SIMPLIFIED LCA

Simplified tools for global warming potential evaluation: when 'good enough' is best

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Abstract

Background, aim and scope In spite of a number of lingering issues, life cycle assessment (LCA) is widely recognised as one of the most powerful tools to investigate the environmental performance of a product or service. Carbon footprint (CF) analysis can also be considered a subset of LCA, limited to a single impact category (i.e. global warming potential (GWP)). However, the inherent complexity of a full LCA or CF analysis often stands in the way of their widespread application in the industry and policy-making sectors. For these latter ambits, this paper advocates the adoption of tailor-made streamlined approaches, with reduced inventory requirements and impact assessment scope. Two such examples are provided, respectively addressing the evaluation of GWP in the development of new product standards and the GWP savings attainable through the use of recycled materials.

Materials and methods Both the application examples presented here are firmly rooted in life cycle thinking, and follow the guidelines provided by the current ISO standards on LCA. At the same time, the employed models are structured in such a way as not to require the deployment of specific LCA software but rely on simple algorithms instead, complemented by tables of data for the associated background processes sourced from standard life cycle inventory databases.

Results In the first example, the simplified algorithm was found to produce reliable and satisfactorily accurate results in terms of GWP, i.e. within 10% of those produced by a fully fledged LCA performed in parallel for validation purposes. In the second example, the adopted simplification only applied to the goal of the study (i.e. assessment of the absolute GWP savings, with no quantitative indication of their relative extent with respect to the total). Within these limits, the proposed simplified tool provided accurate indications, which enabled a clear ranking of the analysed products, in terms of desirability of recycling.

Discussion To the extent possible within the given set of constraints, simplified tools such as those presented here do not lose their scientific rigour and take into account all phases of the product life cycle. Their reduced goal and scope does of course limit the breadth of the information that they can produce, but this can be mitigated through a case-specific selection of the adopted inventory simplifications and impact category/ies.

Conclusions The two application examples presented here have provided solid evidence that streamlined approaches such as these can go a long way in facilitating the introduction of life cycle thinking and LCA in the day-to-day practice of industries and policy makers, while still producing scientifically sound and robust results.

Recommendations and perspectives Simplified LCA tools lend themselves to a wealth of possible applications in the industry and policy-making sectors. More case studies are in order, and it will be advisable not to limit the goal and scope of all streamlined approaches to carbon footprint evaluation but to pick the most relevant impact categories to be included in the model on a case-by-case basis.

Keywords Carbon footprint · Global warming potential · Green procurement · LCA · Product standards · Recycled materials · Simplified tools

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1 Background

Life cycle assessment (LCA) is not perfect. First of all, starting with life cycle inventory (LCI) and contrary to what this very phrase seems to imply, it is never really possible to quantitatively include each and all of the different stages of a product or service's life cycle, and the selection of what is to be included and what is not inevitably implies a certain degree of subjectivity and lack of comprehensiveness (Ayres 1995). Then, in the real world, it is never possible to get access to 'exact' inventory data, which ends up affecting the accuracy, precision and ultimate reliability of the LCA results and leads to the necessity of establishing and abiding to some set of data quality management rules (Weidema and Wesnæs 1996).

Moving on to life cycle impact assessment (LCIA), the uncertainty and subjectivity ranges only become wider. Even refraining from adopting single-score methods (Goedkoop and Spriensma 2001; Frischknecht et al. 2006) that inevitably entail non-scientific value-based choices, a number of serious issues remain. Among these are the still rather inadequate treatment of 'upstream' impact categories related with resource depletion (Steen 2006), a sheer lack of integration with other valuable and complementary methods equally rooted in life cycle thinking (Ulgiati et al. 2006), a problematic and insufficiently detailed treatment of human and ecological toxicity, especially regarding heavy metals (Heijungs et al. 2004), and a still only rudimentary and often altogether neglected consideration of spatial differentiation (Potting and Hauschild 2005; Raugei and Ulgiati 2009).

However, in spite of such a long list of lingering shortcomings, LCA is still among the most powerful tools available to date to investigate the environmental performance of a technology, a product or a service over the different stages of its life span, or 'from the cradle to the grave' as is often said in technical jargon. From its inception in the early 1990s (Consoli et al. 1993; Lindfors et al. 1995), countless LCAs have rightfully found their way to high-ranking scientific journals, and the methodology has also gained larger and larger acceptance in the private sector, where it has gradually established itself as the de facto standard for full-on environmental studies. Recently, the editorial of *Environmental Science and Technology* reaffirmed the pivotal role of LCA as the recommendable framework for all environmental studies (Schnoor 2009).

