy intensity ranges. Furniture was selected as a representative group of products with zero energy intensity because it is the one with the highest number of C2C certifications (C2C Institute, 2012b). Buildings, with high energy consumption but low energy intensity (due to high mass), are represented by office buildings because LCA results from the EU Ecolabel are focused on this typology of buildings. Similarly, cleaning products consider handwashing soap and detergents for dishwasher and laundry, according to the product typologies included in the EU ecolabel reports. TV & Lamps category groups two products with high energy consumption and high energy intensity.

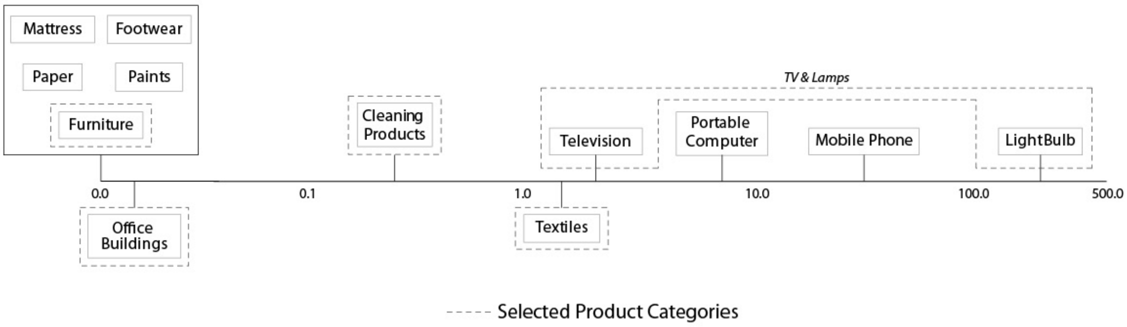

Figure3: Product classification taking into account energy intensity during use (kJ/kg) for one year. A logarithmic scale (x10) is used to represent results. Dashed lines show the selected Product Categories.

4.2. Step 2. Analyzing LCAs for defined product categories

This section defines and analyzes the environmental impact distribution for the defined product categories:

Furniture. The most environmentally relevant impact of this group is associated to a phase that C2C requirements take into account: materials (table 2). Values for this stage depend on materials used: wood, stainless steel, aluminum, leathers, glass, plastics among others (González-García et al., 2012; European Commission, 2008b). Selected materials also determine the environmental impact associated to production. According to table 2, C2C pays attention to life-cycle stages that account for 62% of the impact as the certification is exclusively focused on raw materials and end of life stages. For these products, it can be considered that C2C helps to reduce their environmental impact. However, the 38% of the impact is not accounted. This percentage includes production and transportation.

Table 2.Environmental impact distribution (in percentage rounded to 0 or 5) for different impact categories related to Furniture group. (González-García et al., 2012).

		Impact Categories (%) - values rounded to 0 or 5							Phase tackled by C2C?
		ADP	AP	EP	GWP	ODP	HTP	Average	
Furniture	**Raw Materials**	60%	55%	65%	60%	55%	75%	**60%**	**YES**
	Transportation	10%	5%	10%	10%	10%	5%	**10%**	**NOT**
	Production	30%	40%	25%	30%	35%	20%	**30%**	**NOT**
	Use	0%	0%	0%	0%	0%	0%	**<5%**	**NOT**
	End of life	0%	0%	0%	0%	0%	0%	**<5%**	**YES**

Office buildings. The reference report (European Commission, 2011a) used to analyze the LCA for office buildings group, presents the impact of transportation and production altogether. Then, results for these stages are presented together as is considered that both stages are omitted by C2C approaches.

For office buildings group, the most relevant environmental impact is at the use stage (table 3), associated with energy consumption mainly for lighting, heating or cooling (European Commission, 2011a). However, this stage is not considered by the C2C certification scheme. Then, for this group C2C tackles less than the 10% of the environmental impact. According to these results, C2C does not approach correctly the environmental impact of this Product Category.

Table 3.Relative contribution of the different life cycles stages to the environmental impact (in percentage rounded to 0 or 5) of 1 m^2 of office area during one year in London (European Commission, 2011a). These results are used to analyze the environmental impact distribution for office buildings group.

		Impact Categories (%) -values rounded to 0 or 5							Phase tackled by C2C?
		ADP	AP	EP	GWP	ODP	HTP	Average	
Office buildings	Raw Materials	0%	0%	0%	0%	0%	-	<5%	YES
	Transportation & Production	**90%**	**5%**	**10%**	**10%**	**5%**	-	25%	NOT
	Use	**10%**	**95%**	**90%**	**90%**	**95%**	-	75%	NOT
	End of life	0%	0%	0%	0%	0%	-	<5%	YES

Cleaning products. Because of certain chemical substances that cleaning products contain, the highest environmental impact is at raw materials (Procter &Gamble et al., 2006; Dewaele et al., 2004). The use stage has the second highest impact, principally due to the energy required for heating water during use (European Commission, 2011b).

