Carbon Footprints and Ecodesign of Toner Printer Cartridges

A study commissioned by UKCRA

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SUMMARY

A study has been made of carbon footprints of short-life and long-life toner cartridges, comparing the carbon footprints of OEM cartridges with those of corresponding remanufactured cartridges. The carbon footprints have been evaluated on the basis of actual profiles of components replaced during refilling cycles. In the case of short-life cartridges, the percentage saving in carbon footprint through repeated refilling cycles is about 25 to 40% compared with that of using the equivalent number of new cartridges. In the case of long-life cartridges, the avoidable carbon footprint achieved through use of remanufactured cartridges rises to about 60%. Scaled across world markets, potential savings in CO_2 emissions associated with the use of long-life cartridges are estimated to be about 0.4 Mtonnes CO_2 worldwide / year. It is recommended that ecodesign opportunities for long-life cartridges are examined in the development of extended producer responsibility legislation, such as the European EuP Directive. The avoidable carbon footprint (about 60% of carbon footprint) is a useful metric for customers choosing to purchase long-life remanufactured cartridges in favour of new ones.

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1. INTRODUCTION

1.1 UKCRA

The United Kingdom Cartridge Remanufacturers Association (UKCRA) is an association of printer cartridge remanufacturers, component suppliers and used cartridge collectors in the UK that provide proven high quality remanufactured toner cartridges. It is recognised that remanufactured toner cartridges are a cost effective environmentally-friendly alternative to new toner cartridges and this is leading to increasing numbers of companies purchasing remanufactured toner cartridges.

Members of UKCRA are receiving a growing number of enquiries from customers about the carbon footprint of remanufactured cartridges compared with new cartridges. Cartridge users are specifically interested in opportunities for reducing the carbon footprints of their own businesses and consideration of the contribution to the business carbon footprint from consumables is an area in which attention is being focused[1].

1.2 Metrics for sustainable procurement

It is common for many businesses in support of Corporate Social Responsibility (CSR) to have an environmental policy in place and such policies usually refer to sustainable procurement and business practices favouring the procurement of recycled and remanufactured goods where such items provide high quality and cost-effective alternatives to their traditional counterparts. In addition, environmental policies often form a crucial adjunct to the Environmental Management System (EMS) within a business, and such systems are generally implemented on the premise of continual improvement, supported by monitoring, measuring and confirmation of compliance. Thus, to support achievement of EMS compliance and proof of adherence to the environmental policy, users require metrics to support procurement sustainability. This is where the carbon footprint of a consumable is important, as it provides the user with an important metric to qualify adherence to their own sustainable procurement policy.

Users are generally aware of the potential savings in carbon footprint that they can make based on actions directly under their control. For example, users can choose not to print unnecessarily, they can choose to turn off a printer when not in use, they can print on both sides of the paper, they can choose to use recycled paper that has a lower environmental impact, and they can choose whether or not to send a cartridge for refilling and have the refilled cartridge returned to them. These are matters which are to a large extent under the control of the user and are concerned generally with what is usually referred to as the use phase of the life cycle. As users focus attention on the procurement process, which links directly to the use phase, product carbon footprint is fast becoming a key metric to support decision making.

1.3 Purpose of the Study

Against this background, UKCRA commissioned Xanfeon to carry out a carbon footprint study of two toner cartridges in order to provide answers to questions frequently posed by users. Specifically, users wish to know what is the saving in carbon footprint that might be gained by purchasing a remanufactured toner cartridge in favour of a new cartridge from an Original Equipment Manufacturer (OEM) or through an OEM distribution channel. Furthermore, users also wish to know what is the saving in carbon footprint that might be gained by using a toner cartridge taken through an extended sequence of refilling cycles.

1.4 Short- and long-life cartridges

This study focuses on two specific types of toner cartridge: a short-life cartridge (SLC) and a long-life cartridge (LLC). On the face of it, a user might consider SLCs and LLCs to be the same. They are, however, different on account of the number of remanufacturing cycles each can be taken through while still delivering high quality printing capability. Typically an SLC can be taken through about one to three refilling cycles whereas an LLC can be taken through about fifteen (or more) refilling cycles. A single-cycle cartridge (SCC) is a special case in that it is designed to be used for one use cycle only, after which the cartridge goes directly to its end of life phase. Obviously, the more cycles a cartridge can be taken through the lower the carbon footprint incurred by the user because each time that a cartridge is refilled, a new cartridge does not have to be manufactured. Of interest to the user is the question of how much additional saving in carbon footprint can be achieved through the use of an LLC compared with a SLC.

The question of whether a cartridge is an SCC, SLC or an LLC and what it is about the cartridge that causes the cartridge to be capable of being taken through many rather than just one or a few cycles is important from many perspectives. From the perspective of industrial competition, an OEM may prefer SCCs and SLCs because such cartridges provide opportunity to maximise sales of new cartridges and for this reason a range of anti reuse devices (ARUDs) are deployed by OEMs to restrict the flow of used cartridges into remanufacturing streams. A remanufacturer would prefer cartridges to be LLCs so that repeated cycles lead to repeat business and reduced environmental impact. A user may prefer LLCs in order to have reduced carbon footprint associated with printing activities. Policy makers, particularly those concerned with environmental policy, would wish to nurture markets for products with improved environmental performance. Climate change and producer responsibility legislators would prefer products which result in fewer greenhouse gas (GHG) emissions through their life cycles.

The possible perspectives are many, but in view of climate change few would argue that it is good to cause unnecessary emissions of carbon dioxide (CO_2) and other GHGs. Indeed, Europe has introduced the Energy using Products Directive[2], which is a framework directive within which implementation measures for ecodesign of energy-using products, including printers and their associated consumables, may be legislated. In this regard, UKCRA has commissioned this study to also explore aspects of toner cartridges which may lead to unnecessary and avoidable GHGs. The study is restricted to toner cartridges remanufactured to high standard within the UK.

1.5 Previous life cycle studies of toner cartridges

Several life cycle studies of toner cartridges have been reported in the literature. Berglind and Eriksson presented a life cycle assessment of one particular model taking into account the use phase and reported on environmental impacts both with and without consideration of paper use[3]. The authors found a two-fold environmental improvement in favour of cartridge re-use. In another life cycle study of an OEM toner cartridge compared with its remanufactured counterpart, there was a particular focus on the contribution of environmental impact of paper[4]. The choice in that study of different end of life scenarios for the OEM and remanufactured toner cartridges make straightforward comparison of the two options somewhat problematic.

