The Guide to PAS 2050:2011

How to carbon footprint your products, identify hotspots and reduce emissions in your supply chain

defra
Department for Environment Food and Rural Affairs

DEPARTMENT OF ENERGY & CLIMATE CHANGE

BIS
Department for Business Innovation & Skills

BSI
British Standards

The Guide to PAS 2050:2011

How to carbon footprint your products, identify hotspots and reduce emissions in your supply chain

defra
Department for Environment Food and Rural Affairs
Department of Energy & Climate Change
BIS
Department for Business Innovation & Skills
BSI
British Standards

Acknowledgements

The development of this Guide was co-sponsored by:

Defra (Department for Environment, Food and Rural Affairs)
DECC (Department of Energy and Climate Change)
BIS (Department for Business, Innovation and Skills)

Acknowledgement is given to ERM who authored this Guide. ERM has completed over 1,000 carbon footprints across more than 50 sectors and provides carbon footprinting and carbon reduction services to both UK and international clients.

Acknowledgement is also given to the following organizations who assisted in its development:

ADAS UK Limited
Defra
Food and Drink Federation
Institute of Environmental Management and Assessment
Carbon Trust

First published in the UK in 2011

by
BSI
389 Chiswick High Road
London W4 4AL

Typeset in Futura by Helius – www.helius.biz
Printed in Great Britain by Berforts. www.berforts.co.uk

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN 978-0-580-77432-4

Contents

Introduction

What is PAS 2050?

PAS 2050 is a publicly available specification that provides a method for assessing the life cycle greenhouse gas (GHG) emissions of goods and services (jointly referred to as 'products').

It can be used by organizations of all sizes and types, in any location, to assess the climate change impact of the products they offer.

PAS 2050 Clause X — This symbol is used in this Guide to highlight links to the relevant clauses in PAS 2050.

Why should I use PAS 2050?

While GHG emissions are often viewed at the global, national, corporate or organizational level, emissions also come from supply chains within a business, between businesses and between nations. Increasingly, it is seen as best practice for organizations to consider impacts beyond their own corporate activities – extending the scope of their 'carbon footprints' to include the impacts of the goods and services they produce. PAS 2050 provides a means for this.

PAS 2050 is a tool that can help you:

- carry out internal assessment of the existing life cycle GHG emissions of your products to identify 'hotspots' and related cost/energy saving opportunities
- evaluate alternative product configurations, sourcing and manufacturing methods, raw material choices and supplier selection
- devise ongoing programmes aimed at reducing GHG emissions
- report on corporate responsibility.

For consumers and businesses, carbon footprint information that has been calculated in accordance with PAS 2050 provides a common basis for understanding the life cycle GHG emissions of goods and services.

Neither PAS 2050 nor this guide provide requirements on how to communicate or publicly report emissions. PAS 2050 is intended primarily as a tool for internal, or business to business use. If you wish to communicate externally, you will need to refer to additional documents on environmental communication such as the international standard on self-declared environmental claims (ISO 14021)[1)] and Defra's *Green Claims Guidance*.[2)]

Why this Guide?

Many aspects of PAS 2050 are necessarily technical in nature. This Guide has been developed in order to assist users and provide clarity on specific technical aspects of PAS 2050 and how to use it in practice.

The Guide is intended to be used alongside PAS 2050, not to replace it. It explains how to undertake an assessment in accordance with the specification, and provides more detail and examples for some of the more technical aspects. However, it does not repeat all of the necessary detail within PAS 2050 and cannot be used in isolation.

Each main section in this Guide corresponds to a key step in the footprinting process, and numbered subsections are component steps within these key steps.

Use this Guide to …

- Help you get started on product carbon footprinting initiatives.
- Walk through the footprinting process, with step-by-step guidance on:
  - scoping to make sure your assessment is fit-for-purpose
  - data collection approaches, sources, hints and tips
  - calculating your footprint – how to tackle specific aspects of the calculation.
- Help you interpret footprint results and drive reductions.

[1)] See http://www.iso.org/iso/catalogue_detail?csnumber=23146.
[2)] See http://www.defra.gov.uk/publications/2011/06/03/pb13453-green-claims-guidance/.

The 2011 revision of PAS 2050

In 2011, PAS 2050 was updated to improve and refine the standard – based on initial experiences and international developments in product carbon footprinting. A key aim of the update was to align the PAS 2050 methodology and its use with other internationally recognized carbon footprint methods such as the GHG Protocol Product Standard[3)] and ISO 14067, *Carbon Footprint of Products* (in development).

Further information about the review, including a summary of changes document and a fact sheet about how PAS 2050 and the GHG Protocol Standard align, can be found on the BSI website.[4)]

Supplementary requirements

SR An important addition to PAS 2050 was the introduction of principles promoting the development and use of 'supplementary requirements' for different products or sectors. While PAS 2050 continues to drive consistency through greater prescription, there are instances in which the one-size-fits-all approach has limitations for some sectors or products. Supplementary requirements are intended to aid consistent application of PAS 2050 within product sectors by providing:

- a sector or product group focus for aspects of PAS 2050 assessment where options are permitted
- rules or calculation requirements that are directly relevant to the main sources of emissions for a specific sector or product group
- clarity on how to apply specific elements of PAS 2050 assessment within a specific sector or product group.

PAS 2050 provides the common framework for calculations in all of these instances, but it is envisaged that supplementary requirements will be developed for some sectors or product groups in order to provide greater detail on specifically relevant aspects. By definition, these will supplement PAS 2050, and need not duplicate its provisions. So, in many cases, supplementary requirements could provide further

[3)] See http://www.ghgprotocol.org/standards/product-standard.
[4)] See http://www.bsigroup.com/pas2050.

clarification on only one, or a small number, of aspects of the calculation process. The concept of supplementary requirements is akin to 'Product Category Rules' (i.e. developed through ISO 14025[5]) and 'Product rules' (GHG Protocol Product Standard) and may include either of these (if consistent with PAS 2050).

This symbol is used in this Guide to denote where you might be able to usefully refer to supplementary requirement documents for further clarity or information. Before you begin to carry out your assessment, look to see if there are supplementary requirements that may help you assess the emissions associated with your product. **Where they exist they should always be used.**

If there are no supplementary requirements for your sector, check to see whether other rules or guidance may be applicable.[6] If not, you may even want to consider starting to develop supplementary requirements within your industry.

For further discussion of supplementary requirements, see Annex I.

How do I know if a supplementary requirement or other product rules/PCR is applicable?

In short, you will need to check it complies with the principles in clause 4.3 of PAS 2050. In particular, you should check that it:

- does not conflict with the provisions of PAS 2050 unless this has been explicitly allowed for within a PAS 2050 provision (e.g. if justified, the time period for assessment may be different in supplementary requirements to the 100 year period identified in PAS 2050)
- has been developed through a consensus-based process and well recognized (i.e. within your sector and/or internationally)
- has a scope that is applicable to your industry/stakeholders and it is comprehensive.

[5] ISO 14025:2006 *Environmental labels and declarations – Type III environmental declarations – Principles and procedures.*

[6] For example, see the PCR library at http://pcr-library.edf.org.tw/about/index.asp.

Making product carbon footprinting work in practice

Product carbon footprinting should be used as a practical tool that is tailored to the needs of your organization. It can be used to identify the main sources of emissions for all types of goods and services, from oranges to nappies and from bank accounts to hospitality.

Consideration of the goal/objectives of a carbon footprint study is of paramount importance, to ensure that it will deliver the information that you need. In assessing your own organization's needs, consider the following:

- **Your core business priorities.** How could an in-depth understanding of the wider GHG impacts, risks and opportunities of goods and services support your strategy/business priorities? Are any products, supply chains or markets particular priorities? What are the expectations of your customers and investors?
- **Judicial selection of products.** Identify the products that make most sense to assess and improve, e.g. the top-five best sellers or top-three new designs. Decide where you want to focus your attention, bearing in mind that you cannot do everything at once.
- **The intended audience for a study.** This affects the degree of accuracy and resolution needed. A footprint analysis to be used to identify opportunities for reduction can be undertaken efficiently and at a high level initially, to be built on as needed. For external claims, gaining assurance is best practice, and a rigorous approach to data collection will need to be demonstrated.
- **Your timescale.** How does this process fit in with your product management cycle? Decide how much

can realistically be achieved and to what degree of accuracy, what data are available and what is the project's timescale.

- **Internal stakeholders.** Could the footprinting process provide valuable information for other parts of the business? Buy-in from a wide range of internal stakeholders, from designers to procurement, will aid the internal business case and will provide key support for data collection and, ultimately, drive impact reductions.
- **Supplier engagement.** Identify suppliers that could work with you along the way, and try to involve them at as early a stage as possible. This will help immeasurably with data collection, and can support the development of strong relationships.

It is always important to bear in mind that carbon is just one of a range of environmental indicators. Although for many products a focus on carbon will be justified, where other impacts are particularly important (e.g. sustainable sourcing) you may want to look at other tools as well as, or instead of, PAS 2050. With any choices you make in reducing emissions, you should always consider what trade-offs in other environmental impacts may occur.

Things to have to hand

The following will be useful to have to hand when starting on scoping activities:

- an up-to-date bill of materials, or standard operating procedure for your product/packaging or service
- production/energy use/waste statistics for your operations
- information on the distribution of your product
- a list of suppliers and supplier locations.

The stepwise footprinting process

A footprinting project should always be broken into a series of steps. These are sequential and cannot be carried out in isolation. The following sections of the Guide describe each in detail:

Step 1 – scoping
- Describe the product to be assessed and unit of analysis
- Draw a map of the product life cycle
- Agree the 'system boundary' of the study
- Prioritize data collection activities

Step 2 – data collection
- Draw up a data collection plan
- Engage with suppliers to collect primary activity data
- Collect secondary emission factors and other secondary data to fill gaps
- Check data and assess data quality

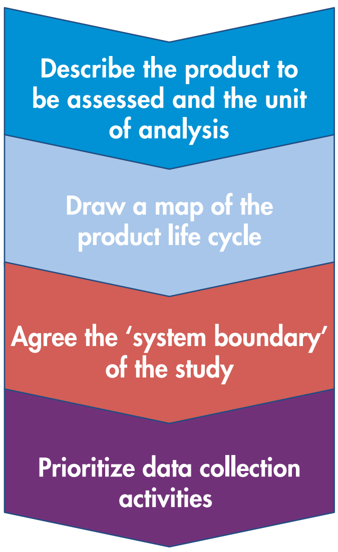
Step 3 – footprint calculations
- Compile activity data and balance flows according to the functional unit
- Multiply activity data by emission factors to generate footprint
- Check calculations and record all data sources and assumptions

Step 4 – interpreting footprint results and driving reductions
- Identify hotspots
- Test sensitivity
- Identify reduction opportunities
- Ensure transparency where communicating

Step I
Scoping

Scoping is the most important step when undertaking any product carbon footprint study. It ensures that the right amount of effort is spent in getting the right data from the right places to achieve robust results in the most efficient manner possible.

There are four main stages to scoping, and they are best undertaken sequentially.



Key terms used in this section

Functional unit – the quantified performance of a product system for use as a reference unit.

Reference flow – the amount of studied product needed to fulfil the functional unit.

System boundary – a description of the processes and activities that are part of a product system and are to be included in the assessment.

1.1. Describe the product to be assessed and the unit of analysis

PAS 2050 Clause 5.9

It is vital that the product to be assessed is clearly defined at the outset. For its carbon footprint, the product must be defined in terms of a 'functional unit'. The functional unit defines the function of the product that will be assessed and the quantity of product to which all of the data collected will relate.

Example: a functional unit for orange juice

Take the carbon footprint of orange juice as an example: the function of orange juice is to be consumed. A sensible quantity of orange juice to assess is 1 litre, being a common unit retailed. Hence, a sensible functional unit for the carbon footprint of orange juice would be '**1 litre of juice available for consumption**'.

Note that there is a difference between 1 litre of juice available for consumption and 1 litre of juice produced, as a proportion of products will be damaged during transportation or unsold past the shelf life, etc. Defining the functional unit in this way means that this wastage is taken into account. The carbon footprint assessment must therefore look at all of the materials and processes required to produce and deliver 1 litre of orange juice to a customer, as well as the downstream implications that occur as a result of its consumption.

SR Supplementary requirement documents may provide guidance for the definition of functional units in certain sectors or for specific products. If these are compatible with PAS 2050, they should be followed.

Why are functional units important?

By defining the product to be assessed as a quantified functional unit, it provides a reference to which all of the studied inputs and outputs across a product system are related, which helps to ensure the consistency and comparability of results. Consider the example of comparing paint products in the box below.

Defining a functional unit for services

Whether the product being assessed is a good or a service, the same general approach should be used. Setting a clear functional unit for services is very important, and needs careful consideration. Annex B provides some further guidance. A few examples of service functional units include:

- car insurance – the provision of car insurance cover for a period of 1 year
- a taxi ride – a journey in a taxi for one passenger for a distance of 1 km
- window cleaning – the service of cleaning of 1 m^2 of window
- online bank account – the provision of online banking services for a period of 1 year.

1.2. Draw a map of the product life cycle

Once the functional unit has been defined, the next step is to map out the life cycle of the product to be assessed. The process-mapping stage is an initial brainstorm exercise to map all of the 'flows' of materials and energy in and out of the product system as they are used to make and distribute the product. This sets the framework for the 'system boundary' (see Step 1.3 of this Guide), which considers these 'flows' in more detail.

The process map can be as simple or as detailed as is deemed necessary or as time permits. It is a good idea to focus on the most important aspects (e.g. heaviest materials, key energy flows) first, to avoid unnecessary detail. The map can always be expanded upon later if needed.

It is useful to include the whole life cycle (even if only a cradle-to-gate/business-to-business assessment is to be carried out) to make sure that important considerations

Defining the functional unit and reference flows to compare products

When making comparisons between the carbon footprints of products, it is very important to have a well-defined functional unit. In order to make these comparisons, the functional unit is translated into a 'reference flow' for each product to be compared. This reference flow is the amount of a product that is required to fulfil the functional unit, and will be specific to each product assessed.

For example, three different paint products may have the following sets of characteristics:

Functional unit: the covering of 1 m^2 of wall area by one coat of emulsion paint for a period of 20 years

Paint	Coverage	Durability	Reference flow
Paint A	50 ml/m^2	20 years	50 ml paint
Paint B	60 ml/m^2	20 years	60 ml paint
Paint C	40 ml/m^2	10 years	80 ml paint

By defining the unit of comparison as the functional unit, rather than a unit of volume, the performance and characteristics of each product are taken into account, and a fair comparison can be drawn.

'downstream' of your activities are not overlooked, such as recyclability at end-of-life, or potential to influence use phase emissions.

For each stage on the process map:

- provide a description of the activity to aid with data collection
- identify the geographic location of each distinct step where possible
- include all transport and storage steps between stages.

An example for orange juice is shown in Figure 1.

1.3. Agree and record the system boundary of the study

PAS 2050 Clause 6.1

Once the process map is complete, it can be used to help identify which parts of the overall system will, and will not, be included in the assessment.

As an output from this scoping stage, you should clearly document and record the 'system boundary' in terms of:

- a list of all included life cycle stages (e.g. raw materials, production, use, end-of-life)
- a list of all included activities and processes within each life cycle stage
- a list of all excluded activities and processes, and the steps taken to determine their exclusion.

Consider the following when setting system boundaries:

- which GHG emissions and removals to include
- cradle-to-gate (i.e. business-to-business) assessments versus cradle-to-grave (business-to-consumer) assessments
- which processes and activities to include or exclude
- time boundaries.

SR

In some cases, supplementary requirements may dictate the system boundary that should be used for a particular product system. Where these are compatible with PAS 2050, the system boundary set out in these documents should be used.

Which GHG emissions and removals to include?

PAS 2050 Clause 5.1 Annex A

According to PAS 2050, a carbon footprint must include all emissions of the 63 GHGs listed in the specification. These include carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), plus a wide range of halogenated hydrocarbons including CFCs, HCFCs and HFCs. Each of these types of GHG molecule is capable of storing and re-radiating a different amount of energy, and therefore makes a different contribution to global warming. The relative 'strength' of a GHG compared with carbon dioxide is known as its global warming potential (GWP), for example 25 for methane.

Product carbon footprints are reported as carbon dioxide equivalents (CO_2e). This refers to the amount of each GHG by its global warming potential (e.g. 2 kg of methane = 2 × 25 = 50 kg CO_2e).

