Methods review to support the PAS for the calculation of the embodied greenhouse gas emissions of goods and services

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METHODS REVIEW TO SUPPORT THE PAS PROCESS FOR THE CALCULATION OF THE GREENHOUSE GAS EMISSIONS EMBODIED IN GOODS AND SERVICES

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Views expressed in this report are those of the authors and do not necessarily reflect those of Defra.
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1 Introduction

Project background – Development of a PAS

Man-made climate change is considered to be one of the greatest challenges we face today. Reducing anthropogenic emissions of greenhouse gases (GHG) is widely accepted as a necessity to mitigate the effects of global warming. At the same time it is increasingly recognised that it is not only the direct burning of fossil fuels but also the consumption of goods and services that gives rise to GHG emissions indirectly. The calculation of these indirect, or "embodied" emissions is the very subject of this report.

Recently the calculation of embodied GHG emissions has prominently featured in the public debate and on the policy level. For example, Tesco, the biggest retailer in the UK, has announced to put carbon labels on every one of its 70,000 products and has put money towards the development of a methodology, which enables the determination of the embodied carbon emissions of its goods and services. At the same time the Carbon Trust has started developing a carbon label for products in cooperation with various stakeholder groups (Carbon Trust 2007b) and put efforts into the development of a standard methodology for the estimation of the carbon footprints of goods and services in the UK (Carbon Trust 2007a). Similar efforts to calculate the life-cycle climate change impacts of products have mushroomed in other countries and the wider international life-cycle assessment community.

Due to these high levels of public and private interest in the climate change impacts of products, DEFRA and the Carbon Trust have teamed-up with the British Standards Institution (BSI) to fast-track the standardisation of a methodology for calculating the GHG emissions embodied in goods and services by developing a Publicly Available Specification (PAS) ¹. Several requirements for the PAS development have been specified in this context. The PAS should:

- Be applicable to all goods and services with consideration given to how and whether it may need customizing for specific product groups, e.g. food, buildings, energy use products;

¹ A PAS is a consultative document based on the British Standard model. Any organisation, association or group who wish to document standardised best practice on a specific subject, both for the benefit of their industry and to help promote their expertise, can commission a PAS, subject to the BSI acceptance process. (http://www.bsi-global.com/en/Standards-and-Publications/How-we-can-help-you/Professional-Standards-Service/PAS-2050/What-is-a-PAS-Publicly-Available-Specification).
• Consider all life cycle stages along the supply/value chain of a good or service, i.e. from raw materials to end of life;
• Consider all GHGs;
• Be usable by all sizes and types of organizations.

**Project aim and objectives**

The overall aim of this project is to inform the development process of a Publicly Available Specification (PAS) for the calculation of the GHG emissions (GHG) of goods and services with an independent fitness-for-purpose review of current, relevant methods. We seek to deliver towards this aim by meeting the following three project objectives:

A. Identify and assess relevant existing methods for the calculation of the GHG emissions of goods and services in a fitness-for-purpose review;
B. Recommend which life cycle methodologies can be used or built upon to meet the PAS requirements;
C. Document the review process and findings in a report and communicate the findings of the review to DEFRA/CT/BSI representatives, PAS team, Steering Group and other interested parties as required.

**Project scope: What is this project about and what not?**

*Which methods are included in the survey?*

Due to the tight time constraints on the project, it was key from the outset to clearly define which methods for calculating the embodied GHG emissions of goods and services will eventually be selected. The PAS requirements make clear that only lifecycle approaches, which cover at least the major life cycle stages of a product, are relevant in the context of this review. We therefore focus the attention of this fitness-for-purpose review mainly on three relevant methods in this project:

• Process-based lifecycle assessment (PLCA);
• Input-output based lifecycle assessment (IOLCA);
• Hybrid lifecycle assessment (HLCA).

All other methods and tools set out in the tender specification by DEFRA did not fulfil this PAS requirement or are already based on one of these three lifecycle approaches. For example, carbon footprint estimates are usually derived by carrying out a process-based LCA or an environmental input-output analysis. These methods
are only briefly touched upon. Other methods and standards for measuring or calculating GHG emissions such as ISO 14064 or the WBCSD GHG protocol are covered to the extent they are relevant in the context of the project.

**Where are the boundaries with the on-going PAS process?**

- This review does not elaborate a draft PAS. It rather assesses the various selected methods in the light of the PAS requirements and intended applications of the PAS and provides general methodological recommendations.
- The review is not an in-depth review of the most recent PAS draft document. It is rather aimed at providing an independent expert opinion, which could be used for the further development of the PAS.

**Outline of report**

The report is divided into seven Sections. The next Section describes the assessment methodology before Section 3 provides a brief introduction to ISO 14040 and 14044. The nature of the challenge of this review is elaborated in this context. Section 4 provides the review results. The recommendations are outlined in Section 5 before possible timelines for the implementation of the recommendations are identified in Section 6. Section 7 concludes this report.
2 Methodological Approach

Fitness-for-purpose review

The fitness of the selected life cycle approaches for calculating the GHG embodied in goods and services is assessed in a SWOT analysis. SWOT analysis emerged as a strategic planning tool in the business literature to develop the strengths, weaknesses, opportunities and threats involved in a project. The objective of the present SWOT analysis is to evaluate the fitness-for-purpose of current methods relevant to calculating GHG emissions embodied in products in general and under the PAS requirements in particular. In this context, we define:

**Strength:** Attributes of the method that are helpful to the purpose of calculating embodied GHG emissions of products;

**Weaknesses:** Attributes of the method that are detrimental to the purpose of calculating embodied GHG emissions in products;

**Opportunities:** External conditions (e.g. data availability) that are favourable to the purpose of calculating embodied GHG emissions in products;

**Threats:** External conditions (e.g. lack of expertise in research community) that are unfavourable to the purpose of calculating embodied GHG emissions in products.

As summarised in Figure 2.1 the methodological assessment concentrates on four main areas:

- **Robustness of data and method used:** We define robustness of a particular LCA methodology with regard to its policy applications: a method is considered robust, if derived estimates are sufficiently precise and accurate to inform a particular policy application. The robustness of a particular method is assessed against its data requirement and availabilities, data uncertainties as well as established procedures to verify the derived estimates. Uncertainties in the final estimates of the GHG emissions embodied in products arise in the collection of primary data as well as the use of secondary data, where primary data is not available. Further uncertainties are associated with the ability of a particular method to include the whole product system in the analysis (system
completeness). This will stimulate a discussion on how boundaries of a product system should be determined in the PAS, identify important data gaps and trigger a discussion on whether and how these can be closed or dealt with within a particular methodological framework.

In terms of emission factors used in the analysis, the key question seems to be associated with non-combustion related GHG emissions, which are more uncertain than others. Authoritative emission factors for the combustion-related emissions per fuel types and process types can be directly used as they have already been scrutinised in an international peer-review process. This means that emissions from mining (CH4 emission from coal matrix), oil and gas exploration (CH4 emission from drilling), cement and lime (CO2 emission via CaCO3 -> CaO + CO2 conversion), livestock and agriculture (CH4 and N2O from manure application and nitrogen fertilizer application), fertilizer (CO2 emission through water-gas shift process), etc. should get much more attention than others. In order to address this issue comprehensively the expert survey will also consult selected experts dealing with those emission sources.

- **Simplicity of application**: The determination of the simplicity of application is important in order to make sure that the PAS can be used by any organisation. In the analysis we will therefore discuss the levels of skills required by a practitioner to carry out the analysis. In this context it will be crucial to consider the available methodological expertise available in the UK and available software tools, which might ease the application of a particular methodology.

- **Consistency with GHG accounting standards**: This description of the relationship between the different life cycle approaches and various GHG accounting standards as well as a critical reflection of the current state in GHG emission accounting.

- **Costs of analysis**: The costs of the analysis are determined by the time and labour intensity of a particular method as well as any additional costs incurred (e.g. purchase of data, license fees for available software tools etc.).

However, robustness, cost and simplicity of application often depend on the aggregation level at which the analysis is carried out. Therefore, three aggregation levels are distinguished in the methodological assessment:

- product groups (e.g. food)
- individual products (e.g. chocolate bar)
- product brands (e.g. “Mars”-bar).

For example, environmental input-output LCA will provide most robust estimates for the product groups (sectors) distinguished in the input-output table. Estimation on
higher or lower aggregation levels will automatically increase the levels of uncertainties associated with the analysis.

The methodological assessment itself was informed in three ways:

- **Literature review:** Key texts in the relevant literature for assessing the fitness-for-purpose of the different lifecycle approaches for meeting the PAS requirements were reviewed and used as evidence source in the evaluation process.

- **Expert survey:** Additional evidence was sought in an expert survey carried out during the first three weeks of the project. The results of this survey were used to directly inform the methodological assessment and used to increase transparency by putting the findings of the project team into context.

- **Team expertise:** The project team was selected in a way that practical expertise in all selected life cycle approaches was available. Only such a team composition could allow a sound understanding of the strength, weaknesses, opportunities and threats of the different life-cycle approaches, the selection of the most relevant literature and the derivation of useful recommendation for the on-going PAS development.

From this fitness-for-purpose review, recommendations on methods, which can be used or built on to meet the PAS requirements for a robust standard, were derived and discussed in the light of the most recent draft methodology for the PAS. The complete structure of the project with all objectives, work packages and deliverables is summarised in Figure 2.2.
Expert survey

An expert survey was undertaken within this project for four reasons:

- To ensure that all key literature was included;
- To inform the methodological assessment where no clear evidence was available;
- To reinforce the impartial nature of this methods review;
- To put the findings of the project team into context and provide a balanced and transparent view in the course of the fitness-for-purpose review and recommendations.

Design

The survey was divided into three major Sections: Section 1 focused on the collection of personal information including self-reported fields of expertise. Section 2 asked specific questions with regard to the completeness of the literature list. In Section 3 expert expertise was sought, (1), with regard to potential boundaries of the analysis in the context of the PAS such as the inclusion of GHG emissions associated with company overheads (e.g. heating of office buildings or factories, facilities for supporting activities etc.) or capital goods (e.g. machinery for production of goods); (2) to evaluate some of the practical and methodological challenges faced in the PAS development particularly in areas where clear evidence was unavailable.

Section 4 was aimed at evaluating the challenge of developing a PAS for estimating the embodied GHG emissions in products. Overall the survey contained 19 questions. The expert survey design is attached in Appendix E.

Expert selection and response rate

An expert list was conducted by the project team with members of the LCA community with expertise in PLCA, IOLCA and HLCA. Care was taken that a balance was struck with regard to the expert expertise in these three different lifecycle approaches. In addition, some specialists in the compilation of GHG inventories where included in order to inform the discussion on the robustness of emission factors applied in LCA. The expert list was finalized after a discussion with the project steering group in the inception meeting. Out of 33 experts, who were approached by the project team, 21 agreed to participate in the survey. Of these 17 returned the survey in time.

Table 2.3 summarises the self-reported fields of expertise of the participating experts. Slightly more experts with expertise in IOLCA than in PLCA responded to the survey. Among the participating experts were 2 specialists in PLCA, 5 specialists in IOLCA and 2 GHG inventory specialists. 5 experts can be seen as “all-rounders” in that they have practical expertise in PLCA, IOLCA and HLCA (see Appendix A).
Table 2.3 – Self-reported expert expertise

Limitations and overall assessment

Due to the tight timelines of the project, the survey was designed in a very short amount of time. This did not leave any room for a pilot survey. Most of the 19 questions could be answered by experts without major difficulties. Problems with the following questions occurred:

- Question 7: Due to an editing error it was not easily understandable from the question that its focus is on the GHG emissions associated with the use phase of products. However, as most experts seemed to understand the question correctly, this editing mistake did not have any major re-percussions in terms of the survey results.

- Questions 9 and 10: Most experts felt unable to answer these questions on various sources of uncertainties associated with different life cycle methodologies adequately. Retrospectively it appears that these questions could have been phrased more clearly. Moreover, the semi-quantitative nature might have been over-ambitious. While a reasonable number of experts still tried to answer these questions, not too much weight can be attached to the answers and great care will need to be taken in their evaluation.

- Question 16: Not all experts seemed happy with the way this question was put. However, most experts indicated their opinion even though some care need to be taken in the interpretation of the results from this question as well.

However, the survey provided very insightful results, was very useful for deriving more informed recommendations and puts the views of the project team into a wider range of expert opinions. Overall, we think that it fully served the purpose it was intended for in the project proposal.
3 Framing the review - ISO LCA and the nature of the challenge

It is important to clearly map out the nature and scale of the challenge associated with the estimation of the embodied GHG emissions in products. With the focus of the PAS on methods spanning the whole life cycle of products, the ISO standards on LCA (the “14040” series) provide a natural starting point for the discussion.

ISO 14040 (BSI 2006a) defines LCA as “compilation and evaluation of the inputs, outputs and the environmental impacts of a product system throughout its life cycle”. The ISO series on LCA was developed with an understanding of LCA as a bottom-up, process based analysis (i.e. PLCA). However, it will be important later that it also leaves room for the use of alternative approaches for assessing the environmental impacts of a product system throughout its life cycle. Operationally, ISO 14040 describes LCA as a process including four phases:

- Phase 1: Goal and scope definition;
- Phase 2: Inventory analysis;
- Phase 3: Impact assessment;
- Phase 4: Interpretation.

The compilation of the life cycle inventory is the by far most resource intensive task in terms of the expense of time and money. Based on the system boundaries defined in phase 1 of a LCA, it is concerned with the collection of the data necessary to meet the goal of a study. ISO 14044 a general indication on how to draw the system boundaries of a product system: “The system should be modelled in such a manner that input and outputs at its boundaries are elementary flows”. According to ISO 14044 an elementary flow is defined as:

1. “material or energy entering the system being studied, which has been drawn from the environment without previous human transformation, or;
2. material or energy leaving the system being studied, which is discarded into the environment without subsequent human transformation” (BSI 2006b).

It might be very difficult to comply with this principle in practice due to the high degree of interdependencies in modern economies and the high degree of complexity of international supply chains. It would rather seem fair to assume that all processes are somehow directly or indirectly connected (e.g. Suh et al. 2004b).

In a perfect world with unlimited resources and full data availability the compilation of a complete life cycle inventory and a robust estimation of the embodied GHG emissions in products based on process data would not be a problem. However,
resources – particularly in the context of the PAS - and data availability are usually very limited. ISO leaves this problem open by including a clause with the option for leaving out insignificant inputs or outputs from a system – generally known as cut-off (BSI 2006b, p.8).

Ultimately the establishment of a robust estimate of the GHG emissions throughout a product life cycle is a data rather than a methodological challenge. The development of a robust PAS becomes only a methodological challenge with incomplete information about processes and their interrelationships as well as very limited resources for data collection. In particular, some authors suggest that the inclusion of top-down data might be a way around the truncation of the product system under study and a good way to improve robustness and comparability of embodied GHG estimates (Suh et al. 2004a).

Hence, the ultimate challenge of this methods review is to identify the methodology for the estimation of GHG emissions associated with the life cycle of product systems, which can provide sufficiently robust estimates for the intended PAS applications and minimises the costs for performing such an analysis as well as potential development costs. Note that some applications might be too ambitious for the PAS given the current state of affairs in terms of data and methodological developments.
4 Assessment Results

In this Section the assessment results of the fitness-for-purpose review are summarised drawing from the selected key literature, the expert survey and the expertise of the project members. Firstly, the results from the SWOT analysis of process life cycle assessment (PLCA), input-output life cycle assessment (IOLCA) and hybrid life cycle assessment (HLCA) are presented. Secondly, the robustness of GHG emission factors are discussed – particularly emission factors for GHGs from non-combustion processes. Finally, the most recent draft methodology of the PAS is discussed.

Process Life-Cycle Assessment (PLCA)

PLCA is conducted by using process data in a bottom-up procedure for the compilation of the life cycle inventory (LCI) of a product system (see, SETAC 1993; Lindfors et al. 1995; Curran 1996; BSI 2006b; BSI 2006a). The data applied in PLCA is usually either collected directly or process-specific secondary data taken from LCI databases or other data sources (grey literature, sector reports etc.) is assumed to be representative for a particular process. A full discussion of PLCA is provided in Appendix B.

Process flow diagram versus matrix based approach

Computationally, there are two different approaches to PLCA: a matrix based and a process flow diagram based approach. It is not difficult to show that computationally only the former can correctly quantify the inputs, outputs and environmental interventions of (unit) processes correctly as it also takes into account those processes that feed back or re-circulate to previous processes.\(^2\)

Not only have the ISO standards ignored this problem and its solution, but also most textbooks on the principles of the compilation of life cycle inventories (see (Curran 1996; Hauschild and Wenzel 1998). Even though matrix based calculations are increasingly implemented in LCA software/inventories such as SimaPro, CMLCA or ECOINVENT many available tools still lack the necessary capabilities (Heijungs 1994; Heijungs and Suh 2002; Gwak and Mi-Ryang Kim 2003; Heijungs and Suh 2006). Clearly, a robust PAS methodology for the calculation of the GHG emissions embodied in products should only be based on a matrix based approach to life cycle inventory calculation.