More recently a study of comparative carbon footprints of toner refills at Cartridge World has been reported[5]. The study examined the refilling of printer cartridges by Cartridge World at one of its sites in the UK over a three month period. The carbon footprint of a refilled cartridge was compared with that of a new one taking into account raw materials, energy, transport and disposal. Since over the three-months studied 490 cartridges of 65 different models were refilled or repaired the study related to an average refilled cartridge compared with a corresponding average new cartridge. The study found that the average cartridge refilled by Cartridge World has a carbon footprint 46% lower than a cartridge that is used once and then thrown away.

2. METHODOLOGY

2.1 Scope and boundaries

The methodology used in this carbon footprint study is based on the assessment of emissions of CO_2 and other GHGs through the life cycle of a product, but exclude the use phase which is common to both OEM and remanufactured cartridges. In those instances in which the footprint corresponds only to emissions of CO_2, the units are given in terms of mass of CO_2. In those cases in which the Kyoto set of GHGs are considered, the units of carbon footprint are given in terms of equivalent mass CO_2 or CO_2e.

Although standards, such as WBCSD's GHG Protocol, ISO14064 and the Publicly Available Specification PAS 2050, exist for carbon footprinting, there is no absolute guidance on specification for deriving system boundaries for a study such as this. The boundaries considered in this project encompass all the stages in the life cycle of a cartridge except for the impacts arising in the use phase. In order to provide a fair comparison between OEM and remanufactured cartridges, the boundaries of both life cycles are consistent. The boundaries are shown schematically in figure 1.

Figure 1 comprises essentially three parts. The left-hand side of the diagram shows the flow from materials manufacturing, transport of materials to a component manufacturing plant, manufacture of cartridge components, transport of components to a cartridge assembly plant, transport of the cartridge to a distribution / sales centre, and subsequent provision of the cartridge to the user. At the end of the use phase, the user either provides the spent cartridge to an end of life (EOL) process or arranges for the cartridge to go to a remanufacturing facility. In the first case, the user would then purchase another new cartridge and in the second case the user would use a remanufactured and refilled cartridge.

In the remanufacturing (ie the central section) of figure 1, there is shown stages which are equivalent to stages on the left-hand side of the figure. Materials are manufactured and transported to a component manufacturing facility and these components (referred to as aftermarket or replacement components) are transported to the remanufacturing facility.

There is an additional section of the diagram in the top right-hand corner which illustrates a further remanufacturing process (called recursive remanufacturing[1]) in which certain components in the used cartridge are individually remanufactured. The mag roller is an example of a recursively remanufactured component in which the OEM aluminium sleeve on the OEM metal core is replaced. After remanufacturing and refilling, the cartridge is returned to the user. In the event that the remanufactured cartridge reaches the end of its possible cycles (eg 3 refilling cycles for a SLC or 15 refilling cycles for a LCC), the cartridge then enters its end of life stage, shown in the bottom left-hand corner of figure 1.

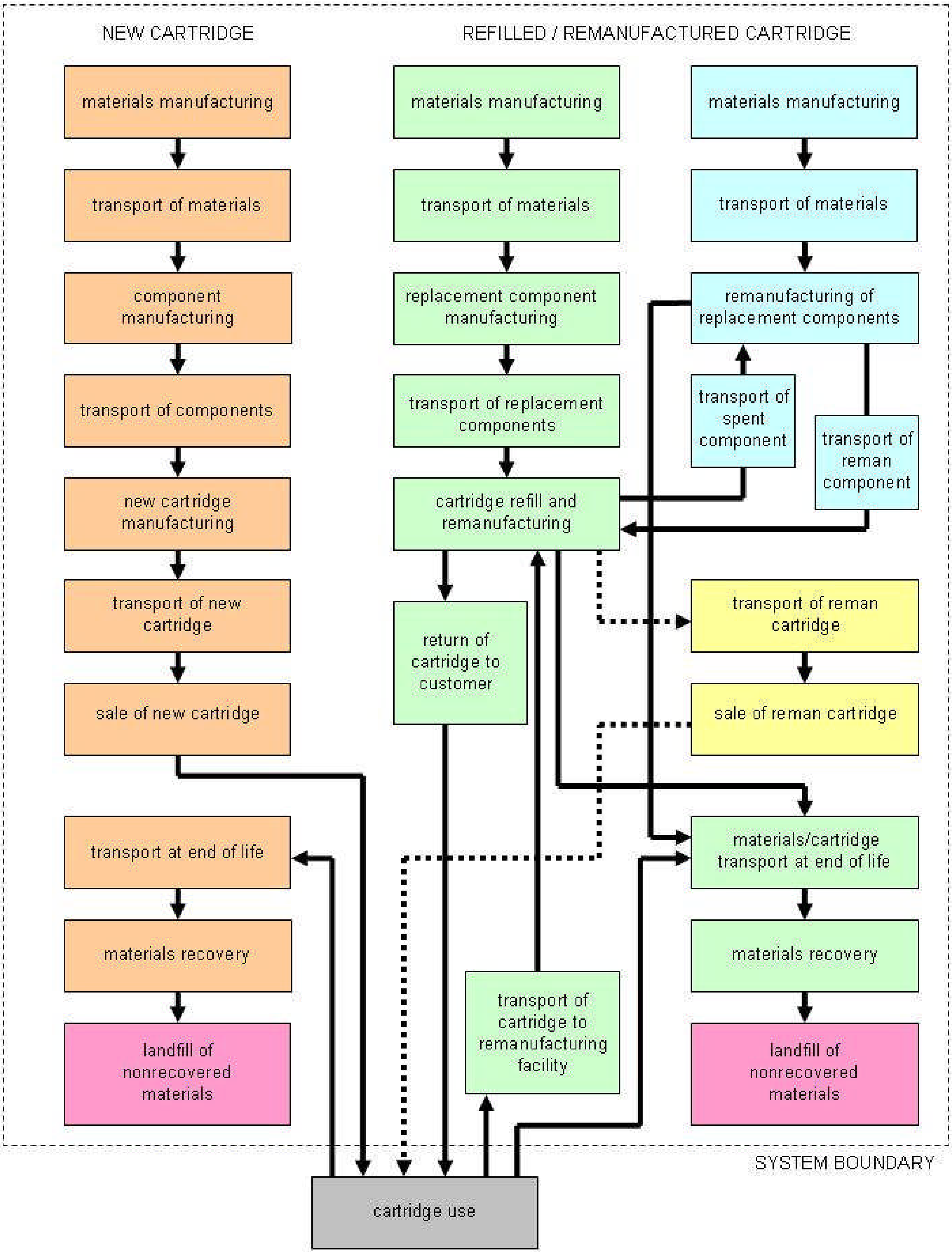

Figure 1. System boundary for the carbon footprint study.