In particular, growing public concern about the issue of climate change has spurred a new wave of widespread interest in many industry sectors towards the evaluation of the global warming potential (GWP) of products, as well as the possible associated offset measures.

Along the same lines, the UK Carbon Trust also recently introduced the concept of carbon footprint (CF), defined as 'the total set of greenhouse gas emissions caused directly and indirectly by an (individual, event, organisation, product) expressed as CO_2e' (Carbon Trust 2007). Carbon footprint can quickly be recognised to be inherently based on life cycle thinking, and indeed, the current PAS2050 carbon footprint standard (BSI 2008; Sinden 2009) borrows most of its concepts and guidelines from the corresponding 14040 series of ISO standards. In fact, in the opinion of the authors, a well-made CF analysis can essentially be looked at as a subset of a full LCA, with its scope limited to a single impact category, i.e. GWP. Hence, in this paper, the choice was made to stick to standard LCA nomenclature and use the GWP acronym (for all intents and purposes, the latter could be replaced by "Carbon Footprint" throughout, without affecting any of the results or discussion).

In any case, LCAs (and similarly structured CF analyses) are by their very nature rather time consuming to perform and invariably require a considerable amount of process-specific information that can at best only be partly replaced by average estimates. As a result, such comprehensive approaches may end up being discarded as impractical in many instances, either because of time or financial constraints or both.

Furthermore, in modern society, decisions with potentially large environmental implications (e.g. development of new legislation or product standards, eco-design strategies for product development, choice of waste management options, ...) often have to be made under pressure from political or economic actors, who are not in a position to be able to afford to wait for clear-cut, indisputable results from complete LCAs (Ekvall et al. 2007). The most likely consequence may end up being, and in many cases has been, the virtually complete neglect of all environmental parameters in the decision-making process.

Streamlined life cycle thinking tools with appropriately reduced goal and scope and more relaxed data quality management standards may come to the rescue in a variety of selected situations, where less-than-perfect results can still be considered better than no results at all. Some attempts have been made to guide the users in how to simplify LCA, mainly within SETAC working groups or activities (Curran and Young 1996; Christiansen 1997; Todd and Curran 1999). In the early stages of LCA standarisation, a simplified LCA standard was also developed in Spain (AENOR 1998).

In this paper, two simplified tools are developed for global warming potential evaluation, respectively tailored to two specific applications, namely the development of a new product standard for plastic bags and the development of guidelines for green procurement.

The authors do not wish to advocate the appropriateness of always and indiscriminately applying a simplified tool in lieu of a more complete LCA (both in terms of the comprehensiveness of the inventory and of the inclusion of additional impact categories beyond GWP). Rather, their goal is to illustrate how individually adapted simplified models can at

times extremely be useful in providing a reliable, quantitative measure of environmental impact, which may just be what is in order for the purposes of imminent political and economic decisions. In these cases, 'good enough' can indeed be best.

2 First application: inclusion of environmental requirements in new product standards

2.1 Aim and scope

The need to reduce the potential adverse impacts of products is recognised around the world and is one of the main purposes of Integrated Product Policy (EC 2003). Within this context, normalisation and product standards have a key role in pushing towards a reduction in the environmental loads associated to products. This idea goes hand in hand with the new context of governance in the EU in which a gradual shift is under way from mandatory approaches to voluntary ones.

The recently updated ISO guide 64:2008 emphasises the concept of life cycle thinking as a cornerstone of a scientifically sound approach to including environmental aspects when drafting new product standards or revising existing ones. Within this guide, LCA is listed as the second source of information in order of preference, after relevant sector guides, to help identify relevant environmental aspects and impacts related to a product's life cycle. However, the examples of recommendations appearing in ISO guide 64 are qualitative.

A large number of simplified LCA methods (qualitative, quantitative or semi-quantitative) have been developed in recent years (Hochschorner and Finnveden 2003) for applications such as Design for the Environment (DfE) and green procurement. Noteworthy examples are Christiansen (1997), Fleischer et al. (2001) or Hur et al. (2005). However, the use of simplified LCT methods for assisting the establishment of quantitative criteria for specific impact categories to be included in product standards has not yet been documented in the scientific literature.