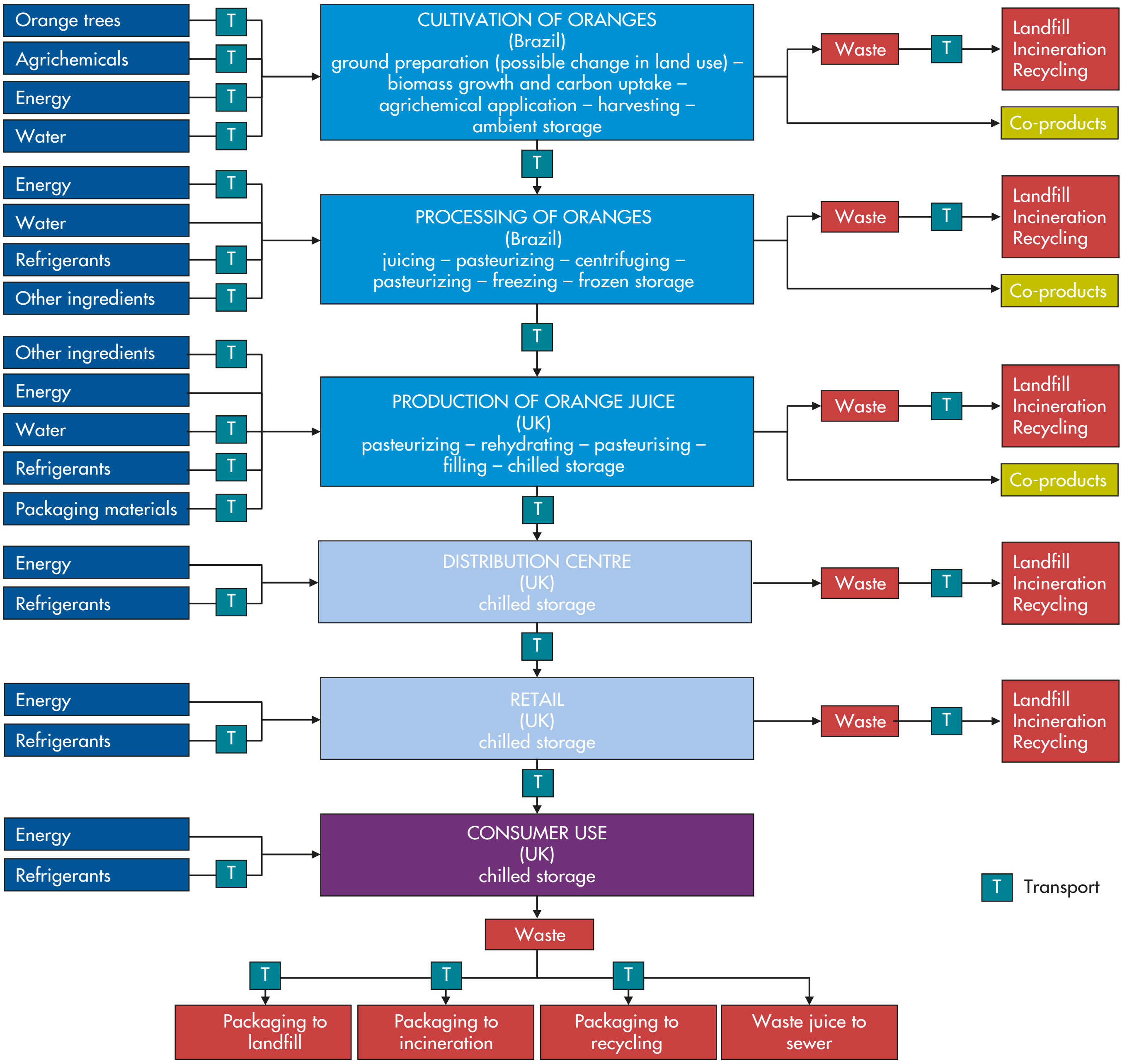


Figure 1: An example process map for orange juice

Table 1 shows the global warming potentials and common sources of some of the most important GHGs covered under PAS 2050.

Removals of carbon from the atmosphere (e.g. by plants and trees) must also be included in the assessment, except in the case of the biogenic carbon contained within food or feed products. This can be a tricky aspect of the footprint calculation process (e.g. for paper- and wood-based materials), and is a new PAS 2050 requirement. Further guidance is provided in Step 3.2, heading 'Biogenic carbon accounting and carbon storage', and Annex G of this Guide.

A cradle-to-gate or cradle-to-grave assessment?

PAS 2050 Clauses 4.5, 6.2

PAS 2050 allows for two standard types of assessment (Figure 2), which are often used for different purposes:

Table 1: Global warming potentials and common sources of some of the most important GHGs

CHG	GWP	Key sources
Carbon dioxide (CO_2)	1	Combustion of fuels, cement manufacture
Methane (CH_4)	25	Agriculture, oil and gas extraction and processing, mining, landfill, wastewater and sludge treatment
Nitrous oxide (N_2O)	298	Agriculture, adipic acid (a precursor of nylon) and nitric acid production, waste water treatment, combustion processes
Hydroflurocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs)	77–14,800	Refrigerant manufacture and use
Perfluorocarbons (PFCs)	7390–17,700	Refrigerant manufacture and use, aluminium and magnesium smelting
Sulphur hexafluoride (SF_6)	22,800	Aluminium and magnesium smelting, high-voltage switching equipment

Source: IPCC (2007), Table 2.14; see Clause 2.[7)] 100-year time horizon.

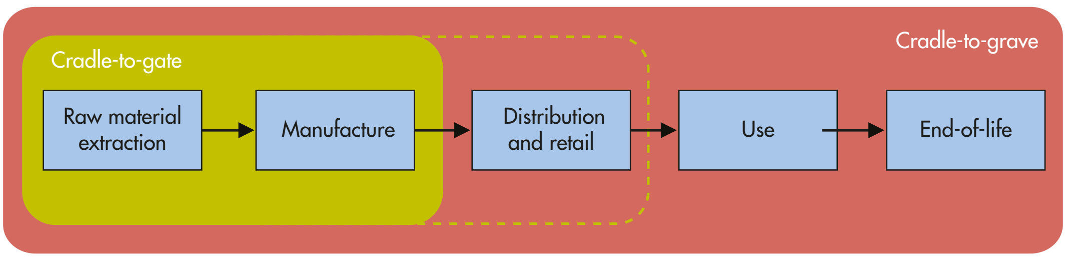
Note: the GWP actually used in calculations should be the latest available from the Intergovernmental Panel on Climate Change (IPCC), and you should check this periodically.

1. **Cradle to gate** – which takes into account all life cycle stages from raw material extraction up to the point at which it leaves the organization undertaking the assessment.
2. **Cradle to grave** – which takes into account all life cycle stages from raw material extraction right up to disposal at end of life.

Cradle-to-gate and cradle-to-grave assessments

Cradle-to-gate assessments are commonly used where a buyer has asked a supplier to provide information on the carbon footprint of the product they supply. In this case, it makes sense to report emissions that occur only up to the point at which the product is transferred to the buyer. It also enables footprints to be incrementally calculated and reported across a supply chain.

While useful in this context, cradle-to-gate assessments lack the completeness of a full cradle-to-grave assessment, and may miss a large proportion of the impact for certain products. For example, for energy-using products, the vast majority of the overall carbon footprint will result from the electricity used in the use phase. This impact would only be included in a cradle-to-grave assessment.



Note: cradle-to-gate boundaries can vary according to the position of the 'gate'

Figure 2: Cradle-to-gate and cradle-to-grave assessments

[7)] IPCC (2007) *Climate Change 2007: Synthesis Report*. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Core Writing Team: R. K. Pachauri and A Reisinger (eds)). IPCC, Geneva.

For this, and other reasons, care should be taken when recording a cradle-to-gate assessment to ensure that it cannot be mistaken for a full cradle-to-grave assessment (see Step 4 of this Guide).

Which processes and activities to include?

PAS 2050 Clause 5.1.2

Every single process and activity occurring within the defined system boundary needs to be considered in a PAS 2050 assessment. These processes and activities are directly connected to the product and are required to enable it to perform its function.

PAS 2050 Clause 6.4

Clause 6.4 of PAS 2050 gives requirements on the elements of a product life cycle that need to be included (see the box below).

Although every product is different and will involve different processes and activities, these examples may help in the thought process when considering what needs to be included. Also refer to the process map you developed in Step 1.2.

Collecting data on and subsequently modelling every single process and activity may sound like a daunting task, but remember that publicly available, secondary data can be used for portions of the life cycle, which can cover multiple processes and activities (see Step 2 of this Guide).

PAS 2050 also allows you to exclude things that are likely to be very small contributors to the footprint – as discussed in the following section.

Elements of a product life cycle

- Production materials (e.g. extraction of raw materials from the earth, crop production, rearing of livestock, direct land use change).
- Energy (e.g. electricity required to run machinery, fuel used to heat a building).
- Production processes and service provision (e.g. electricity required to drive a process, direct GHG emissions resulting from a chemical reaction).
- Operation of premises (e.g. electricity used to light a retail outlet, fuel used to heat an office, leakage of refrigerants from a warehouse).
- Transport (e.g. transportation of raw materials to processing plant by road, rail, air or water, conveyor belt movements within a site, operation of pipelines)
- Storage (e.g. energy required to heat, cool or light a warehouse, energy used to operate a freezer used to store a product prior to use).
- Use phase (e.g. energy consumed when using the product).
- End-of-life (e.g. waste disposed of in a landfill, waste recycled into another product).

Excluding processes and activities

PAS 2050 Clause 6.3

PAS 2050 (through Clause 6.3) allows some elements of the footprint to be excluded in order to simplify the process. Flows anticipated to contribute less than 1 per cent of the total footprint can be excluded from the system boundary of the carbon footprint, provided that at least 95 per cent of the total anticipated emissions are included.

A general rule of thumb is that components or materials contributing less than 1 per cent of the dry mass of a product can be excluded, as they are likely to be immaterial.

Before excluding a flow from a study on this basis, check whether there is anything about those components or materials that could mean they have higher than usual emissions. This can occur when there is the potential for land use change emissions (see Step 3.2, heading 'Land use change') or when they include a very high-intensity material (e.g. aluminium) among otherwise low-intensity materials. Table 2 gives some common examples of high- and low-intensity materials and processes.

Such excluded flows may include the smaller components of a complex product, provided their impact is likely to be low (e.g. seasonings in food products or door handles in residential buildings). Cleaning chemicals and other minor or ancillary chemical inputs can also often be excluded in this way, as can transport packaging for bulk raw materials.

Table 2: Examples of high- and low-intensity materials and processes

Very high (>5 kg CO_2e per kg)	High (1–3 kg CO_2e per kg)	Medium (<1 kg CO_2e per kg)	Low (<0.1 kg CO_2e per kg)
Refrigerants Electronic components Meat products Aluminium Other metals (except steel) Pigments/dyes Some concentrated foodstuffs Laundry/hot water treatment	Plastics Most chemicals Fuels Dairy products Greenhouse crops Rice Peat Freezing Cooking	UK/EU field crops Glass Paper and cardboard Plastics processing Landfill of biodegradable materials	Unprocessed minerals (e.g. gravel, sand) By-products (e.g. straw, woodchips, some animal feeds) Water production and processing Transport <1,000 km by articulated lorry, or <20,000 km by sea Landfill of non biodegradable materials

It is vital that at least 95 per cent of the total mass and at least 95 per cent of the total anticipated impact of the final product is being assessed. Double check this during data prioritization calculations (see Step 1.4).

Other things that are excluded from a PAS 2050 assessment

PAS 2050 Clause 6.4.4

SR

- Emissions associated with the production of 'capital goods' – i.e. machinery or buildings that have a lifespan >1 year (consumables that have a lifespan of <1 year should be included though), except where supplementary requirements dictate otherwise.
- Human energy inputs to processes and/or pre-processing (e.g. if fruit is picked by hand rather than by machinery).

PAS 2050 Clause 6.5

- Transport of consumers to and from the point of retail purchase.
- Transport of employees to and from their normal place of work.

System boundaries for services

Setting system boundaries for services, in particular, can be challenging. Some guidance on doing so is provided in Annex B.

System boundaries for services

Product systems are typically categorized into a series of interconnected stages that can be applied to the majority of products (i.e. extraction of raw materials, manufacture, distribution and retail, use and end-of-life). However, describing life cycles in this way can be more difficult for services, as not all life cycle stages may be relevant, and some may appear more than once throughout the life cycle. An attempt should be made to categorize the life cycle of the service in the same way as a good, combining life cycle stages where necessary (e.g. combining production and use into the service delivery stage). Where it is not appropriate to categorize the life cycle in this way, processes and emissions should be categorized according to the major activities of the service. This is particularly relevant for the delivery of an intangible product (e.g. provision of knowledge). Take the two differing examples of servicing a car and providing car insurance. The former may categorized into some of the typical life cycle stages used for a good (i.e. extraction of raw materials, manufacture, distribution and retail, use and end-of-life), but the latter should be categorized according to its major activities – this may include provision of the quote, period of cover, servicing of the claim and renewal of the policy.

Time boundaries

PAS 2050 Clause 5.2

Carbon footprints carried out according to PAS 2050 are assessed within a 100 year time boundary. This affects calculations where carbon is stored within a product. For example, carbon dioxide stored in timber or concrete may persist in a building, a piece of furniture or another long-lasting product for more than 100 years. If this is the case, the eventual emission of this carbon to the atmosphere is beyond the scope of PAS 2050, and is not included in the carbon footprint of the product.

Step 3.2, heading 'Biogenic carbon accounting and carbon storage', and Annex H of this Guide discuss how you should account for carbon storage where it occurs. The most common instances are where products have an anticipated lifespan of more than 100 years, or where slowly degrading organic materials (e.g. wood, paper, natural textiles) are disposed to landfill.

SR

Note that, where significant emissions are expected to occur beyond 100 years, supplementary requirement documents may specify that these should be included.

1.4. Prioritize data collection activities

PAS 2050 Clause 6.3

Having defined a system boundary, the next step in the scoping stage is to prioritize data collection activities. Data collection is commonly the most time- and resource-intensive step in any carbon footprint assessment; therefore, prioritizing the data that are needed is a very good idea. It is usually not worth spending significant time and effort getting precise and accurate data for a life cycle stage that have very little impact on the overall footprint. Efforts and priorities should also be linked to the intended purpose of the study.

Identify potential emissions 'hotspots' at a high level early on in the process, and focus your efforts.

A good initial check is to look for any previous carbon footprint or life cycle assessment (LCA) studies that have been carried out on the product system (or a similar product system) to be studied. A quick internet search, using typical search engines, or specialized hubs, such as Seeds4Green[8] can help with this.

Industry guides, like Best Available Technique Reference documents (BREFs)[9] and handbooks may also provide a high-level overview of a product system, as well as technical data, from which potential hotspots can be identified.

- Raw materials are commonly a hotspot for the carbon footprint of a product. By using a bill of materials and/or the process map, it is possible to do some quick, 'back of the envelope' calculations to identify areas where the impact is likely to be high, and therefore primary data collection should be prioritized (e.g. see Annex C for a worked example for orange juice).
- Processing energy is also often a large contributor to emissions. By looking at the process map it is possible to identify potential processes that are likely to use a lot of energy. Even if a rough amount for energy consumption is known (e.g. from industry guidance), it is possible to do the same 'back of the envelope' calculations to ascertain where in the life cycle specific information is likely to be needed. An example for orange juice is shown in Annex C.

SR

Note that supplementary requirement documents may contain guidance as to where potential hotspots of emissions may occur within a product system, and may even provide guidance on data collection and prioritization.

[8] See http://www.seeds4green.net.
[9] See http://eippcb.jrc.es/reference.

Step 2
Data collection

Types of data

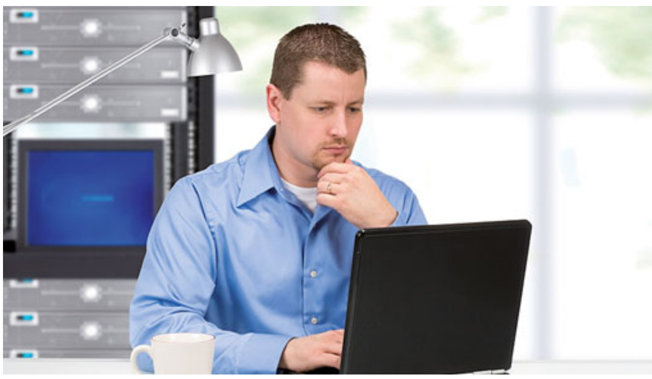
The data needed to carry out a product carbon footprint calculation fall into the following categories:

- **Activity data**: referring to quantities of **inputs** and **outputs** (materials, energy, gaseous emissions, solid/liquid wastes, co-products, etc.) for a process – typically described for a unit of production for a specified year of production (e.g. kg of oranges per kg of concentrate production in 2011). This also includes details of any transportation of incoming materials, wastes or distribution of the final product (distances travelled, vehicles used, etc.).