\(^2\) However, note that there are a few techniques to solve this problem including iterative methods and infinite geometric progression, the process flow diagram approach is generally not adequate for a complex system (see (Heijungs and Suh 2002) or (Suh 2004)
Strength of PLCA

There was a broad agreement amongst experts that it is the major strength of PLCA is that it is performed at the relevant process level (see Appendix A: Question 14). Its detail allows the consideration of specific characteristics of products. Primary data, which is frequently collected for key processes in lower orders (tiers) during the inventory phase, provides robust information that can often be directly applied e.g. for process improvement or product design. Important opportunities associated with PLCA lie in the relatively wide acceptance of the approach across stakeholder groups (due to the indirect ISO endorsement) and the available expertise of practitioners in the UK of using the methods. Both raise substantiated hopes that a roll-out of the PAS could be undertaken timely and smoothly without the encounter of major obstacles.

Weaknesses of PLCA

Experts highlighted particularly two weaknesses of PLCA: cost and labour intensity of carrying out a PLCA and the system boundary problem (see Appendix A, question 14). PLCA deals with the complexity of product systems through the exclusion of particular inputs and outputs (BSI 2006a, p.12). This “system cut-off” is unavoidable in PLCA as most processes are directly or indirectly related in modern economies and results in truncation error. The cut-off criteria suggested by ISO can be misleading and do not provide a satisfactory basis for a transparent system boundary selection (Suh et al. 2004a). Input-output studies have suggested that the truncation error is potentially very large (>50% for some product groups) and can lead to misleading conclusion (e.g. Lenzen 2001; Lenzen and Treloar 2003). The fundamental issue with cut-offs is that an unknown share is left out and that this share may be different for different comparable products and across studies (Weidema 2007). Therefore the arbitrary system boundary choice of PLCA can limit robustness, transparency and comparability of estimates derived from different LCA studies. This is further aggravated when restrictions are imposed on the budget as typical in simplified PLCA approaches. Such simplified approaches usually fail to reliably reproduce results from detailed PLCA (e.g. Hunt et al. 1998). However, only simplified PLCAs work under tight budget constraints required for the PAS to be applicable to organisations of all sizes. This seriously limits the usefulness of PLCA for the PAS development.

Threats

There are two main threats associated with the use of PLCA for establishing robust GHG estimates associated with the life-cycle of products.
Primary data is often not easily available and collection must be restricted to a minimum for the PAS to be applicable to organisations of all sizes. However, unless a crucial minimum of primary data is available, it might be difficult to establish robust estimates of embodied GHG emissions in products. Whether this crucial minimum for robust and product specific analysis can be afforded by organisations of all sizes is an open question.

Secondary data sources are often not complete. LCI databases, for example, do not cover capital goods, service inputs and many other final goods. These databases are not likely to be complete in the foreseeable future either. Unless this data is collected directly, a substantial amount of the GHG emissions of a product can be neglected (Suh 2006a; Frischknecht et al. 2007). Moreover, LCI databases also often lack comparability (even internally). GHG estimates might substantially differ depending which database has been used for a particular study.

Opportunities for PLCA

However, there are also a variety of opportunities for improving the comparability and robustness of results from PLCA through the PAS:

- Product group specific guidance on data collection and system boundary selection building upon ISO 14040 and ISO 14044 (BSI 2006a; BSI 2006b) could ease the PAS application and increase comparability of results.
- Consistent use of a selected number of secondary data sources endorsed by the PAS and emission factors would increase the comparability of embodied GHG estimates. Using a central LCI database as available for Japan and Denmark (Itsubo and Inaba 2003; Rebitzer et al. 2004; Weidema et al. 2005) would maximise comparability and provide full control over the development and quality of the secondary data used in the PAS.
- Input-output methods could also help PLCA studies in the identification of system boundaries (see, Guinée et al. 2001; Weidema and Nielsen 2001) through structural path analysis. This might allow for a more consistent system boundary definition across studies, increase comparability and also improve the robustness of estimates through the prioritisation of inventory items for different product groups.

Implications for policy applications

PLCA clearly works best on the product and product brand level. This was also clearly highlighted by experts (see Appendix A). Due to high information demands uncertainties can be expected to be much higher on the product group level. An application of PLCA in the PAS on the product group level cannot generally be
recommended unless all required process information is available (see, Tukker et al. 2006; Tukker and Jansen 2006).

For particular policy applications, we would take a differentiated view. PLCA provides sufficiently robust information for typical business applications such as process design/improvement/optimisation. Also supply chain management seems to lie within the reach of the method. However, as soon as the robustness of the final estimates is of importance as for environmental labelling or information of carbon trading systems, we do not think that it provides sufficiently robust results. Limited project resources and data availability seem to impose severe restrictions on comparability, accuracy and precision, which we do not expect to be solvable in the foreseeable future. This is particularly true as the PAS would need to be based on a simplified PLCA approach, in order to be applicable to organisations of all sizes. Apart from the difficulties in establishing a comprehensive process map, sufficiently comprehensive sources of secondary process data are not in sight in the foreseeable future to cater the needs of a robust PAS.

**Input-Output Life-Cycle Assessment (IOLCA)**

Input-output life cycle assessment (IOLCA) is a top-down method for analysing the environmental interventions of a product (functional unit) from cradle-to-gate based on environmental input-output analysis (see, Hendrickson et al. 2006). Input-output analysis was developed by the Russian Nobel Prize Winner in Economics Wasilly Leontief for analysing the industrial interdependencies in a defined economic system (usually national or regional economy). The underlying input-output table is part of the national accounts and shows how much of an industry’s inputs are used to produce its own outputs. Generally, all economic transactions occurring within a reporting period (usually one year) are recorded (usually) in monetary terms (Leontief 1966; Miller and Blair 1985). Leontief himself generalised the method for environmental applications (Leontief and Ford 1970). Hendrickson (Hendrickson et al. 1998b) were among the first to apply environmental input-output analysis to life-cycle assessment. Computationally, the structure of IOLCA and matrix based process life cycle assessment (PLCA) is almost identical (Heijungs and Suh 2002).

**Strength**

Utilising the complete description of transactions in a national economy in input-output tables, IOLCA covers all emissions (environmental interventions) from upstream processes in the supply chain taking place directly or indirectly for the production of an arbitrary final demand/ functional unit. Unlike PLCA, there is no need for cutting-off upstream processes and no associated truncation error. This is usually referred to as **system completeness**.
In this course, services and overheads are fully taken into account. The former are of particular importance to derive robust GHG emission estimates associated with the life cycle of products. Suh (Suh 2006a) showed that the cradle-to-gate emissions from services accounted for 37.6% of the total GHG emissions in the U.S. in 1998. With some additional capital flow data it is further possible to fully account for the GHG emissions associated with capital inputs to all (domestic) production processes (Lenzen and Treloar 2005a).\(^3\) Multi-regional model specifications allow differences in production technologies in different countries-parts of the world to be accounted for (Weber and Matthews 2007; Wiedmann et al. 2007a; Peters et al. in press).

The high level of standardisation in the compilation of input-output tables (United Nations Statistics Division 1993) and their complete description of the national economy allows the derivation of consistent, comparable and robust estimates of GHG emission estimates associated with a final product from cradle-to-gate. Little scope is given for biasing results through bad practise. Moreover, if adequate input-output and environmental account data is available, IOLCAs are quick and fast to carry-out reducing costs to a minimum (Lave et al. 1995; Hendrickson et al. 2006).

**Weaknesses**

The main weaknesses of IOLCA are associated with its high level aggregation, which does not easily allow for a product or brand specific analysis and leads to a generic aggregation error. This is particularly true for industry-atypical products (Lenzen 2001; Suh et al. 2004a). Furthermore, the monetary representation might not always reflect the physical realities adequately due to price inhomogeneities (e.g. Dietzenbacher 2005). Additionally, IOLCA does not fully cover the whole life cycle of a product. IOLCA is a cradle-to-gate approach. Emissions associated with end-of-life and use phases are not adequately represented. Therefore, it is not fully compliant with the ISO standards, cannot meet one of the basic PAS requirements and will not provide robust GHG emission estimates associated with the full life cycle of a product.

**Threats**

Threats are mainly associated with data availabilities. Input-output tables are commonly provided with some delay. In the UK there is currently a severe gap with the last analytical input-output table provided for the year 1995 (ONS 2002). Further, input-output and environmental accounts are provided at a comparatively high aggregation level. While the U.S. input-output accounts distinguish 480 sectors, environmental accounts – as the most aggregated data source – are provided at a

\(^3\) While the exclusion of capital goods can completely change the results from a life cycle assessment (Frischknecht et al. 2007), PLCAs often exclude most of the capital inputs to production processes (Suh et al. 2004a).
93 sector level (ONS 2007). Further problems are caused through the lack of sectoral GHG emission data from non-combustion processes, which currently cannot be covered in a multi-regional model.

**Opportunities**

Recent efforts on the European level have shown that UK input-output data could be disaggregated based on more detailed information from countries with similar production structures (Tukker et al. 2006; Tukker and Jansen 2006). There are ways to control for the relevance of aggregation errors through the application of methods for the identification of key links in the supply chain in combination with industry expert knowledge (see, Lenzen 2003; Suh et al. 2004a). A new time series of input-output tables for the UK recently estimated for DEFRA may shortly be available with 2004 being the most recent year. However, this data does not have the same quality as the official analytical tables published by ONS (Wiedmann et al. 2007b). Finally, ongoing research raises hopes that better environmental account data for many countries will be available in the foreseeable future (Tukker 2007).

**Implication for Policy Applications**

Results from a basic IOLCA analysis are generally not suitable for any PAS application. While the lack of coverage of use and end-of-life phases of a product would not necessarily be relevant for certain applications such as supply chain management, the information provided is usually too coarse. Further, unless a hybrid analysis is undertaken, IOLCA cannot provide robust GHG emission estimates associated with the full life cycle of a product – even at a product group level. However, extending IOLCA to a hybrid approach opens-up a whole new range of opportunities for making best use of the strength of IOLCA and PLCA.

**Hybrid Life-Cycle Assessment (HLCA)**

Hybrid life cycle assessment (HLCA) is carried out through the combination of process and sectoral input output and environmental account data. The methodological framework is not new with roots in the energy-economic literature in 1970s (IFIAS 1974; Bullard et al. 1978). In these studies IO supplied information for sector typical products or processes, while all remaining processes were modelled using process data (Suh et al. 2004a). Such a hybrid approach for a full life cycle assessment was first used by Moriguchi (Moriguchi et al. 1993b; Moriguchi et al. 1993a). Over time three interrelated ways of conducting a HLCA have developed (Suh 2004; Suh and Huppes 2005):

- **Tiered hybrid analysis** utilises process-based analysis for the use and disposal phase as well as for several important upstream processes, while the
remaining input requirements are calculated separately with IO-based LCA. Tiered hybrid analysis can be performed simply by adding IO-based LCIs to the process-based LCI result.

- **IO-based hybrid analysis** is carried out by selectively disaggregating industry sectors in the IO table, thus expanding the technical coefficient matrix by using process and trading information. The use phase and end-of-life phase (reuse, remanufacturing, recycling or disposal) of a product can be treated as a hypothetical industry sector that draws inputs from the existing sectors and has some associated environmental burden.

- **Integrated hybrid analysis** is the most sophisticated from of combination: The IO table (in monetary units) is fully interconnected with the matrix representation of the physical product (or process) system in physical units, thus forming one consistent computational structure. The interconnection is located at upstream and downstream cut-off points where process data are not available.

Note that computationally integrated HLCA is a functional generalisation of input-output and tiered HLCA. While it might be important to keep the advantages and disadvantages of each method in mind, it is important to understand that it is easy to move from one approach to the other depending on resources and scope of the analysis. Compared to PLCA approaches, the main differences of hybrid life cycle methods is that they can overcome system boundary problems by using sectoral data from environmental input-output analysis as an additional source of secondary data, where no primary or secondary process level data is available.

**Strength**

The main strength of HLCA identified by expert is that it combines the strength of PLCA and IOLCA – using specific process data where possible, whilst covering the remaining system with average IO data. Instead of starting to collect process data without knowing the complete system as typically done in PLCA, HLCA starts from the complete system and adds process specific data, where available. The problem of system boundary setting disappears as the study system is inherently complete. In this sense, only HLCA can select system boundaries in full compliance with the ISO standards and provide a sound basis for achieving comparability across estimates of the GHG emissions associated with the life cycle of different products. These also include emissions associated with service inputs, overheads and capital goods\(^4\) – emissions components, which have often been covered only very partially in PLCAs studies (Mongelli et al. 2005; Suh and Huppes 2005; Weidema 2007).

\(^4\) At least once capital flow data is added. However, this is a standard procedure in input-output analysis (Lenzen and Treloar 2005a).
In an iterative process an optimal delineation between the process and input-output part of the system can be found based on contribution analysis. In this way it streamlines the process data collection and seeks to optimise data quality in a transparent procedure. Therefore, HLCA approaches raise hopes to achieve higher level of robustness for the expense of a given amount of (project) resources (Suh 2006b). This makes HLCAs particularly appealing for streamlined LCA applications, which are required for allowing the PAS to be applicable to organisations of all sizes. The adequate boundary setting between process and input-output part of the model also allows to control for limitations associated with the input-output part of the model (see, Suh et al. 2004a). A fully integrated HLCA approach provides the only way of taking into account all feedback loops associated with the life cycle of a product (Suh and Huppes 2005).

Costs of the analysis depend on the approach chosen and the particular requirements of a study. Hybrid approaches are all aimed at achieve best quality and highest level of comparability in estimates with the least effort. The step-wise process can help to effectively construct a LCA system considering available time and money (Suh 2006b). Overall we believe that HLCA can derive the most robust and comparable estimates of GHG emissions associated with the life cycle of products of all three methods reviewed.

**Weaknesses**

Concerns associated with the linkage between process and IO data were highlighted by some experts. However, we believe that the method described in (Suh 2004) is sufficiently robust to do the job. Further weaknesses are associated with individual methods. Input-output based HLCA and tiered HLCA can in some cases miss out a considerable amount of emissions associated with feedback loops associated with downstream processes (Peters and Hertwich 2006b; Suh 2006b). Integrated HLCA analysis in some cases can be as resource and time intensive as PLCA (Suh and Huppes 2005) with similarly high data requirements.

**Threats**

HLCA combines many of the threats IOLCA and PLCA are confronted with. Even though a higher degree of comparability can be achieved than in PLCA, robustness of the estimates will also depend on the availability and quality of primary and secondary process data (see threat Section for PLCA). Equally the quality of a HLCA analysis will partially depend on the quality, timeliness and detail of the available environmental account and input-output data (see threat Section for IOLCA). Like PLCAs, HLCA approaches are more dependend on good practises than IOLCA. For example, if the border between the process and input-output system is not defined adequately, significant error can be introduced. Finally, HLCA cause more
challenges computationally requiring advanced mathematically and modelling skills, whilst at the same time there seems to be little expertise in HLCA modelling in the UK.

**Opportunities**

Many opportunities associated with the application of HCLA in the PAS overlap with those outlined for PLCA and IOLCA. In terms of maximising the comparability of the process part of the analysis, primary data collection should be defined for specific product groups building on the ISO standards, whilst secondary data should only come from PAS endorsed sources (see opportunities in PLCA Section). Ideally, a hybrid LCI database for the UK would also give full control over quality standards and database development.

In terms of the input-output data, recent data developments should have improved the data situation for HLCA even though the higher uncertainties associated with the data needs to be highlighted (Wiedmann et al. 2007b). The biggest opportunities lie in new, more detailed analytical tables provided by the Office for National Statistics. These are scheduled for 2010. Providing additional resources for the development of such data on a regular basis would be a good investment for taking forward a comprehensive analysis of the GHG emissions in products. A further disaggregation of the existing UK tables might help in the meantime to improve the analysis (Tukker et al. 2006; Tukker and Jansen 2006).

Regardless of all computational complexities, available HLCA software tools such as SimaPro or Bottomline3 demonstrate that these complexities do not need to be at the forefront of the practitioners mind as they can run in the background of these tools. Well designed software tools might therefore make the HLCA approach accessible to any organisation interested in life cycle assessment.

**Implication for Policy Applications**

HLCA is the only approach, which can provide robust GHG emission estimates associated with the life cycle of products at any aggregation level – product groups, individual products and product brands. Moreover, we believe that it is the only approach, which might be able to provide sufficiently robust and comparable final estimates for application in product labelling (particularly type 3 labelling) and carbon trading. However, even based on a HLCA approach these applications might not be achievable today due to the limitations imposed by the available secondary data, the resource restrictions of the PAS and the quality of available input-output data. A strategic hybrid database development could bring these applications into reach in the foreseeable future.
Less demanding applications such as supply chain management or process improvement could be supported today by a HLCA based PAS methodology. Estimates should be sufficiently robust to be applied for general consumer information systems. Overall, we believe that only a HLCA approach can adequately fulfil the PAS requirements and serve the various potential PAS applications with adequate levels of robustness of GHG emission estimates embodied in products.

**Greenhouse gas emission factors**

GHG emission factors from the combustion of fuels have undergone international peer review and are of sufficient quality for robust estimations of the GHG emissions associated with the life-cycle of products. The emission factors published by DEFRA are of sufficient quality for this purpose (e.g. DEFRA 2007). GHG emissions factors associated with non-combustion processes are much more uncertain. This concern was generally shared by experts. Most of the experts (3 out of 5) with expertise in GHG emission inventory development did not think that the emission factors are sufficiently robust for inclusion in the PAS. However, we agree with the majority of the remaining experts that it might be better to use slightly more uncertain emission factors than excluding these emission sources. Therefore, we recommend the compilation of a best-practise set of GHG emission factors. They should be reported together with the attached uncertainties and continuously updated. At least some level of comparability across studies could be achieved immediately in this way. The most recent IPCC guidelines provide a good starting point for this (IPCC 2006).