A case study on the development of a new standard for reusable plastic bags (AENOR 2009), developed by the Spanish Certification Body, AENOR, was selected by the authors as the basis for discussion. This first application goes beyond the recommendations of ISO Guide 64 and has a double aim. Firstly, it intends to establish quantitative limits for the emission of greenhouse gases for polyethylene (PE) bags, by using a simplified model focused only on the GWP indicator and using standard background data. Secondly, it is also aimed at evaluating the appropriateness of using such simplified model to establish this limit, comparing the obtained results in terms of GWP to those of a number of fully fledged LCAs, which were performed in parallel following standard procedure on the basis of a comprehensive life cycle inventory. Four case studies were analysed this way, namely 100% virgin high-density polyethylene (HDPE) bags, 15% recycled HDPE bags, 100% virgin low-density polyethylene (LDPE) bags and 15% recycled LDPE bags.

3 Method

The simplified algorithm developed here to calculate the GWP of the product moves from a life cycle thinking perspective. The first step in the algorithm definition was to identify the key processes along the life cycle of PE bags that contribute the most to GWP, by means of a set of complete LCAs of the four different types of plastic bags described above, following ISO 14040:2006 and 14044:2006 standards and using the GaBi 4.3 software with industry-standard databases (PE International 2007; Ecoinvent 2008). Although these full LCAs produced results for a number of impact categories (the CML 2001 Life Cycle Inventory Assessment Method was used), only GWP was considered for the purposes of this paper.

The results of these LCAs revealed the following phases as the most relevant ones in terms of GWP for PE bags, i.e. raw material production, bag production and distribution from production site to retail establishments. Depending on the specific case study, these three processes collectively represent approximately 85–90% of the GWP associated to the complete life cycle of the bags (including production and transport of all chemical inputs, as well as end-of-life disposal and treatment). Clearly, these precentages also represent the theoretical maximum extent to which the results of the simplified tool can be expected to replicate those of the full LCAs.

Consequently, a simplified GWP algorithm including all the relevant parameters for these key processes was developed:

$$GWP_{TOT} = GWP_{PE} + GWP_{El} + GWP_{tr1} + GWP_{tr2}$$

where

$$GWP_{PE} = (\%PE_{vir} \times CO_2\text{-eq}_{PEvir}) + (\%PE_{rec} \times CO_2\text{-eq}_{PErec})$$
$$GWP_{El} = (ED \times CO_2\text{-eq}_{El})$$
$$GWP_{tr1} = \left(\frac{1}{1,000} \times dist_1 \times CO_2\text{-eq}_{tr1}\right)$$
$$GWP_{tr2} = \left(\frac{1}{1,000} \times dist_2 \times CO_2\text{-eq}_{tr2}\right)$$

where

$\%PE_{vir}$	Ratio of virgin polyethylene weight to total bag weight (ranging from 1 to 0)
$\%PE_{rec}$	Ratio of recycled polyethylene weight to total bag weight (ranging from 0 to 1)

$CO_2\text{-eq}_{PEvir}$	Mean GWP value for production of virgin polyethylene (kilogramme (CO_2-eq) per kilogramme)
$CO_2\text{-eq}_{PErec}$	Mean GWP value for production of recycled polyethylene (kilogramme (CO_2-eq) per kilogramme)[1]
ED	Electricity demand for producing a kilogramme of bags (megajoules per kilogram (bags))
$CO_2\text{-eq}_{El}$	Mean GWP value for electricity production according to the employed power grid mix (kilogramme (CO_2-eq) per megajoules)
$dist_1$	Distance between polyethylene production site and bag production site (kilometres)
$dist_2$	Distance between bag production site and destination country (where the bag will be used; kilometres)
$CO_2\text{-eq}_{tr1}$	Mean GWP value for transportation of polyethylene according to used means of transportation (kilogramme (CO_2-eq) per tonne-kilometre)
$CO_2\text{-eq}_{tr2}$	Mean GWP value for transportation of bag according to used means of transportation (kilogramme (CO_2-eq) per tonne-kilometre)

As this algorithm was intended to be included in the new standard for reusable plastics bags being developed by AENOR, recommended mean values for the GWP associated to the background processes to be employed (e.g. production of virgin polyethylene granulate, transportation by lorry, ship and airplane, etc.) were provided (Table 1), based on internationally accepted databases such as the European Reference Life Cycle Data System (ELCD 2008), PE International (2007) and Ecoinvent (2008).