2.2 Cartridges and their components

This study is on monochrome printer cartridges refilled and remanufactured by a UKCRA member that has been remanufacturing for over 20 years. One of the printer cartridges (cartridge B) is a short-life cartridge in that it is possible to refill the cartridge only three times, because two of the components that would be required in further cycles are not available as aftermarket components. In addition, the process of dismantling this particular model cause screw threads in the plastic housing to wear. The other cartridge model (cartridge C) is a long-life cartridge in that it is possible to remanufacture the cartridge numerous times. In practice print quality would degrade after 15 cycles and so in practice cartridge C is only refilled for customers up to 15 cycles in order to ensure print quality as good as or better than the OEM model. It is not the intention of UKCRA to disclose model numbers of cartridges B and C as the purpose of this report is to highlight carbon footprint characteristics leading to ecodesign opportunities potentially for all toner cartridges.

The components in each cartridge are shown in table 1 with an indication of which components may be replaced in a refilling cycle. In any given refilling cycle, the only components that are always included are the toner and microchip in the case of cartridge B and the toner in the case of cartridge C. One or more of the other possible aftermarket components (OPC drum, wiper blade, PCR, mag roller, DR blade, and seal) may be replaced depending on whether or not it is necessary to do so. For the remanufactured cartridges considered in this study, the distribution channels are serviced mostly by own transport within the UK. It is therefore unnecessary to replace the seal, which is otherwise required either to protect against toner leakage during long distance transportation or replaced for aesthetic purposes.

Component	Cartridge B (Short life cartridge)	Cartridge C (Long life cartridge)
Housing assembly	Original always used.	Original always used.
OPC drum	May be replaced.	May be replaced.
Wiper blade	May be replaced.	May be replaced.
Primary Charge Roller (PCR)	Not available as an aftermarket component.	May be replaced.
Magnetic developer roller (Mag roller)	Not available as an aftermarket component.	May be replaced.
DR blade	May be replaced.	May be replaced.
Seal	May be included in every refill cycle.	May be included in every refill cycle.
Microchip	A new microchip is included.	Not applicable. The cartridge does not have a microchip.
Toner	Included in every refill cycle.	Included in every refill cycle.

Table 1. Main components in each of the two cartridges under study.

This work also makes reference to the average cartridge (refilled and OEM versions) in the study of Cartridge World refilling and repairing[5]. That average cartridge, which obviously does not correspond to one specific model, is referred to here as cartridge A and is used is an introductory benchmark.

2.3 Calculations and data quality

The calculation of the carbon footprint is performed by first identifying and mapping out the inputs of each life cycle stage. Conversion factors for each input are applied to convert material use and energy / fuel consumption into carbon dioxide or carbon dioxide equivalent emissions. Components of the carbon footprint are calculated for each stage of the life cycle shown in figure 1. In the case of OEM cartridges, a credit to the carbon footprint is evaluated at the end of life stage (corresponding to energy recovery through an incineration process or materials recovery through a materials recycling process). The credit is applied to the carbon footprint of the OEM cartridge and a cumulative carbon footprint is derived by summing OEM cartridge footprints over a given number of cycles.

Thus, if we consider the case of cartridge B taken through 3 refilling cycles, the carbon footprint corresponding to OEM cartridge B would be the sum of four OEM cartridge footprints, each with an end of life credit applied. The calculation of the carbon footprint corresponding to the refilling starts with an OEM cartridge for which an end of life credit is not applied, because the cartridge enters the remanufacturing stream after its first use cycle. At each refilling stage, account is taken of which components are replaced, and end of life credits for recycled components are applied to the carbon footprint associated with that cycle. After the final refilling cycle, for example, the third refill cycle for cartridge B, an end of life credit is applied for the whole cartridge. The carbon footprints calculated for each cycle are summed over the cycles to determine a cumulative carbon footprint for each of the OEM and remanufactured cartridges and at each cycle the percentage saving in carbon footprint is determined from the corresponding cumulative carbon footprints.

Data for the calculations were obtained from a variety of sources, and correspond very closely with sources and approaches described in reference 5, to which the reader is referred. In particular, examples of new and remanufactured cartridges B and C and aftermarket components and packaging were investigated to determine materials and their masses. Wherever possible data were obtained directly from source (eg energy usage from electricity bills), although it should be appreciated that informed estimates were necessary for some aspects of the calculations.

Since the objective of this study is to compare OEM and remanufacturing routes for two contrasting cartridges (SLC and LLC), the same assumptions were made for the OEM and remanufactured cartridge wherever possible. Where it is known that specific differences do occur then these are taken into account. For example, in the case of the remanufactured cartridge, the remanufacturer's cardboard box and resealable bubble bag are reused through all refilling cycles (provided these are returned to the remanufacturer and found not to be damaged). This is not the case for the OEM cartridges as each new cartridge comes with new packaging.

Where few data were available, particularly in relation to the location of manufacturing plants and supply chain logistics which OEMs and aftermarket component suppliers keep as commercially confidential, supply chains for the compared cases have been assumed to be identical. This is considered to be an acceptable assumption on the grounds that it is known in the industry that both OEM and aftermarket components often have common sources, supply chains may change in time, and supply chains may involve a variety of routes. To test the importance of assumptions, calculations are made using a range of possibilities so that sensitivities to assumptions can be tested.

Component				**Cartridge**	
Sources of materials for component			**Manufacture of component**	**Manufacture of OEM cartridge**	**OEM cartridge or REM component shipped to**
Steel	**Aluminium**	**Plastics etc**			
Assembly housing					
Shanghai		Shanghai	Hong Kong	Hong Kong	Europe
OPC drum					
	Seoul	Seoul	Seoul	Hong Kong	Europe
Wiper blade					
Kuala Lumpur		Singapore	Singapore	Hong Kong	Europe
PCR					
Australia		Australia	Taipei	Hong Kong	Europe
Mag roller					
Australia	Australia	Australia	Tokyo	Hong Kong	Europe
DR blade					
Kuala Lumpur		Singapore	Singapore	Hong Kong	Europe
Microchip					
OEM microchip manufactured in Tokyo and transported to Hong Kong. Aftermarket microchip manufactured in Milan and transported to remanufacturing facility.				Hong Kong	Europe
Toner					
OEM toner manufactured in China from materials sourced in China. Aftermarket toner manufactured in Delaware from materials sourced in US.				Hong Kong	Europe

Table 2. Supply chain configuration used in the calculations. Sensitivity to variations in the configuration have been tested.