Arround 64% of the environmental impact (raw materials and end of life) is taken into account under C2C approaches. Therefore, environmental improvements could be obtained when applying C2C requirements to this Product Category. Nevertheless these improvements are limited, as C2C fails to catch the other 36% of the environmental impact (transportation, production and use stages).

To obtain LCA results from cleaning products, reference reports are those ones used by the European Commission (European Commission, 2011b) to define the bases of the EU Ecolabel for cleaning products (Procter &Gamble et al.(2006) and Dewaele et al. (2004)).

Table 4.Environmental Impact categories distribution (in percentage rounded to 0 or 5) cleaning products category (Procter &Gamble et al., 2006; Dewaele et al., 2004).

		Impact Categories (%) -values rounded to 0 or 5							Phase tackled by C2C?
		ADP	AP	EP	GWP	ODP	HTP	Average	
Cleaning Products	Raw Materials	-	70%	30%	55%	60%	60%	55%	YES
	Transportation	-	15%	0%	5%	25%	5%	10%	NOT
	Production	-	5%	25%	5%	0%	5%	5%	NOT
	Use	-	10%	30%	20%	15%	25%	20%	NOT
	End of life	-	0%	25%	15%	0%	5%	10%	YES

Textiles. Within this Product Category, the use stage is the one with the highest environmental impact (62%) (Table 5). The second most relevant environmental impact is at raw material sources (21%). Values for this stage vary according to the selected natural or synthetic fibers and coloring agents (Beton et al.,2010). C2C cares for life-cycle stages responsible for the 28 % of the environmental impact (raw material plus end of life), therefore does not approach the whole environmental impact of the product.

LCA results from the European Commission report (Beton et al., 2010) include the environmental impact from raw materials extraction and production phase. However, the report just specifies the raw materials distribution for GWP, HTP and Freshwater Ecotoxicity categories. In consequence, another report from the Danish Ministry of The Environment was used (Møller Kristensen et al., 2007).

Table 5. Environmental impact distribution for different impact categories related to Textiles group. Values are given in percentage and rounded to 0 or5 (Møller Kristensen et al., 2007).

		Impact Categories (%) -values rounded to 0 or 5							Phase tackled by C2C?
		ADP	AP	EP	GWP	ODP	HTP	Average	
Textiles	Raw Materials	-	15%	20%	10%	30%	30%	**20%**	**YES**
	Transportation	-	0%	0%	0%	0%	5%	**<5%**	**NOT**
	Production	-	10%	10%	10%	10%	5%	**10%**	**NOT**
	Use	-	75%	70%	80%	25%	60%	**60%**	**NOT**
	End of life	-	0%	0%	0%	34%	0%	**5%**	**YES**

TV & Lamps. To analyze TVs' the European Commission report does not present specific LCA results (European Commission, 2008c). This report informs about the fact that at least 80% of the environmental impact from TVs comes from use stage due to energy consumption. For light bulbs the European Commision document does not give LCA results neither (EuropeanCommission, 2011c), however it refers to another report from the ELCF (European Lamp Companies Federation, 2005). This one facilitates the general percentage distribution of light bulbs showing that 90% of the environmental impact comes from use stage because of energy consumption. In contrast, raw materials and end of life represent an irrelevant environmental impact. A second report with more actualized information from the ELCF in 2009 (European Lamp Companies Federation, 2005) maintains this impact distribution (Table 6). According to this, the environmental impact of TV & Lamps Product Category is concentrated in a stage that is not considered within the C2C approach. For products using electricity, such as in this group, it should be taken into account that there may be a variability of LCA results depending on the energy mix used for the analysis (Ecoinvent, 2009). Fox example, Norwayenergy mix at consumer produces 96% less CO2 equivalent emissions per MJ generated than the energy mix from Protugal because of the use of hydroelectricenergy (Ecoinvent, 2009). Consequently, an energy mix highly based on renewable resources may reduce the environmental impact of the use stage.

Nevertheless, assuming that a renewable energy mix is used, results may not be affected. Use stage will probably continue being the stage with the highest environmental impact. For example, if a lamp lifespan is 15 years, during this period the lamp will be consuming energy. Then, despite it is using green energy, which also have an environmental impact associated, this energy will be the most important input of this product in its lifecycle. Mentioned aspects could lead to a sensitivity analysis; however, it is out of the scope of the paper.