It is important to mention that the factor $CO_2\text{-eq}_{PEvir}$ largely depends on the specific fossil fuel used as primary source of energy, heat and steam. For that reason, the following formula to estimate this factor was recommended to be used whenever accurate information is available:

$$CO_2\text{-eq}_{PEvir} = ES \times CO_2\text{-eq}_{steam} + EH \times$$
$$CO_2\text{-eq}_{heat} + EE \times CO_2\text{-eq}_{El} + OE$$

where

ES	Energy to produce high pressured steam (megajoules per kilogram)

$CO_2\text{-eq}_{steam}$	Mean GWP value for steam production depending on the fossil fuel used (kilogramme (CO_2-eq) per megajoules)
EH	Energy to produce heat (megajoules per kilogramme)
$CO_2\text{-eq}_{heat}$	Mean GWP value for thermal energy production depending on the fossil fuel used (kilogramme (CO_2-eq) per megajoules)
EE	Electricity demand (megajoules per kilogramme)
$CO_2\text{-eq}_{El}$	Mean GWP value for electricity production depending on the electricity mix used (kilogramme (CO_2-eq) per megajoules)
OE	Other GWP emissions due to other inputs in the system (kilogramme (CO_2-eq) per kilogramme; the relative contribution of this term is usually below 10%)

If the bag is produced in a country for which the mean GWP value for electricity production is unknown, the latter can be estimated using the following formula:

$$CO_2\text{-eq}_{El} = \sum_k CO_2\text{-eq}_k * f_k$$

where

$CO_2\text{-eq}_k$	GWP value for electricity produced using technology k (e.g. coal, oil, natural gas, hydro, ...)
f_k	The fraction of electricity produced using technology k

In order to check the degree of accuracy of the algorithm, the latter was tested by comparing its results to those obtained through complete LCAs for the four case studies mentioned in Section 2.1, i.e. (1) 100% virgin HDPE bags, (2) 15% recycled HDPE bags, (3) 100% virgin LDPE bags and (4) 15% recycled LDPE bags. Bag characteristics are shown in Table 2. LDPE bags are single-use whereas HDPE bags are reusable (up to 15 times); hence, the latter are much heavier than the former.

3.1 Results

In Fig. 1, a comparison is made between the GWP results of the complete LCAs and those of the simplified algorithm for the four analysed case studies, using the parameters and assumptions illustrated in Table 2. As can be seen, the simplified algorithm was found to underestimate the global GWP of the systems under study by 10–12%.

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[1] An open loop recycling systems was considered in this study. Thus, neither environmental credits nor impact allocation was considered. Only the collection and physical treatment of the PE waste to generate new pellets are considered.

Table 1 GWP associated to background processes employed in the simplified algorithm

	Amount	Unit	Reference
CO_2-eq$_{PEvir}$ (virgin PE)			
Type of plastic (country of origin)			
HDPE (EU)	1.80	kg(CO_2-eq)/kg	PE International 2007
LDPE (EU)	2.23	kg(CO_2-eq)/kg	PE International 2007
HDPE (ES)	2.35	kg(CO_2-eq)/kg	This work[a]
LDPE (ES)	2.8	kg(CO_2-eq)/kg	This work[a]
HDPE (China)	2.41	kg(CO_2-eq)/kg	This work[a]
LDPE (China)	2.99	kg(CO_2-eq)/kg	This work[a]
CO_2-eq$_{PErec}$ (recycled PE)			
Type of plastic			
Recycled PE	0.76	kg(CO_2-eq)/kg	This work
CO_2-eq$_{El}$ (electricity mix)			
Country/region			
UCTE[b]	0.16	kg(CO_2-eq)/MJ	ELCD 2007
Spain	0.18	kg(CO_2-eq)/MJ	ELCD 2007
France	0.040	kg(CO_2-eq)/MJ	ELCD 2007
Germany	0.20	kg(CO_2-eq)/MJ	ELCD 2007
China	0.32	kg(CO_2-eq)/MJ	PE International 2007
CO_2-eq$_{tr}$ (transport)			
Type of transport			
Truck (22 t, EURO-3)	0.067	kg(CO_2-eq)/tkm	ELCD 2007
Ship (27,500 t)	0.013	kg(CO_2-eq)/tkm	ELCD 2007
Airplane (68 t)	2.5	kg(CO_2-eq)/tkm	ELCD 2007

[a] These values were calculated through extrapolation from those contained in the GaBi database PE International (2007) by assuming the use of Chinese coal instead of light fuel oil as primary thermal energy source and the Chinese electricity mix instead of the UCTE one

[b] Union for the Coordination and Transmission of Electricity

Such differences are mainly caused by the fact that the complete LCAs also include additional, secondary processes such as the production of paints and pigments, primary and secondary packaging (cardboard bags and pallets) and the treatment of waste produced at the manufacturing sites (for LDPE bags) and the internal recycling of waste produced at the manufacturing site (for HDPE bags). This moderate level of discrepancy is in line with expectations, and it can in fact be considered a very encouraging result.