The main material components in a cartridge are steel, aluminium, and plastics (and various other materials of a minor nature). Packaging generally includes paper, card, and plastics. Supply chain assumptions made for the components, assumed to be the same for both OEM and aftermarket components, are given in table 2. For OEM cartridge B the total masses of each of the components (including toner), component packaging and cartridge packaging are 658g, 126g, and 308g respectively. For OEM cartridge C the total masses of each of the components (including toner), component packaging and cartridge packaging are 1141g, 130g, and 358g respectively.

The supply chain configuration in table 2 corresponds to results presented through the report, although it should be appreciated that alternative supply chains have also been investigated. Where sources are known specifically, these are used in preference in the calculations. The packaging supply routes have been assumed to follow the component routes with packaging materials being sourced reasonably locally to the component or cartridge manufacturing facility. Component packaging of OEM and remanufactured components has been assumed to be identical. Unless specifically stated otherwise, conversion factors corresponding to the place of manufacture of a material, component or cartridge (as per table 2) have been used in the calculations. All carbon footprints of cartridges presented in this report include the carbon footprint of toner.

	Component							
Refill Cycle	**Housing**	**OPC drum**	**Wiper blade**	**PCR**	**Mag roller**	**DR blade**	**Micro chip**	**Toner**
0	OEM cartridge							
1							√	√
2		√					√	√
3							√	√
EOL								

Table 3. Profile of replaced components in the three refilling cycles of cartridge B.

	Component							
Refill Cycle	**Housing**	**OPC drum**	**Wiper blade**	**PCR**	**Mag roller**	**DR blade**	**Micro chip**	**Toner**
0	OEM cartridge							
1							n/a	√
2		√			√		n/a	√
3			√	√		√	n/a	√
4		√			√		n/a	√
5							n/a	√
6		√	√	√	√	√	n/a	√
7							n/a	√
8		√			√		n/a	√
9			√	√		√	n/a	√
10		√			√		n/a	√
11							n/a	√
12		√	√	√	√	√	n/a	√
13							n/a	√
14		√			√		n/a	√
15			√	√		√	n/a	√
EOL								

Table 4. Profile of replaced components in the fifteen refilling cycles of cartridge C.

The calculations are carried out in such a way that at each refill cycle a different set of aftermarket components may be used. Thus, it is not possible to state a fixed value for the carbon footprint of a refilled cartridge because the replacement component profile (and its associated footprint) may vary from cycle to cycle. Although a wide range of profiles have been investigated, the profiles in tables 3 and 4 are those corresponding to results presented in this report, unless stated otherwise. In tables 3 and 4 cycle 0 corresponds to the OEM cartridge which starts the refilling sequence; there has to be an original cartridge to enter the refilling system.

3. CARBON FOOTPRINT ANALYSIS

3.1 Benchmark comparison

Since a detailed study of comparative carbon footprints is available for an average cartridge (cartridge A), it is instructive to repeat the calculations described in reference 5 using identical assumptions, except for the specific material profiles for cartridges B and C and also to account for the use of toner. In order to make such a comparison, however, it is necessary to use averages of the materials represented by the profiles in tables 3 and 4.

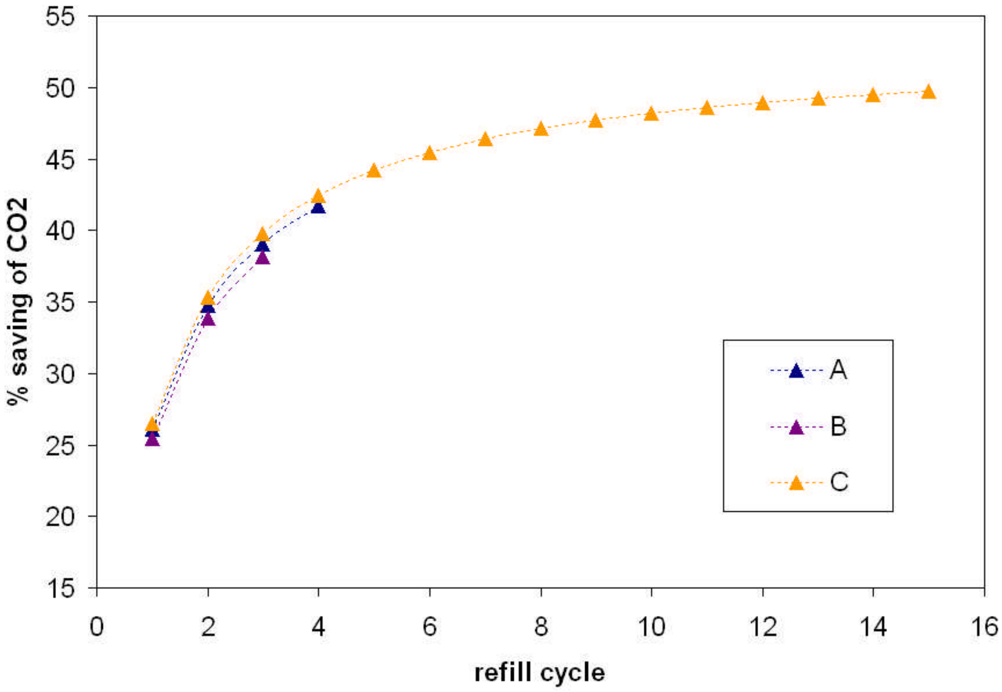

Figure 2. Percentage saving in CO_2 emissions for remanufactured cartridges A, B and C compared with OEM cartridges.

Using the same data and assumptions the results presented in that report[5] were recalculated (to agreement) and then average masses for cartridges B and C were used. The reader is referred to the extensive report on the Cartridge World cartridges for specific details of the calculations[5]. It should be noted, however, that various assumptions were made in the published study[5] concerning average shipping distances from the Far East, the use of United Kingdom conversion factors for all direct energy use, omission of direct energy emissions for component manufacturing, and end of life energy recovery[6] processes. The same assumptions have been deployed here only in this preliminary benchmark comparison. For other calculations described in this report, full international manufacturing and supply chain logistics as well as recovery of materials through recycling have been deployed (and tested extensively for sensitivities).