  Activity data can be from either:

  – **primary sources** – first-hand information, specific to the activity in question (e.g. producing orange concentrate at plant x), collected internally or from the supply chain or

  – **secondary sources** – average, or typical, information about a general activity (e.g. juicing of oranges, concentration of juice) from a published study or other source.



- **Emission factors**: values that convert activity data quantities into GHG emissions – based on the 'embodied' emissions associated with producing materials/fuels/energy, operating transport carriers, treating wastes, etc. These are usually expressed in units of 'kg CO_2e' (e.g. kg CO_2e per kg of orange cultivation, per litre of diesel, per km of transport or per kg of waste to landfill), and are most often from secondary sources.

Choosing between primary and secondary data

Collecting primary activity data for specific activities across the supply chain can be time consuming, and so often dictates the amount of resource needed for a footprinting study. But the use of primary data generally increases the accuracy of the carbon footprint calculated, as the numbers used in the calculation relate directly to the real-life production or provision of the product or service assessed. Secondary data are usually less accurate, as they will relate to processes only *similar* to the one that actually takes place, or an industry average for that process.

The choice between primary and secondary data should be guided by the scoping/prioritization activities undertaken in Step 1, as well as the underlying PAS 2050 principles of:

PAS 2050 Clause 4.2

- **relevance** – selection of appropriate data and methods for the specific products
- **completeness** – inclusion of all GHG emissions and removals arising within the system boundary that provide a material contribution

- **consistency** – applying assumptions, methods and data in the same way throughout the assessment
- **accuracy** – reducing bias and uncertainty as far as practical
- **transparency** – where communicating externally, provide sufficient information.

In accordance with the principles of 'relevance' and 'accuracy', primary data are generally preferred.

PAS 2050 Clause 7.3

Specific primary data requirements for PAS 2050

PAS 2050 requires that the company undertaking a carbon footprint collects primary data for its own operations and the operations under its control (e.g. product distribution). In addition, at least 10 per cent of the total cradle-to-gate emissions must have been calculated from primary data. Often, especially if the company undertaking the footprint is the manufacturer, this 10 per cent threshold will be reached though the company's emissions alone. In situations where this is not the case, there is a need to collect primary activity data from the supply chain. You can determine where this may occur as part of the data prioritization calculations undertaken during scoping.

Note that, while the general rule is that primary data are preferred, there are some exceptions to this; for example, the case of commodity goods (see the following box).

Commodity goods

In the case of commodity goods – i.e. those bought from variable suppliers according to the current price at time of purchase – primary data from one or several suppliers will not necessarily be representative of the purchased product. Average secondary data regarding the emissions resulting from this product are likely to be more accurate than primary data from a restricted and potentially biased sample. Wherever possible, geographically specific averages should be used.

A key first task in the data collection process is to consider primary and secondary data needs and draw up a data collection plan.

2.1. Draw up a data collection plan

PAS 2050 Clause 7.3

Having prioritized data needs during scoping, it is good practice to develop a data collection plan, to focus efforts and provide a reference to draw on.

PAS 2050 Clause 7.6

The data collection plan should outline top targets for primary data collection, and highlight areas where secondary data will be sought instead, recognizing where primary data collection may not be feasible. It does not have to be too detailed, or formal, but should cover all of the data you will need for the carbon footprint assessment (see Table 3).

2.2. Engaging suppliers to collect primary data

Engaging suppliers in the carbon footprint process will help you to collect specific primary data for your supply chain, giving greater insight into emissions sources. It can also encourage future co-operation in terms of finding practicable opportunities to reduce the footprint.

- Suppliers should be approached as early on in the process as possible, ideally as part of the scoping exercise. This will give you a clearer idea of the level of involvement you can expect, and give them the opportunity to get engaged.
- Some suppliers might be sensitive about providing data. A clear explanation of the purpose of the carbon footprint exercise, and why their production data are important, can go a long way in providing reassurance about how their information will be used.

Data collection templates

A carefully considered data collection template is a very useful tool to ensure that you get the right information from suppliers. The most successful data collection templates are tailored to a specific product or process. If tailoring the data collection template is not possible, a generic template will still offer a valuable tool to provide you with the primary activity data you need for your footprint calculations.

Table 3: An example data collection plan for orange juice (drinks producer collecting data)

Data required	Anticipated source
Primary data	
Inputs and yields for the cultivation of oranges	Primary data from three farmers (Spain)
Energy and material use in the manufacture of concentrate	Primary data from OrangeCo (Spain)
Energy and material use in the production of drink product	Internal primary data
Energy use in filling	Internal primary data
Primary and secondary packaging	Weights – internal primary data
Distribution details	Internal primary data for pallet plans
Secondary data/assumptions	
Transport of raw materials	Assumed available locally – 150 km, secondary emissions factors
Transport of oranges from farms to OrangeCo, and concentrate from OrangeCo to Superdrinks	Distance calculated from addresses Secondary emissions factors
Fuels, electricity and agricultural input production	Secondary emissions factors
Packaging material production (including any biogenic carbon removals)	Secondary emissions factors
Chilled storage at distribution centres, and retail	Secondary/average data and assumptions
Use and end-of-life profile (e.g. length of refrigeration, amount wasted)	Secondary/average data and assumptions

Some example data collection templates, showing both generic and tailored approaches, as well as some useful tips, are provided in Annex D.

The data collection template can also be used to ask for information to assess the quality of data provided. This involves a few additional questions for each data point, which will help you to ascertain how much confidence you can have in the accuracy of the data and, consequently, the accuracy of the carbon footprint.

PAS 2050 Clause 7.7

Sampling

In some cases, a product will be produced at a large number of sites. Milk in the UK, for example, is typically supplied by a large number of small/medium-sized farms, each providing an identical product (note: as suppliers are known and constant, this is different from a commodity good as earlier described). In this case, data collection for each site could be prohibitively time consuming, and a sampling approach is required. Annex E provides some guidance on sampling options.

As with all footprinting tasks, resources should be allocated in the most efficient manner, while giving consideration to the core PAS 2050 principles earlier described.

2.3. Collecting and using secondary data

Secondary data are typically used in footprinting studies as a source of:

- emission factors – which convert primary activity data (material/energy/process inputs and outputs) into GHG emissions (in kg CO_2e)
- information to fill gaps in primary activity data
- information to calculate the impact of 'downstream' life cycle stages e.g. use and end-of-life (you do not need primary data for these stages).

Secondary data sources

In describing the different types of secondary data available, and the ways in which they should be differently handled, the terms 'aggregated' and 'disaggregated' are useful:

- Aggregated data comprise previously calculated emission factors (in kg CO_2e), and are often contained in technical reports and published studies. This category also includes cradle-to-gate carbon footprint values that your suppliers might give you in response to a data request.
- Disaggregated data are most often found in life cycle inventory (LCI) databases that list all the inputs and outputs for a given process. These detail the consumption of specific raw materials/energy carriers and individual emissions, as opposed to a summary of the total CO_2e emissions.

Aggregated data/emission factor sources

Table 4 provides a list of useful sources of easily accessible emission factors. These are a starting point, but are by no means a definitive list of available resources.

If you are using aggregated secondary data/emission factors, be careful to check that they are fit for purpose. For example, is the system boundary used compliant with PAS 2050 boundaries? Some useful things to check are outlined in the box on page 17.

Table 4: Useful sources of emission factors – some examples

Data category	Aggregated secondary data source
Electricity, fuel	Department for Environment, Food and Rural Affairs (Defra)/Department of Energy and Climate Change (DECC) GHG reporting factors US EPA eGRID database
Transport	Department for Environment, Food and Rural Affairs (Defra)/Department of Energy and Climate Change (DECC) GHG reporting factors US Department of Energy GREET Model
Agrochemicals, Biomaterials and Food products	National Non-food Crops Centre (NNFCC), Environmental Assessment Tool for Biomaterials
	Food Climate Research Network (FCRN) and World Wildlife Fund (WWF), *How Low Can We Go?*
	Danish Food LCA database
	Carbon Trust Carbon Footprint Registry
Building materials	University of Bath. Inventory of Carbon and Energy (ICE) database Carbon Trust Carbon Footprint Registry

Emission factors: quick checks

Do the numbers look reasonable?

- Check the table of typical emissions included in Step 1.3 (Table 2).

Does the emission factor reflect cradle-to-gate emissions, or cradle-to-grave emissions?

- Use and end-of-life emissions may need to be removed to avoid double counting.
- If transportation is not included, it will need to be added. Transportation should include all incoming transport of materials to the process, as well as transport of the finished material to the next supply chain stage.

Does the emission factor need to be location-specific?

- If the emission factor is a large contributor to the footprint and the product is likely to be produced in different ways in different locations (e.g. salad crops), consideration of location will be required.
- If the emission factor is a large consumer of grid electricity, consideration of the country of manufacture will be required. Grid electricity emissions differ significantly between some countries.

Are there any potential inconsistencies with the PAS 2050 method?

- Is biogenic carbon uptake, and subsequent release, accounted for appropriately?
- If there is potential for land use change that has not been accounted for in the emission factor, this will need to be added.
- If the product processes are likely to generate co-products (e.g. agricultural processes), appropriate allocation methods should have been used (see Step 3.1, heading 'Co-product allocation'). Supporting evidence should be provided to demonstrate this.
- Capital burdens are often included in secondary databases. As such, emissions might be overestimated in comparison with PAS 2050 boundaries. These emission factors can be used, but the inconsistency should be noted.

Disaggregated/inventory data sources

A list of common life cycle inventory (LCI) databases can be found at: http://lca.jrc.ec.europa.eu/lcainfohub/databaseList.vm. Some databases are free, whereas some charge a licence fee.

- An example of a licensed database is the ecoinvent LCI database found at http://ecoinvent.org. This is a useful source of data for over 4,000 materials and processes.
- Examples of free databases are the European Reference Life Cycle Database (ELCD) found at http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm, and US Life Cycle Inventory Database found at http://www.nrel.gov/lci/database/default.asp, both of which contain LCI datasets for selected materials and processes.

Typically, when using LCI databases, the inventory data are modelled in an LCA software programme, to provide emission factors (aggregated data) that can be used in a carbon footprint. However, if needed, the values for individual emissions listed in the LCI database can be used to estimate the global warming potential without the use of LCA software. Tips for using LCI data in this way are as follows:

- Copying the LCI data into a spreadsheet (e.g. Microsoft Excel) might make it easier to view and interrogate.

- Identify emissions of key GHGs. As a minimum, emissions of fossil/biogenic carbon dioxide, methane and nitrous oxide should be identified, which are the predominant GHGs in the majority of instances. However, other key GHGs, such as CFCs and HCFCs, might also be included in the inventory data.
- The identified GHG emissions values can then be multiplied by their respective global warming potential, and the results summed to derive a 'kg CO_2e' emission factor that can be used in your product carbon footprint calculations.
- Ideally, the quantity of all key GHGs will be identified. In practice, this can be a laborious task that might only involve very minor emissions. In this case, it should be recognized that the resulting emission factor might be an underestimate, and should be clearly labelled as such in the product carbon footprint calculations.

2.4. Collecting data for 'downstream' activities

'Downstream' activities refer to processes that occur during product distribution, retail, use and end-of-life. Of these, you typically only need to collect primary activity data for distribution (unless retail is part of your business activities). However, the use phase can be the most important life cycle stage for products that need energy for operation, require cooking, etc.

Distribution

PAS 2050 Clauses 6.4.6, 6.4.7, 6.4.8

In many instances you will need to collect primary data for product distribution, if under your operational control. Distribution typically comprises transportation to a retail market and a period of storage in a distribution centre or warehouse. Specific data needs and emissions calculations for these activities are discussed in Step 3.2, headings 'Refrigeration' and 'Storage emissions', of this Guide.

Whether this distribution step represents an average geography (e.g. products retailed in the UK, or Europe – taking a weighted average based on sales in different locations) or specific region (e.g. products retailed in London/England/Wales) can be defined within your functional unit.

Retail

PAS 2050 Clause 6.4.6

For the majority of products, emissions from retail operations will represent a very small part of the overall carbon footprint. The main source of emissions will be energy use for both lighting and refrigeration.

If primary data for energy use by a retail facility are not available, emissions from retail of products stored at **ambient** temperatures can reasonably be assumed to be comparable to those from a warehouse (see Step 3.2, heading 'Storage emissions', of this Guide).

Refrigerated or **frozen** storage at retail may represent a significant source of emissions, and so should be considered in more detail. See further information on refrigeration in Step 3.2, heading 'Refrigeration', of this Guide.

You will typically need to consider the volume of space occupied by a product, and how long it is typically stored for at the point of sale (e.g. slow-moving items must be stored for longer, and so incur greater emissions).

Use

PAS 2050 Clause 6.4.9

A 'use profile' is a description of the typical way in which a product is consumed, or of the average user requirements. For example:

- a use profile for product that requires cooking will refer to the proportion of users that will typically bake, boil or microwave the product and the amount of time required in each case
- a use profile for an electrical item will refer to a typical length of time the product is used for, or a typical setting (e.g. the proportion of washing machine cycles at 30/40/60 degrees).

For some products, the choices made at this stage can make a significant contribution to the footprint, and introduce considerable variability, and so require careful consideration.

SR

Wherever possible, supplementary requirement documents should be referred to in order to determine the use profile for a product footprint.

If a use profile is not defined in a supplementary requirement document, published international standards, national guidelines or industry guidelines that specify a use phase for the product being assessed should be sought (in that order of preference).

If a standard use profile is not defined in any of the above sources, the use profile of a product should be determined by investigating the function of the product and its typical application. Key questions to consider are:

- Does the product need anything done to it or added to it in order for it to be used? For example, shower gel requires water for use; pasta requires water and cooking for use.
- Does the product consume energy during use? For example, a light bulb requires electricity to be used.
- Does the product need to be kept chilled or frozen prior to or between uses by the end user? For example, perishable foods and certain medicines will require chilled storage, which requires energy to be used.

End-of-life

PAS 2050 Clause 6.4.10

An 'end-of-life profile' is a description of the typical fate of a product and its packaging at the end of its useful life (i.e. the proportion disposed to landfill/incineration, or the proportion recycled).

SR

Where possible, supplementary requirement documents should be referred to in order to determine the end-of-life profile. If an end-of-life profile is not defined in a supplementary requirement document or in supporting reference information, it can be estimated based on typical or average waste management practices. Any assumptions should be clearly noted in the carbon footprint calculations.

For all materials in the product and associated packaging, the following information is needed:

- the mass and type of each material that is discarded at end-of-life
- the waste management methods employed for each type of material at end-of-life.

2.5. Assessing and recording data quality

The accuracy or 'quality' of your product carbon footprint result is ultimately dependent on the quality of the data used to calculate it. It is critical that you consider the quality of the primary and secondary data you have used, and demonstrate that they appropriately represent the footprinted product.

When assessing data quality, always keep in mind the underlying PAS 2050 principles earlier outlined: relevance, completeness, consistency, accuracy and transparency.

It isn't an exact science – there are many ways in which data quality assessments can be performed, and different scoring approaches could be used in each case. The important thing is that due consideration is given to the quality of the data, and that this done in a transparent way. An example of how data quality can

Useful sources of information for end-of-life profiles

- Average wastage rates for food products consumed in the UK can be found in a study from WRAP, Household Food and Drink Waste in the UK (WRAP, 2009) (http://www.wrap.org.uk/downloads/Household_food_and_drink_waste_in_the_UK_report. 4757e7ac.8048.pdf).
- EUROSTAT reports waste management statistics across Europe (http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/data/sectors/municipal_waste).
- Equivalent sources are available across different geographies.

be assessed against the principles of PAS 2050 is presented in Annex F. Note that this example outlines only one of the ways in which you could undertake a semi-quantitative assessment to flag areas of uncertainty (and potential need for data improvement).