**PAS draft methodology**

All comments on the PAS draft methodology are related to the third version of the first draft of the PAS as published as circulated at the 9th August 2007. For the remainder we will refer to this document as the ‘PAS draft methodology’. We are fully aware that the PAS draft methodology is revised at the moment and might consider many more aspects in the next version. We hope that this report might provide some support in this process.

**Terminology**

Adjustments in terminology used in the PAS specification are recommended for conformity with international standards and to avoid mis-guidance of the inexperienced reader/user:

- Throughout the document the term ‘product’ is used inter-changeably with the term ‘good’ and clearly distinguished from ‘service’. However, product as defined in ISO 14040 (BSI 2006a) as well as the System of National Accounts (United Nations Statistics Division 1993) can refer to either a good or a
services. According to international standard terminology referring to “products and services” as frequently done in the PAS draft methodology is incorrect.

- The document continuously refers to the ‘measurement’ of the GHG emissions associated with the life cycle of a particular product. This does not adequately reflect the nature of the challenge the PAS is confronted with. Instead, the terms ‘calculation’ or ‘estimation’ seem much more appropriate.
- Two experts also pointed out that the misleading nature of the term ‘embodied’. Even though we have used the term throughout this report, it might be more appropriate to refer to the “GHG emissions associated with the life cycle of a product”.

**System boundary selection**

The PAS draft methodology suggests system boundary cut-offs through the application of the mass criteria: “Calculations carried out in accordance with this PAS shall include all emissions, relating to the processes specified in 5.2.3, that make a significant contribution to the embodied GHG emissions of the product or service. Significant contribution is defined by mass, and shall be at least 90% by mass of the embodied GHG emissions from the functional unit being analysed, including at least 90% of any packaging included in the functional unit” (BSI 2007, p.7).

All limitations of applying such a mass based cut-off criteria apply:

- “There is no theoretical or empirical basis that guarantees that a small mass or energy contribution will always result in negligible environmental impacts;
- There are input flows – ancillary materials and process energy – that bypass the product system and do not contribute mass or energy content to the final product. Further, the environmental impacts by inputs from services cannot be properly judged on the basis of mass and energy either.
- Although each single cut-off may have an insignificant contribution to the overall result. The sum of all cutoffs may change the results considerably” (Suh et al. 2004a, p.657).

Referring to discussions within the course of this project, it should be noted that using additional cut-off criterions such as energy or environmental relevance won’t solve the problem either (e.g. Suh and Huppes 2002; Suh et al. 2004a; Suh and Huppes 2005). We urge the use of environmental input-output analysis at least for informing system boundary setting as discussed in (Weidema and Nielsen 2001; Weidema et al. 2002; Suh et al. 2004a).

Capital goods, overheads and use phase emissions are (widely) excluded in the PAS draft methodology. However, we agree with the majority of experts that these
GHG emission sources should be comprehensively included (see, Frischknecht et al. 2007).

**Use of primary and secondary data**

The PAS draft methodology highlights the use of primary data unless data collection is impractical. We agree with the comment in the draft document that further consideration needs to be given to the term 'impractical' during the PAS consultation so that the division between primary and secondary data requirements is clearly defined. This definition needs to take into account the limitations in terms of primary data collection imposed by the PAS requirements. If the PAS is supposed to work under tight budget constraints in order to be generally applicable for organisations of all sizes including SMEs, primary data collection needs to be reduced to a minimum. This was highlighted by the majority of experts in the survey. Therefore, the core of the PAS should describe a “simplified” or “streamlined” LCA approach.

We do not believe that it is sufficient to simply record the source of secondary used. We agree with the majority of experts that a selected number of secondary data sources should be endorsed by the PAS.

Currently, the relationship between the PAS and ISO 14040 and 14044 (BSI 2006b; BSI 2006a) remains unclear. There is no use in duplication the ISO standards. It would be even worse to provide a new standard, which is not in line with these international consensus documents. If undertaken, the PAS should provide a clear value-added. This could be provided in a product group specific guidance on the application of ISO, i.e. requirements that have to be met, while ensuring efficient data collection as well as consistent use of secondary data. In this way the PAS could build upon ISO 14040 and 14044. It might also be interesting to build-in incentive mechanisms to encourage the collection of primary data beyond a defined minimum.

**Emission factors**

The PAS draft methodology currently seems to mainly focus only on GHG emissions from fuel combustion including electricity generation. While GHG emission factors from non-combustion processes are associated with higher uncertainties, we agree with the majority of experts that it is important to cover these emission sources in the PAS.⁵

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⁵ It was not clear to us whether non-combustion emissions were covered by the PAS draft methodology. This might have been a matter of confusing terminology when the document distinguishes emissions from fuel use, emissions from electricity, and direct emissions. At other parts of the document it is referred e.g. to methane emissions from agriculture.
5 PAS Recommendations

This Section provides only a summary of our recommendations due to a shortage of space. However, the reader is urged to read the full recommendations in Appendix C.

1. The method most suited to meet the needs of the PAS various applications eg type 3 eco-labelling is a fully integrated, ISO-consistent Hybrid-LCA approach, which combines the detail of Process-LCA with the complete supply chain coverage of input-output LCA. This will require a work programme, which could be completed once the new, more detailed input-output tables are published by the Office for National Statistics in 2010 and the multi-national input-output and environmental account data is available from the EXIOPOL project. Less ambitious tiered Hybrid-LCA applications should be encouraged by the PAS from the beginning.

2. For some PAS applications such as Type 3 eco-labelling, carbon trading or product comparisons, the robustness of the final estimates is of great importance. For these applications the PAS should demand 'complete' system boundaries and include GHG emissions from the input of capital goods and (intermediate) services in production processes as well as company overheads. Once the work programme is finalised, 'complete' system boundaries should be generally required by the PAS.

3. GHG emissions from the use phase of products should always be included in the PAS.

4. The PAS specification should stipulate a user-friendly and streamlined Hybrid-LCA approach based on a combination of primary data for key processes and secondary data for the remaining processes. In this course the PAS should directly build on ISO 14040 and ISO 14044 by providing product group specific guidance for these data collection efforts. Depending on resource availability in the project the process IO system boundary could be adjusted selectively based on contribution analysis and the addition of process data where most urgently needed to obtain more robust results. Such additional data collection should be encouraged by the PAS.

5. The PAS should endorse one particular hybrid life cycle inventory (LCI) database to maximise the comparability of embodied GHG estimates across studies. This database should pull together best available process information from a variety of existing LCI databases and link it with available input-output and GHG emissions data from the environmental accounts. Such a database does not exist currently for the UK; its construction should be initiated. A set of
best practise GHG emission factors for non-combustion processes should be compiled based on a review. National and international experts should oversee the development and maintenance of such a database. The inclusion of multi-national input-output data should be considered.

6. A PAS working group should review and appraise existing software tools in relation to their PAS compliance. Suitable Hybrid-LCA software should be listed. A public or private organisation should support the development of existing or new software tools.

7. The choice between attributional and consequential\(^6\) LCA depends on the PAS application. Ideally the PAS should clearly set-out when a consequential or attributional approach should be used. However, there are concerns about the feasibility of implementing a consequential approach in the course of the PAS. The current state-of-the art in consequential LCA modelling should be further investigated by PAS working groups.

8. Applications of the PAS depend on the quality and comprehensiveness of available data. Therefore, PAS applications should be reviewed annually taking into account the database in use. It seems that a variety of applications can already be achieved today such as product design/improvement or supply chain management. However, applications requiring greater robustness of the final estimate such as Type 3 eco-labelling, carbon trading or product comparisons, seem not achievable in the immediate future given the data situation. Further distinctions in applications considering different levels of uncertainties associated with products in different product groups (e.g. food) should be considered.

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\(^6\) We use the term ‘attributional LCA’ to denote a description of a product system and the term ‘consequential LCA’ to denote a description of the expected consequences of a change.
6 Time Lines

In this report we have highlighted that it is not possible to achieve system cut-off in a systematic and comparable way, and that it must be the aim in the PAS to avoid cut-off as much as possible. This has been emphasised in a similar way in the “operational guide to the ISO standards” (Guinée et al. 2001, p.41). Avoiding cut-off requires the use of environmental input-output data, which is not subject to system boundary problems as process data. Therefore, we recommend to develop the PAS towards a fully integrated hybrid life cycle assessment methodology, which is fully consistent with and builds upon the existing ISO standards (BSI 2006b; BSI 2006a).

However, there are limitations associated with currently available input-output and environmental account data. Moreover, the development of such a fully integrated hybrid life cycle methodology will require time for database and software development. We therefore recommend moving forward in a stepwise process. The database development, which is key to moving towards an ISO consistent hybrid approach, should be completed by 2010, when the new, more detailed input-output tables are published by the Office for National Statistics. This also provides the opportunity to include newly available international input-output and sectoral environmental account data from the EXIOPOL project (e.g., Tukker 2007), which can be used to account comprehensively for international supply chains and differences in production technologies across countries.

However, first steps towards such an integrated hybrid life cycle assessment model can already be undertaken today. Very soon new input-output and environmental account data will be published by DEFRA. This data can be used to improve the robustness of the GHG emission estimates derived from the PAS. Firstly, structural path analysis applied to the UK input-output tables should be used to inform more appropriate system boundary setting (e.g., Weidema and Nielsen 2001) by prioritising inventory items for a particular product groups in the various production layers. This will help to reduce truncation error through the neglect of GHG emissions in higher supply chain layers of a product system. Secondly, generic coefficients derived from an environmental input-output model should be used to adequately include the GHG emissions associated with service inputs and overheads. Ultimately, this means the estimation of a simple tiered hybrid life cycle assessment model. Further operational guidance can be found in (Guinée et al. 2001: Part 2B) or (Suh 2004). The current PAS draft methodology should be extended accordingly. Finally, a survey should be undertaken on the availability of hybrid tools in the UK (or ones that could be adjusted for the UK), which could already be used for assessment today.

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7 In the course of the 'Embedded Emissions Indicator' project (Wiedmann et al. 2007b).
In the medium term additional input-output coefficients should be derived from international input-output models in order to adequately account for the international supply chain and differences in production technologies between countries. Several models have been implemented and could be used for this purpose (e.g., Nijdam et al. 2005a; Nijdam et al. 2005b; Peters and Hertwich 2006c; Peters and Hertwich 2006a; Wiedmann et al. 2007b). Particularly for agriculture and food manufacturing the GTAP dataset provides unique opportunities for improving the estimates of the GHG emissions associated with the life cycle of a product. Further, in order to better account for the GHG emissions from capital inputs, a sectoral capital flow matrix should be compiled and used for industry-typical products and processes, where no process based capital input data is available. If required, further detail could be added to the available UK input-output tables and environmental accounts following recent examples on the European level (Tukker et al. 2006; Tukker and Jansen 2006).

The ambition to avoid any system cut-off through the use of secondary process data and the step-wise integration of sector level environmental input-output data, should be clearly stated in the PAS from the beginning. This will not cause a major challenge due to the consistency of hybrid approaches with ISO 14040 and 14044. Methodological details can be added to the PAS over time.

**Figure 6.1 – A step-wise process towards a fully integrated hybrid life cycle assessment model**
7 Conclusion

In this fitness for purpose review we have assessed the suitability of different life cycle methods for establishing a robust estimate of the GHG emissions associated with the life cycle of a product. We found that it is difficult at the moment with any methodology under the restrictions imposed by the PAS requirements to provide a robust and comparable final estimate. Therefore, limitations are currently imposed on applications such as carbon labelling or carbon trading. However, sufficiently robust information can already be gathered today for applications such as supply chain management or process improvement – at least for most product groups.

In terms of the methodological choice this review revealed that input-output life cycle assessment (IOLCA) is generally not suited for the PAS. Process life cycle assessment (PLCA) and hybrid life cycle assessment (HLCA) both have their PAS applications. We recommend the use of a HLCA methodology in the PAS for at least 4 reasons:

- Robustness, comparability and transparency of embodied GHG estimates can only be achieved by taking into account the complete product system - not through arbitrary truncation of the system.

- HLCA approaches are very cost efficient and have further advantages when the resources (time and money) of a project are limited and the analysis needs to be “streamlined” or “simplified”. Such a simplified approach is key to the development of a PAS, which is applicable to organisations of all sizes.

- HLCA approaches save further valuable resources in the development of life cycle databases, as they can help to streamline and prioritise the data collection.

- Lifecycle inventory databases as sole sources of secondary process data in PLCA are far from being complete today and will not be complete in the foreseeable future either. Unless environmental input-output models are used as an additional source of secondary data as in HLCA, there is no systematic way of overcoming this data shortage.

Based on HLCA approach we would expect the PAS to guide the users to find out the least cost pathways to improve on the quality of the results. The iterative refinement of the internal system boundary and collection of additional primary data for priority processes need to be continued until required quality of the result is met.

Due to the problems associated with input-output data and the time requirement for data and software development, the PAS should be developed towards a fully integrated hybrid life cycle assessment model in a step-wise process as outlined in
Gearing the PAS towards a HLCA approach does not suggest a move away from PLCA or ISO standards. It only means that flows, which would normally be cut-off from the study system in PLCA, are covered by a particular kind of secondary data provided by the input-output part of the HLCA model. In this way a full ISO compliance can be achieved, where at the system boundaries of the product system under study are only elementary flows. The PAS should not attempt to substitute, but build upon ISO 14040 and 14044 through the provision of practical product group specific guidance on methodology and data collection and use. With our recommendations we, therefore, hope to contribute towards the development of a PAS specification, which provides more transparent, robust and comparable estimates of the GHG emissions associated with the life cycle of a product.

Finally, if a Process-LCA approach is pursued in the PAS, applications of the PAS need to be restricted. We perceive that Process-LCA – given the PAS requirements (see Section 1) - will not deliver sufficiently robust and comparable results in the foreseeable future for applications such as Type 3 eco-labelling, carbon trading or product comparisons, where the robustness of the final estimate is of great importance. In such a case shortcomings of the PAS draft reviewed in the course of this project should be addressed - most importantly the shifting from a process flow diagram towards a matrix-based Process-LCA approach, the inclusion of use-phase emissions as well as GHG emissions from the use of capital goods, intermediate services and company overheads. Relevant aspects of recommendations 2, 3, 4, 5, 7 and 8 (Section 5) should be taken into account as well.

8 Acknowledgements

We are grateful to all experts, who have participated in the survey: Nigel Carter, Andreas Ciroth, Faye Duchin, Jeroen Guinee, Klaus Hubacek, Gjalt Huppes, Atsushi Inaba, Shigemi Kagawa, James Lennox, Manfred Lenzen, Bobby Lippiatt, Yuichi Moriguchi, Keisuke Nansai, John Watterson, Bo Weidema, Kazuyo Yokoyama and one expert, who does not want to be named. We want to stress that the views expressed in this review are only our own ones and might not be supported by individual experts. Furthermore, we wish to thank Kate Scott at Stockholm Environment Institute York (SEI) for compiling some of the tables and the team at DEFRA, who has been helpful throughout the project. Finally, thanks to all people, who have contributed to the discussion in the inception and interim meeting.
9 Appendix A: Focus on Experts – Survey results

In this Appendix the results from the expert survey are presented and briefly discussed. Please note that we often aimed for a classification of the answers into discrete groups (e.g. “yes”, “no”, “depends”). In some of the cases it was difficult to clearly assign an expert to a particular group. In these cases we did our best not to misrepresent the expert’s opinion by assigning her to the most suitable group. In some cases we created further sub-groups, if it helped to better maintain the spirit of the expert answer. This involved some degree of judgement on our side. The completed questionnaires have been returned to DEFRA for reference. The questionnaire is attached in Appendix E.

Moreover, in order to allow the reader of this report to judge what the influence of particular methodological backgrounds of experts might be on the answer provided, we have assigned all experts to one of four groups according to their self-reported fields of expertise:

- **PLCA** refers to a process life cycle assessment specialist. An expert was assigned to this group, if she had experience in process life cycle assessment, but not in input-output life cycle assessment;
- **IOLCA** refers to input-output life cycle assessment specialist. An expert was assigned to this group, if she reported expertise in input-output life cycle assessment, but not in process life cycle assessment;
- **Allrounder** refers to experts with self report expertise in process life cycle assessment, input-output life cycle assessment and hybrid life cycle assessment;
- **GHG** refers to greenhouse gas inventory specialists, who have no practical experience in process life cycle assessment, input-output life cycle assessment and hybrid life cycle assessment.
Question 5

Do you think GHG emissions from the general operation of a company (e.g. payroll/administration) should be factored in when estimating the embodied emissions of a good or service produced by the company?

<table>
<thead>
<tr>
<th>Expertise</th>
<th>Yes</th>
<th>No</th>
<th>No answer and other</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLCA</td>
<td></td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>IOLCA</td>
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<td>2</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>All-rounder</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>GHG</td>
<td>1</td>
<td>1</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>7</td>
<td>6</td>
<td>3</td>
<td>17</td>
</tr>
</tbody>
</table>

Table A.1 – Expert answers to question 5

There was broad agreement among experts that GHG emissions from the general operation of a company – often referred to as ‘overheads’ – should be included in the estimate of embodied GHG emissions in products. In principle, 13 of the 17 were of the opinion that this emission component should in principle be considered. Of these 7 (IOLCA specialists and all-rounder) were in favour of a general inclusion, while 6 experts (PLCA, IOLCA and all-rounder) thought that this emission component should only be considered, if its contribution to the final estimate is sufficiently large. 3 experts preferred a general exclusion of GHG emissions associated with ‘overheads’. 1 expert did not answer the question.