Cartridges A and B are both SLCs and the results in figure 2 are shown only to 4 and 3 refill cycles respectively. The average number of refill cycles that cartridge A is taken to is 3.5 cycles[5]. Cartridge C is a LLC and the number of refill cycles is shown to 15 cycles. The dashed lines shown in this (and other figures in this report) are a guide for the eye.

Results in figure 2 are repeated in figure 3 to illustrate the concept of the CO_2 saving opportunity. Figure 3 shows that compared with OEM cartridges SLCs provide a CO_2 saving of about 25 to 35%, whereas the percentage increases to about 50% with increasing numbers of refill cycles in the case of the LLC. It should be recognised that these results are for averaged materials. The question to address is: what are the CO_2 savings when actual replacement profiles (tables 3 and 4) are used and detailed descriptions are used of the supply chains and manufacturing processes. This is addressed in the next sections.

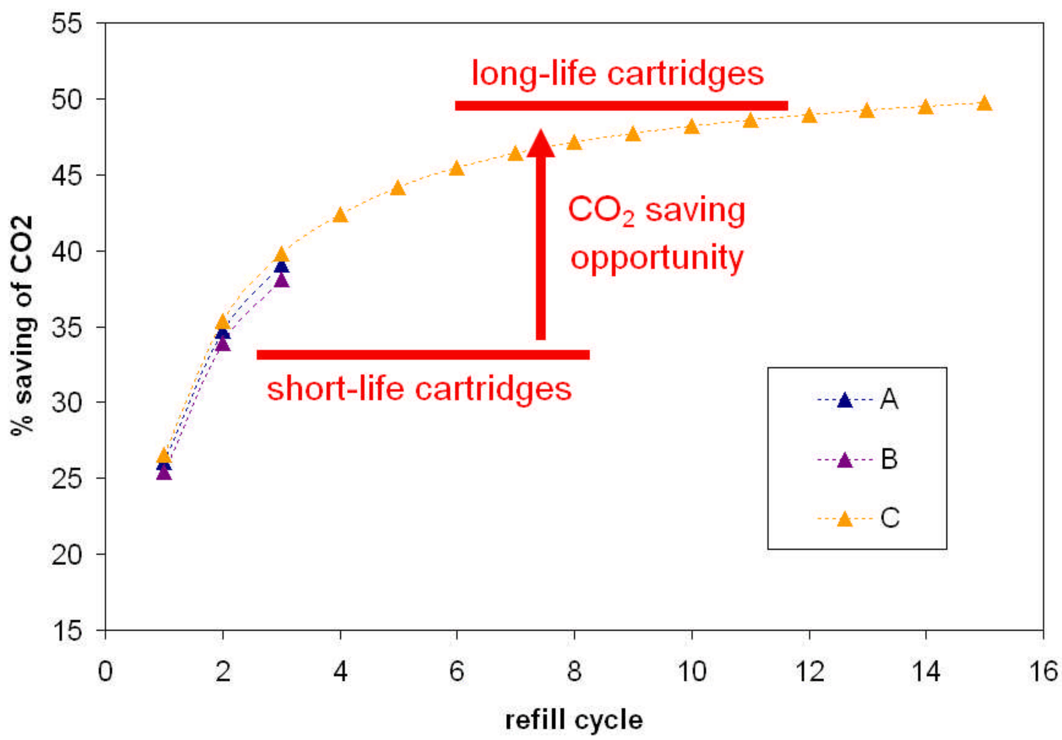

Figure 3. CO_2 saving opportunity between short- and long-life cartridges.

3.2 Total footprint

Cumulative carbon footprints calculated for cartridges B and C through the OEM and refilling cycles are given in table 5. Figure 4 shows the cumulative carbon (CO_2)

footprints listed in table 5 for OEM and remanufactured cartridges B and C for the profiles described in tables 3 and 4. The corresponding percentage savings in CO_2 emissions provided by remanufactured cartridges B and C are shown in figure 5.

It can be seen from figure 5 that there are dips in the curve for cartridge C at refill cycles 6 and 12. This is because these particular cycles have more components replaced than in any of the other refill cycles (as can be seen from the profiles in table 4) and so the carbon footprint of the refilled cartridge at those particular refill cycles is higher, giving lower saving compared with the OEM carbon footprint. The cumulative savings for cartridge B rise rapidly because very few replacement components are required in the first three refilling cycles (see table 3). By extending the calculations in the case of cartridge B through to 15 refill cycles assuming that aftermarket components could be obtained, the cumulative saving in CO_2 is estimated to converge to around 50%.

cycle	**cartridge B (new cartridge for each cycle)** kg CO_2	**cartridge B (new cartridge for cycle 0 and remanufactured cartridge thereafter)** kg CO_2	**cartridge C (new cartridge for each cycle)** kg CO_2	**cartridge C (new cartridge for cycle 0 and remanufactured cartridge thereafter)** kg CO_2
0	5.2	5.6	6.7	7.5
1	10.3	7.2	13.4	9.1
2	15.4	9.0	20.1	11.6
3	20.6	9.8	26.7	14.6
4			33.4	17.1
5			40.1	18.8
6			46.8	22.6
7			53.5	24.3
8			60.2	26.8
9			66.9	29.8
10			73.5	32.3
11			80.2	33.9
12			86.9	37.8
13			93.6	39.4
14			100.3	42.0
15			107.0	44.3

Table 5. Cumulative carbon footprints for cartridge B and C. The values at cycle 0 are higher for the remanufactured series compared with the corresponding OEM series because the end of life credit for recycling the whole cartridge is applied at cycle 0 in the case of the OEM cartridge and at the end of cycle 3 (15) for the remanufactured cartridge B (C).

The end of life routes used both for the OEM and remanufactured cartridges are recycling routes in which a cartridge (or spent component / subcomponent) at the end of its life is sent for materials recovery, leading to an estimated 20% credit in the carbon footprint calculation associated with materials. The recycling routes used are from the UK Midlands to a recycling plant near Nantes in France (for OEM) and to a recycling plant in Genk in Belgium (remanufacturing). The recycling route described for the remanufactured cartridges is always used. It is not known whether the OEM cartridges always go to recycling although the assumption that they do is in favour of the OEM cartridge carbon footprint.