The best-quality data should always be sought in an assessment, but is of particular importance where external communication is an ultimate goal of the study. In this case, a full data quality assessment, along with any accompanying assumptions or calculations, should be recorded with the product carbon footprint calculations.

For internal assessments (e.g. to identify hotspots in the value chain), formal assessment/recording may not be needed, but you should ensure that differences in data quality are not unduly influencing the findings of your study (see Step 4 of this Guide for further discussion on this).

Step 3

Footprint calculations

3.1. General calculation process

PAS 2050 Clause 9

A useful first step in the calculation process is to map all of the 'flows' occurring and calculate the quantities associated with each flow. Having already developed a process map as in Step 1.2 of this Guide, it can be used to map out all of the inputs, outputs, distances and other useful 'activity' data for each process stage.

Consider the examples for orange juice (Figure 3 and Table 5, and Figure 4 and Table 6), which show calculations for the first two life cycle stages.

Activity data are often collected in many different formats and relating to different units (e.g. inputs and outputs for a tonne of raw material produced, or a year's worth of production, or a hectare's worth of production). An important next step is to balance the flows shown in

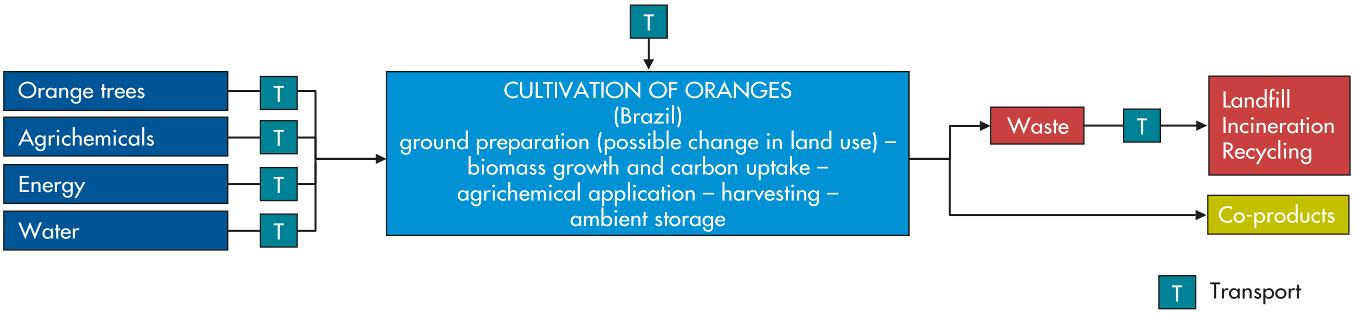


Figure 3: Mapping activity data – cultivation of oranges for the production of orange juice

Table 5: Example – 1 hectare of orange cultivation

	Quantity	Unit	Transport distance (for input or waste)	Transport mode and type	Data source
Input					
Fertilizer, total[a]	800	kg	100 km	Articulated HGV >33 t	Fertistat, transport assumed
Fertilizer, as N	150	kg	–	–	Fertistat
Fertilizer, as P_2O_5	50	kg	–	–	Fertistat
Fertilizer, as K_2O	200	kg	–	–	Fertistat
Pesticide, total[a]	40	kg	100 km	Articulated HGV >33 t	Published/reviewed LCA, transport assumed
Pesticide, active ingredient	15	kg	–	–	Published/ reviewed LCA
Energy					
Diesel	50	litres	–	–	Published/ reviewed LCA
Electricity	65	kWh	–	–	Published/ reviewed LCA
Output					
Oranges	22,000	kg	(included below)		FAOSTAT
Emissions					
N_2O from soil (fertilizer application and crop residues)	5	kg	–	–	Published/reviewed LCA/IPCC
Waste					
Un-harvested oranges to land-spreading	200	kg	10 km	Rigid HGV >7.5–17 t	Published/ reviewed LCA, transport assumed
Damaged oranges to land-spreading	100	kg	10 km	Rigid HGV >7.5–17 t	Published/reviewed LCA, transport assumed

HGV, heavy goods vehicle.

[a] The emissions from fertilizers and pesticides are dictated by their content of minerals or active ingredients (e.g. the proportion of fertilizer that is nitrogen or the proportion of pesticide that is anthraquinone) not the total weight. However, transport of the fertilizer or pesticide to use should be calculated based on the total weight.

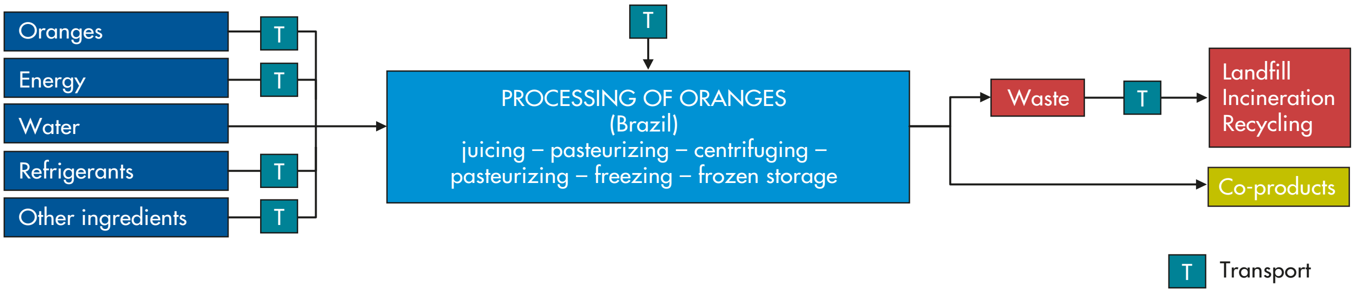


Figure 4: Mapping activity data – processing of oranges for the production of orange juice

Table 6: Example – to produce 1 tonne of concentrate

	Quantity	Unit	Transport distance (for input or waste)	Transport mode and type	Data source
Input					
Oranges	5,000	kg	100 km	Articulated HGV >33 t	Published/reviewed LCA, assumed transport
Water	100	litres	–	–	Published/reviewed LCA
Refrigerants	0.05	kg	100 km	Articulated HGV >33 t	Published/reviewed LCA, assumed transport
Cleaning detergent	10	kg	100 km	Articulated HGV >33 t	Published/reviewed LCA
Energy					
Natural gas	30	kWh	–	–	Published/reviewed LCA
Grid electricity	65	kWh	–	–	Published/reviewed LCA
Product outputs					
Orange concentrate	1,000	kg	–	–	Published/reviewed LCA
Orange pulp	400	kg	–	–	Published/reviewed LCA
Orange peel oil	125	kg	–	–	Published/reviewed LCA
Waste					
Damaged oranges	100	kg	10 km	Rigid HGV >7.5–17 t	Published/reviewed LCA, assumed transport
Pith/peel/pips	150	kg	50 km	Rigid HGV >7.5–17 t	Published/reviewed LCA, assumed transport
Waste water	3,325	litres	–	–	Published/reviewed LCA
Cleaning detergent to waste water	10	litres	–	–	Published/reviewed LCA
Refrigerant emissions	0.05	kg	–	–	Published/reviewed LCA

Balancing data for the production of a 1 litre carton of orange juice

To balance the data for the production of a 1 litre carton of orange juice from concentrate (FC), we need to understand the flow of materials through each life cycle stage.

- Cultivation of 1 hectare produces 20,000 kg of oranges
- Juicing 1,000 kg of oranges produces 500 kg of juice
- Centrifuging 1,000 kg of juice produces 200 kg of concentrate

1 litre of orange juice FC thus contains 0.2 kg concentrate. For every litre of orange juice produced, 0.01 kg of concentrate is wasted in the process.

Production of 1 litre of orange juice requires (0.2 kg + 0.01 kg) = 0.21 kg of concentrate.

Therefore, for the production of a carton of 1 litre of orange juice FC:

	Unit	Per 1,000 kg harvested oranges	Per 1,000 kg juice	Per 1000 kg concentrate	Per 1 litre carton of orange juice FC
Oranges	kg	1,000	2,000	10,000	2.10
Juice	kg	500	1,000	5,000	1.05
Concentrate	kg		200	1,000	0.21
Orange juice FC	kg				1.00

All data can now be normalized to reflect the functional unit: 1 litre of orange juice.

the process map so that all inputs and outputs reflect the provision of the functional unit/reference flow defined in Step 1. This can be either done within the process map itself, or in an Excel spreadsheet or other software tool.

This can be the most difficult part of the calculation process. Golden rules are to:

- always consider waste in the process
- make calculations as transparent as possible, so they can be traced backwards
- record all assumptions and data concerns.

Once the flows are balanced to reflect the functional unit, the calculation process is simple.

Remember that some flows might be negative, where there are biogenic carbon removals (see Step 3.2, heading 'Biogenic carbon accounting and carbon storage', and Annex H of this Guide).

Carbon footprint =

activity data (kg/litres/kWh/tkm, etc.) × emission factor (kg CO_2e per kg/litre/kWh/tkm, etc.)

These are summed to give a total carbon footprint against each life cycle stage, and for the total system.

A simplified example for orange juice is shown in Table 7. Specific calculation aspects, such as transport, refrigerant or waste management are also discussed later in this section.

Table 7: Footprint calculations for the production of a 1 litre carton of orange juice (example data only)

	Quantity (original)	Quantity (per litre of orange juice)	Unit	Emission factor (kg CO_2e/unit)	GHG emissions (kg CO_2e)
RAW MATERIALS					
The following data refer to the cultivation of 1 hectare of oranges, which yields 22,000 kg. The production of 1 litre of orange juice requires the cultivation of 2.1 kg of oranges					
Transportation of materials to cultivation					
Articulated HGV >33 t	84	0.008	tkm	0.10	0.001
Cultivation of oranges					
N fertilizer (production impacts)	150	0.014	kg	7.5	0.107
P_2O_5 fertilizer (production impacts)	50	0.005	kg	2.0	0.010
K_2O fertilizer (production impacts)	200	0.019	kg	1.0	0.019
Pesticide, active ingredient (production impacts)	15	0.001	kg	7.0	0.010
N_2O emissions from soil (from fertiliser application and residue management)	5	0.0005	kg	298[a]	0.149
Diesel	50	0.005	litres	3.2	0.015
Electricity	65	0.006	kWh	0.09	0.001
Unharvested oranges to land-spreading	200	0.019	kg	No emissions allocated[b]	
Damaged oranges to land-spreading	100	0.010	kg	No emissions allocated[b]	
Transportation of waste					
Rigid HGV >7.5–17 t	3	0.00029	tkm	0.10	0.00003
MANUFACTURE					
The following data refer to the processing of oranges to produce 1 tonne of orange concentrate. The production of 1 litre of orange juice requires the production of 0.21 kg of concentrate					
Transportation of oranges to processing					
Articulated HGV >33 t	502	0.105	tkm	0.10	0.011
Processing of oranges to concentrate					
Oranges	Calculated in previous stage				
Water	100	0.021	litres	0.0003	<0.001
Refrigerant (production)	0.05	0.00001	kg	100	0.001
Cleaning detergent	10	0.002	kg	1	0.002
Natural gas	30	0.006	litres	0.2	0.001
Grid electricity	65	0.014	kWh	0.09	0.001
Orange pulp (co-product)	*See Step 3.1, heading 'Co-product allocation'*				
Orange peel oil (co-product)	*See Step 3.1, heading 'Co-product allocation'*				
Damaged oranges to land-spreading	100	0.021	kg	No emissions allocated[b]	
Pith/peel/pips to land-spreading	150	0.032	kg	No emissions allocated[b]	

(Continued)

Table 7: Footprint calculations for the production of a 1 litre carton of orange juice (example data only) (continued)

	Quantity (original)	Quantity (per litre of orange juice)	Unit	Emission factor (kg CO_2e/unit)	GHG emissions (kg CO_2e)
MANUFACTURE *(Continued)*					
Processing of oranges to concentrate *(Continued)*					
Waste water	3,325	0.698	litres	0.0008	0.001
Cleaning detergent to waste water	10	0.002	litres	0.0008	0.000
Refrigerant (emissions)	0.05	0.00001	kg	2,000	0.021
Transportation of waste to cattle feed production					
Rigid HGV >7.5–17 t	3	0.001	tkm	0.10	<0.001
Transportation of orange concentrate to orange juice production					
Articulated HGV >33 t	2000	0.42	tkm	0.10	0.044
Container ship (frozen)	10000	2.1	tkm	0.015	0.032
The following data refers to 1 litre of orange juice.					
Production of orange juice					
Water	–	1.3	litres	0.0003	0.0004
Cleaning detergent	–	0.0001	kg	1	0.0001
Refrigerants (production)	–	0.00005	kg	100	0.005
Production of cardboard carton (including biogenic carbon removals)[c]	–	0.003	kg	–0.5[c]	–0.002
Plastic closure cap	–	0.001	kg	3	0.003
Natural gas	–	0.04	kWh	0.203	0.008
Grid electricity: UK	–	0.05	kWh	0.545	0.027
Waste water treatment	–	0.5	litres	0.0008	0.0004
Refrigerants (emissions)	–	0.00005	kg	2,000	0.100
DISTRIBUTION					
Articulated HGV >33 t	–	0.5	tkm	0.10	0.052
Grid electricity: UK	–	0.00015	kWh	0.545	<0.001
Refrigerants (production)	–	0.000005	kg	100	0.001
Refrigerants (emissions)	–	0.000005	kg	2,000	0.010
RETAIL					
Grid electricity: UK	–	0.00015	kWh	0.545	<0.001
Refrigerants (production)	–	0.000005	kg	100	0.001
Refrigerants (emissions)	–	0.000005	kg	2,000	0.010
USE					
Grid electricity: UK	–	0.00015	kWh	0.545	<0.001

(Continued)

Table 7: Footprint calculations for the production of a 1 litre carton of orange juice (example data only) (continued)

	Quantity (original)	Quantity (per litre of orange juice)	Unit	Emission factor (kg CO_2e/unit)	GHG emissions (kg CO_2e)
USE					
Grid electricity: UK	–	0.00015	kWh	0.545	<0.001
END OF LIFE					
Waste water treatment	–	0.2	litres	0.0008	<0.001
Recycling of packaging waste	–	0.0008	kg	0	<0.001
Landfill of cardboard packaging waste (including biogenic carbon emissions)[c]	–	0.0024	kg	1.5[c]	0.003
Landfill of plastic packaging waste	–	0.0008	kg	0	0.000

[a] This is the global warming potential (GWP) of N_2O gas – not an emission factor. The gas is released directly, and so does not need multiplying by an emission factor. It does, however need to be multiplied by its GWP of 298 to translate into CO_2 equivalents (CO_2e).

[b] Land-spreading – this is put to useful purpose, and so is a co-product, albeit with minimal value. A simple approach is to allocate this co-product zero emissions, as its relative value is very small (see Step 3.1, heading 'Co-product allocation', of this Guide).

[c] These values include removals and emissions of biogenic carbon within the packaging material. See Step 3.2, heading 'Biogenic carbon accounting and carbon storage', of this Guide.

Making simplifying assumptions

It is often possible to use simplifications or estimations to streamline the carbon footprinting process. For example:

- grouping all cleaning chemicals and using a generic 'chemicals' emission factor, estimating the quantities used
- assigning a set of general assumptions for transport – e.g. 50 km to waste treatment, 200 km for inputs from the UK and 1,000 km from central Europe.

When making any simplifying assumptions it is important to make them conservative/worst case, and make sure that you record them and are able to change them if needed.

In the calculation step of the footprint, it is a good idea to check and confirm that these simplified inputs or activities are not significant contributors to the footprint (e.g. >5 per cent of the footprint). If they are, you may need to go back and collect more specific information. As discussed in Step 2.5 of this Guide, the best quality (and specific) data should always be sought in an assessment, but is of particular importance where external communication is an ultimate goal of the study. For both external and internal assessments, it is most important to ensure that differences in data quality are not unduly influencing the findings of your study (discussed further in Step 4 of this Guide).

Co-product allocation

PAS 2050 Clause 8.1

Some processes in the life cycle of a product may yield more than one useful output ('co-products'). For example, in the life cycle of orange juice above, the juicing of oranges yields not only orange juice but also a large volume of pulp (a low-value co-product that can be used as an animal feed) and a small amount of peel oil (a high-value essential oil that can be used as a fragrance in perfumes or household cleaners).

In these cases, the input and output flows, or emissions, of the process (juicing) must be split, or 'allocated' between the product being studied (the juice) and any co-products (the pulp and peel oil).