4 Second application: assessment of carbon footprint savings through use of recycled materials

4.1 Aim and scope

This second application example is focussed on estimating the reduction in GWP resulting from the use of recycled materials in a range of selected products. The latter were chosen among those in the list made available by the

Table 2 Main values for bags analysed in the full LCA

		HDPE bag		LDPE bag	
		LCA	SA	LCA	SA
Bag inputs	PE[a]	95.07%	100%	92.64%	100%
	Pigments	2.69%	0%	6.18%	0%
	Ink	2.17%	0%	1.19%	0%
	Adhesive	0.07%	0%	0.00%	0%
Electricity consumption in the production site (MJ/kg)		2.07	1.96[2]	1.97	1.96[b]
Distance between polymer production site and bag production site (km)		1,500	1,500	1,500	1,500
Distance between bag production site and selling point (km)		260	260	260	260
Location of the production site		Spain	Spain	Spain	Spain

[a] Two alternatives are investigated for both HDPE and LDPE, i.e. 100% virgin and 15% recycled

[b] Value of 0.55 kwh/kg bag included in the new bags standard in agreement with producers' data

Fig. 1 Comparison of GWP calculated with simplified algorithm vs full LCA for 1 kg of HDPE bags (100% virgin, reusable), 1 kg of HDPE bags (15% recycled PE, reusable), 1 kg of LDPE bags (100% virgin, single use) and LDPE bags (15% recycled PE, single use)
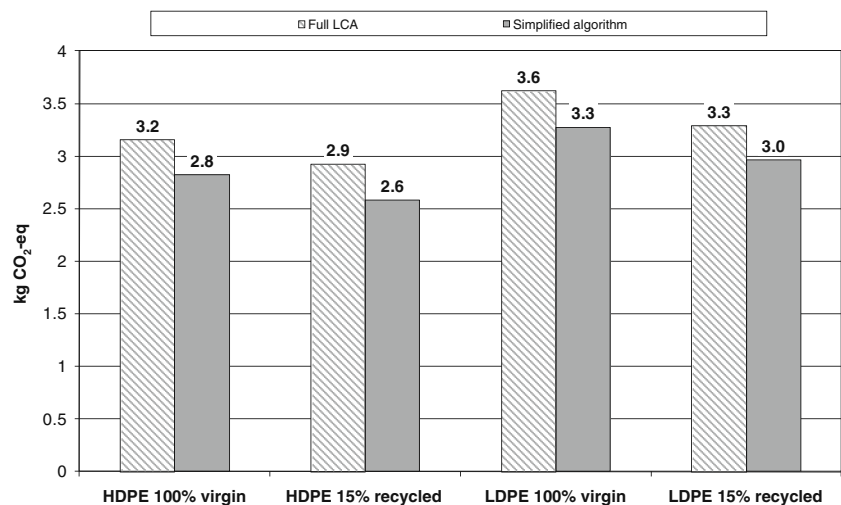
Catalan Waste Agency (ARC) for both public and private procurement.

In order to evaluate the potential GWP savings and taking into account the suggestions from the European Platform on Life Cycle Assessment of the European Commission Joint Research Centre (EPLCA 2009), a reduced-scope life cycle assessment was performed. Such reduced-scope GWP analysis was applied to a selection of the most representative items in the ARC list, which are composed of common materials such as PE, ploypropylene, polyethylene-terephtalate, polyvinylchloride, steel, aluminium, paper, cardboard and gravel.

The overall objectives of the application example presented here can be summarised as follows:

- To establish and test a simple and user-friendly tool for the calculation of the potential GWP savings associated to the use of recycled materials in common products
- To provide a communication tool, whereby to promote products made from recycled materials and thereby also spur producers to make increased use of secondary materials

4.2 Method

The analysis was carried out within the LCA methodological framework, as defined in ISO standards (ISO 2006a, b).

The entire life cycles of the products were taken into account, including the provision of raw materials, energy, as well as the end-of-life stages. System boundaries for a generalized product are as illustrated in Fig. 2.