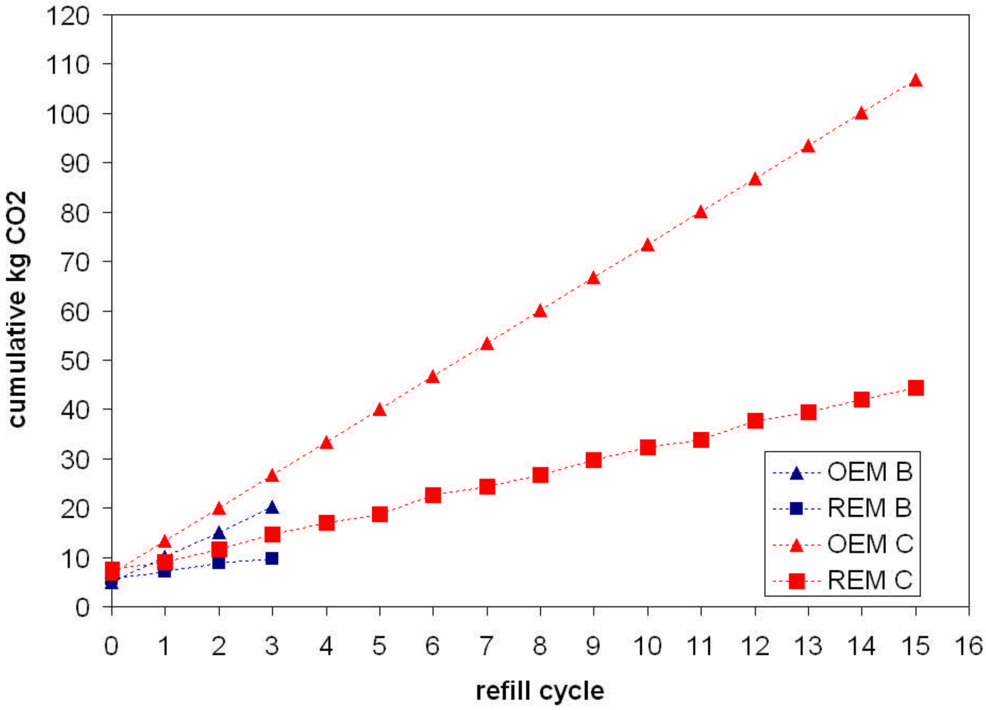

Figure 4. Cumulative carbon (CO_2) footprints for OEM and remanufactured cartridges B and C for the profiles described in tables 3 and 4.

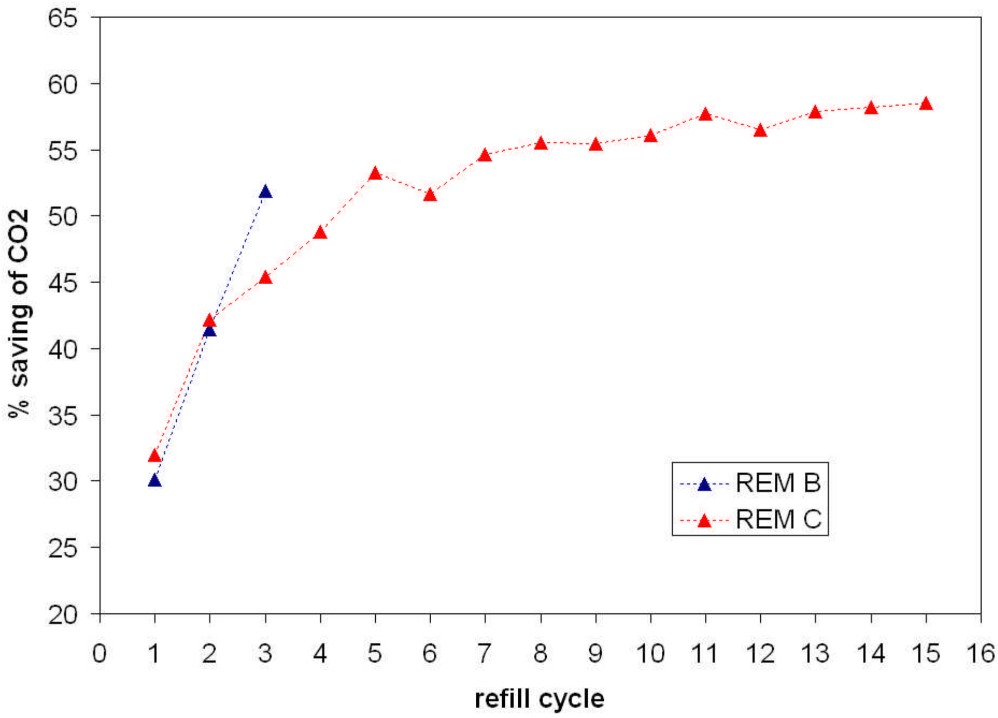

Figure 5. Percentage saving in CO_2 emissions provided by remanufactured cartridges B and C for the profiles described in tables 3 and 4 and presented as cumulative footprints in figure 4. The percentage savings for cartridge B rise rapidly because very few replacement components are required in the first three refilling cycles (see table 3).

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In Figure 6 percentage savings in carbon footprint provided by remanufactured cartridge C for the profile described in table 4 with various assumptions are shown. The uppermost curve in figure 6 corresponds to savings in CO_2e. The next curve down corresponds to CO_2 only (and is the same as that shown in Figure 5). The next curve down corresponds to results obtained when all conversion factors for direct energy use correspond to the UK conversion figures. The next curve down corresponds to the use of UK conversion figures for direct energy use as well as simplification of the international supply chain to that used to derive the results in Figure 2. The lowest curve in Figure 6 corresponds to the case in which the simplified international supply chain is retained and all direct energy use associated with component manufacturing is omitted. The lowest curve in Figure 6 corresponds both in calculation configuration and results most closely to the curve for cartridge C in Figure 2. The results presented in Figure 6 show that the potential saving in CO_2 as provided by an LLC may be underestimated by about 15% if detailed aspects of supply chain configuration and component manufacturing are not taken into account.