There are a number of ways in which this can be done, although certain methods may not be possible, depending on the product system. PAS 2050 outlines an order of preference for the available methods.

1. The first choice is to divide the process into two or more 'sub-processes', in order to isolate the activities that yield only the product being studied.

For example, flue gas desulphurization, a process that extracts sulphur dioxide from the exhaust gas at power stations, can produce saleable gypsum as a by-product through additional process inputs and additional processing of the slurry waste (e.g. dewatering). The additional inputs and processing can be attributed to the gypsum product, with all other emissions being attributed to the energy produced at the power plant. This example is simplified because the co-product is a result of a waste management process. In another example, where you have a system such as a refinery that produces many products through distillation and further processing of the distillates, a mixture of sub-division and allocation is required. Where refinery processes can be directly and wholly attributed to a refinery product (e.g. diesel) they should be, and where others are shared, allocation is required between the refiner products that result from that process. Such an approach will see the emissions from distillation and crude oil inputs being allocated across all refinery products, and the emissions associated with subsequent processes being attributed to the refiner products they are associated with.

Once isolated, data relating to the input and outputs for this sub-process should be used.

2. If it is not possible to isolate sub-processes as above, the next preferred method is to expand the system boundaries to incorporate the products that are displaced by the production of co-products. This should only be undertaken if a known and specific product is displaced.
   - For example, if the beneficiation 'sub-process' cannot be separated out in the power plant described in the box above: the gypsum product is commonly sold for use in plasterboard, and will replace mineral gypsum mined from the ground; and the emissions from mining an equivalent amount of mineral gypsum can be used to represent the proportion allocated to FGD gypsum, with the remainder of emissions allocated to power generation.
   - On the other hand, in the orange juice example in Table 7, the pulp is produced as a co product and replaces animal feed: there are a wide range of types of animal feed, and orange pulp is not a direct replacement for a single type; in this case, the system expansion approach taken for gypsum above is not possible.
   - System expansion is commonly used where a production process exports electricity to the national grid as a co-product: an equivalent amount of grid electricity is displaced, and the emissions to produce this are allocated to the energy co-product (and are subtracted from the product system).

Multi-product factories with no sub-metering/monitoring by product line

In some cases, emissions must be split between products that are not co-products: co-products occur only where one cannot be produced without the other (e.g. orange juice and pith/peel oil). Take the example of a factory that produces many different products (e.g. different types of shampoo and conditioner) and these products are not dependent on each other's production, but are processed alongside each other or share equipment (if a batch system), and no sub metering or monitoring of emissions by product line is undertaken. In these cases, emissions must be apportioned through calculation and estimation.

The best option in these instances is to try and isolate the process that produces the product being studied. In a factory situation this may be achieved by recording the specific current draw with a clamp-on ammeter while the line manufacturing the product is running. Alternatively, the energy use could be calculated from the current draw specified in the technical specifications, or the nameplate of a particular machine.

If this is not possible, for example in situations where all lines run off a common power source such as an air compressor, the site-level energy data should be apportioned to the product system according to a sensible physical relationship. For example the number, mass or volume of a product produced as a proportion of total output may be applicable if the process for all items produced at the site is similar. In cases where different products have very dissimilar production processes, other relationships such as the proportion of man-hours spent producing a particular product may be used.

The most applicable method of apportioning must be decided on a case-by-case basis, depending on the details of the system. It is important that this apportioning method is clearly stated during reporting.

SR

3. If neither of the two methods above is appropriate for the product system studied, any appropriate supplementary requirement documents should be consulted to see if there is a standard approach to the allocation of co-products for that system.
4. Should no supplementary requirements exist, or be deemed appropriate, the inputs/outputs/emissions of the process should be allocated to the co-products on an economic basis. This means that the proportion of the emissions assigned to each co-product should be equal to the proportion of revenue generated through the sale of that product.

For example , producing 1 litre of orange juice has an impact of 0.7 kg CO_2e (see Figure 5). As well as 1 litre of orange juice, consider that 500 g of pulp and 1 ml of peel oil are produced. Orange juice can be sold for 90p a litre, pulp for £100 per tonne and peel oil at £50 per litre. So, from the production of 1 litre of orange juice, 90p is gained from the sale of the juice itself, 5p from the pulp and 5p from the peel oil (a total of £1). Of the revenue gained, 90 per cent is from the juice, 5 per cent from the pulp and 5 per cent is from the peel oil. The emissions should be allocated according to the same proportions. So, for the juicing

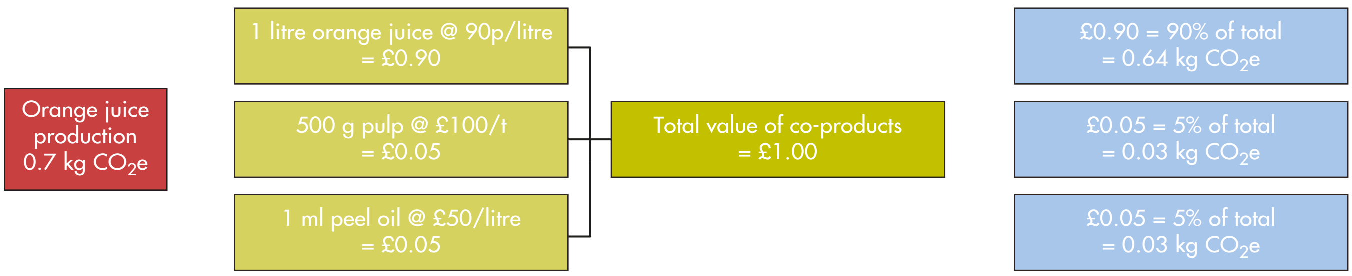


Figure 5: Orange juice allocation

process, 1 litre of orange juice is assigned an impact of (0.7 × 90%) kg CO_2e. In addition, the pulp and peel oil are both assigned (0.7 × 5%) kg CO_2e.

3.2. Calculations for specific aspects of the footprint

Biogenic carbon accounting and carbon storage

PAS 2050 Clauses 5.1, 5.2, 5.5, 6.4.9.3, 6.4.10.1

PAS 2050:2011 contains a number of revised clauses with regard to the accounting procedures for biogenic carbon emissions/removals/potential storage within a product system. The implications of these are as follows:

- Instead of the 'zero-weighting' approach,[10] biogenic carbon **removals** across the product system must be included – **except for food and feed products**.
  - biogenic carbon removals (as carbon dioxide (CO_2)) are given a global warming potential of –1 to signify CO_2 removal from the atmosphere (or, alternatively, input of carbon to the system can be considered as a negative value).
  - the quantity of biogenic CO_2 removals for a product system can be calculated based on the estimated carbon content of biogenic material inputs multiplied by the relative mass of carbon versus CO_2: 3.67.[11] See the example in Annex G for how this is applied in practice. Carbon contents can be determined via an internet search – taking care that the carbon content used reflects the moisture content of the material (the carbon content based on wet/dry weight should be adjusted accordingly).
- Subsequent biogenic carbon **emissions** are also to be included – **except for food and feed products**.
  - biogenic CO_2 emissions are given a global warming potential of 1 (as for fossil CO_2)
  - biogenic methane (CH_4) emissions are given a global warming of 25 (see Step 1.3 of this Guide).
- The timeframe of the assessment is 100 years. Biogenic carbon that is taken up but not subsequently released after 100 years remains as a negative credit to the system (i.e. a carbon storage benefit).[12]
- **For food and feed products**, carbon removals from the atmosphere, and the subsequent emission of this biogenic carbon as carbon dioxide at end-of-life, can be excluded in order to simplify footprint calculations.
  - both biogenic carbon removals (as CO_2) and biogenic CO_2 emissions are given a global warming potential of zero.
  - biogenic CH_4 emissions are given a global warming potential of 22.25. This corrects the global warming potential to take into account the removal of the CO_2 that gave rise to the biogenic carbon source.
  - in the unlikely event that the carbon within food and feed products can be shown to not be re-emitted within the 100 year assessment period, a carbon storage credit should be added (as a negative emission of CO_2).

If products contain both food/feed and, for example, cardboard packaging, then either a different approach

[10] The carbon contained within food and green waste materials is often termed 'biogenic' or 'short-cycle carbon'. This carbon has, on a relatively recent timescale, been taken up from the atmosphere during plant photosynthesis and growth. Subsequently, when it is degraded in an aerobic environment and released as carbon dioxide, it has been common practice to allocate to this no GHG burden. This was the approach taken in PAS 2050:2008.

[11] Atomic mass of carbon = 12; atomic mass of oxygen = 16; atomic mass of CO_2 = 12 + 16 + 16 = 44 divided by 12 (atomic mass of carbon) = 3.67.

[12] This is the same time boundary as specified in PAS 2050:2008, and so the net effect of removals/emissions across a given system should be the same as previously calculated (previously, they were allocated a carbon storage credit where not re-emitted).

will be taken for the food/feed and the packaging elements of the product, or a user can choose to include the biogenic carbon uptake and release for the entire product. In both cases, the resulting footprint should be the same, but it is important to very transparently record your calculations, as carbon flows and emissions/storage can be easily confused with elements either erroneously missed, or added.

It is recommended that both carbon flows and subsequent emissions are fully traced through the system whenever biogenic carbon forms a significant component. An example calculation for a paper-based product is shown in Annex G, outlining one way in which the flows might be recorded.

The example set out in Annex G is based on a series of hypothetical assumptions, for example surrounding the proportion of emissions released as CO_2 or CH_4 at end-of-life, and the proportion of carbon not re-emitted within 100 years. Such assumptions can have significant implications for some products (e.g. where paper-, wood- or natural-textile-based materials are landfilled). Step 3.2, heading 'Residual waste disposal: landfill and incineration', of this Guide also discusses the uncertainty surrounding estimates of the longevity/degradation of materials in landfill. You should be aware of these implications if trying to make choices between products or packaging options that include these materials. It is also important to make sure that you record any assumptions and data sources used.

Energy and combined heat and power (CHP)

PAS 2050 Clauses 6.4.3, 7.9.1

Emissions resulting from all energy use, both energy produced off-site and energy produced on site must be taken into account in the calculation of a carbon footprint. This section describes how to account for the most common types of energy using publicly available secondary emissions factors.

Emission factors for fuel and electricity are often relatively well described and available country-by-country. For example, the best publicly available source of emissions factors for UK grid electricity and common fuel types are the Defra/DECC GHG conversion factors available at http://www.defra.gov.uk/environment/economy/business-efficiency/reporting/.

Grid electricity

The most common form of energy used in the life cycle of a product is grid electricity. The emissions that result from grid electricity are a function of the emissions from the production and combustion associated with all of the fuels used in the different types of power stations that make up a country's grid electricity mix.

For the UK, the emissions from the use of grid electricity can be found in Defra/DECC GHG conversion factors (see above). There are three tables, detailing the emissions from production, losses and consumption of electricity for various years. The figure that should be used is the emissions for electricity **consumed** for **all scopes** for the appropriate year (see box for explanation).

You will need to obtain specific grid electricity factors for electricity consumed in different countries, and these can vary widely because of the mix of energy sources/fuel types used (e.g. France with a high proportion of nuclear and China with a high proportion of coal). Different US states can also have very different grid electricity factors. Good sources of information for global electricity factors are:

- Annex 10 of the Defra/DECC GHG conversion factors, which provide electricity emissions factors for 57 countries (including the whole of the EU27) as well as average emissions for Africa, Latin America, the Middle East and non-OECD Europe.

Production, loss and consumption of electricity

Grid electricity is usually produced many kilometres away from where it is consumed. The transmission of this electricity is a complex process that results in some of the electrical energy being lost as heat at various stages. Thus, 1 kWh produced at a power station may only translate to 0.98 kWh of energy available for use by the end user. The production, loss and consumption emissions factors calculated by Defra/DECC above account for this phenomenon. Essentially, in order to consume of 1 kWh of electricity, more than 1 kWh of electricity must be produced (about 1.02 kWh in the example above). The consumption emission factors are therefore scaled up to account for this fact.

- The US EPA eGRID database (http://www.epa.gov/cleanenergy/energy-resources/ egrid/index.html), which provides electricity emissions factors for various regions in the USA. Note: these emissions are associated with generation, and are not scaled up to account for distribution losses. Loss scale-up factors for regions can, however, be found in Table III-4 of the Technical Support Document.

Renewable energy and renewable electricity tariffs

PAS 2050 Clause 7.9.4

Renewable energy can only be accredited to a product system under certain circumstances under PAS 2050 in order to avoid double counting. The following two criteria must be met:

1. It must be proven that the process studied – and only the process studied – used the renewable energy generated.
2. The renewable energy generated must **not** contribute to a national average emissions factor for energy generation.

Essentially, there must be a direct and isolated causal link between the generation of renewable electricity

and its use in a product system in order for it to count as renewable when calculating the carbon footprint of a product. If either of the criteria above is not met, emissions for average grid electricity must be used.

On-site electricity production

PAS 2050 Clause 7.9.2

Where electricity is produced on-site for use by a process, a suitable emissions factor must be calculated for the combustion of any fuels used to produce this electricity. For details on how this emissions factor should be calculated, see the sections below on CHP and fuel combustion.

Electricity and heat from CHP

PAS 2050 Clauses 7.9.3, 8.5

Under the PAS 2050 method, emissions from energy generation are allocated only to useful energy, i.e. the energy that is used by a process. In most cases of electricity generation, where the excess heat energy is dissipated, all of the emissions related to the combustion of fuels are allocated to the electricity produced. Where energy is produced from CHP, however, emissions must be allocated to the useful heat energy as well as the useful electricity produced.

The allocation should take place as follows:

- for boiler-based CHP systems (e.g. coal, wood, solid fuel) – emissions per MJ of electricity: emissions per MJ of heat should be allocated in the ratio of 2.5:1
- for turbine-based CHP systems (e.g. natural gas, landfill gas) – emissions per MJ of electricity: emissions per MJ of heat should be allocated in the ratio of 2:1.

It is important to note that these ratios apply to 1 MJ of energy produced. In most situations more energy of one type will be produced than the other, for example 6 MJ heat for every 1 MJ of electricity. The ratio of the emissions must therefore be adjusted accordingly.

A worked example of the calculation process is shown in Annex H.

Once net emissions from electricity and heat have been calculated (see Annex H), these emission factors can be used in the same way as any other emission factors – to translate specific energy inputs (electricity/heat) into CO_2e. Specific energy use for different products produced at the site should be apportioned to the product system, as described above.

Export of energy from CHP

If some or all of the energy produced by on-site CHP is exported, this is treated as a co-product. As co-products, energy exports are subject to the system expansion allocation approach wherever they are exported to the national grid, or to displace a known heat source (see the earlier discussion on allocation approaches). The avoided emissions that result from the displacement of grid electricity/heat should be calculated using an average emission factor (e.g. from Defra/DECC reporting factors or for a specific country, as relevant). These emissions can be subtracted from the footprint of the product under study, as they represent the proportion of emissions allocated to the energy co-product.

Applying emissions from off-site CHP to a product system

Displaced energy production is only included in the emissions factor for CHP when it is produced **on-site**. If energy is bought from a local, off-site CHP provider, the emission factor for heat/electricity should be calculated as described above, but should not include any displacement credits (these would already have been claimed by the energy producer, where relevant).

Agriculture

Agriculture is a complex process in terms of GHG emissions that results in many direct non-carbon dioxide emissions in addition to direct carbon dioxide and indirect GHG emissions.

Table 8 describes the data that are needed when considering the carbon footprint of agricultural or horticultural products.