The authors defined scenario 1 as the life cycle of a product entirely made of 100% virgin materials and scenario 2 as the life cycle of the same product but made of (partially) recycled materials. Since the final objective of the analysis was the evaluation of the potential GWP savings produced by

replacing virgin materials with secondary materials in each product, the functional unit was defined as the product itself, and the analysis was performed on the 'virtual product' representing the difference between the two aforementioned scenarios. Thus, all phases of the product life cycle that remain unchanged in the two scenarios (i.e. product manufacturing, use phase and decommissioning) could be neglected. It should be noted that in some instances, the product manufacturing phase may actually vary depending on whether virgin or recycled materials are used (e.g. in some plastic extrusion processes the amount of feedstock and melting temperature have a strong dependence on the property of the material). A product made of recycled materials might also be comparatively less durable. Finally, potential differences in post-consumer recycling of product wastes are not considered. Thus, the simplification adopted here strictly applies only to those products for which no relevant differences exist between the two scenarios in the manufacturing, use and decommissioning phases.

Primary data were obtained from the information collected from each producer, while data on background processes were taken from standard databases (PE International 2007; Ecoinvent 2008).

All the producers of the selected items for this case study are located in the same geographical region (Catalonia, Spain), and all secondary materials are produced out of locally collected waste. The following assumptions apply:

- Primary materials were assumed to be sourced from typical international suppliers, while recycling facilities were generally assumed to be local (except when the producer explicitly specified a different location of the recycling facility)
- Primary materials may be transported to the manufacturer by air, sea or road transport; for all transport methods, a mean travel distance of 1,000 km was assumed

Fig. 2 System boundaries and life cycle stages of a generalised product
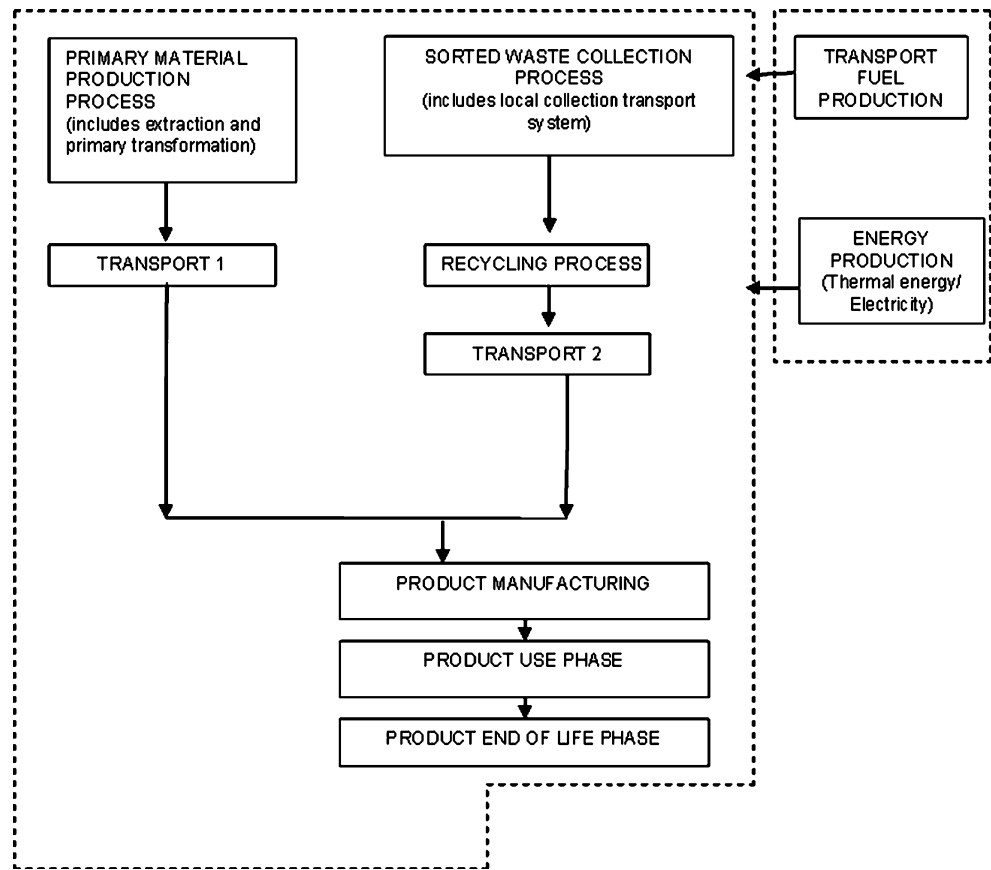
– Secondary materials are obtained from the local waste collection system; only road transport was assumed here, with a mean distance of 100 km to and from the recycling facilities (except when the producer explicitally specified a different location)

The model is highly dependent on the energy mix associated to each process. As a general rule, since the products concern a specific regional scenario, it was considered that the electricity consumed in the recycling processes was that of the local grid mix; when the producer specified a different location of the recycling process, the correspondingly appropriate energy mix was used, instead.