There seems to be a tendency of experts with experience in IOLCA to be more positive about the inclusion of the GHG emissions associated with the ‘overheads’ of a company, while experts with experience in PLCA were more cautious. These opinions might be closely related to common practise in the fields. In IOLCA direct emission components from overheads get automatically assigned to final products groups depending on a sector’s contribution to production processes in other sectors, while ISO 14040 and 14044 (BSI 2006b) generally recommend the inclusion of overheads only if they are likely to contribute significantly to the environmental impacts of a product trying to avoid unnecessary data collection efforts. Interesting additional comments of the experts include:

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[8] Recall that the potential significance of a flow is usually determined by using a set of indicators such as mass or energy. For a discussion see Section 4.
• One “PLCA specialists” highlighted the need for a proper method for the estimation of relevance and contribution of GHG emission from overhead activities to products. This is supported by an “all-rounder” pointing out the potential difficulties in producing this data.

• One “IOLCA specialist” stressed the importance of including these GHG emission associated with overhead activities as a matter of consistency. Why include emissions caused by service sectors but not services provided within the company? On a similar line, one “all-rounder” highlights that all GHG emissions should be attributed to the specific activity/product that causes it as a matter of principle.

• Another “all-rounder” pointed out the support of the World Resource Institute and the World Business Council for Sustainable Development for the inclusion of such an ‘overheads’ related emission component.
Question 6:

Is the inclusion of capital goods and GHG emissions thereof desirable?

<table>
<thead>
<tr>
<th>Expertise</th>
<th>Yes</th>
<th>No</th>
<th>No answer and other</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Always</td>
<td>if contribution significant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLCA</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>IOLCA</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>All-rounder</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>GHG</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>7</td>
<td>1</td>
<td>17</td>
</tr>
</tbody>
</table>

Table A.2 – Expert answers to question 6

There was broad agreement amongst experts that capital goods and their associated GHG emissions should be included in a embodied GHG emission estimate of products. Expert opinion large coincided with their stance on GHG emissions associated with ‘overheads’. 15 of 17 experts favoured the inclusion of GHG emissions associated with capital goods, in principle. Of these 8 (IOLCA, all-rounder, GHG) thought that these emissions should always be included, while 7 experts (PLCA, all-rounder, IOLCA) would only include GHG emissions associated with capital goods, if relevant. Only one “all-rounder” felt that – even though desirable – the inclusion of capital goods and GHG thereof is not practical. One expert did not answer the question.

As for question 5 there is a tendency of IOLCA experts to favour the inclusion of capital goods related GHG emissions, while PLCA experts (this time) advocated case dependency. All-rounders were split between the two choices again. Therefore, expert opinions were closely associated with their practical experience. In EIOLCA the inclusion of capital goods is generally recommended. In PLCA the inclusion of capital goods is recommended, while the inclusion will ultimately depend on definition of goal, scope and system boundary of a study (BSI 2006b).

Interesting additional comments of the experts include:

- A PLCA expert highlighted the importance of the inclusion of capital goods in the case of renewable energies referring to a study by (Frischknecht et al. 2007). One “all-rounder” also pointed towards the usefulness of this article for deciding on whether or not capital good related GHG emissions should be included.
• An IOLCA expert stressed that, if capital goods are included in the analysis, it is key to agree on an allocation method and document it transparently.

• Two IOLCA experts highlighted the importance of GHG emissions associated with capital goods. The first indicated that about 23% of the total CO₂ emissions in the were induced by capital formation. The second elaborated that at least private capital goods need to be included even though the attribution of public capital might be considered as well as specific industries may use public capital goods more intensively than others.⁹

• One PLCA experts refers to the instructions provided in ISO 14040 and 14044 (BSI 2006b).

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⁹ In fact, in the German Environmental Accounts capital investment in road maintenance and building is attributed to industries and households according to their use behaviour.
Question 7

Do you think GHG emissions associated with the use of a good or service shall be included in the estimate of the embodied GHG emissions of the respective good or service?

<table>
<thead>
<tr>
<th>Expertise</th>
<th>Question understood</th>
<th>Unclear whether question understood</th>
<th>No</th>
<th>No answer and other</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLCA</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>IOLCA</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>All-rounder</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>GHG</td>
<td></td>
<td>2</td>
<td>2</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>7</td>
<td>17</td>
</tr>
</tbody>
</table>

Table A.3 – Expert answers to question 7

Recall that an editing error occurred in this question. As a result the question could not be understood by all authors. Some indicated their problems with the questions, others just provided an answer. However, from some of the answers we could clearly see what the expert’s opinion towards the inclusion of GHG emissions associated with the use phase of products was. We therefore clearly separate those cases in Table A.3 where we could not see whether the expert had understood the question.

Of the 17 experts 10 provided an answer. 9 experts thought the GHG emissions arising in the use phase of a product should be included in its embodied GHG estimate. In 5 cases we could be sure that the question was understood, while in 4 cases this remains unclear. One expert highlighted that that use phase emissions should not be part of the “embodied” GHG emissions of a product and that they should be recorded separately. However, at the same time he highlighted the “misleading” nature of the term embodied. This was re-inforced by the comments of another expert. The terminology might therefore be reviewed by the PAS team. Overall, we still feel confident that most experts would agree that the use phase emissions should be part of an estimate of the GHG emissions associated with the life cycle of a product.
Question 8

Would the distinction between consequential and attributional lifecycle approaches be relevant for the estimation of the embodied GHG emissions in goods and services in general, and the PAS development, in particular?

<table>
<thead>
<tr>
<th>Expertise</th>
<th>Yes</th>
<th>No</th>
<th>Na</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLCA</td>
<td>3</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>IOLCA</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>All-rounder</td>
<td>5</td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>GHG</td>
<td>2</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td>1</td>
<td>5</td>
<td>17</td>
</tr>
</tbody>
</table>

Table A.4a – Expert answers to first part of question 8

If so, which one would be used?

<table>
<thead>
<tr>
<th>Expertise</th>
<th>Attributional</th>
<th>Consequential</th>
<th>Depends</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLCA</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>IOLCA</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>All-rounder</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>GHG</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
<td>3</td>
<td>6</td>
<td>11</td>
</tr>
</tbody>
</table>

Table A.4b – Expert answers to second part of question 8

Not all of the GHG and IOLCA experts were familiar with the distinction between attributional and consequential LCA. As a result 5 of the 17 experts could not provide answers to question 8. 11 of the 12 remaining experts broadly agreed that the distinction between attributional and consequential LCA approach is important and requires attention in the PAS development (see Table A.4a). Note that this distinction is not yet covered by the ISO standards, which solely focuses on attributional LCA.

Much less agreement among these 11 experts could be established with regard to the follow-on question, which approach should be chosen for the PAS. This is shown in Table A.4b. 6 experts provided either a very generic answer or highlighted the case-dependency. Some clearly highlighted that it would ultimately depend on the policy application: a consequential approach should be applied if the results are to
be used for decision-making (i.e. influencing decisions), while an attributional approach should be applied if the results are to be used for reporting. Another expert stressed that there is no international agreement on what is best practice for which purpose.

Two experts generally favoured an attributional approach, of which one emphasised that this decision was taken only for matters of practicality (data availability and methodological issues) even though a consequential approach would be better suited in certain situations (particularly where changes in GHG emissions are supposed to be induced through consumer choices; e.g. labelling). Three experts generally favoured a consequential approach. It was not possible to get a clear picture about the state of methodological development and data issues. Generally, some experts seemed to be concerned, while others appeared confident that it can be applied. One expert highlighted that it will be case-dependent whether a product system can be modelled based on a consequential approach or not. Overall, there certainly seem more data concerns and less methodological standardisation with consequential than with an attributional LCA approach.
Question 9

Please evaluate the data requirements and relevance of the following three lifecycle approaches.

<table>
<thead>
<tr>
<th>Product commodity groups (e.g, food)</th>
<th>Individual products (e.g. chocolate bar)</th>
<th>Product brands (e.g. Snickers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of replies</td>
<td>Data requirements</td>
<td>Relevance</td>
</tr>
<tr>
<td>PI-CA</td>
<td>13</td>
<td>7.88</td>
</tr>
<tr>
<td>IO-CA</td>
<td>13</td>
<td>4.54</td>
</tr>
<tr>
<td>HLCA</td>
<td>13</td>
<td>6.96</td>
</tr>
</tbody>
</table>

Table A.5 - Average expert rating of data requirements and relevance of different LCA approaches (1 low; 10 high)
**Question 10**

For each product category, what are the implications of applying each of the three life cycle approaches to derive robust embodied GHG estimates of goods and services under reasonable budget restrictions? In terms of budget restrictions, note that the PAS needs to be specified in a way that it can also be used by small and medium sized enterprises.

<table>
<thead>
<tr>
<th>PLCA</th>
<th>Truncation error</th>
<th>Uncertainty due to temporal system boundary</th>
<th>Input-data uncertainty</th>
<th>Aggregation error</th>
<th>Overall uncertainty</th>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of replies</td>
<td>Avg</td>
<td>No. of replies</td>
<td>Avg</td>
<td>No. of replies</td>
<td>Avg</td>
</tr>
<tr>
<td>Agriculture, fishery and wood products</td>
<td>10</td>
<td>5.90</td>
<td>9</td>
<td>5.11</td>
<td>9</td>
<td>4.67</td>
</tr>
<tr>
<td>Feed and beverages</td>
<td>10</td>
<td>6.50</td>
<td>9</td>
<td>5.11</td>
<td>9</td>
<td>4.44</td>
</tr>
<tr>
<td>Basic materials</td>
<td>10</td>
<td>5.20</td>
<td>9</td>
<td>4.90</td>
<td>9</td>
<td>4.90</td>
</tr>
<tr>
<td>Parts and semi-finished manufactured products</td>
<td>10</td>
<td>6.30</td>
<td>9</td>
<td>4.09</td>
<td>9</td>
<td>5.22</td>
</tr>
<tr>
<td>Finished manufactured products</td>
<td>10</td>
<td>7.40</td>
<td>9</td>
<td>5.06</td>
<td>9</td>
<td>5.96</td>
</tr>
<tr>
<td>Energy and utilities</td>
<td>10</td>
<td>4.50</td>
<td>9</td>
<td>3.76</td>
<td>9</td>
<td>3.00</td>
</tr>
<tr>
<td>Building and construction</td>
<td>11</td>
<td>5.91</td>
<td>10</td>
<td>5.30</td>
<td>10</td>
<td>4.70</td>
</tr>
</tbody>
</table>

**Table A.5a – Expert uncertainty assessment PLCA: average rating (1 low; 10 high)**

<table>
<thead>
<tr>
<th>IOLCA</th>
<th>Truncation error</th>
<th>Uncertainty due to temporal system boundary</th>
<th>Input-data uncertainty</th>
<th>Aggregation error</th>
<th>Overall uncertainty</th>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of replies</td>
<td>Avg</td>
<td>No. of replies</td>
<td>Avg</td>
<td>No. of replies</td>
<td>Avg</td>
</tr>
<tr>
<td>Agriculture, fishery and wood products</td>
<td>10</td>
<td>3.70</td>
<td>8</td>
<td>4.98</td>
<td>9</td>
<td>5.44</td>
</tr>
<tr>
<td>Feed and beverages</td>
<td>10</td>
<td>3.70</td>
<td>8</td>
<td>4.76</td>
<td>9</td>
<td>5.22</td>
</tr>
<tr>
<td>Basic materials</td>
<td>10</td>
<td>3.00</td>
<td>8</td>
<td>4.63</td>
<td>9</td>
<td>5.52</td>
</tr>
<tr>
<td>Parts and semi-finished manufactured products</td>
<td>10</td>
<td>3.60</td>
<td>8</td>
<td>4.63</td>
<td>9</td>
<td>5.96</td>
</tr>
<tr>
<td>Finished manufactured products</td>
<td>10</td>
<td>3.90</td>
<td>8</td>
<td>4.96</td>
<td>9</td>
<td>5.66</td>
</tr>
<tr>
<td>Energy and utilities</td>
<td>10</td>
<td>3.20</td>
<td>8</td>
<td>4.13</td>
<td>9</td>
<td>4.11</td>
</tr>
<tr>
<td>Building and construction</td>
<td>11</td>
<td>3.18</td>
<td>9</td>
<td>4.44</td>
<td>10</td>
<td>4.20</td>
</tr>
</tbody>
</table>

**Table A.5b – Expert uncertainty assessment IOLCA: average rating (1 low; 10 high)**
<table>
<thead>
<tr>
<th>HLCA</th>
<th>Truncation error</th>
<th>Uncertainty due to temporal system boundary</th>
<th>Input-data uncertainty</th>
<th>Aggregation error</th>
<th>Overall uncertainty</th>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture, forestry, and wood products</td>
<td>10 3.40</td>
<td>8 4.38</td>
<td>9 4.66</td>
<td>10 4.90</td>
<td>8 5.25</td>
<td>9 6.44</td>
</tr>
<tr>
<td>Food and beverages</td>
<td>10 3.20</td>
<td>8 4.25</td>
<td>9 4.11</td>
<td>10 5.00</td>
<td>8 5.25</td>
<td>9 6.67</td>
</tr>
<tr>
<td>Basic materials</td>
<td>10 2.50</td>
<td>8 4.00</td>
<td>9 4.00</td>
<td>10 5.00</td>
<td>8 5.00</td>
<td>9 6.67</td>
</tr>
<tr>
<td>Raw and semi-finished manufactured products</td>
<td>10 2.90</td>
<td>8 4.00</td>
<td>9 4.11</td>
<td>10 5.60</td>
<td>8 5.38</td>
<td>9 6.67</td>
</tr>
<tr>
<td>Finished manufactured products</td>
<td>10 3.20</td>
<td>8 4.26</td>
<td>9 4.22</td>
<td>10 6.30</td>
<td>8 6.25</td>
<td>9 6.89</td>
</tr>
<tr>
<td>Energy and utilities</td>
<td>10 2.60</td>
<td>8 3.90</td>
<td>9 2.78</td>
<td>10 5.60</td>
<td>8 4.36</td>
<td>9 7.22</td>
</tr>
<tr>
<td>Building and construction</td>
<td>10 2.30</td>
<td>9 3.69</td>
<td>10 3.20</td>
<td>10 5.30</td>
<td>9 5.78</td>
<td>10 6.80</td>
</tr>
</tbody>
</table>

Table A.5c – Expert uncertainty assessment HLCA: average rating (1 low; 10 high)
Question 11

To what extent could the collection of primary data be required by the PAS given that small and medium sized enterprises would work under tight budget restrictions? In which areas would you expect major difficulties if there were not sufficient resources for the collection of primary data?

There seems to be an agreement among experts that a) the collection of primary data is essential; and b) data collection efforts should be minimised for the PAS to also work under tight budget constraints. However, there is some disagreement of what such a minimum should be.

- 9 experts recommend the collection of primary data for on-site processes directly controlled by the enterprise.
- 4 experts suggest the collection of primary process data for (other) key processes. Product group specific data requirements are recommended in this context. 2 experts refer to upstream and downstream process data collected in addition to the on-site data. 2 experts seem to favour a more selected approach to on-site data collection.
- Other experts make more generic recommendations. One expert suggests to focus primary data collection in the areas “parts and semi-manufactured products” and “fishery” highlighting that basic materials and energy are well-covered in existing LCI databases. Another expert highlights the importance of “transport” data associated with the production of goods and services.
- Finally one experts suggests the sufficiency of physical on-site and purchasing and sales information of a company as implemented in the BL³ software tool (http://www.isa.org.usyd.edu.au/consulting/BL3.shtml) highlighting his positive experience in working with SMEs.

Some other interesting comments were provided by the experts:

- One experts points out the problems in the collection of primary data in small and medium sized enterprises. In SMEs primary data for energy use are usually collected at a company or facility level, not at a process level. It is often difficult to attribute this total to a specific product.
- Another expert suggests that it might be useful to install a reward system for businesses, which collect more data (subsequent validation) than the minimum required by the PAS.
Finally, one expert suggests that the collection of upstream and downstream data could be left to the enterprise. It would collect data for processes where it would like to claim lower than average emissions, which would be applied otherwise.
Question 12

There are various sources of secondary data, which can be used to fill data gaps or to substitute primary data (where data collection is costly) to derive robust estimates of the embodied greenhouse gases in goods and services. Should a selected number of secondary data sources be endorsed in the PAS description? If so, do you think available LCA databases are sufficiently comparable that they could all be endorsed as a secondary data source in the PAS specification?

Experts generally agreed on the importance of using secondary data in the course of the PAS. 9 experts provided a clear indication to whether they think that a selected number of secondary data sources should be endorsed by the PAS or whether the choice of secondary data source is left to the practitioner carrying out the study. Of these 7 (1 PLCA, 2 IOLCA, 4 all-rounder) recommended to endorse a selected number of secondary data sources. This seemed to be driven by their concerns about the quality and comparability of available LCI databases, which were explicitly addressed by 4 of these experts.

1 expert (all-rounder) thought that it is not necessary to specify secondary data sources. He argued that what one is ultimately interested in is accuracy and precision of the final estimates. How this is achieved does not matter. It is only important that these attributes are conclusively proven for each study. Another expert (PLCA) is less clear about whether or not a selected number of secondary data sources should be endorsed by the PAS. He highlighted that with proper expert judgement the usable secondary data from different data sources can be identified and used. The remaining 8 experts provided either no (2) or a more generic answer (6).