Land use change

When natural or semi-natural vegetation is cleared to make way for another land use such as agriculture,

PAS 2050 Clauses 5.6, 5.7, Annex C

SR

Table 8: Data required for the carbon footprint of agricultural or horticultural products

	Data required	Recommended sources (primary data)	Recommended sources (secondary data)
	Inputs to the agricultural system (including fertilizers, pesticides, fuels, etc.)	Farm inventory or procurement documents	• UN Food and Agriculture Organization (FAO) or other guidance documents on fertilizer and pesticide use • LCI data from previous LCA studies • Supplementary requirement documents
PAS 2050 Clauses 7.3, 7.8	Direct nitrous oxide emissions from the application of nitrogenous fertilizers to soils	(Primary data collection is not advised, or required under PAS 2050)	Whichever of the following two approaches yields the highest quality assessment: • the highest-tier approach set out in the IPCC Guidelines for National Greenhouse Gas Inventories, Clause 2, or • the highest-tier approach employed by the country in which the emissions were produced *Note: guidance may also be provided in* supplementary requirement documents
	Energy use data for intensive atmospheric growing conditions (e.g. a heated greenhouse)	Farm inventory or procurement documents	• FAO or other guidance documents on fertilizer and pesticide use • LCI data from previous LCA studies
PAS 2050 Clauses 7.3, 7.8	Direct emissions from crop production (e.g. methane from rice cultivation) and livestock rearing (e.g. methane from cattle)	(Primary data collection is not required under PAS 2050)	Whichever of the following two approaches yields the highest quality assessment: • the highest-tier approach set out in the IPCC Guidelines for National Greenhouse Gas Inventories, Clause 2, or • the highest-tier approach employed by the country in which the emissions were produced *Note: guidance may also be provided in supplementary requirement documents*
PAS 2050 Clauses 7.3, 7.8	Direct emissions (e.g. nitrous oxide and methane) from bedding materials and manure management	(Primary data collection is not advised, or required under PAS 2050)	Whichever of the following two approaches yields the highest quality assessment: • the highest-tier approach set out in the IPCC Guidelines for National Greenhouse Gas Inventories, Clause 2, or • the highest-tier approach employed by the country in which the emissions were produced *Note: guidance may also be provided in supplementary requirement documents*
	Waste generated at each stage of the production of the crop or livestock	Farm inventory or procurement documents	• FAO or other guidance documents on fertilizer and pesticide use • LCI data from previous LCA studies
	Emissions from direct land use change	(See Step 3.2, heading 'Land use change', of this Guide)	(See Step 3.2, heading 'Land use change' of this Guide)
	Carbon removals from the atmosphere *(Agricultural products that are not food or feed only)*	(See Step 3.2, heading 'Biogenic carbon accounting and carbon storage', of this Guide)	(See Step 3.2, heading 'Biogenic carbon accounting and carbon storage' of this Guide)

industry or other non-natural land uses, the carbon stored in that biomass is released to the atmosphere as carbon dioxide. The GHG emissions resulting from this direct land use change are included under PAS 2050. Although technically all of these emissions occur in 1 year, the function of the change in land use is the continued use of that land (e.g. the production of an agricultural crop on that land). Therefore, in PAS 2050, the emissions from land use change are divided equally over a 20 year period (or, in the case of agriculture, the length of one crop cycle, referred to in PAS 2050 as the 'harvest period', whichever is the longer).

SR If supplementary requirement documents compatible with PAS 2050 provide guidance as to the inclusion of emissions from direct land use change, they should be followed. Otherwise, the guidelines set out below should be used.

When to include emissions from land use change in the carbon footprint

Emissions from land use change must be included in the carbon footprint of a product if the land used to produce it has been converted from natural or semi-natural vegetation (including permanent pasture) within the past 20 years or the length of one harvest period, whichever is the longer. Where it can be demonstrated that the land use change occurred more than 20 years prior to assessment, no land use change emissions should be included.

Where it cannot be proved exactly when the change in land use took place, the land use change should be assumed to have occurred on either 1 January of the earliest year in which it can be proved that the land use change had already taken place (e.g. the year a piece of land was bought by the current owner already in a converted state) or, as a worst case assumption, 1 January of the year of the assessment.

Calculating emissions from land use change

The complexity of the calculation of emissions from land use change will be different depending on the location of the land or the source of the product. Products from a known single source will be relatively straightforward, products known to be imported from a particular country will be more complex and commodity products will be more complex still.

General calculation procedure

The general procedure for calculating emissions from land use change is as follows:

1. Identify whether the emissions from land use change are relevant (see above).
2. Identify the location or the place of origin.
3. Identify the 'previous land use' of the location or the place of origin.
4. Find the relevant land use change emissions factor from PAS 2050, Annex C (t CO_2e/ha/year).
5. Multiply the percentage land area subject to land use change by the emissions factor.
6. Divide the emissions from step 5 by the yield (ha/year).

For changes in land use at a known location, for example the establishment of a farm or factory, these steps can be followed directly. For more complex situations, such as the indirect sourcing of agricultural products, more detailed guidance is provided below.

Determining previous land use where the exact source location is not known: an example for agricultural products

In cases where products are imported from a known country, but not specific area, or where they are bought on the commodity market, the exact location of their cultivation, and therefore the previous land use, may not be known.

According to PAS 2050, 'Knowledge of the prior land use can be demonstrated using a number of sources of information, such as satellite imagery and land survey data. Where records are not available, local knowledge of prior land use can be used.'

The most comprehensive publicly available data on land use by agricultural crops is the UN FAO's statistical database (FAOSTAT) – http://faostat.fao.org/site/567/default.aspx#ancor.

From the data provided on the FAOSTAT website, it is possible to calculate the likely extent of land use change

Land use change example – known country of import

A tofu manufacturer imports soya beans from Brazil.

According to FAOSTAT, the yield of soya beans in 2009 in Brazil was 2,636 kg/ha.

Following the six steps outlined above, the total emissions for Brazilian soya beans are calculated as follows:

1. Are emissions from land use change relevant?

   Yes. It cannot be proven that no land use change has taken place in this area in the past 20 years.

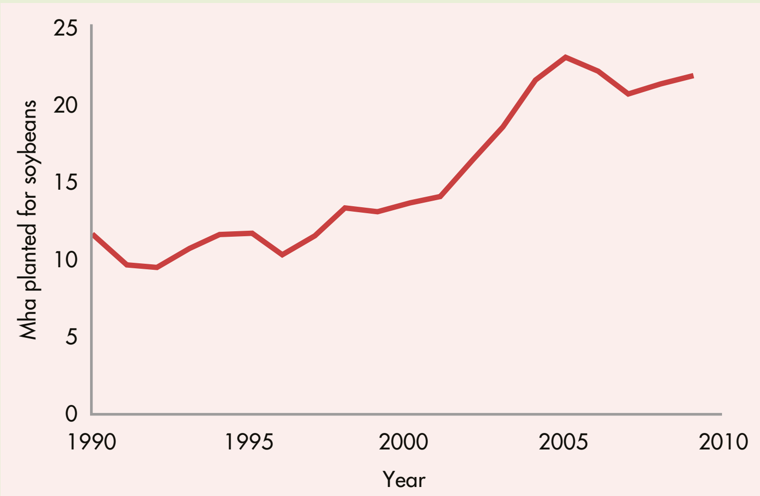
2. Place of origin – Brazil.

3. Previous land use – previous land use must be calculated from statistics available at FAOSTAT. It is possible to get time series data for land planted for soya beans in Brazil for the past 20 years.

There are two main ways in which the land converted as a result of the new land use over the prior 20 years can be calculated, known as the 'end-point' approach and the 'maximum' approach. Both of these approaches are consistent with PAS 2050, and are applicable in different situations.

Under the end-point approach, the area of land converted is calculated by subtracting the amount of land used 20 years ago from the amount of land used today. This approach is applicable where there is a high degree of inter-annual variation in the area used by a crop, as is common with annual crops, because it excludes the effect of this variation in the 20 years prior to assessment. The end-point approach is a reasonable worst-case approach.

Under the maximum approach, the area of land converted is calculated by subtracting the amount of land used 20 years ago from the maximum amount of land used in the previous 20 years. This approach is applicable where land used for the growth of a crop, or for industrial use, is unlikely to be used immediately for another use once abandoned, and hence should still be classed as 'changed'. Perennial cropland, such as orchards, may be an example of such a situation. The maximum approach is a worst-case approach.



In the case of soya beans in Brazil, inter-annual variation is low. It is also advisable to take a worst case approach, given the sensitivity of natural vegetation in this area. For these reasons, the maximum approach has been deemed appropriate in this case.

There has been a steady increase in land planted for soya beans in Brazil over the past 20 years, peaking in 2005:

- in 1990, 11.5 Mha was planted for soya beans
- land planted for soya beans peaked in 2005 at 22.9 Mha
- in 2009 (the year for which the most recent data are available), 21.8 Mha was planted for soya beans.

(Continued)

(Continued)

From these figures, it can be calculated that, taking the worst-case approach, a maximum of 11.4 Mha of land has been converted from natural vegetation to soya bean agriculture in the past 20 years. This is a worst-case assumption because the land converted may have previously been used to grow a different crop. Further analysis of trends in the area used for other crops grown in Brazil can determine whether agricultural land as a whole is expanding or not, and by how much. This can provide a more accurate representation of the land being converted. Such further investigations are not prohibited by PAS 2050; however, they are not a requirement.

This represents 53% of the currently harvested area.

The most prevalent natural vegetation type in the region of Brazil in which soya beans are grown is forest. (Note: should the specific region be unknown, a sensible approach could be to use the World Resources Institute's EarthTrends data to calculate a country-wide weighted average of land use types.)

4. Emissions factor for forest land converted to cropland in Brazil = 37,000 kg CO_2e/ha/year.
5. Percentage of the land area affected – 53%:
   53% × 37,000 = 19,610 kg CO_2e/ha/year.
6. Yield of soya beans – 2,636 kg/ha/year:
   19,610/2,636 = 7.4 kg CO_2e/kg from land use change.

for a given crop in a given country. This website also has data on the average yield of crops in a given country. See the box on page 36 of this Guide for an example.

In the case of commodity crops, a calculation such as that described in the box above should be carried out for each of the countries that supply the largest percentage of that crop to the global market, until a cumulative percentage above 90 per cent has been reached.

Refrigeration

PAS 2050 Clause 6.4.8

Refrigeration and climate control systems commonly contain substances such as hydrochlorofluorocarbons (HCFCs, e.g. R-22) and hydrofluorocarbons (HFCs, e.g. R-134a). These are highly intensive to produce, and when emitted to the atmosphere have a global warming potential often in excess of 1,000 times that of carbon dioxide (see Annex A of PAS 2050). This is why, even in very small quantities, refrigerant leakages can be an important source of emissions.

In calculating your footprint, identify the type of refrigerant used and obtain maintenance records to show the annual level of gas replacement (system top-ups). This is a system input, but should also be assumed to reflect the amount of refrigerant that has leaked from the system over that period. You need an emission factor for both the production of the refrigerant (e.g. from a proprietary database, see Step 2.3) and for the release of the gas (e.g. the global warming potential of HCFC-22 from Annex A of PAS 2050). The gas emissions are typically of greater significance in this respect.

Other useful sources of information with regard to refrigeration:

- Annex 8 of the Defra/DECC GHG conversion factors outlines two methods for estimating refrigerant emissions from the use of refrigeration and air conditioning equipment
- Defra's Market Transformation programme contains data on energy use and carbon dioxide emissions from commercial refrigeration (http://www.mtprog.com/cms/product-strategies/subsector/commercial-refrigeration)
- The Carbon Trust's Refrigeration Systems technology guide introduces the main ways in which you can reduce the energy you use for refrigeration (http://www.carbontrust.co.uk/cut-carbon-reduce-costs/products-services/technology-advice/pages/refrigeration-introduction.aspx (PDF file)).

Transport emissions

PAS 2050 Clauses 6.4.7, 8.6

Transport steps will occur at many points throughout the supply chain, upstream and downstream of production, and so transportation calculations will always be needed in a product carbon footprint calculation.

SR

If supplementary requirement documents compatible with PAS 2050 provide guidance as to the inclusion of emissions from transport, they should be followed. Otherwise, the guidelines set out below should be used.

Emission factors for transport are widely available – for example from the Defra/DECC reporting guidelines, the US GREET model or the European Reference Life Cycle Database (see Step 2.3). These are most commonly reported in the unit 'tonne-kilometre' (tkm).

1 tkm refers to transporting 1 tonne of material a distance of 1 km.

To use the tkm transport emission factors, the following information is needed for each transport step:

- the distance from a to b travelled by each mode of transport (e.g. 10 km by lorry, 100 km by ship, 20 km by rail)
- if the vehicles you use are likely to return back empty to their point of origin, you should also include the return journey distance
- an approximate size/capacity of the road vehicles used (if unknown, a small, medium or large truck will do)
- whether the truck is refrigerated
- the mass of the product or material being transported (in tonnes).

The information above can be converted to a tkm value with a simple calculation – distance travelled (km) × mass transported (tonnes) – and multiplied by the corresponding emission factor for the relevant vehicle type, to give the GHG emissions for that transport step (in kg CO_2e).

Refrigerated transport

If transport is refrigerated, more fuel will be used to drive the on-board refrigeration equipment, and therefore the emissions per tkm will be higher. In the absence of primary data, an 'uplift factor' of 14 per cent is typically applied.[13] For example, if transport is in a 32 tonne refrigerated lorry, the emission factor per tkm for a regular 32 tonne lorry should be scaled up by 14 per cent (i.e. multiplied by 1.14).

Transporting bulky/low-density materials

The above calculations and emission factors assume that transport emissions are apportioned equally between the mass of goods transported in a vehicle – and are dependent on the maximum weight that the vehicle can carry. However, for some materials or products, the quantity that can be transported in one vehicle might be limited by volume, rather than by mass. For example, polystyrene is a lightweight but bulky material, and a relatively low mass will take up a lot of space in a vehicle.

Volume-limited transport – example calculation

- Expanded polystyrene is transported by road in a 20 tonne lorry that can carry a maximum volume of 12 m^3 of polystyrene.
- The polystyrene has a density of 20 kg/m^3; therefore, 240 kg (= 0.24 tonne) can be transported in a 20 tonne lorry.
- The average operation emissions of a 20 tonne lorry are 0.7 kg CO_2e/km.

The emission factor for transporting this polystyrene = 0.7/0.24 = 2.92 kg CO_2e/tkm.

[13] Garnett, T. (2006) *Fruit and Vegetables & Greenhouse Gas Emissions: Exploring the Relationship*. Guildford: Food Climate Research Network.

As rule of thumb, if the density of the material or product is less than 0.5 kg/litre, the amount of material transported is likely to be limited by the volume of the vehicle. In this case, an emission factor for the average operations of the mode of transport in question per km (rather than per tkm) must be used. These emissions are then divided by the mass of the theoretical maximum amount of product that could be transported by this vehicle, to calculate the emissions generated from transporting 1 tonne of a product 1 km.

Storage emissions

PAS 2050 Clause 6.4.8

Periods of storage will occur throughout the supply chain, upstream and downstream of production. They all must be considered as part of the carbon footprint calculations.

SR

If supplementary requirement documents compatible with PAS 2050 provide guidance as to the inclusion of emissions from storage, they should be followed. Otherwise, the guidelines set out below should be used.

For each storage step you will need to find out:

- the mass or volume of the product or material being stored (e.g. in kg/tonnes/litres)
- the storage requirements of the product or materials being stored (i.e. heated, cooled, refrigerate or ambient temperature)
- the approximate number of days that the product or material is stored for
- an emission factor (emissions per kg stored per day) for each type of storage requirement (see the box below).

Calculating an emissions factor for storage

Emissions from storage will mainly arise from energy use. If the specific energy use at a storage facility is not known, the average energy use for a variety of sizes of refrigerated and non-refrigerated warehouses can be found via a web search – for example on the US Energy Information Administration website (http://www.eia.gov/emeu/cbecs/pba99/warehouse/warehouseconstable.html).

An emissions factor for storage can be calculated from this energy data as described in Step 3.2, heading 'Energy and combined heat and power', of this Guide.

Recycling

PAS 2050 Clause 8.3, Annex D

The recycling of materials and the use of recycled material both have the potential to reduce the amount of virgin material that needs to be produced. This reduction in the need for virgin materials is associated with a reduction in emissions that can be allocated to a product system. The reduction in emissions must, however, either be allocated to the acquisition of the recycled material or to recycling of this material at the end of the products' life – but not to both.

SR

If supplementary requirement documents compatible with PAS 2050 provide guidance as to the inclusion of emissions from recycling and recycled materials, they should be followed. Otherwise, the guidelines set out below should be used.

In order to account for materials recycling in a carbon footprint assessment, emission factors must be calculated

Table 9: PAS 2050 methods for calculating recycling emissions factors

	Recycled content method	Closed-loop approximation method
Should be used when…	Material is 'down-cycled' – i.e. the recycled material is of a lower grade or has different intrinsic properties to the virgin material, and is therefore not a direct substitute	The recycled material maintains the same intrinsic properties as the virgin material, and is therefore a direct substitute
	The manufacturing company has control over the recycled content of the materials it uses	The manufacturing company has no power over the recycled content of the material it uses: it must use the production mix
	The market for recycled materials is not saturated – i.e. there is more supply of recycled material than there is demand	The market for recycled material is saturated – i.e. recycled materials displace virgin materials to the point where an increase leads directly to an increase in the recycled content of materials
	The product contains recycled material independent of whether it is recycled downstream	The recycled content of the product is dependent on whether it is recycled downstream
Examples	Most plastics Most complex recyclable products	Steel, aluminium Other metals

for recycled/recyclable materials that enter the system; and for the emissions at end-of-life for that material. These recycling emission factors can then be applied in the same way as earlier described.