In the LCIA phase, applying the same 'virtual product' concept, the GWP savings can be calculated as follows:

$$GWP_{savings} = GWP_{scenario1} - GWP_{scenario2}$$

Each product may be made from n different materials. For each of these, the following two equations apply:

$$GWP_{i,primary} = GWP_{i,prod} + GWP_{i,tr1}$$

$$GWP_{i,secondary} = GWP_{i,coll} + GWP_{i,rec} + GWP_{i,tr2}$$

where

$GWP_{i,primary}$ GWP of required amount of material i for product manufacturing, assuming 100% primary material

$GWP_{i,prod}$ GWP for production of required amount of material i, assuming 100% primary material

$GWP_{i,tr1}$ GWP for transport of required amount of material i from its primary production site

$GWP_{i,secondary}$ GWP of required amount of material i for product manufacturing, assuming 100% secondary material

$GWP_{i,coll}$ GWP for collection of scrap equivalent to required amount of material i for product manufacturing

$GWP_{i,rec}$ GWP for recycling of scrap equivalent to required amount of material i

$GWP_{i,tr2}$ GWP for transport of required amount of secondary material i from recycling facility

In particular, for those organic fibre materials whose life cycles entail absorption and release of biogenic carbon (e.g. paper and carboard), such both flows were excluded from the GWP calculation of the corresponding secondary (recycled) material. The rationale behind this modelling choice is illustrated in Fig. 3. The life cycle of the recycled organic fibre material is looked at as an additional internal loop within the larger life cycle of the parent primary material. As such, the recycled material carries neither the credit for the CO_2 absorption that takes place during plant growth nor the burden of end-of-life biogenic carbon emissions (be they CO_2 and/or other carbon compunds such as methane

Fig. 3 Model for life cycle of primary and secondary materials (e.g. paper and cardboard) made of natural vegetable fibres
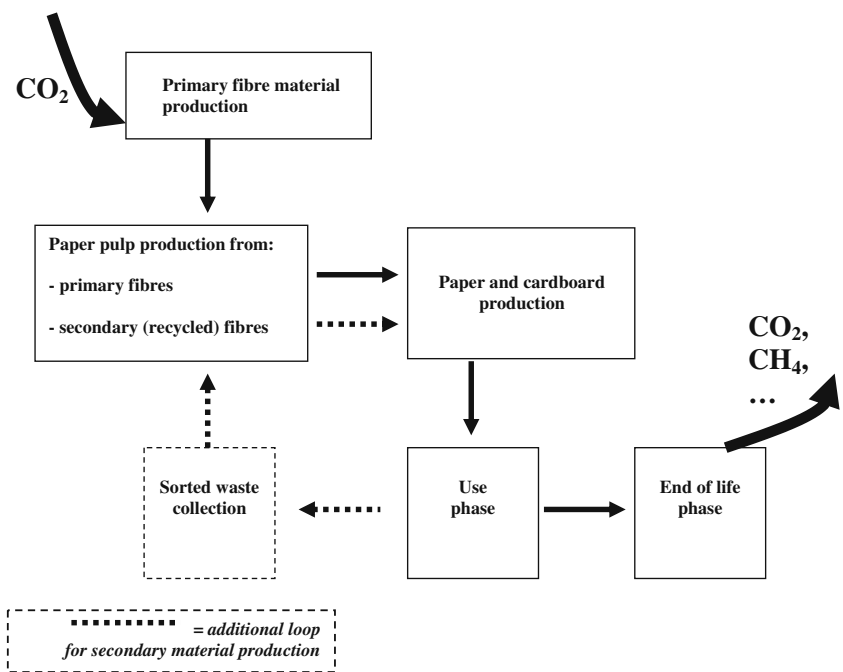
etc.). This holds true regardless of the assumed end-of-life treatment option and, therefore, regardless of the individual fractions of the biologically absorbed carbon that end up being emitted, respectively, as CO_2, methane, etc.

For the full product, we have

$$GWP_{scenario1} = \sum_{i=1}^{n} \left(GWP_{i,primary} \right) + GWP_{manufacturing}$$
$$+ GWP_{use} + GWP_{decommissioning}$$

and indicating with k_i the weight fraction of recycled material i in scenario 2, we have

$$GWP_{scenario2}$$
$$= \sum_{i=1}^{n} \left[(1 - k_i) \times GWP_{i,primary} + k_i \times GWP_{i,seecondary} \right]$$
$$+ GWP_{manufacturing} + GWP_{use} + GWP_{decommissioning}$$

which leads to

$$GWP_{savings} = \sum_{i=1}^{n} k_i \times \left(GWP_{i,primary} - GWP_{i,secondary} \right)$$

4.3 Results

Results for a small subset of the analysed products are shown in Table 3. Positive GWP savings were found when comparing the use of partially recycled materials (scenario 2) to 100% primary materials (scenario 1). This equally applies to very simple, single-component products (e.g. printer paper) as well as to more complex products which are composed of several different materials, only a fraction of which are recycled (e.g. office chair).