Some of the other comments provided by the experts are listed below:

- One expert (IOLCA) highlighted the need for international agreement on how the secondary data is derived and verified. For inputs where emissions are highly variable, secondary data should not be used.

- One expert (PLCA) referred to the European PRTR (ex EPER) register (www.prtr.de)

- One expert (all-rounder) stressed that there are no available LCI databases that are adequately comparable - even internally (i.e. between different products in the same database) – to be endorsed straight away. One consistent hybrid database could be constructed at relatively low costs, using the best parts of existing databases.
Question 13

GHG Emission factors from non-combustion processes – in particular for human induced agricultural and biological emissions - are much more uncertain than emission factor of fuel combustion processes. Do you think emission estimates can be established with sufficient confidence to be included in the PAS? What is most urgently required to deal with these emission sources?

<table>
<thead>
<tr>
<th>Expertise</th>
<th>Include non-combustion GHG</th>
<th>Do not include non-combustion GHG</th>
<th>Depends or other</th>
<th>No answer</th>
<th>Check/</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG expert</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Other</td>
<td>6</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>17</td>
</tr>
</tbody>
</table>

Table A.6 – Expert answers to second part of question 8

Note that we have changed the classification of experts for the result presentation of this question as shown in Table A.6. We have separated all experts with experience in the compilation of GHG emission inventories from the rest due to the nature of the question. For the discussion of GHG emission intensities from non-combustion processes, two issues might need to be distinguished:

- Experts’ opinions with regard to the uncertainties attached with these emission factors;
- Experts’ opinions with regard to the applicability of the emission factors in the PAS;

Generally, with regard to the uncertainties attached to GHG emission factors of non-combustion processes there seems to be agreement across experts that these uncertainties are considerably higher than for fuel combusting processes. Even though opinions on the issue seem to vary considerably across experts, 9 experts explicitly expressed their concerns about these high levels of uncertainties. Only one expert suggested that “the necessary knowledge and studies to estimate these emissions essentially exist” even though some other experts mentioned that in some specific areas, relatively robust estimates could be established. In this sense the expert review delivered interesting, but inconclusive evidence.

In terms of the suitability of these emission factors for application (in the PAS), the majority of experts favoured the inclusion of GHG emission estimates of non-
combustion processes rather than excluding them (see Table A.6). However, only 7 of the 15 experts, who provided an answer, clearly stated that these emissions should be included. Another 5 experts seemed to be positive about the inclusion, but the answer provided did not allow for a fully conclusive judgement. These experts are listed separately in Table A.6 (“depends or other”). Only 3 experts clearly stated that they are against the inclusion of GHG emissions from the non-combustion processes in the PAS. Interestingly, all of them were GHG inventory experts. Only 1 of the 6 GHG emission inventory experts was clearly in favour of the inclusion of GHG emissions from non-combustion processes, while another one did not give a clear indication to whether these emissions should be included or not. One expert did not provide an answer at all. Therefore, the very people working with GHG emission inventories were much more concerned about the quality of the available emission factors for GHG emission from non-combustion processes and their empirical application than the community of life-cycle practitioners (“other”).

It is difficult to identify a smallest common denominator for at least the majority of the expert opinions. Most experts would probably agree that it is currently difficult to establish robust GHG emission estimates of non-combustion processes. At the same time they feel that it is most important not to omit them. As long as the same (best-practise) emission factors are used, estimates of emissions from non-combustion processes might not be very robust, but studies are at least comparable.

A variety of interesting comments and suggestions were made.

- A PLCA practitioner recommended to state GHG emission factor from non-combustion processes together with the attached uncertainties. He also highlights that there should be sufficient freedom in the PAS definition for enterprises to provide empirical data themselves.

- Several experts suggested the compilation of best-practise emission factors for non-combustion processes in a comprehensive inventory.

- Experts most frequently raised their concerns about non-combustion GHG emissions associated with agricultural practises/food and end-of-life stages (particularly landfill).

- One expert pointed towards a growing pool of knowledge and information being collected in CDM projects around the world.
Question 14

Please describe what are, in your opinion, the main strengths and weaknesses of P-LCA, IO-LCA and Hybrid-LCA.

The Tables below (A.7a – A.7c) summarise the strength and weaknesses experts identified for the different LCA approaches. For matters of transparency the table also shows how often an issue was raised by experts with a particular methodological background.

<table>
<thead>
<tr>
<th></th>
<th>PLCA</th>
<th>IOLCA</th>
<th>All-rounder</th>
<th>GHG</th>
<th>Tot</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strength</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More widely known and acknowledged</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Detailed process description/ data resolution/ product specific data</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Intuitive method</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Reflect an understanding of physical processes</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Precision</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Direct application of data (e.g. process improvement)</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Usable for decision making</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Weaknesses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of consistency in application</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Data availability/ data requirements</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Use of non-representative data for specific processes</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Time and cost intensity</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Danger to rely on artificial processes</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Incomplete upstream system (cut-off)/ truncation</td>
<td>5</td>
<td>4</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ignores capital inputs</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of economic aspects such as household lifestyle</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Limitations for macro view</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table A.7a – Strength and weaknesses of PLCA identified by experts
<table>
<thead>
<tr>
<th>Strength</th>
<th>PLCA</th>
<th>IOLCA</th>
<th>All-rounder</th>
<th>GHG</th>
<th>Tot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehensiveness/ complete upstream system boundaries</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Data availability</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Fast and cheap (if data exists), easy to use</td>
<td>2</td>
<td>2</td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Real data data/ no artefacts</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Consistency of approach/ standardisation/ comparable results</td>
<td>3</td>
<td>1</td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Quality of average product group data</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Consideration of economic aspects, household lifestyle, trade etc.</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Weaknesses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggregation level for product specific analysis/ Aggregation error/ product specific questions cannot be answered/ lack of precision/ data resolution</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>IO table only includes national economy/ does not account for global life cycles</td>
<td>1</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Often manipulated without knowledge of physical processes</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Lacking methods</td>
<td>2</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Lacking transparency of data sources</td>
<td>2</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Difficult to link specific process/product</td>
<td>2</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Incomplete sectoral environmental accounts (only few substances)</td>
<td>1</td>
<td>1</td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Poor data quality of IO accounts</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Delay in publication of IO data</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Costs of compiling IO data, if not available</td>
<td>2</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Results cannot be used for decision making</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Table A.7b – Strength and weaknesses of IOLCA identified by experts
<table>
<thead>
<tr>
<th>Strength</th>
<th>PLCA</th>
<th>IOLCA</th>
<th>All-rounder</th>
<th>GHG</th>
<th>Tot</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Combines strengths PLCA and IOLCA/ detailed in foreground and complete in background/ avoids truncation</td>
<td>1</td>
<td>6</td>
<td>5</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>• Supplement of PLCA</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>• Moderate costs</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>• Identification of complete downstream effect of a specific product</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>• Consistent system</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>• Screening of unknown generic product</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Weaknesses</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Interface between IO and PLCA/ sound combination of process and IO data</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>• Limited sectoral environmental account data in many countries</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>• Not yet guided by a sufficiently expanded theory of the system’s operation</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>• Supplement of PLCA</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>• High data requirements</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>• Lack of economic aspects such as household lifestyle</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>• Aggregation error if process component insufficient</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>• Brings with it also weaknesses of other two</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>• More costly than IOLCA, less specific than PLCA</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>• Lack of available databases</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>• Lack of sufficient knowledge across practitioners</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>• Potential for double-counting</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>• Unnecessary fuzziness and complexity</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

Table A.7c – Strength and weaknesses of HLCA identified by experts
**Question 15**

What are the main areas where improvements are most urgently required to derive robust estimates of the GHG emissions embodied in goods and services?

<table>
<thead>
<tr>
<th>Improvement</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methodological improvements (how to estimate and report/ increase consistency of quantification processes)</td>
<td>2</td>
</tr>
<tr>
<td>Getting more empirical data and information on its robustness/ authenticity and consistency of data/ data collection by companies</td>
<td>4</td>
</tr>
<tr>
<td>Getting businesses involved into the “game”, by offering a chance to report and benefit from the improvements they make</td>
<td>1</td>
</tr>
<tr>
<td>Dealing with global life cycle and international transportation</td>
<td>3</td>
</tr>
<tr>
<td>Methodological harmonization/ standardization of approaches</td>
<td>2</td>
</tr>
<tr>
<td>Manuals and training courses for companies (roll-out PAS)/ education of LCA practitioners</td>
<td>2</td>
</tr>
<tr>
<td>Agriculture and horticulture: clear system description, measurement and allocation procedures; more specific and robust emission factors</td>
<td>2</td>
</tr>
<tr>
<td>Deal with double counting and supply chain overlap</td>
<td>1</td>
</tr>
<tr>
<td>Data issues associated with end of life phases and recycling</td>
<td>2</td>
</tr>
<tr>
<td>Existing energy consumption data which is indispensable to estimate GHG emissions is usually collected by industries, companies, facilities and processes. Relationship between these management units and goods and services is not easy in many cases.</td>
<td>1</td>
</tr>
<tr>
<td>PLCA reporting format directly linked to IO</td>
<td>1</td>
</tr>
<tr>
<td>Standard hybrid database</td>
<td>1</td>
</tr>
<tr>
<td>Establishment of specific requirements regarding data and methodological choices for specific product groups, based on detailed LCAs according to ISO 14040 (2006) in order to prevent misuse and provide credible and commonly acceptable assessments</td>
<td>1</td>
</tr>
</tbody>
</table>

Table A.8 – Main areas for improvements

As shown in Table A.8 opinions of experts varied concerning the main areas of improvements for the deriving robust estimates of embodied GHG emissions in products. Shortage and consistency of process data seems to be one of the major concerns. Equally, the dealing with “global life cycle” was seen to be an important area for further development. End-of-life phases, recycling activities and agriculture/horticulture were identified as areas, which need special attention in terms of the system description. Methodological development and harmonisation was another broad field, where improvements might be required in the future. One expert pointed out the coarse nature of ISO 14040 and suggested the establishment
of specific requirements and methodological choices for dealing with particular product groups. This could rule out bad practise and increase comparability of results.
**Question 16**

Different policy applications require different levels of robustness of the embodied GHG emissions estimates in goods and services. Which of the lifecycle approaches can provide sufficiently robust estimates of the embodied greenhouse gas emissions in goods and services for the following applications given reasonable budget constraints? In terms of the budget restrictions, note that the PAS needs to be specified in a way that it can also be used by small and medium sized enterprises.

<table>
<thead>
<tr>
<th>Product groups</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PLCA</td>
</tr>
<tr>
<td></td>
<td>DOLCA</td>
</tr>
<tr>
<td></td>
<td>HLECA</td>
</tr>
<tr>
<td>PLCA</td>
<td>Supply chain management labelling</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>all products</td>
<td>0</td>
</tr>
<tr>
<td>GHG</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2</td>
</tr>
</tbody>
</table>

**A.9a - Suitability of methods for policy applications (positive responses) at product group level**

<table>
<thead>
<tr>
<th>Individual products</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PLCA</td>
</tr>
<tr>
<td></td>
<td>DOLCA</td>
</tr>
<tr>
<td></td>
<td>HLECA</td>
</tr>
<tr>
<td>PLCA</td>
<td>Supply chain management labelling</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>all products</td>
<td>2</td>
</tr>
<tr>
<td>GHG</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>6</td>
</tr>
</tbody>
</table>

**A.9b - Suitability of methods for policy applications (positive responses) at individual product level**

<table>
<thead>
<tr>
<th>Product brands</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PLCA</td>
</tr>
<tr>
<td></td>
<td>DOLCA</td>
</tr>
<tr>
<td></td>
<td>HLECA</td>
</tr>
<tr>
<td>PLCA</td>
<td>Supply chain management labelling</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>all products</td>
<td>0</td>
</tr>
<tr>
<td>GHG</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>8</td>
</tr>
</tbody>
</table>

**A.9c - Suitability of methods for policy applications (positive responses) at product brand level**
Question 17

Should this "Publicly Available Specification" (PAS) a) define and stipulate one specific methodology in great technical detail or should it b) define a more generic framework and set of criteria/guidelines for the estimation of embodied GHGs, thus allowing for the inclusion of different methodologies.

<table>
<thead>
<tr>
<th>Expertise</th>
<th>Option a</th>
<th>Option b</th>
<th>Neither of the two</th>
<th>Both</th>
<th>Other and no answer</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLCA</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>IOLCA</td>
<td>5</td>
<td></td>
<td>2</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All-rounder</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GHG</td>
<td>1</td>
<td></td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4</td>
<td>8</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>17</td>
</tr>
</tbody>
</table>

A.10 – Expert response question 10

There is no clear opinion across experts to whether the PAS should define one methodology in great detail or provide a more general framework and set of criteria for the estimation of embodied GHG emissions in products. Most experts are in favour of option b. In particular, 8 of 17 experts preferred this option even though several highlighted that this decision were driven by matters of practicality. Interestingly most of the experts with a preference for option b were IO specialists. All four experts in favour of option a were “all-rounder”. One PLCA expert suggested that it might not a matter of a) or b), but a combination of the two: a general framework and specific methodological descriptions.

A second PLCA expert stressed that from his opinion both options are inappropriate as a methodological framework already exists in ISO 14040 (2006) and that there is no use in duplicating it. Even worse would be to establish a new standard that is not in line with this international consensus document. In his opinion it would be much more useful to provide product group specific guidance on the application of ISO 14040 (2006), i.e. requirements that have to be met while ensuring efficient data collection and aggregation. A similar opinion was expressed by one of the “all-rounders” even though he perceived this still in line with option a).

Below further interesting comments are listed:

- One PLCA stressed that a combination of the two options might be best. A framework, and one preferred method as an "application" of the framework,
plus motivations why this is the preferred method, plus indications where deviations seem possible. Less ideally option a.

- One IOLCA expert recommended the evaluation of the different ratings for a set of products using more than one approach before settling on one to describe in detail. If ratings are very similar, the one should be chosen, which is easiest to implement. Further attention should be devoted to selected problem areas.

- One all-rounder – in favour of option a - directed the attention towards legal issues. If choices are left too open in the PAS it will be come possible for interested parties to appeal to PAS results claiming that other methods - with other results - might also be defendable.

- Another all-rounder highlighted that a) would be favourable as it would be much easier to implement by SMEs. A domain specific form to fill in should produce the outcomes. By necessity these outcomes will be coarse, but at least repeatable.

- The PLCA expert in favour of option b emphasised that the methodology must be different for different industries.

- The all-rounder in favour of option b highlighted the continuous need for adjustment. Too specific methodological description would either need to be permanently updated or not take into account latest methodological development.

- One IOLCA exerts in favour of option b stressed that option a would be preferable, but might not be operational due to its cost and time intensity.
**Question 18**

Overall, do you think it is possible to establish a robust PAS methodology, which can be used by all types of organizations including including small and medium enterprises, in terms of available time, money resources, knowledge and skills?

<table>
<thead>
<tr>
<th>Expertise</th>
<th>Yes</th>
<th>Depends</th>
<th>No</th>
<th>Other and no answer</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Now</td>
<td>In the future</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLCA</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>IOLCA</td>
<td>3</td>
<td></td>
<td>3</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>All-rounder</td>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>GHG</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>9</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

*Table A.11 – Main areas for improvements*

The majority of experts believes that robust estimates for the embodied GHG emissions in products can be established through the PAS. 9 of the 15 experts, who provided an answer to this question, seemed to think that this can already be achieved today. Two experts were a bit more careful and suggested that a robust PAS should be possible in the future implying that it might be too early days for the PAS development at the moment. However, one of them highlighted that “waiting until everything is perfect” won’t help things either. Something must be put out to stakeholders and policymakers at some point, who can then take their shots at it.

Three experts (“depends”) thought that it might not be possible to establish robust results with a PAS in all areas:

- It might be difficult to establish a robust and practical PAS for SMEs;
- It might be difficult to establish a robust PAS for particular product, but not for others (e.g. agricultural products);

Only one expert thought that it is not possible at all to establish a robust methodology for calculating the embodied GHG emission in products. Two experts did not answer the question.

Some other interesting comments providing a view on the broad range of expert opinions are presented below:

- The PAS will need to address different application areas;
• The PAS may need to force consensus numbers or methods in some cases, which may not be the best knowledge, but will at least create a common basis for comparison of results;

• The PAS may need to look specifically for solutions in areas were uncertainties are largest. Current uncertainties are largest with carbon fluxes in soils but ranges and mean values could be established which is also true for sectors and other GHG emissions e.g. in agriculture.

• The PAS should take into account the strength of input-output analysis. Statistical Bureaux collect data already and regularly, there are UN Standards on National (IO-) Accounting (the so-called UN SNA), there is an accepted, decade-old, Nobel-Prize-equipped theory, hence a lot of existing infrastructure that the PAS can build on. IO-based hybrid LCAs are very elegant and efficient when it comes to time, labour and money. The BL$^3$ tool in Australia, for example, works fine.

• A robust “methodology” can be established. However, a robust result or embodied GHG emission intensity may not be obtained due to large differences in data quality provided by various types of companies. Especially, knowledge and skill of a company will highly influence on the quality of inventory data of the company. A software tool, which enables everyone to correctly compile inventory data, would be useful to make a good use of the PAS methodology.