There are two ways in which recycling emissions factors can be calculated under PAS 2050: the 'recycled content method' and the 'closed-loop approximation method'. They are used in different situations, depending on both the properties of the material in question and the control the producer has over the recycling process or material choices.

The respective equations to be used in each instance are provided in Annex D of PAS 2050. Table 9 outlines which is most appropriate in different recycling situations.

Residual waste disposal: landfill and incineration

PAS 2050 Clauses 6.4.10.3, 8.2

Obtaining emission factors for residual waste disposal can be a big challenge, as many publicly available data sources are not PAS 2050-compliant with regard to their handling of GHG emissions, predominantly with regard to the time period of emissions accounting.

Some available sources of information, and things to consider, are set out in Table 10.

PAS 2050 Clause 8.2

Table 10: Waste disposal: information sources and other considerations

Waste management route	Accounting procedure, data sources and common assumptions
Incineration with energy recovery	Emissions associated with incinerating wastes where energy recovery occurs are zero. According to PAS 2050 (Clause 8.2.2), when energy is produced from waste, any emissions are allocated to the energy produced, as opposed to the waste treated.
Incineration without energy recovery	Emissions associated with incinerating wastes where energy recovery does not occur can be calculated based on the carbon content of the material and the assumption that all carbon is oxidized to carbon dioxide (use the relative mass of CO_2/C, and multiply by 44/12 (= 3.67)).
Landfill of inert wastes	Emissions associated with non-biodegradable wastes to landfill can usually be assumed to be zero, as no carbon will be released from this material, and processing burdens at a landfill site will be minor.
Landfill of biodegradable wastes	Where landfill is not an important part of the product system, emissions can be estimated using the material-specific factors in Annex 9 of the Defra/DECC reporting guidelines (http://www.defra.gov.uk/environment/economy/business-efficiency/reporting/). These factors are inconsistent with the PAS 2050 boundaries in two key respects: • They are based on an infinite time period (as opposed to 100 years), and so assume that all the carbon within the waste material degrades. This is appropriately conservative for an estimate. • They do not include biogenic carbon dioxide emissions. This will lead to an underestimate of emissions, and so should be noted as a limitation. Where considered potentially significant, an estimate of 50% of the carbon contained within the material could be assumed to be released as carbon dioxide, and these emissions should be added to the existing factor. Where landfill is an important part of the product system, a more detailed estimate should be sought, based on: • the estimated percentage of carbon released over 100 years • the percentage released as carbon dioxide versus methane • the percentage of methane captured and burned • the percentage of gas burned to generate electricity or useful heat. These values are variable, dependent on the type of material/landfill operations, and are typically very uncertain. Good sources of estimates are as follows: • Doka, G. (2009) *Life Cycle Inventories of Waste Treatment Services*. Final report ecoinvent v2.1, No. 13. Dübendorf: Swiss Centre for Life Cycle Inventories • Defra (2006) *Carbon Balances and Energy Impacts of the Management of UK Waste Streams*, WR0602 (Annex B). London: Defra.

Step 4

Interpreting footprint results and driving reductions

Arguably the most important step of a PAS 2050 assessment is interpreting carbon footprint results and identifying carbon reduction opportunities. Results of the assessment provide valuable information that can be used to understand and manage the GHG emissions associated with the assessed product and, more widely, at an organizational level. It is also important to understand the uncertainty of results to assess the extent to which the assessment can be used to influence decision making.

4.1. Understanding carbon footprint results

The output from footprint calculations will be a 'total' footprint value for the agreed functional unit (e.g. 1 litre of orange juice available for consumption). This will be broken down according to the contributions for each material, process and life cycle stage. For example, the orange juice example discussed earlier gave the footprint and contributions shown in Table 11 and Figure 6.

This is powerful information, showing the emissions hotspots across the life cycle. Through breaking down results in a variety of ways, the materials, processes or life cycle stage of most concern can be identified to

Table 11: Carbon footprint results for a 1 litre carton of orange juice

Life cycle stage	GHG emissions (kg CO_2e per process stage)	% of total
Cultivation of oranges	0.31	49%
Processing of oranges to concentrate	0.04	6%
Transportation of concentrate to orange juice production	0.07	11%
Production of orange juice	0.14	22%
Distribution	0.06	9%
Retail	0.01	2%
Use	<0.001	<0.01%
End of life	0.004	0.6%
Total	**0.64**	

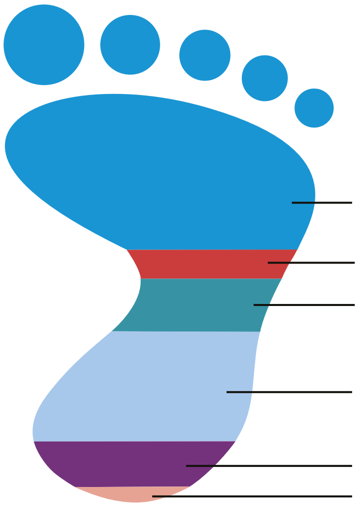


Figure 6: Carbon footprint results for a 1 litre carton of orange juice

allow for a targeted reduction strategy. The granularity of the results is only limited by the amount and type of inventory data used. To identify the main contributors for each process or activity you can 'dig down' into the results as far as the data will allow.

When interpreting results, it is useful to describe exactly what the results are showing you, however obvious it may be. Alongside each observation, try to provide some explanation as to the reason for the result, to provide more insight internally and also for later reference. An example has been given below for the results of the orange juice footprint:

- Cultivation of oranges contributes a significant proportion of the carbon footprint. This is predominantly due to the use of fertilizers and the resulting soil emissions.
- The transport of orange juice concentrate to the UK also contributes significantly. This is due to the time that concentrated orange juice is stored frozen prior to transport to the juice supplier.
- Production emissions are important, arising principally through the use of electricity and the consumption of refrigerants.
- The distribution of products to retail outlets is also a significant contributor to the total footprint. This is due to the large distances travelled and the need for refrigerated transport.

Outputs of this exercise should then feed directly into discussions over where to focus efforts for carbon reduction and how reduction might be achieved.

It may also be useful to compare/benchmark the carbon footprint of the product studied with other similar products externally or different types of products internally. In either case, comparisons need to be carefully considered, using the same level of data quality (see Step 2.5 of this Guide), ensuring consistent system boundaries (see Step 1.3) and an appropriate functional unit (see Step 1.1).

4.2. How certain can I be about the footprint and hotspots?

A PAS 2050 product carbon footprint can only be regarded as an estimate. Inevitably, there will be inaccuracies in standard emission factors used, data collected, knowledge gaps filled by assumptions and global warming potentials used. This is not necessarily a problem, providing it is known what purposes the carbon footprint can and cannot be used for. It is important to understand the uncertainties associated with the results, and what aspects of the assessment are leading to these uncertainties. In doing this, the confidence in results can be established, and this can be considered when making decisions on hotspot prioritization, material choices, process choices, etc.

Through meeting the requirements of PAS 2050, the product carbon footprint will be accompanied by a thorough assessment of data quality (see Step 2.5 of this Guide). This assessment can be seen as a first step in assessing uncertainty, where a clear indication of those areas contributing to uncertainty is established. Scores given to individual data points, datasets or all data can be used to assess uncertainty in a semi-quantitative way. Poor-quality data with large uncertainty could be, for example, where the emission factors used do not reasonably represent the actual process in question or where an estimate was required in the absence of data.

A more formal **uncertainty analysis** can also be undertaken by employing a statistical approach such as Monte Carlo analysis, if desired. Monte Carlo analysis allows uncertainty to be quantified, and will provide a more in-depth understanding of uncertainty than the data quality assessment alone. However, in order to carry out a Monte Carlo analysis, detailed information about the likely variability around each data point is required, which may be difficult to obtain. If sufficient information can be collected on the variability around each data point, then an LCA package (e.g. SimaPro or GaBi) can be used to perform the uncertainty analysis. Running a Monte Carlo analysis of your results in such an LCA package generates many carbon footprints using randomly selected values within the upper and lower bounds of each data point. The resulting carbon footprint is represented as the median of all carbon footprints, with ± per cent error bars showing the range of possible values.

After the uncertainty has been assessed, by either (or both) of the methods described above, a common-sense approach should be used to determine which data uncertainties are of most concern. For example, if data used to model an insignificant process or activity have high uncertainty, then it is not necessarily a problem. However, where data are uncertain and the process or activity in question is an important emissions source, then it should be flagged as such. In these cases, it is recommended that **sensitivity analysis** is carried out.

Sensitivity analysis

Sensitivity analysis is a simple approach that can be used to show how key data and assumptions influence the results. It can be applied to any part of the footprint, and involves simply changing the value (activity data or emission factor) over which there is uncertainty, to see how this affects the results. For example, to investigate the significance of uncertainty around orange juice transportation, the vehicle type or distance could be varied within a range of reasonable values (e.g. changing to a smaller/larger vehicle, increasing/decreasing the distance by 20 per cent). The sensitivity of the final results to this change can subsequently be assessed. Does the footprint change considerably, or only a by very small amount? Are your conclusions affected by the change? Do hotspots alter, or product comparisons change? Following sensitivity analysis, it may be necessary to collect additional data in order to improve the assessment in this respect.

4.3. Recording the footprint

Footprint records

Annex B of PAS 2050 provides requirements for the recording of supporting information, which should be followed. PAS 2050 Clause 4.4 Annex B

For cradle-to-gate carbon footprints, the product's use and end-of-life fate are unknown, which has implications for the storage and release of carbon. Therefore, it is particularly important that adequate records on removals of carbon and carbon content are provided to downstream companies using cradle-to-gate information in their carbon footprint assessments.

Communicating

There are no specific requirements given in PAS 2050 on the communication of carbon footprint results. If you choose to communicate information about your footprint or how you have reduced it, please refer to further international or national guidance, standards and regulations on communication of environmental claims to ensure it is clear, accurate, relevant and substantiated, e.g. Defra's *Green Claims Guidance*.[14)] Communication should follow the normative references given in Clause 2 of PAS 2050. The key to reporting is to be as transparent as possible and to match the language to the audiences' understanding. PAS 2050 Clause 10

Communication of the footprint can be in many different formats, including:

- presentations to stakeholders
- press releases
- corporate responsibility reporting
- carbon labelling (e.g. on the pack, on the website, at the point of sale).

[14)] See http://www.defra.gov.uk/environment/economy/products-consumers/green-claims-labels/.

Footprint verification

PAS 2050 Clause 10

If the decision is made to communicate externally, assurance is strongly recommended. By gaining third-party assurance, footprinting claims can be 'bullet-proofed', and provide stakeholders with the confidence that claims are robust and well founded. Typically, assurance involves:

- reviewing and testing data collection and calculation procedures to confirm these are sound and that activity data are of the appropriate quality
- reviewing the reported footprint claims to ensure that these reflect what has been undertaken and delivered in the given reporting period.

It is important to remember that there are different levels of assurance (i.e. self-verification, other third-party verification or independent third-party certification), and it is a requirement of PAS 2050 that claims of conformity state the level of assurance.

4.4. How can I use footprinting to drive reductions?

Carbon footprinting can be a basis for reducing carbon emissions and energy use, while also conveying a positive message to different stakeholder groups. Through the interpretation of the carbon footprint of your product, it should be evident which areas of the life cycle, which materials and which processes should be targeted for reduction.

Tips for carbon reduction

Energy

- Reduce the need for air conditioning by reducing solar gain and using natural ventilation.
- Change conventional light bulbs to compact fluorescent lamps (CFLs).
- Produce energy from renewables on site and use it to drive processes.
- Insulate buildings and lag all pipe work.

Manufacturing

- Focus on process efficiency.
- Consider emerging technologies.
- Ensure regular maintenance of processing equipment.
- Reduce fugitive emissions by replacing leaking refrigeration equipment.

Transport

- Use low-emissions vehicles (e.g. teardrop lorries).
- Retrofit the existing fleet with technology to reduce emissions (tracking devices, automatic idling cut-off, etc.).
- Improve delivery routes and increase backhaul where possible.
- Run driver training programmes to reduce over-revving, late gear changing, etc.

Identify efficiencies in your own process

Focus reduction initiatives on those processes identified by the assessment as being of most concern. The nature of these reduction initiatives will largely be specific to the product being assessed, and the production processes involved. However, some general tips for carbon reduction opportunities are outlined in this section.

These are generic measures given for illustrative purposes. Advice from trade bodies, consultants or internal sources should be sought on more specific carbon reduction initiatives that deliver the greatest possible saving for the lowest cost. For example, a good source of specific sector guidance on emerging technologies is the Carbon Trust's Industrial Energy Efficiency Accelerator programme.

Other tools, such as cost-benefit analysis and options appraisals, can be used alongside product carbon footprint information to decide on the most appropriate reduction strategy.

Help to design more sustainable products

The potential influence of design changes can also be assessed using product carbon footprinting. By manipulating carbon footprint models to change material inputs, processing requirements or use phase configurations, different design intervention options can be investigated and compared against the original product life cycle. It is also possible to go further and develop simple tools that allow designers to use 'what if' scenarios and determine the impact on total GHG emissions when changing a particular material or process.

Some examples are given in the box below on how this approach could be used.

Work with suppliers and customers to reduce emissions

Although you may have very little influence over your upstream and downstream supply chain, there is considerable benefit in making attempts to help achieve reductions more widely across the product life cycle. After all, the results of your carbon footprint could indicate that a particular material, process or life cycle stage that is not under your direct control could contribute the largest proportion to total emissions. Examples of actions that you could take include:

- communicating the results of, and insights from, your carbon footprinting work to your suppliers and customers

1. Materials

- What would the effect be of changing the material this component is made from?
  - Emission factors for a range of potential alternative materials could be included in the footprint model to enable a choice to be made.
- What would the effect be of reducing the weight of this component?
  - Weights could be directly changed in the footprint model.
- What would the effect be of sourcing the material for this component from a supplier closer to the manufacturing site?
  - Transport distances from the supplier to the point of manufacture could be directly changed in the footprint model.

2. Manufacture

- What would the effect be of increasing energy efficiency at this manufacturing site?
  - Estimates of likely potential savings (e.g. *x* per cent) could be used to enable the adjustment of energy use in the footprint model. This could also extend to savings in raw material consumptions and reduced volumes of waste.
- What would the effect be of increasing the recycling of waste materials at this manufacturing site?
  - The fate of factory waste could be directly altered in the footprint model, to increase the proportion of waste being recycled.

3. Use and end-of-life

- What would the effect be of making the product more energy efficient?
  - Energy consumption in the use phase could be directly changed in the footprint model.
- What would the effect be of making the product easier to recycle at the end of its useful life?
  - The fate of waste could be directly altered in the carbon footprint model to increase the proportion of waste recycled. This could also be linked to the emission factor used for recyclable material inputs, as the end-of-life fate can influence this.

- sharing lessons learned from the carbon footprinting exercise
- encouraging your suppliers to also undertake carbon footprint assessment, to increase the proportion of the product life cycle for which good and specific data have been collected
- working with suppliers to suggest reduction measures
- benchmarking your suppliers and measuring improvements over time.

As well as working with your upstream supply chain, educating your customers on carbon reduction measures can also lead to reductions in the footprint of your product. The use phase can represent a large proportion of emissions for certain products, and, therefore, advice given on their use can yield significant savings. It is important that this advice is backed up by sufficient research.