5 Conclusions

The two application examples presented here have provided preliminary evidence that streamlined approches such as these can go a long way in facilitating the introduction of life cycle thinking and LCA in the day-to-day practice of industries and policy makers, while still producing scientifically sound and robust results.

Table 3 GWP savings for selected products making use of partially recycled materials

Product	Recycled material(s)	Total product weight kg	Combined weight of recycled materials kg	GWP savings kg(CO_2-eq)	GWP savings per kg of recycled materials kg(CO_2-eq)/kg
Office chair	Al, steel, Zn	15	2.6	14	5.4
Floor tiles	Plastic mix	2.3	2.3	7.6	3.3
Printer paper (500 sheets)	Paper	2.5	2.5	5.7	2.3
Desktop organiser	Cardboard	0.23	0.23	0.49	2.1

Even reduced-scope, single impact category LCA tools such as the one presented here may be extremely useful for quick, routine applications, and for use by inexperienced practitioners having limited access to LCA software and databases. In particular, it is the authors' opinion that they are extremely helpful in the process of including selected environmental criteria (such as GWP) in product standards, in order to avoid the adoption of measures based on arbitrary choices which may fail to properly consider the most environmentally critical stages or aspects of its life cycle.

In particular, the first case study has shown that well-guided simplification can be essential in applying LCA principles to the context of product standards. In fact, in the end, even the streamlined algorithm proposed by the authors was still perceived to be too complicated and impractical by a Spanish consortium of plastic bag producers (CICLOPLAST), who decided to simplify it even further, leading to a single formula for CO_2 emissions with an additional explanation in an annex. Clearly, the option of requiring a fully fledged LCA, requiring a complete LCI and addressing several more impact categories, would have been ruled out even more quickly. This is an important issue, for in the opinion of the authors, the multitude of impending environmental problems can no longer be relegated into oblivion when making important policy decisions.

As regards the second case study, it can be maintained that a simplified analysis such as the one presented here, in spite of being reduced in scope (i.e. only one impact category is considered, and only the absolute reduction of the impact is measured), does not lose its scientific rigour. In fact, in principle, all the phases of the entire product life cycle are taken into account, and only those which are identical in the two scenarios are discarded in the calculations.

Its limitation lies in the fact that this simplified method can only be applied to those cases where the only target is the measurement of the *absolute* potential savings in terms of GWP, since no information is produced on the *relative* GWP savings, nor of course on the overall environmental performance of the product, from the point of view of other impact categories. The latter point is especially important, since in the authors' opinion, policy decisions in terms of green procurement aimed at improving goods and services should only be taken on the basis of the joint evaluation of a number of impact types, such as e.g. acid rain, summer smog, eutrophication, carcinogenic effects and land use. In fact, ISO 14044:2006 explicitly asks for not using only one impact category in public comparisons. Additional impact categories, however, could be approached in a similarly streamlined manner in many instances, by means of case-specific simplified tools appropriately developed by LCA experts.

Still, it should be acknowledged that the Catalan network of recycled materials established by the Catalan Waste Agency contains more than 400 recycled products, and this number is continuously increasing. Using a comprehensive LCA approach to this network would have required a sizeable percentatge of the total budget of the Catalan Waste Agency, and hence, it probably would have never been started. On the contrary, in spite of its limitations due to its reduced scope, the simplified tool presented here may play an important role in fostering discussion and improvements in the next years.

6 Recommendations and perspectives

Moving on from the premises of the first application examples presented here, further tailor-made simplified tools may be developed for the specific purposes of a number of additional case studies, thus effectively circumventing the often voiced problem of lack of available resources to implement a fully fledged LCA.

Of course, in many instances, it will be advisable not to limit the scope of all streamlined approaches to the sole global warming potential impact category. Instead, the most relevant impact indicators to be included in the model should be selected on a case-by-case basis, and appropriate simplified tools should be developed for their evaluation. In this way, simplification will not come at the expenses of scientific soundness or relevance, while still removing unnecessary impediments to the much needed widespread application of life cycle thinking outside the academic and research realms.

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