• The main problem is in fact not the methodology, but the social organisation of a scheme. For example, it is crucial to keep costs to a minimum, that one single standard database is established, so that each individual enterprise shall not use resources in collecting the same data as everone else.

Question 19

Are there areas where methodological improvements can be expected in the short or medium term for a more robust and/or a more PAS?

A complete list of expert answers to this question is provided in Table A.12 below.

- Some other similar developments in other countries, but nothing specific that I am aware of.
- Depends if food and soil related, non-combustion based GHG emissions are included, there is quite some research going on in that area. Otherwise I feel that the most important advances are (as so often) social rather than technological, i.e. agreement and standardization of approaches.
- The problem of systematic system definition and allocation has not been solved at a theoretical level, and may well be impossible to solve. Subtraction/substitution/expansion methods abound and in combination with allocation methods can give virtually any outcome. So, e.g., either the allocation method has to be reduced to a single one based on partitioning (economic allocation; mass/energy allocation which however hardly may encompass services). Improvements would be based on hybrid systems analysis of totals, avoiding a substantial part of allocation, but surely not available within the next few years.
- Awareness of the importance of P-LCA is the most important to accept the PAS in the society. As the methodology of P-LCA is not new, the support system of data collection is the most important to conduct P-LCA.
- Significant advances should be made in the area of agricultural emission factors in the medium term.
- Yes. One is uncertainty assessment. An international expert group is being formed as this survey is conducted. I have more details if required. The other is deal with double-counting.
- End of life carbon data
- Methodologies in LCA and emission estimates have been matured. The major problem is the lack of systematic, regular and timely data collection and compilation in national and international level.
- 1) A Method to quantify GHG emission relating to imported goods used in a company; 2) Method to quantify the reliability and representation of embodied GHG intensities based on the very limited sample data or secondary data.
- The methodology of consequential modelling and integrated hybrid LCA is quite mature. The main improvements that can be foreseen is in education of practitioners and in data availability.
- Provision of more product group specific guidance on the application of ISO 14040 (2006), i.e. requirements that have to be met while ensuring efficient data collection and aggregation. One could imagine recommendations regarding what are the data that need to be collected in order to provide robust estimations.

Table A.12 – List of expert answers to question 19
10 Appendix B: Detailed SWOT Analysis

Process Life-Cycle Assessment (PLCA)

PLCA is conducted by using process data in a bottom-up procedure for the compilation of the life cycle inventory of a product system. The data applied in PLCA is usually either collected directly or process-specific secondary data taken from LCI databases or other data sources (grey literature, sector reports etc.) is assumed to be representative for a particular process.

Process-flow diagram vs matrix based approach

Computationally, there are two different approaches to PLCA: a matrix based and a process flow diagram based approach. It is not difficult to show that computationally only the former can correctly quantify the inputs, outputs and environmental interventions of (unit) processes correctly as it also takes into account those processes that feed back or re-circulate to previous processes.\(^\text{10}\)

Not only have the ISO standards ignored this problem and its solution, but also most textbooks on the principles of the compilation of life cycle inventories (see, Curran 1996; Hauschild and Wenzel 1998). Even though matrix calculations are increasingly implemented in LCA software/inventories such as SimaPro, CMLCA or ECOINVENT many available tools still lack the necessary capabilities (Heijungs 1994; Heijungs and Suh 2002; Gwak and Mi-Ryang Kim 2003; Heijungs and Suh 2006). Clearly, a robust PAS methodology for the calculation of the GHG emissions embodied in products should only be based on a matrix based approach to life cycle inventory calculation.

Strength of PLCA

There was a broad agreement amongst experts that it is the major strength of PLCA is that it is performed at the relevant process level (see Appendix A: Question 14). Its detail allows the consideration of specific characteristics of products. Primary data, which is frequently collected for key processes in lower orders (tiers) during the inventory phase, provides robust information that can often be directly applied e.g. for process improvement or product design. Important opportunities associated with PLCA lie in the relatively wide acceptance of the approach across stakeholder groups (due to the indirect ISO endorsement) and the available expertise of practitioners in the UK of using the method. Both raise substantiated hopes that a

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\(^\text{10}\) However, note that there are a few techniques to solve this problem including iterative methods and infinite geometric progression, the process flow diagram approach is generally not adequate for a complex system (see (Heijungs and Suh 2002) or (Suh 2004))
roll-out of the PAS could be undertaken timely and smoothly without the encounter of major obstacles.

**Weaknesses of PLCA**

Experts mentioned particularly three weaknesses of PLCA: cost and labour intensity of carrying out a PLCA, lack of data availability and the system boundary problem. As we will see, all three problems are closely related to each other (see Appendix A: Question 14).

Let us start this discussion with the elaboration of the system boundary problem. There is a variety of reasons why there is an inherent need for PLCA practitioner to limit the product system under consideration:

- **System complexity:** We have outlined in Section 3 that it is virtually impossible to model a product system only with process data in a way that its system boundaries are only elementary flows as suggested in ISO 14040 as it seems reasonable to assume that at least the majority of processes in modern economies is directly or indirectly connected. Hence, a complete map-out of all these interconnections on the process level and full ISO compliance cannot be achieved (Suh et al. 2004a).

- **Limited time and money resources:** Even so called “detailed or comprehensive LCA” studies cannot deal with all direct and indirect processes associated with a particular product system. However, this problem is aggravated for “simplified” or “streamlined” approaches, which try to make LCAs applicable to many organisation, which cannot afford detailed LCA studies. In fact, Todd and Curran (1999) ask whether the LCA community has established a methodology with conventional, detailed PLCA that is, beyond the reach of most potential users. Such a streamlined LCA approach is very relevant in the context of the PAS as the applicability to organisation of all sizes is one of its basic requirements.

- **Limited availability of primary process data:** Primary data collection is restricted by the time and money resources of a project and the unavailability of primary data for many processes e.g. for reasons of data sensitivity.

- **Incompleteness of secondary data sources:** Available LCI databases as the major source of secondary product and process data are incomplete themselves. Services or capital goods, for example, are usually not covered, whilst the information on final goods is also very incomplete. It is not perceivable that this will change in the foreseeable future.

In order to deal with such complex product systems, PLCA needs to operationalise any analysis through the exclusion of certain processes. This is commonly referred to as system cut-off. The possibility for system cut-off is provided by clause 4.2.3.3.1
in ISO 14044 (BSI 2006b, p.8): “Decisions shall be made regarding which unit processes to include in the study and the level of detail to which these unit processes shall be studied. The deletion of life cycle stages, processes, inputs or outputs is only permitted if it does not significantly change the overall conclusions of the study. Any decisions to omit life cycle stages, processes, inputs or outputs shall be clearly stated, and the reasons and implications for their omission shall be explained.”

However, the fundamental problem is that the complete system with all processes and their interactions remains unknown. Therefore, it is difficult to establish scientifically whether the exclusion of a process, input or output significantly changes overall conclusion. PLCA as described in ISO 14040 and 14044 always starts with some set of process and expands the system boundaries in an iterative process: “It is an iterative process to identify the inputs and outputs that should be traced to the environment, i.e. to identify which unit processes producing the inputs (or which unit processes receiving the outputs) should be included in the product system under study. The initial identification is made using available data. Inputs and outputs should be more fully identified after additional data are collected during the course of the study, and then subjected to a sensitivity analysis (see 4.3.3.4)” (BSI 2006b, 4.2.3.3.2, p.8). However, due to the complexity of the overall system, (Lenzen 2001) suggests that this still only covers processes in lower tiers and that the system boundary in PLCA is chosen based on the implicit assumption that the addition of successive upstream production stages has a small effect on the total inventory.

Process based LCA cover only a limited amount of the whole system. What is excluded due to the truncation is usually not known (Lenzen 2001).
How is a system cut-off achieved? ISO 14044 (BSI 2006b, 4.2.3.3.3, p.8p) also provides guidance on this issue: “Several criteria are used in LCA practice to decide which inputs to be studied, including a) mass, b) energy and c) environmental relevance. Making the initial identification of inputs based on mass contribution alone may result in important inputs being omitted from the study. Accordingly, energy and environmental relevance should also be used as criteria in this process”.

However, there are several difficulties in selecting system boundaries based on these criteria:

- “There is no theoretical or empirical basis that guarantees that a small mass or energy contribution will always result in negligible environmental impacts;

- There are input flows – ancillary materials and process energy – that bypass the product system and do not contribute mass or energy content to the final product. Further, the environmental impacts by inputs from services cannot be properly judged on the basis of mass and energy either.

- Although each single cut-off may have an insignificant contribution to the overall result. The sum of all cutoffs may change the results considerably” (Suh et al. 2004a, p.657).

Alternative criteria for system cut-off such as the mass-energy-economic approach as proposed by Raynolds and colleagues (Raynolds et al. 2000a; Raynolds et al. 2000b) run into similar difficulties in the establishment of a degree of system completeness that is sufficient to guarantee valid conclusions (see, Lenzen 2001).

What is the size of the truncation error? Several authors have tried to estimate this error resulting from system cut-off. However, this is an equally difficult exercise as the complete product system is not known as previously mentioned. Many authors have therefore used environmental input-output methods in order to get an idea about the potential size of the truncation error.

Lenzen (Lenzen 2001), for example, tried to estimate the possible truncation error by assuming that PLCA only cover processes up to the 2nd tier. This still meant the consideration of more than 10000 process inputs. The results showed that almost a third of all 135 sectors in the Australian economy had truncation errors higher than 50%. Whilst the limitations of such input-output based approach to the evaluation of the truncation error need to be kept in mind, these results are confirmed by a variety of other studies which reached similar conclusions (Lave et al. 1995; Born 1996; Norris 1996; Hendrickson et al. 1998a; Pick and Wagner 1998; Weber et al. 1999; Lenzen and Dey 2000; Nansai et al. 2001; Treloar et al. 2001; Yoshida et al. 2001; Lenzen and Treloar 2003; Suh et al. 2004a).

Further evidence on the effects of truncation on results can be found in the PLCA literature. There have been some studies comparing results from detailed and simplified/streamlined PLCAs. Hunt and his colleagues (Hunt et al. 1998) looked at
10 different ways of streamlining detailed PLCA through additional system cut-off. One of the study’s conclusion is that there are no generic cut-off criteria, which guarantees streamlined PLCA to arrive at the same qualitative results than detailed PLCA (in terms of ranking of products). If this is the case, it might be said that there is no reason that a detailed PLCA will arrive at the same results than a PLCA carried out for the complete product system (without any cut-off).

What are the implications of system cut-off on results of PLCA studies? With system boundaries chosen in an iterative process without knowledge of the complete product system and in the absence of reliable criteria for system cut-off, comparability in system boundary choice and ultimately of results from PLCA studies cannot be guaranteed. In absence of more robust criteria/methods for system boundary cut-offs, system boundary choice is arbitrary. Comparability is further limited by the differences in availability of resources between projects (time and money) and heavily depends on good practise of PLCA practitioners carrying out the study. Finally streamlined LCA, which are purely based on process data, might have particular difficulties in providing robust estimates for the PAS.

We might conclude this discussion on system boundaries as follows. System cut-off is unavoidable in PLCA due to the interdependence of processes in modern economies. This also means that truncation error is unavoidable. It is not possible to make a fully informed decision about the inclusion and exclusion of processes as the full product system remains unknown in PLCA. The cut-off criteria suggested by ISO can be misleading and do not provide a satisfactory basis for a transparent system boundary selection. Ultimately system boundaries remain arbitrary. It is not possible to establish the size of the truncation error. Input-output studies have suggested that the truncation error is potentially very large even though the result remain to some degree speculative. However, it seems fair to say that arbitrary system boundary selection seriously limits the comparability of results across PLCA studies as such comments are widespread in the LCA literature.

**Threats**

The threats associated with the establishment of an embodied GHG estimate based on PLCA are mainly related to the quality and the availability of process information.

- **Primary process data:** There are two problems associated with the collection of primary process data. First, primary data collection is expensive. In order to make the PAS applicable to any organisation primary data collection needs to be reduced to a minimum. This was highlighted by the experts (see Appendix A: Question 11). However, if primary data collection is too restricted, there is the danger that the main characteristics of a product are not adequately represented by the inventory data and the results from the analysis become useless. Second, the collection of primary data itself is restricted by data
availability. Process specific data is often confidential and companies are reluctant to give out these information. This limits the amount of relevant primary data, which can be collected. In such cases this data either needs to be substituted through secondary data or the system boundary needs to be adjusted. In both cases this might negatively affect the final estimate of the GHG emissions embodied in products.

- **Secondary process data:** There are two similar threats associated with the application of secondary process data. First, LCI databases themselves are incomplete and do not always provide the required data. Particularly, there is a lack of information on capital goods and services. A recent studies by (Suh 2006a) shows that the embodied GHG emissions associated with services in the US account for 37.6% of the total GHG emissions in the U.S. already in 1998. Similarly, one experts pointed out that 23% of the CO\textsubscript{2} emissions in Japan in 2000 were associated with capital formation. It seems reasonable to assume that services and capital goods provide some inputs to almost all processes. Unless they are widely covered it seems very difficult to establish robust estimates of embodied GHG emissions in products. Second, data from different LCI databases is often not comparable. Not only do they cover different processes and products, but might also provide different estimates for the same process. Some authors point out that even within databases this comparability is often not fully secured. Differences across LCI databases can therefore further negatively affect the comparability across PLCA studies.

**Opportunities for PLCA**

However, there are also a variety of opportunities for improving the comparability and robustness results from PLCA. Most of them are associated with the PAS specification itself:

- Comparability and good practise can be established through the PAS. One expert, for example, suggests that the PAS should complement ISO 14040 and ISO 14044 (BSI 2006a; BSI 2006b) through the provision of product group specific on the application (see Appendix A: Question 17). This could comprise the specification of detailed data requirements, ensure efficient data collection and comparability.

- The PAS could also make specific recommendations concerning the use of secondary process data (see Appendix A: Question 12). The majority of expert suggested that only a selected number of secondary data sources should be endorsed (most importantly LCI databases). Several experts indicated that only a single database should be endorsed to maximise comparability of studies. Similarly, expert suggested that best practise GHG
emissions factors for non-combustion processes could be specified. Consistent use of secondary data sources and emission factors would increase the comparability of embodied GHG estimates derived from the PAS.

- One expert in the review suggested that there is no available LCI database, which could be endorsed by the PAS straight away suggesting the construction of a LCI database (taking best pieces of existing databases) specifically for the PAS. National LCI databases, for example, have been constructed for Japan and Denmark (Itsubo and Inaba 2003; Rebitzer et al. 2004; Weidema et al. 2005). Clearly, this would not only provide the comparability mentioned above, but also give full control over the development and quality of the database for the PAS.

- Input-output methods could also help PLCA studies in the identification of system boundaries (see, Guinée et al. 2001; Weidema and Nielsen 2001). This might allow for a more consistent system boundary definition across studies, increase comparability and also improve the robustness of estimates.

**Implications for policy applications**

PLCA clearly works best on the product and product brand level. This was also clearly highlighted by experts (see Appendix A). Due to high information demands uncertainties can be expected to be much higher on the product group level. An application of PLCA in the PAS on the product group level cannot generally be recommended unless all required process information is available (see, Tukker et al. 2006; Tukker and Jansen 2006).

For particular policy applications, we would take a differentiated view. PLCA provides sufficiently robust information for typical business applications such as process design/improvement/optimisation. Also supply chain management seems to lie within the reach of the method. However, as soon as the robustness of the final estimates is of importance as for environmental labelling or information of carbon trading systems, we do not think that it provides sufficiently robust results. Limited project resources and data availability seem to impose severe restrictions on comparability, accuracy and precision, which we do not expect to be solvable in the foreseeable future. This is particularly true as the PAS would need to be based on a simplified PLCA approach, in order to be applicable to organisations of all sizes. Apart from the difficulties in establishing a comprehensive process map, sufficiently comprehensive sources of secondary process data are not in sight in the foreseeable future to cater the needs of a robust PAS.
Hybrid-LCA Methods

Linking process-based and IO-based analysis, with the aim of combining the strengths of both, is generally called a Hybrid-LCA (HLCA) method. A Hybrid-LCA analysis can be conducted or implemented in different ways:

- **Tiered hybrid analysis** utilises process-based analysis for the use and disposal phase as well as for several important upstream processes, while the remaining input requirements are calculated separately with IO-based LCA. Tiered hybrid analysis can be performed simply by adding IO-based LCIs to the process-based LCI result.

- **IO-based hybrid analysis** is carried out by selectively disaggregating industry sectors in the IO table, thus expanding the technical coefficient matrix by using process and trading information. The use phase and end-of-life phase (reuse, remanufacturing, recycling or disposal) of a product can be treated as a hypothetical industry sector that draws inputs from the existing sectors and has some associated environmental burden.

- **Integrated hybrid analysis** is the most sophisticated form of combination: The IO table (in monetary units) is fully interconnected with the matrix representation of the physical product (or process) system in physical units, thus forming one consistent computational structure. The interconnection is located at upstream and downstream cut-off points where process data are not available.

**Strengths of Hybrid-LCA**

**Robustness of methodology (and data)**

Hybrid-LCA methods present the most accurate, precise and complete calculation of embodied GHG emissions possible. While the process-based part provides more accurate and detailed process information, the IO-based part achieves full system completeness. The strengths of both, Process-LCA and IO-LCA, can be combined (see Appendix A: Question 14). Advantages that are in addition to either of these two approaches alone, include the following:

- Full interactions between individual processes and industries can be modelled in a consistent mathematical framework through the representation of use and end-of-life phase phases in a LCA technology matrix. The process-based component is completely integrated in the IO matrix, thus eliminating the need for cut-off points.