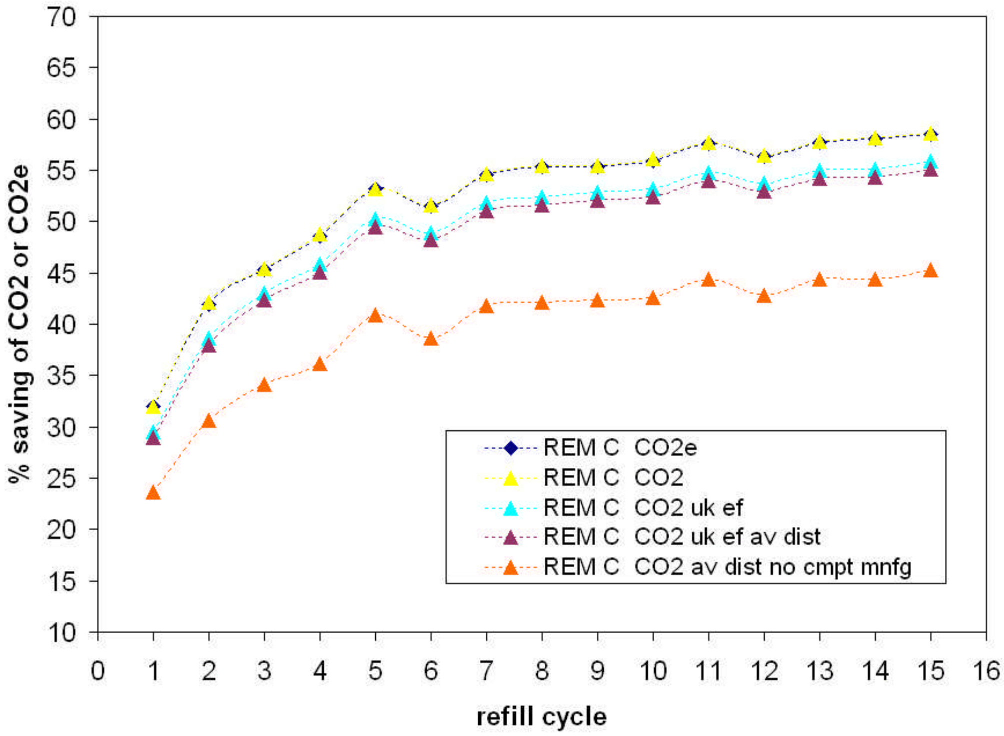

Figure 6. Percentage saving in CO_2 and CO_2e emissions provided by remanufactured cartridge C for the profile described in table 4 with various assumptions (see text).

To test the sensitivity of the CO_2 savings curves to the component replacement profile, a wide range of profiles has been investigated. A sample of these are provided in table 6 for the case of cartridge C and the corresponding CO_2 savings curves are plotted in figure 7. The profiles in table 6 include profile 1, which is the typical profile as described in detail in table 4. Profiles 2 to 7 are variations around the typical profile. A profile in which no components are replaced except for refilling the cartridge with toner at each refill cycle is also included. This "toner refill only" (TRO) profile would not occur in practice but is shown as a theoretical limit on the CO_2 savings given the cartridge and its comparative OEM and remanufacturing logistics.

	Numbers of components replaced over 15 refill cycles							
Profile	**Housing**	**OPC drum**	**Wiper blade**	**PCR**	**Mag roller**	**DR blade**	**Micro chip**	**Toner**
1	0	7	5	5	7	5	n/a	15
2	0	7	6	6	7	6	n/a	15
3	0	7	7	8	7	8	n/a	15
4	0	7	7	7	7	6	n/a	15
5	0	4	5	6	6	5	n/a	15
6	0	8	5	6	6	6	n/a	15
7	0	8	7	8	8	8	n/a	15
toner refill only (TRO)	0	0	0	0	0	0	n/a	15

Table 6. Numbers of replaced components through fifteen refilling cycles of cartridge C with different component replacement profiles (CO_2 savings are shown in Figure 7). Profile 1 is the profile described in detail in table 4.

The CO_2 savings curves for profiles 1 to 7 and for the TRO profile (in figure 7) show that the curves have a large dispersion during the early refill cycles (cycles 1 to 3) but converge with less dispersion in later cycles. The curve in figure 7 corresponding to the TRO profile is monotonically varying because the same amount of toner is put into the cartridge during each refill cycle, whereas for the other profiles (profiles 1 – 7) the components individually selected for replacement within any given refill cycle have various carbon footprints.

The CO_2 saving in the early cycles ranges from about 20 to 45% whereas the CO_2 saving in the later cycles ranges from about 53 to 60%. It is clear from figure 7 that it would not possible to state that cartridge C has one specific carbon footprint or one specific carbon footprint history or that it provides one specific value of CO_2 saving compared with the OEM cartridge because the metrics depend both on refill cycle number and the details of which components have been replaced up to that point. This has implications for carbon labelling of remanufactured toner cartridges because the carbon footprint of a remanufactured cartridge depends on the specific remanufacturing profile of the cartridge. Thus, if packaging materials for remanufactured cartridges were to carry a carbon footprint designation, it would be necessary for the labelling to take account of cartridge life history and specifics (or, for example, averages) of the remanufacturing process.

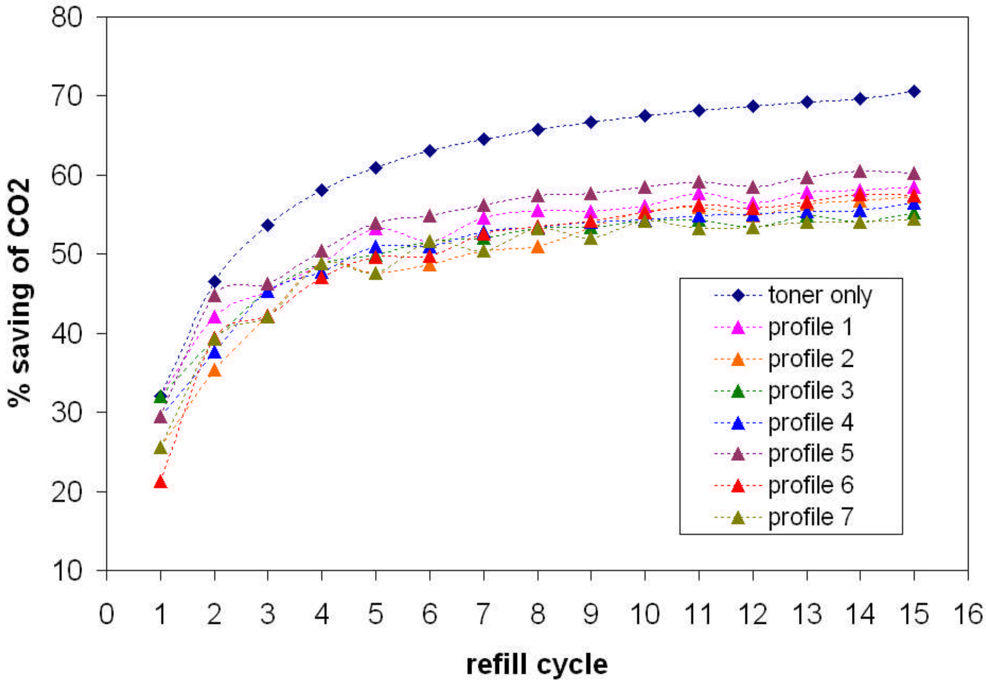

Figure 7. Percentage saving in CO_2 emissions relative to OEM cartridges provided by remanufactured cartridge C for profile 1 – 7 summarised in table 6 and the (theoretical) case in which the cartridge is only ever refilled with toner and no components are replaced.