Table 6. Percentage environmental distribution of lamps for the different life cycle stages (European Lamp Companies Federation, 2009)

		Average	Phase tackled by C2C?
TV & Lamps Environmental Impact Distribution	Raw Materials	**4%**	**YES**
	Transportation	**3%**	**NOT**
	Production	**5%**	**NOT**
	Use	**90%**	**NOT**
	End of life	**-2%**	**YES**

4.3. Step 3.Energy intensity and LCA results discussion

According to the previous results, it seems that there is a trend which shows that a higher energy intensity means a higher environmental impact related to use stage. However, office buildings Product Category does not fit to this trend. The energy intensity of this group should be higher than textiles and cleaning products to maintain the relationship. However, it must be taken into account that to calculate material intensity from buildings, the energy consumption per year and the whole mass of the building were used. Therefore if it was only used the proportional mass relative to one year of life of the building the energy intensity would be higher. If our predictions were correct, energy intensity might be one of the indicators to determine if a product could be correctly certified by C2C.

Secondly, it was seen that for office buildings, textiles and TV & Lamps categories, with high environmental impact on use stage, C2C certification omits the most environmentally unfriendly stages because it focuses on raw materials and end of life stages. Then it cannot be considered that these products are really more environmentally friendly when are certified by C2C, since the life cycle stages that concentrate most of the environmental impact are not considered.

However, it must be taken into account that C2C works well on materials and human toxicity frameworks (MBDC, 2012; McDonough, 2013). For example, electronic devices (light bulbs, TVs or computers) use many hazardous materials. Despite these products have a low impact related to materials phase are commonly used, so lots of these products are present in our society. Then, the concentration of hazardous substances increases. Consequently, at planetary scale their impact could affect negatively to ecosystems. Therefore, C2C approach could help to produce less toxic products what could lead, for example, to the conservation of biodiversity and freshwater resources quality. Then, C2C could be useful to distinguish products produced with materials of low toxicity.

Finally, and according to last paragraph the C2C certification has a great potential for the development and selection of more environmentally friendly materials. Nevertheless, the fact that the certification does not always consider the most important environmental aspects of products means that consumers cannot trust C2C certified products to be environmentally desirable.

C2C certifies the application of good strategies in the material management, but this is only a part of the life cycle of a product, and not always the most relevant.

5. Conclusions

The analysis done showed that:

- The C2C does not tackle environmental aspects of products from a life-cycle approach. Its requirements focus exclusively on raw materials and end of life stages; therefore, it gives partial environmental solutions, which do not always adapt correctly to the life-cycle distribution of environmental impacts for products. For example, for office buildings and TV & Lamps Product Categories, the 90% of their environmental impact is concentrated on transportation, production and use stages. Consequently, C2C does not take into account the most relevant environmental impact of these products. Hence, C2C requirements have some limitations to guarantee the global environmental performance of such product categories. Then, C2C certification cannot be considered an ecollabelling scheme able to distinguish all types of environmentally preferable products.
- There is a direct relationship between energy consumption during use and the increase of the global environmental impact for almost all impact categories. It is suggested that C2C certification, which does not take into account energy intensity, may not be appropriate for products with high energy intensity as it does not tackle the most relevant environmental impacts for these products (that is, the use stage). However, this connection should be further analyzed. For example, the use of an energy mix, which uses high percentage of renewables, could reduce the environmental impact of use stage. Using other parameters, as the carbon

footprint, to classify products could be interesting for further research but may lead to similar conclusions.

- The C2C certification requirements are adequate to develop products made of more environmentally friendly materials. Thus, the certification could be used as a tool to reduce the presence of hazardous materials in our society and ecosystems as well as to distinguish non-hazardous products. However, it fails in lacking a holistic life cycle approach despite the circular approach given. Using a life-cycle approach could be a good solution to adapt certification requirements for each type of products, according to those specific issues that produce most of its environmental impact. Therefore, the certification should include environmental requirements for all life cycle stages.
- Further research could expand the range of products typologies analyzed and contrast products under other certifications with products certified by C2C.
- The number of environmental private certifications is increasing. Adding a minimum control on these certifications from the government (e.g. promoting supervision policies by independent third parties) would be interesting to ensure transparent and truthful certificates.
- Finally, we suggest that C2C should include eco-efficiency strategies (such as dematerialization; minimize energy consumption) to reduce environmental impacts, considering that any human activity has an impact on nature, including renewables, and taking into account the planetary limits for growth.

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