- The integration of process-based LCA data into an IO framework improves the reliability of the analysis: The uncertainty of results from hybrid analysis
are low as both, process and IO data, are applied in a way that creates the best accuracy and precision. The truncation error is eliminated from the process analysis and the aggregation error is minimized in the IO analysis.

- In integrated hybrid analysis, the upstream, downstream and technological system are complete and the geographical system boundary is not limited.

- An integrated hybrid approach enables full feedback loops to be modelled, including inputs from the embedding economy to the detailed functional flow-based system and vice versa.

- The integrated approach enables a consistent allocation method throughout the hybrid system and avoids double counting by subtracting the commodity flows in a process-based system from the input-output system.

- Hybrid approaches preserve process-specificity as much as possible, while at the same time enable comparative LCAs between two product systems on the basis of equivalent system boundaries.

- In the inventory phase of a hybrid assessment, the data collection and the boundary selection can be tailored by using structural path analysis (SPA). This provides an excellent tool for systematically adjusting the coverage of the process part of a hybrid LCA, which is necessary to achieve a given minimum level of accuracy. Furthermore, it can be used to prioritise inventory items and complete existing process-based life-cycle inventories.

- GHG emissions embodied in a service product can be modelled with the completeness and accuracy of the IO system while processes specific to the service can be included.

- Databases and case studies are well documented for all three types of hybrid analysis, in particular for tiered hybrid analysis.

Simplicity of application

Tiered hybrid analysis provides relatively fast inventory results. IO analysis identifies the most important (most impacting) pathways for a product or process and therefore helps to prioritise, focus and minimize data collection for the process-based analysis.

Although some expert knowledge is required to build an IO-model, IO-based software tools are readily available and simple to apply for any good or service. Additional time requirements for a tiered hybrid analysis are small compared to conventional (process-based) LCA.

Software tools for integrated hybrid analysis are in the process of development and commercially available packages can be expected in the next few years. It can be
expected that these tools, once available, will not require a high level of expert knowledge and will be easy to apply in practice.

**Costs of analysis**

Hybrid-LCA enables the analyst to focus data acquisition cost-effectively and to target it more specifically towards processes with high data uncertainty with the aim to maximize precision and accuracy. For the same expenditure in data collection effort, hybrid analysis therefore can obtain a higher degree of data quality and a lower uncertainty than a pure process-based LCA.

For the evaluation of products groups, costs can be as low as for a pure IO-LCA as product groups can in many cases be directly represented by IO industry sectors. For a further sector disaggregation, as performed in IO-based hybrid analysis, costs will be higher but still fall below those for a pure process-based analysis.

**Consistency with other standards**

Hybrid-LCA methods combine (and therefore include) life cycle inventory result from all stages of a product life cycle with IO data and thus the scope of the analysis is fully in line with the ISO 14040 and 14044 standards. Although the current ISO standards are based on process analysis, there are no restrictions in using IO accounts to describe upstream process relationships if the model and assumptions are clearly noted. Moreover, selecting a system boundary in compliance with ISO standards is, in practice, impossible without using the IO model, and hybrid techniques using IOA can therefore form a central element of ISO-compatible system boundary selection practices.

**Weaknesses of Hybrid-LCA**

**Robustness of methodology (and data)**

There are some weaknesses associated with tiered hybrid analysis as this type of hybridisation does not fully integrate the process-based system with the IO-based system so that the interaction between them cannot be assessed in a systematic way. The border between the two systems should be carefully selected, since significant error can be introduced if important processes are modelled using the aggregated IO information. Also, the commodity flows of the process-based system need to be subtracted from the IO part (or process-based results need to replace IO-based results), or otherwise double-counting might occur.

In the IO-based hybrid approach, use and end-of-life phase are externally added to the main system and recurring flows between the main system and use and end-of-
life phase are not properly described. The method should be combined with other methods if the national economy is highly dependent upon imports.

These shortcomings can all be addressed with a fully integrated hybrid-LCA but this comprehensive method brings with it a relative complexity and resource intensity as described below.

The data requirements for hybrid analysis can be as high as for PLCA. Primary data have to be gathered for the process-based part of hybrid analysis. Input-output data need to be reasonably up-to-date and detailed in order to enable accurate calculations (see also Threats).

**Simplicity of application**

Integrated hybrid-LCA is the most sophisticated but also most complex method of calculating embodied GHG emissions in products. The intricate part lies in the formulation of a process flow matrix and its interlinkage with the IO system and advanced mathematical and modelling skills are required. Although all model components and data can be (and have been) described in a transparent way, the increased complexity of integrated models can lead to a lower degree of understanding and acceptance than in traditional life cycle assessments. However, when wrapped into software tools these methodological issues do not need to be at the forefront of a practitioners mind. Some tools like CMLCA or SimaPRO can deal with fully integrated hybrid systems already today.

**Costs of analysis**

Time and labour requirements are highest for integrated hybrid analysis. Costs will depend upon the skills and expertise of the analyst, in particular whether an IO-system is at hand or not. The costs for compiling the process flow matrix are estimated to be similar to pure process-based LCA and will increase when going from product groups to individual products or even product brands.

Costs for fully integrating this matrix will be lower but come on top of the compilation costs. Since information on the process-based system is gathered by direct inspections and questionnaires, purchase and sales records for cut-offs required to link the process-based system with the IO table may be relatively easy to obtain.

**Opportunities for Hybrid-LCA**

The use of (integrated) hybrid approaches is particularly recommended for comparative LCA studies. Only models that are supported by input-output analysis provide the complete background system needed for meaningful comparisons on
the basis of equivalent system boundaries. Hybrid-LCA is also useful for various applications where product specific AND wider economic impacts are important, e.g. cleaner production, industrial ecology, integrated chain management, life cycle management and green/environmental supply chain management.

Both, process analysis and input-output analysis, theoretically require the same data and would yield the same result if a fully disaggregated data base were available. If data are collected and assembled with hybrid analysis in mind, the great opportunity is that both techniques will 'come closer' to each other. Suitable process data can help improving top-down IO data and more detailed IO data will help filling secondary data gaps in process databases.

Hybridisation will also encourage multi-disciplinary thinking and help Process- and IO-LCA communities to widen their horizon. Comprehensive system thinking is as much required as detailed process knowledge in order to achieve accurate results that are close to the true value.

Input-output databases are slowly developing into multi-national systems, with global or regional coverage, linked through trade data (OECD, GTAP, EXIOPOL, and others). High-quality IO databases can be set up on the basis of supply and use tables, with detailed commodity flows available in most primary data sources where the supply and use tables are constructed from. Detailed environmental data are or can become available for many countries through integrated environmental and economic accounting (SEEA, NAMEA). These improving data situation can help hybrid analysis become more accurate and available, with the prospect of building multi-national models that allow for the analysis of international trade and supply chains.

**Threats for Hybrid-LCA**

The non-existence of databases specific to Hybrid-LCA for the UK is a threat for a wider application of the method. Conventional LCA databases are yet to be adapted to the integrated hybrid method by supplying monetary data on process flows. Existing energy consumption data which is indispensable to estimate GHG emissions is usually collected by industries, companies and facilities. The relationship between these management units and goods and services is not easy in many cases. Data on end-of-life and in particular on recycling activities also need to be improved before they can adequately be modelled with hybrid approaches. The creation of a standard hybrid database which is continuously updated has been suggested to overcome some of these threats.

Detailed economic IO data (400-500 sectors) is available for several countries, but for other countries, IO data with enough sectors is not available, which means that
the merits of Hybrid-LCA cannot be realized. It can be said that generally the availability and quality of IO data has a high significance on the robustness of Hybrid-LCA results. So far, the demand for more reliable environmental analyses has not been a driver for the improvement of IO data, at least in the UK.

IO databases are mainly still only available at the single country level and single-region IO models have an error associated with the imports assumption (that resource use, emissions and pollution intensities are the same as in the domestic economy. Furthermore, the omission of domestically produced as well as imported capital flows – often driven by insufficient IO data – can lead to distortions of multipliers.

Most commercially available LCA software is not yet able to handle matrix inversion for LCI computation; a software tool development that enables broad application of hybrid analysis by LCA practitioners is required. So far, there is a lack of practical experience in carrying out integrated hybrid analyses and training and eduction will be crucial for a wider implementation.
11 Appendix C: Detailed Recommendations

In this Section we turn the insights from our SWOT analysis and expert survey into recommendations for the further development of the PAS. We agree with the majority of experts that a PAS methodology can be established in the foreseeable future, that is able to provide sufficiently comparable and robust estimates - at least for some applications. However, we feel that the best way in terms of robustness, comparability and cost effectiveness will require major changes in the current draft methodology.

From our review and the survey we conclude that the application of a Hybrid-LCA (HLCA) methodology seems to be most suited for the PAS process as it builds on the strengths of both PLCA and IOLCA. Both the detail of PLCA and the complete supply chain coverage of IOLCA are essential to provide broadly comparable estimates. This is even more true for a “streamlined” or “simplified” PAS,\(^\text{11}\) which can be used by organisations of all sizes, as there is no reliable method for the determination of system cut-offs in PLCA. Not all of the experts would agree with this recommendation. Particularly the PLCA specialists did seem to think that a PLCA approach would be more appropriate. However, note that following a HLCA approach does not mean abandoning neither PLCA nor the ISO standards (BSI 2006b; BSI 2006a). HLCA just builds upon PLCA and adds information where flows were cut-off previously. This is fully compliant with ISO and has been recommended by (Guinée et al. 2001) in their practical discussion of the standards.

**Methodologically, the PAS development should be re-directed from a process life cycle assessment approach towards a (matrix-based) HLCA approach.**

**System boundaries**

Taking a HLCA approach means a change in ideology in terms of the selection of system boundaries. In the absence of reliable cut-off criteria in PLCA, the best strategy for comparable estimates of GHG emissions embodied in products seems not to cut-off any processes and to take them all into account through the use of environmental input-output analysis. Guinée et al. (2002) already highlight in their guide to the ISO standards that cut-offs must be avoided as much as possible through the collection of primary process data. Where such data is not available or

\(^{11}\) In this context, the PAS developers should also keep close contact with on-going LCA projects such as CALCAS, where some of the leading European LCA experts try to advance the streamlining of LCA.
resource restrictions on the project rule out any further collection of primary data, data gaps should be filled through imputation by:

- using information of the same or a similar process from a LCI database; or
- environmental input-output analysis.

For the PAS this means that (primary and secondary) process-specific data is used where possible given the resource constraints (time and money) of the project as commonly done in PLCA, while the environmental input-output part completes the model. The expert survey further highlighted that these boundary extensions should also fully account for the following inputs and ancillary processes in production:

- capital goods;
- service inputs;
- overheads.

A GHG embodiment study shows that services in the US excluding electric utilities and transportation generate over 35% of total industrial GHG emission throughout its life-cycle. Much of such contribution is made indirectly through capital goods, other service inputs and overhead. Excluding these increasingly more important inputs, the method would fail capturing a substantial portion of carbon footprint of our society. Moreover, use-phase emissions should also be included in the PAS.

The PAS should demand 'complete' system boundaries and include input of capital goods and (intermediate) services in production processes, company overheads and use phase emissions.

Primary and secondary process data

There seems to be a general agreement among experts that primary data collection required by the PAS should be kept to a minimum in order to reduce resource requirements, especially for smaller enterprises. Therefore, the PAS should be set-out as a streamlined or simplified LCA approach. Only through such a streamlined or simplified LCA approach can the PAS be applicable to organisations of all sizes.
Iterative procedure for finding optimal boundaries between IO and process data. Circles with boxes and arrows identify process data. In Step 1, process data are gathered and filled in as required by PAS. Dotted areas show macro-level hot-spots identified through contribution (structural path) analysis. In the next steps, process data are added in hot-spot areas depending on availability of time and money resources (adjusted from Tukker et al. 2006).

HLCA approaches raise hope that a reasonable data quality can be achieved with comparatively little effort. We propose an iterative procedure for finding the optimal delineation for the interface between process and IO part of the model. Such a procedure will provide the most robust and comparable results under reasonable resource constraints. Initially, practitioners should focus on specifying a set of core processes (e.g. on-site processes) using primary data based on the minimum process data requirements set out in the PAS. These should also include atypical products and processes, which are not well represented by input-output categories (Bullard et al. 1978; Rebitzer et al. 2004; Suh et al. 2004a). The remainder of the system should then be covered by IO data. A contribution analysis and/or structural path analysis can indicate which inputs need further attention. If additional time and money is available, further process specific data can be added where needed, e.g. where assumptions from the IO part of the model are too far-reaching. This way, the process-based share of the analysis can be increased successively and selectively similar to the conventional iterative procedure of system boundary definition as described in the ISO standards (BSI 2006b), whilst guaranteeing the highest level of data quality and comparability.

The PAS specification should stipulate a simplified and streamlined Hybrid-LCA approach based on a defined minimum amount of primary process data.

Additional collection of primary and secondary process data should be encouraged.
Life cycle inventory database and emission factors

To further maximize the comparability across studies, we recommend that the PAS endorses a single LCI database. Several experts were in favour of a more “open” approach to the use of secondary data sources. We feel that this would be best achieved through the development of a national LCI database which would:

- **Minimization of costs** for users of PAS methodology;
- **Control over database development** – timely data development in key areas according to (government) priorities;
- **Control over data quality standards and assurance**;
- **Use of UK specific IO data.**

National LCI databases including characterization factors for LCIA are currently available for Japan (Itsubo and Inaba 2003) and Denmark (Rebitzer et al. 2004; Weidema et al. 2005). A UK specific LCI database would pull together best available process information from a variety of existing databases and link it with available input-output and environmental account data on GHG emissions. In the initial stages of database development, gaps in process data will become apparent. These should be filled in a step-wise procedure starting with products and processes in known hot spot areas for key product groups, which are very different from the sector average and therefore are not well represented by IO categories. We highlight that a Hybrid-LCA approach makes best use of the existing process-based LCA resources and provides a strategic and efficient way forward to the further development of a national LCI database.

Prioritisation of the database maintenance should be informed by an uncertainty assessment, ensuring that such maintenance action is chosen which reduces the overall uncertainty most and guarantees best cost effectiveness (Weidema et al. 2005). The development of such a hybrid LCI database could be guided by some of the members of the existing PAS working groups with experience in HLCA such as Bo Weidema or Gjalt Huppes amongst others.

It is conceivable that data gathered in PAS-compliant projects could find entry into the LCI database (in anonymised form so as to guarantee confidentiality). This would help improving the database and contribute to the minimisation of the burden imposed on organisations by the PAS: the expense of resources (time, money) for the collection of the same data by other organisations or projects would be avoided.

As with the LCI database, a set of GHG emission factors should be endorsed by the PAS and reported in combination with attached uncertainties. GHG emission factors for fuel combusting processes have already undergone international peer review and are commonly available. For GHG emissions from non-combustion processes a set of best practise emission factors should be compiled.
this is not the case for GHG emissions from non-combustion processes. Even though almost all experts were concerned about
Defra’s GHG emission factor for fuel combustion processes can be used. Due to the high uncertainties associated with GHG emissions from processes not related to the combustion of fuels, a set of best practise emission factors for non-combustion processes should be established. For matters of consistency, engagement with the Environmental Accounts division of the Office for National Statistics should be sought.

The PAS should endorse a National Life Cycle Inventory Database to maximise the comparability of embodied GHG estimates across studies. The construction of such a data base should be initiated.
This database should include both process and input-output data as well as GHG emission factors. A set of best practise GHG emission factors for non-combustion processes should be compiled based on a review.
National and international experts should oversee the development and maintenance of such a database.
The inclusion of multi-national input-output data should be considered.

Software tool
As one of the experts highlighted in the course of the survey, the main challenge for the PAS might not be its methodological specification, but the establishment of an adequate data system and Institutional management of the scheme. A wide applicability of the PAS to organisations of all sizes requires that practitioners with relatively little experience in LCA must be able to perform an analysis consistent with the PAS specification. At the same time we have highlighted the lack of experience in the UK LCA community in applying HLCA approaches.
Much of the problem could be overcome through the use of software tools that help practitioners through the various stages of the calculation process. Once it is established that these tools comply with the PAS, the computational aspects do not need to be at the forefront of the practitioners mind. Nevertheless, some level of training of LCA practitioners will be necessary and should be considered as a part of the wider PAS development.
There are already software tools available, which can deal with hybrid LCA systems such as SimaPro, Bottomline\textsuperscript{3} or CMLCA. Software tools meeting the methodological specifications of the PAS could be approved or endorsed by an independent body (e.g. Carbon Trust, BSI). It is also conceivable that a public or private organisation
supports the development of existing or new software tools that are easy-to-use and fully compliant with the PAS. PAS-compliant and therefore approvable software would have to fulfil the following requirements:

- adhere to methodological specifications of the PAS;
- enable Hybrid-LCA analysis;
- estimate the uncertainty of results;
- use data from the National LCI Database (once established).

A PAS working group should review and appraise existing software tools in relation to their PAS compliance.

Suitable Hybrid-LCA software should be listed and endorsed by the PAS.

A public or private organisation should support the development of existing or new software tools.

Attributional or consequential PAS?