4. DISCUSSION OF RESULTS

4.1 CO_2 savings across markets

The results presented in the previous section show that the use of long-life cartridges refilled over many refill cycles offers significant opportunities for reductions in GHG emissions. Those opportunities are suppressed when ARUDs are deployed with cartridges and render them either single cycle or short-life. The analysis shows that remanufactured LLCs can have cumulative carbon footprints which are about 60% lower than their OEM counterpart, but this saving is reduced to about 25 – 40% in the case of SCCs.

Estimates of the annual sales of toner cartridges in the UK, European and World markets are about 15, 44 and 100 million cartridges respectively. Assuming that an average cartridge has a carbon footprint of about 7 kg CO_2 and assuming that the average saving per cartridge is 4 kg CO_2 (ie about 60%), the potential savings in emissions for the UK, European and World markets are indicatively 0.06, 0.18 and 0.4 Mtonnes CO_2 / year respectively.

4.2 Remanufactured cartridges from outside the UK

By definition this study is confined to the carbon footprint of toner cartridges remanufactured to high standard within the UK. The study does not apply to imported remanufactured toner cartridges or clones of OEM cartridges. The inherent carbon costs in movement of empties, components and finished goods, together with the difficulties of disposal of end of use remanufactured imports and clones and other factors would, depending on the point of origin, suggest a significant difference in the resulting carbon footprint.

4.3 Ecodesign opportunities

A wide range of ARUDs are deployed with toner cartridges in today's markets. Some specific examples of ARUDs are:

> *Sonic welding* – some cartridges are welded sonically to prevent their entry into the remanufacturing sector or make the process of remanufacturing prohibitively expensive. The only way to remanufacture a sonically welded cartridge is to cut it open and then screw it together again, a process which is time consuming and expensive. Some welds are made in zig-zag pattern which makes remanufacturing even more difficult.
>
> *Unnecessary adhesive tapes* – to prevent remanufacturing some cartridges which have served the market well based on a design with plastic clips and screws are vitiated through the introduction of unnecessary ultra-strong double-sided adhesive tapes. It is almost impossible to remanufacture cartridges for which the original design is corrupted in this way.

Identification and assessment of ARUDs provides an opportunity for the cartridge industry to improve the ecodesign of printer cartridges within the context of their life cycles. Such life cycles should include all remanufacturing stages. Noting that the EuP Directive[2] is concerned with life cycle ecodesign and improvement in the environmental performance of energy-using products, there is opportunity to consider the development of implementation measures to discourage the use of ARUDs where such devices lead to unnecessary and avoidable emissions of GHGs.

In preparing for the development of implementation measures under the EuP Directive, the EU has commissioned various preparatory studies. One of these studies[7] has focused on Imaging Equipment, which includes printers and associated consumables. ARUDs were not addressed in the preparatory study, although a range of other ecodesign opportunities, such as the use of biopolymeric-based toner materials, were noted. In terms of carbon footprint, the use of ARUDs to restrict toner cartridges to being either single-cycle or short-life cartridges leads to lost opportunities in GHG emissions reduction. ARUDs, whether deliberate or unintentional, constitute poor ecodesign. The development of the EuP Directive is an opportunity to reassess them from the points of view of both good ecodesign and climate change mitigation.

The deployment by OEMs of model-specific microchips on printer toner cartridges to provide localised features and logic, such as security logic, creates a significant burden for the remanufacturing industry. For some cartridge models it may be cost beneficial for the remanufacturing industry to invest in the duplicate R&D to develop a replacement microchip to enable the cartridge model to enter the aftermarket. However, in the period before the aftermarket microchip is developed, the cartridge model cannot enter the remanufacturing market and users therefore will not have the choice of opting for the lower carbon footprint associated with cartridge reuse. For other models, the R&D costs to redevelop the model-specific microchip are prohibitively expensive; these cartridge models will not enter the remanufacturing streams at all and users will not be able to benefit from reduced carbon footprint associated with extended cartridge life cycles. In responding positively to the universal challenge of GHG emissions reduction, there is scope for the cartridge industry as a whole to adopt increasingly collaborative and synergetic approaches. The topic of cartridge microchips is one that provides significant scope for such approaches to facilitate the evolution of a broader market in which users can readily access the 50-60% reductions in carbon footprints offered by long-life cartridges.

5. SUMMARY

A study has been made of carbon footprints of short-life and long-life toner cartridges, comparing the carbon footprints of OEM cartridges with those of corresponding remanufactured cartridges. The carbon footprints have been evaluated on the basis of actual profiles of components replaced during refilling cycles. In the case of short-life cartridges, the percentage saving in carbon footprint through repeated refilling cycles is about 25 to 40% compared with that of using the equivalent number of new cartridges. In the case of long-life cartridges, the avoidable carbon footprint achieved through use of remanufactured cartridges rises to about 60%. Scaled across world markets, potential savings in CO_2 emissions associated with the use of long-life cartridges are estimated to be about 0.4 Mtonnes CO_2 worldwide / year. It is recommended that ecodesign opportunities for long-life cartridges are examined in the development of extended producer responsibility legislation, such as the European EuP Directive. The avoidable carbon footprint (about 60% of carbon footprint) is a useful metric for customers choosing to purchase long-life remanufactured cartridges in favour of new ones.

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Caution with result interpretation

The conversion factors used for calculating footprints are constantly changing as new studies are completed and data released from official sources. Xanfeon commits to having the most up to date information possible. Xanfeon has a monitoring system to capture new data as it is published, and an internal process to ensure these data are incorporated into our tools. As a reader of this report, you should realise that the conversion factors used were appropriate at the time of writing but may be subject to change in the future.