The choice between an attributional or a consequential LCA approach depends on the applications of the PAS. Generally, an attributional approach should be used for reporting exercises, while a consequential approach can be recommended, if the results are used in decision making to induce change (e.g. changing production or consumption patterns). A good example for an application requiring a consequential approach would be carbon labelling of products. This was supported by most of the experts, who were familiar with this terminology. Even though the consequential approach seems more relevant to the PAS, the specification should comprise both approaches mapped against their applications. This seems important as it was suggested in the course of the expert survey that there is a lack of international consensus of what is best practise for which particular application.

However, in the course of this review it could not be finally established what the current state of the art in consequential LCA modelling is due to contradictory evidence. While some documents suggest problems in the wide availability of appropriate data and models (CALCAS 2007), others suggest that “average” data used for attributional LCA can be easily adjusted for consequential modelling (Rebitzer et al. 2004). Therefore, we suggest that the PAS working groups on “LCA topics” and “data” should further investigate on the issue. Consequential modelling should be applied in the PAS, if practical.

Note that this was not always the case GHG emission inventory experts and IOLCA specialists.
The choice between consequential and attributional LCA depends on the PAS application. Ideally the PAS should clearly set-out when a consequential or attributional approach should be used.

However, there are concerns about the feasibility of implementing a consequential approach in the course of the PAS. The current state-of-the-art in consequential LCA modelling should be further investigated by PAS working groups.

What type of PAS and what applications?

There was considerable disagreement among experts whether the PAS should

- a) define and stipulate one specific methodology in technical detail, or
- b) define a more generic framework and set of criteria guidelines for the estimation of the embodied GHG emissions in products.

Our opinion is that the first option seems most suitable for deriving robust and comparable embodied GHG estimates of products.

However, can the derived estimates be expected to be sufficiently robust for serving the various policy applications including eco-labelling, product design and supply chain management at the various levels of application (product brands, individual products and product groups) across products? This will crucially depend on the amount of primary process data collected, the availability of sufficiently robust secondary data for key processes involved in the production of products, the quality and detail of the IO data (including sectoral environmental and capital flow data), and whether a product or process is a typical or atypical part of an IO category.

The PAS is expected to guide the users to find out the least cost pathways to improve on the quality of the results. The iterative refinement of the internal system boundary and collection of additional primary data for priority processes need to be continued until required quality of the result is met. For the applications of PAS for eco-labelling and carbon trading, the required quality of the result should certainly be much higher than other applications, which may potentially require time and money as well.

Less ambitious applications such as the use of estimates in general consumer information systems seem less problematic and would greatly benefit from the increased comparability provided by the HLCA approach. The definition of some maximum levels of uncertainties allowed might still be considered. Applications areas in which PLCA studies have been successfully used in the past such as process analysis and design, supply chain management etc. can be supported by
the PAS immediately. The lack of robustness of the final estimates might not be of major concern as long as sufficiently robust process information is available. Interestingly, (Rebitzer et al. 2004) highlight that particularly SMEs can benefit from the application of LCA through cost-savings once they have overcome the initial barrier of directing resources towards such efforts. Ultimately, we would recommend a first review of PAS applications once a national LCI database is established.

Applications of the PAS depend on the quality and comprehensiveness of available data. Therefore, PAS applications should be reviewed on an annual basis alongside with the database itself.

It seems that a variety of applications can already achieved today such as process improvement or supply chain management.

However, applications requiring high accuracy and precision of the final embodied GHG estimates of products such as Type 3 labelling or carbon trading, seem not achievable in the immediate future.

Further distinctions in applications considering different levels of uncertainties associated with products in different product groups (e.g. food) should be considered.

Finally, if a Process-LCA approach is pursued in the PAS against our recommendations, applications of the PAS need to be restricted. We perceive that Process-LCA – given the PAS requirements (see Section 1) - will not deliver sufficiently robust results in the foreseeable future for applications such as Type 3 carbon-labelling, carbon trading or product comparisons, where the robustness of the final estimate is of great importance. In such a case shortcomings of the PAS draft reviewed in the course of this project should be addressed (see Section 4) - most importantly the shifting from a process flow diagram towards a matrix-based Process-LCA approach, the inclusion of use-phase emissions as well as GHG emissions from the use of capital goods, intermediate services and company overheads. Relevant aspects of recommendations 3,4,5,6, 8 and 9 (Section 5) should be taken into account as well.
12 Appendix D - Limitations

While we are confident that HLCA provides the best methodological framework for dealing with the inevitably imperfect data situation the PAS development is confronted with in a cost-efficient way, there are also several limitations imposed by taking such a route.

- **Quality and detail of input-output and sectoral environmental account data:** Input-output data in the UK is outdated and provided at a comparatively high aggregation level. The last official analytical input-output table published by the Office for National Statistics (ONS) is for the year 1995 (ONS 2002) and distinguished 138 sector. More, recently a series of supply and use tables for the time period 1992-2004 (ONS 2006a) has been updated and made usable for input-output studies in a recent project for DEFRA (Wiedmann et al. 2007b). However, the flows documented in these tables will inevitably be associated with higher levels of uncertainties. Equally, sectoral GHG emission data for the UK is only available at a 91 sector level. While there are ways of providing more detail to existing input-output data as documented in (Tukker et al. 2006; Tukker and Jansen 2006), this requires further - partly strong - assumptions entering more uncertainties into the model. Finally, to our knowledge a detailed sectoral capital flow matrix is also not readily available for the UK and can only be derived through imputation as outlined in (Lenzen and Treloar 2005b). Ultimately, the PAS development should provide another incentive to actively engage with ONS for the timely provision of adequate national and environmental account data like in other countries.

- **Time and resources for database and software development:** Developing and endorsing a single LCI database in order to maximise comparability between studies, data quality and guide database improvements according to policy priorities and data needs, will take up some resources initially and might delay the introduction of the PAS. The same might hold for software developments depending on the route taken.

- **Training requirements:** There might be further training requirements as practitioners might not be able to use software and database they are familiar with. However, these costs might be comparatively small compared to the training requirements associated with a broader roll-out in SMEs.

There were further concerns by experts concerning the linkage between process and IO data. We believe that current methods are sufficiently developed to deal with this issue (see, Suh 2004).
Appendix E – Expert Survey Design

Methods review to support the PAS for the calculation of the embodied greenhouse gas emissions in goods and services

Background info
In response to market interest in understanding the contribution products and services make to climate change, there is a requirement for a standardised, consistent method organisations can use for measuring the GHG emissions embodied in products and services. Having an agreed method for measuring embodied GHG emissions in products and services will enable an accurate and consistent approach for this measurement. This will enable business and other organisations to effectively understand the GHG emissions associated with the products and services they manufacture, buy or sell and hence their impact on climate change.

The Department for the Environment, Food and Rural Affairs (DEFRA) and the Carbon Trust (CT) are co-sponsoring the British Standards Institution (BSI) to develop a Publicly Available Specification (PAS) for the measurement of the embodied greenhouse gas emissions (GHG) of products and services (for more information see, http://www.defra.gov.uk/nea/m/a/2007/07/03/gas.htm). A PAS is a fast-track standard process taking 8-12 months, compared with a typical 3 years for standards. Using this route it is the intention that the measurement method can be developed, agreed and promulgated quite quickly. The PAS process will draw on existing relevant international knowledge, methods and tools, such that it is open, independent and consultative.

This DfE project is to conduct a short fit-for-purpose review of the current methods relevant to measuring embodied GHG of products and services to inform the PAS team and Steering Group. It is the ultimate goal to recommend which methods can be used or built upon to meet the PAS requirements and to identify where the PAS development might be limited by methodological and data issues.

The PAS requirements
The PAS specifies requirements for the measurement of the GHG emissions associated with the provision of products and services and should:
- Be applicable to all products and services with consideration given to how and whether it may need customising for specific product groups, e.g. food, buildings, energy use products;
- Consider all life cycle stages along the supply/value chain of a product or service, i.e. from raw materials to end of life;
- Consider all GHGs;
- Be usable by all sizes and types of organisations.

Please keep these PAS requirements always in mind when answering the survey questions!

Some abbreviations and definitions:
In this survey use will be made of the following abbreviations:
- LCA: life cycle assessment
- P-LCA: process life cycle assessment
- IO-LCA: environmental input-output life cycle assessment
- H-LCA: hybrid life cycle assessment
- GHG: greenhouse gas emissions

Moreover, to avoid confusion, the following definitions apply:
- Product: Products are goods and services. This is also consistent with system of national accounts (UN, 1992: 2.49). We will distinguish products at three aggregation levels:
  - Individual product: We define individual products as the elements of the most detailed breakdown of a standard product classification system such as CPC;
  - Product groups: Any aggregation of individual products;
  - Product families: Any further distinctions of individual products by brand names.
- Primary data: Process-specific data collected directly from the respective processes.
- Secondary data: Process or non-process specific data obtained from sources other sources than the respective processes under study.
- Precision: Agreement among repeated measurements of the same variable. Better precision means less random error.
- Accuracy: Agreement between the true value and the average of repeated measured observations or estimates of a variable.

1 The term “hybrid” in the context of this survey refers to the integration of sector- and process-level data in the inventory phase.
An accurate measurement or prediction lacks bias or, equivalently, systematic error.

- Method Robustness: A method will be deemed robust, if the resulting estimates are accurate and precise. The level of robustness required from a method depends on the application.
- Environmental Labelling: Environmental labelling includes a number of activities, ranging from business-to-business transfers of product specific environmental information to environmental labelling in retail marketing. The overall goal of environmental labelling (or eco-labelling) is to encourage the demand for, and supply of, those products and services that are environmentally preferable through the provision of verifiable, accurate and non-deceptive information on environmental features of products and services:
  - Type 1: "Seal of approval" labels are awarded to products by a third party — either government or private. Products meeting a set of predetermined criteria earn the label. Criteria are established for distinct product categories by the labelling body and deal within or with respect to environmental aspects of the product. Labels usually indicate that a product is environmentally preferable, in order to increase the demand for environmentally preferable products. These labels are usually represented by a logo on the product or product packaging.
  - Type 2: "Type II" or "self-declaration" labels are based on a manufacturer’s self-declared claim about a product’s environmental performance. These labels typically deal with one or more environmental aspects of the product (e.g., recycled material content). Like Type 1 labels, it is expected that Type II labels inform the public and help raise the demand for products that are less environmentally damaging.
  - Type 3: Type III "environmental product declarations" provide environmental data about a product. These declarations are produced by the company making the product or service, and are often certified by a third party. The declaration is typically based on a life cycle study, as required by the ISO technical report for Type III declarations. The declaration contains quantified data from various life cycle stages of the product, including: material acquisition, manufacturing, transportation, use and end-of-life disposal or recycling. The declaration may also contain qualitative data about the product and the company. Type III declarations allow consumers to compare products based on all of their environmental impacts and make their own decision about which product is preferable.
- Green Supply chain management: Supply chain management (SCM) is the process of planning, implementing, and controlling the operations of the supply chain as efficiently as possible to minimise resource use and pollution. Green Supply Chain Management spans all movement and storage of raw materials, work-in-process inventory, and finished goods from point-of-origin to point-of-consumption.
- Eco-design: Eco-design is the process of addressing environmental parameters when designing products.
- Individual Carbon trading: Individual carbon trading refers to the act of allocating emissions credits to individuals on a per capita basis, within national carbon budgets. Individuals would then have to surrender these credits when buying fuel or electricity. Individuals wanting or needing more energy would be able to partake in emissions trading to secure more credits.

Box 1 – Precision and accuracy (See IPCC, 2006)²

Section 1: Personal Information
Note that survey results will be anonymised prior publication, i.e. personal details will not be published.

Personal details:
Name
Institution
Position
Contact details

1. What are your main fields of expertise? Choose as many as applicable:
   □ Process LCA
   □ Environmental Input-Output Analysis/Environmental input-output lifecycle assessment
   □ Hybrid LCA
   □ Carbon Footprinting
   □ Compilation or design of greenhouse gas emission inventories
   □ Other: please specify

Section 2: Review of literature list
Please have a look at the attached literature list. Due to the tight deadlines of the project this literature list cannot be comprehensive and must focus on a careful selection of key texts. In order to avoid the neglect of material important to the success of this fitness-for-purpose review, it is important for the project team to get your expert opinion on our choice of literature. While making your suggestions, please keep in mind that it will not be possible to expand the list considerably. Therefore, we would equally appreciate if you highlight references in the list that do not need to be included in your opinion. After reading the literature list, please answer the following questions:

2. Does the reference list contain the most relevant literature focusing on the comparison of methods for the estimation of greenhouse gas emissions embodied in goods and services in general or the comparison of IO-LCA, P-LCA and H-LCA in particular?
   □ Yes
   □ No
3. Is there any other important additional literature concerned with system boundary problems (upstream, downstream, technological, geographical) and other sources of uncertainty in ED-LCA, P-LCA and H-LCA? This also includes literature associated with emissions factors for non-combustion related GHG emissions. In addition to the provided list, are you aware of any literature concerned with the accuracy, precision and comparability of GHG emission estimates from lifecycle approaches for particular policy applications (e.g. labelling, supply chain management, product design, carbon trading etc.)?
   ○ Yes
   ○ No

4. Is there any other important field in the literature relevant for this fitness-for-purpose review, which has been neglected so far?
   ○ Yes
   ○ No

Section 3: Methodological questions

5. Do you think GHG emissions from the general operation of a company (e.g. payroll/administration) should be factored in when estimating the embodied emissions of a good or service produced by the company?

6. Is the inclusion of capital goods and GHG emissions thereof desirable?

7. Do you think GHG emissions of a good or service shall be included in the estimate of the embodied GHG emissions of the respective good or service?

8. Would the distinction between consequential and attributional lifecycle approaches be relevant for the estimation of the embodied GHG emissions in goods and services in general, and the PAS development, in particular? If so, which one would be used?
   ○ Yes
   ○ No
   Please comment
9. Please evaluate the data requirements and relevance of the following three lifecycle approaches:
   (1: low; 10: high)

<table>
<thead>
<tr>
<th>Product/commodity groups (e.g. food)</th>
<th>Individual products (e.g. chocolate bar)</th>
<th>Product brands (e.g. Skittles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data requirements</td>
<td>relevance</td>
<td>Data requirements</td>
</tr>
<tr>
<td>P-LCA</td>
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<tr>
<td>IO-LCA</td>
<td></td>
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<tr>
<td>H-LCA</td>
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</table>

10. For each product category, what are the implications of applying each of the three life cycle approaches to derive robust embodied GHG estimates of goods and services under reasonable budget restrictions? In terms of the budget restrictions, note that the PAS needs to be specified in a way that it can also be used by small and medium sized enterprises.
11. To what extent could the collection of primary data be required by the PAS given that small and medium-sized enterprises would work under tight budget restrictions? In which areas would you expect major difficulties if there were not sufficient resources for the collection of primary data?


12. There are various sources of secondary data, which can be used to fill data gaps or to substitute primary data (where data collection is costly) to derive robust estimates of the embodied greenhouse gases in goods and services? Should a selected number of secondary data sources be endorsed in the PAS description? If so, do you think available LCA databases are sufficiently comparable that they could all be endorsed as a secondary data source in the PAS specification?


13. GHG Emission factors from non-combustion processes – in particular for human induced agricultural and biological emissions – are much more uncertain than emission factor of fuel combustion processes. Do you think emission estimates can be established with sufficient confidence to be included in the PAS? What is most urgently required to deal with these emission sources?


14. Please describe what are, in your opinion, the main strengths and weaknesses of P-LCA, IO-LCA and Hybrid-LCA (keywords sufficient)

<table>
<thead>
<tr>
<th>Strength</th>
<th>P-LCA</th>
<th>IO-LCA</th>
<th>H-LCA</th>
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<tr>
<td>Weaknesses</td>
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</table>

15. What are the main areas where improvements are most urgently required to derive robust estimates of the GHG emissions embodied in goods and services?


Section 4: Evaluation

16. Different policy applications require different levels of robustness of the embodied GHG emissions estimates in goods and services. Which of the lifecycle approaches can provide sufficiently robust estimates of the embodied greenhouse gas emissions in goods and services for the following applications given reasonable budget constraints? In terms of the budget restrictions, note that the PAS needs to be specified in a way that it can also be used by small and medium sized enterprises.

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<thead>
<tr>
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<th>Product group</th>
<th>Individual products</th>
<th>Product brands</th>
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</thead>
<tbody>
<tr>
<td><strong>F-LCA</strong></td>
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<tr>
<td>Environmental labelling (type 1, type 2, type 3; not environmental claims)</td>
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<tr>
<td>Supply chain management</td>
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<tr>
<td>Eco-Product Design</td>
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<tr>
<td>Carbon trading</td>
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<tr>
<td><strong>IO-LCA</strong></td>
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<td>Environmental labelling (type 1, type 2, type 3; not environmental claims)</td>
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<td><strong>H-LCA</strong></td>
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<td>Environmental labelling (type 1, type 2, type 3; not environmental claims)</td>
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<td>Carbon trading</td>
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</table>

Please comment
17. Should this "Publicly Available Specification" (PAS) a) define and stipulate one specific methodology in great technical detail or should it b) define a more generic framework and set of criteria/guidelines for the estimation of embodied GHGs, thus allowing for the inclusion of different methodologies. Please tick:

- Option a
- Option b
- Neither of the two

Comment:

18. Overall, do you think it is possible to establish a robust PAS methodology, which can be used by all types of organisations including including small and medium enterprises, in terms of available time, money resources, knowledge and skills?

19. Are there areas where methodological improvements can be expected in the short or medium term for a more robust and/or a more PAS methodology?
14 References