Annex A

PAS 2050 Clause 5.9

Further examples of functional units

Product System	Functional unit	Description
Energy-saving light bulb	The provision of 500 lumens of light for a period of 25,000 hours by a bayonet-fitting light bulb	By describing the system in terms of its function, it encapsulates the use phase of the product as well as its production. In the case of energy-using products, the use phase is likely to be the most significant life cycle stage to the overall carbon footprint.
Paint	Colouring and protection of 1 m^2 of wall area by one coat of matte emulsion paint for a period of 20 years	By reflecting the function of the paint (by specifying an area and a time period of coverage) rather than simply using a volume, it allows fair comparisons to be made between thicker or less durable paints, where more or less paint would be required to perform the same function.
Cleaning fluid for central heating	The treatment of 1 litre of central heating system fluid to allow the system to operate at maximum efficiency	This functional unit considers how effective the treatment method is, which is important when comparing products. For example, two products may have the same carbon footprint per litre but one may require twice the dose to treat the same quantity of system fluid. Comparing the carbon footprint of 1 litre of each cleaning product does not consider the effectiveness of the products, and therefore is not a true reflection of its function. Some products have multiple functions, e.g. paint both protects surfaces and makes the surface look good by providing a colour. Where this is the case, try to use a functional unit that captures as many functions of the product as possible.
Electric heater	A system with an output of 5 kW	This functional unit could be used as a reference unit for the carbon footprint of a many other types of heating systems (e.g. wood burner, electric storage heaters, gas central heating). By quantifying the output delivered, comparability between different products can be measured.
Bread	One 400 g loaf	The function of food can be difficult to define. It could be argued that we consume food to provide nutrition; however, this is not the only function of food. As it is also important to consider the communication of carbon footprints, a simple reference unit can often be the best approach.

Annex B

PAS 2050 Clauses 5.9, 6.4

Setting functional units and boundaries for services

Defining the functional unit for a service

When defining the functional unit of a service, the same principals described for goods also apply. In particular, it is important to identify the purpose that the service fulfils, and to consider this in your definition. With any product (good or service), the life cycle will cross over many other product life cycles. However, for services it may be more difficult to differentiate where the service under investigation begins or ends due to the intangible elements. Therefore, it is important to ask yourself the question 'What purpose does this service fulfil?' when attempting to define your functional unit.

Take the example of the carbon footprint of a debit card transaction. The purpose of the service is to allow the purchase of a product by transferring money from one account to another. There are many other financial services that take place before and after this transaction that could be confused as being part of this service (e.g. banking money, savings, making investments). So, it is important to define the functional unit to make it clear what the carbon footprint refers to. In this case, your functional unit could be defined as 'the transaction of £1 spent via debit card'.

For many, but not all, services, the delivery of that service is bound by time (e.g. one night's stay in a hotel, provision of car insurance for 1 year, operation of a bank account for 1 year). In these cases, it is likely that within the description of your functional unit you will want to include reference to a temporal boundary. As the purpose of a functional unit is to provide a reference point to which the carbon footprint of the service refers, where delivery is bound by time, the duration of that service should also be provided for transparency.

When defining the functional unit for a service also keep in mind the level of data collection involved and what may or may not be possible under the budget of the project. For example, when choosing a functional unit for a carbon footprint of home insurance, a decision needs to be made whether data will be collected on the replacement of stolen or damaged goods. There are many possible products that can be replaced under the provision of home insurance – from a stolen DVD to an entire house destroyed by fire – therefore, the collection of this amount of data may be not possible under the budget of the project. In this case, it should be made clear in the functional unit definition that the study refers to cover only, and not to cover and replacement.

Whatever functional unit is decided on, it is important when reporting carbon footprint results that this functional unit is reported alongside them. This is particularly important for services, where there are likely to be a greater amount of choices necessary in the scoping stage, which need to be made clear to users of carbon footprint information. In this respect, it may also be useful to present results broken down in a number of different ways, to allow easier comparison between similar studies, where different decisions on scope have been made.

Some examples of other functional units of services follow:

- Car insurance: the provision of car insurance cover for a period of 1 year.
- A taxi ride: a journey in a taxi for one passenger for a distance of 1 km.
- Window cleaning: the service of cleaning of 1 m^2 of window.
- Online bank account: the provision of online banking services for a period of 1 year.

Developing system boundaries for services

When developing a system boundary for a service, it may not always be clear how to define where the life cycle begins or ends, particularly where boundaries between other product life cycles are seemingly blurred. While a good has a tangible point of creation (i.e. the cradle) and conclusion (i.e. the grave), it may be less clear for a service with both tangible and intangible elements. In order to help visualize the attributable processes of the life cycle, the process map should be used alongside the defined functional unit.

You should assess which processes are directly connected to the service that allows it to deliver the performance of the defined functional unit. It may also be useful to ask yourself, again, 'What purpose does this service fulfil?', to help identify attributable processes, particularly where there is confusion as to which life cycle a process belongs.

Take the example of the carbon footprint of a package holiday. There are many services involved in providing a package holiday – booking the holiday, the flight, the hotel stay, excursions, meals, etc. – which can be viewed as separate services or grouped together in different ways to form one or more services. This is no different from the life cycle of a good, where various life cycles overlap. However, in the case of services, the boundaries of these life cycles may be more difficult to determine.

In order to identify which processes are attributable to the packaged holiday, consider the defined functional unit. If the functional unit was defined as 'the delivery of all aspects of a package holiday', the system boundary will include many more processes than if it was defined as 'the booking of a package holiday'. The system boundary and functional unit will largely be determined by the position in the supply chain of the company implementing the PAS 2050 assessment (e.g. the airline, the travel agent or the hotel) and the intended goal of the study.

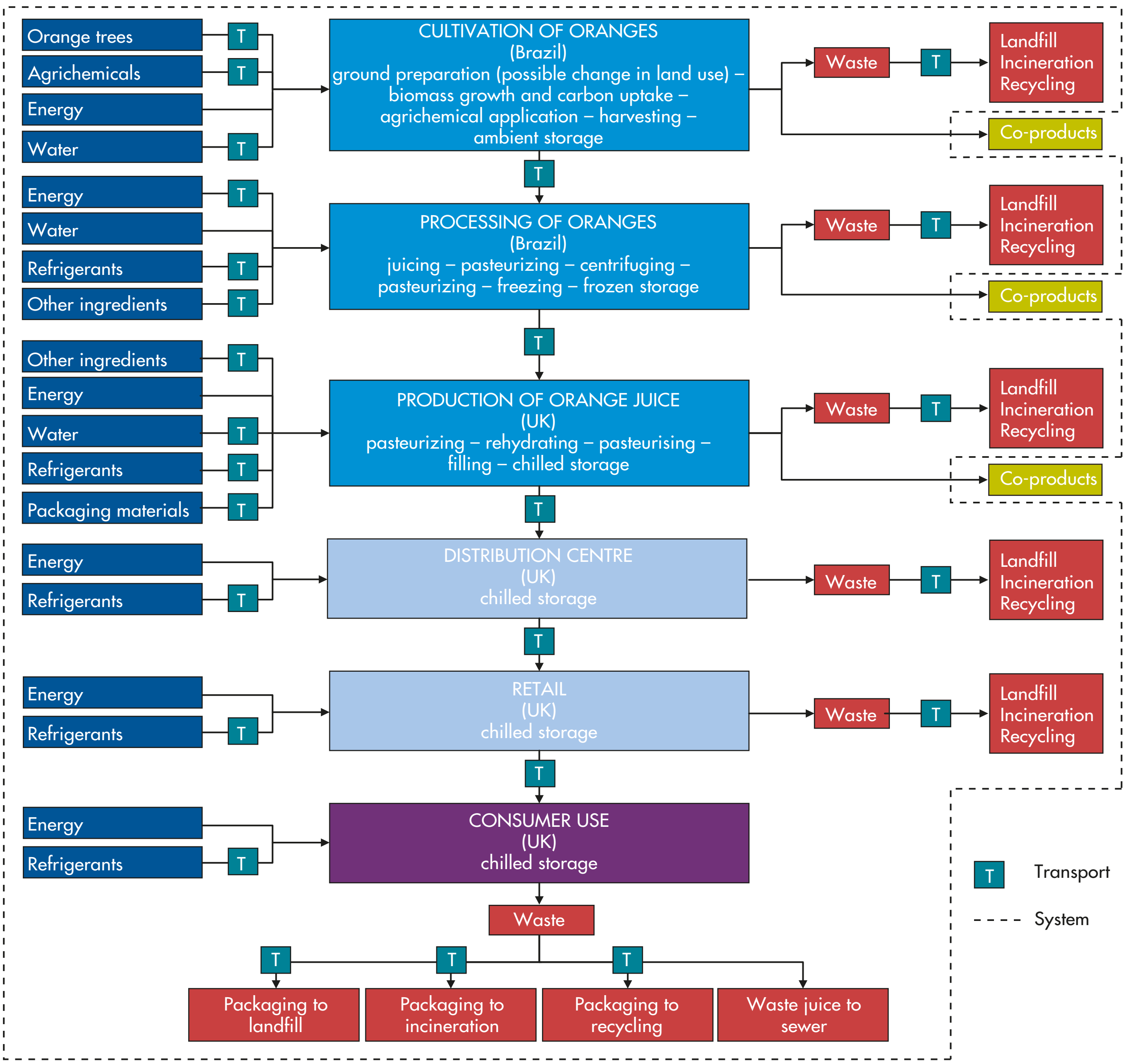
As with all products, but particularly with services, it is important to be as transparent as possible with the description of the system boundary, so it is clear which processes have been included and which have been excluded.

Annex C

PAS 2050 Clause 6.3

Orange juice example: data prioritization

Having defined the system boundary for calculating the carbon footprint of orange juice, it is useful to identify the life cycle stages or activities for which to prioritize data collection.



Life cycle stages in the production of orange juice

The first step is to identify whether any previous carbon footprint studies have been undertaken for orange juice, or for parts of the orange juice life cycle. A previous study will identify which life cycle stages will have the most influence on the total carbon footprint, and therefore which should be prioritized.

If a previous study is not available, an estimation is needed. Consider which life cycle stages comprise raw material or processes that are known to be particularly high intensity.

Looking at the orange juice life cycle, the key things to note are heat treatment processes for pasteurization and repeated refrigerant use for chilling and freezing. These are high-intensity processes and materials, and it will be important to accurately understand their relevance in the orange juice production process. However, the impact from different refrigerants varies considerably, and it is not likely that very much is used in any one life cycle stage.

Taking things a step further and undertaking some high-level calculations will give further confidence.

If a bill of materials is available, you can use this to estimate the carbon footprint and identify which life cycle stages are likely to have the most influence. If a bill of materials is not available, you can base your high-level calculations on the process map previously drawn, and by picking out the materials and processes that are known to be of higher intensity.

The table overleaf provides an example of rough calculations for orange juice. Based on the list of ingredients found on an orange juice carton, we can determine that concentrate makes up about a fifth of the juice ingredients. It is therefore assumed that the concentrate is about a fifth of the original pressed juice (i.e. 1 kg of pressed juice will make 0.2 kg of concentrate). It is further estimated that approximately half of an orange fruit is juice (i.e. 1 tonne of oranges will make 500 kg of juice).

The high-level calculations in the table show that the following are likely to be important for the footprint, and so are data collection priorities:

- The impact of N fertiliser application at the cultivation stage is potentially very influential to the carbon footprint. It will be important to achieve an accurate understanding of such fertiliser inputs in the orange juice life cycle.
- The energy consumption at the processing and production stages is also noteworthy. At the orange-processing stage, in particular, the orange juice is evaporated and pasteurized, which both require substantial amounts of heat. The carbon footprint could vary considerably, depending on the type of fuel used.
- The refrigerant used in several life cycle stages to freeze or chill the materials and the type and quantity of the refrigerant used could be significant for the footprint. Energy requirements for refrigeration – particularly during transportation/storage – are unknown and could be significant.

Data prioritization estimates for the production of orange juice (example data only)

Data description	Activity data			Emission factor		kg CO_2e	% contribution
	Quantity	Unit	Data source	kg CO_2e/ unit	Data source		
Cultivation of oranges							
Fertilizer – 57% nitrogen	0.035	kg	Sourced from publicly available data on the energy requirement for citrus fruit production in Turkey,[a] and have been calculated to represent 1 kg of orange juice, based on the mass assumptions described earlier Yield data for crops can also be found at FAOSTAT (http://faostat.fao.org/site/567/ default.aspx#ancor) and fertilizer data at Fertistat (http://www.fao.org/ag/agl/ fertistat/)	1.18	Google search: http://www.leaftc.co.uk/ downloads/cc/GHG_Emission_ Fertilizer_Production_ June2004.pdf	0.0413	9%
Farmyard manure	0.127	kg		0		0	0%
Pesticides	0.0001	kg		0.002	Google search: https://dspace. lib.cranfield.ac.uk/bitstream/ 1826/3913/1/Estimation_of_ the_greenhouse_gas_emissions_ from_agricultural_pesticide_ manufacture_and_use-2009.pdf	0.0000002	0%
Fungicides	0.0005	kg		0.002	Google search: https://dspace. lib.cranfield.ac.uk/bitstream/ 1826/3913/1/Estimation_of_ the_greenhouse_gas_emissions_ from_agricultural_pesticide_ manufacture_and_use-2009.pdf	0.000001	0%
Herbicides	0.00001	kg		0.002	Google search: https://dspace. lib.cranfield.ac.uk/bitstream/ 1826/3913/1/Estimation_of_ the_greenhouse_gas_emissions_ from_agricultural_pesticide_ manufacture_and_use-2009.pdf	0.00000002	0%

(Continued)

Data description	Activity data			Emission factor		kg CO_2e	% contribution
	Quantity	Unit	Data source	kg CO_2e/ unit	Data source		
Diesel	0.017	litre	As above	3.18	2010 Defra/DECC GHG guidelines: http://archive.defra.gov.uk/environment/business/reporting/pdf/101006-guidelines-ghg-conversion-factors.pdf	0.054	11%
Grid electricity: Brazil	0.043	kWh		0.112	2010 Defra/DECC GHG guidelines	0.005	1%
Water	0.017	m^3		0.0003	2010 Defra/DECC GHG Guidelines	0.00469	1%
Nitrous oxide (N_2O) emissions	0.000486	kg	Calculated based on IPCC emission factors for N_2O emissions in agriculture	298	Global-warming potential (GWP) of N_2O	0.145	30%
Incoming road transport	0.16	tkm	Estimated based on an assumed distance of 100 km	0.018	2010 Defra/DECC GHG guidelines	0.003	1%
Processing of oranges							
Natural gas for evaporation	0.099	kWh	Based on the mass assumptions described earlier and http://www.engineeringtoolbox.com/heat-work-energy-d_292.html, 4.19 kJ of energy is needed to heat 1 kg of water by 1°C: therefore, 335 kJ of energy is needed to heat water from 20°C (assumed ambient temperature) to 100°C (point of evaporation) It is assumed that natural gas is used as the fuel	0.226	2010 Defra/DEC GHG guidelines	0.022	5%

(Continued)

Data description	Activity data			Emission factor		$kg\ CO_2e$	% contribution
	Quantity	Unit	Data source	$kg\ CO_2e$/ unit	Data source		
Natural gas for pasteurizing	0.081	kWh	Based on the mass assumptions described earlier and http://www.engineeringtoolbox.com/heat-work-energy-d_292.html, 4.19 kJ of energy is needed to heat 1 kg of water by 1°C: therefore, 293 kJ of energy is needed to heat water from 20°C (assumed ambient temperature) to 90°C (assumed temperature for pasteurization) It is assumed that natural gas is used as the fuel	0.226	2010 Defra/DECC GHG guidelines	0.018	4%
Refrigerant (production)	0.00001	kg	Assumed	100	Estimated	0.001	0%
Refrigerant (emissions)	0.00001	kg	Assumed	1000	2010 Defra/DECC GHG guidelines	0.010	2%
Transport to production							
Road transport	0.2	tkm	Estimated based on an assumed distance of 500 km from processing to the port and 500 km from the port to orange juice production	0.018	2010 Defra/DECC GHG guidelines	0.004	1%
Sea transport	1.926	tkm	Estimated based on the distance from São Paulo, Brazil, to Avonmouth, UK (http://www.portworld.com).	0.015	2010 Defra/DECC GHG guidelines	0.029	6%

(Continued)

Data description	Activity data			Emission factor		kg CO_2e	% contribution
	Quantity	Unit	Data source	kg CO_2e/unit	Data source		
Production of orange juice from concentrate							
Grid electricity: UK	0.043	kWh	Estimated	0.617		0.027	6%
Natural gas for pasteurizing	0.081	kWh	Based on the mass assumptions described earlier and http://www.engineeringtoolbox.com/heat-work-energy-d_292.html, 4.19 kJ of energy is needed to heat 1 kg of water by 1°C: therefore, 293 kJ of energy is needed to heat water from 20°C (assumed ambient temperature) to 90°C (assumed temperature for pasteurization) It is assumed that natural gas is used as the fuel	0.226	2010 Defra/DECC GHG guidelines	0.018	4%
Cardboard packaging	0.02	kg	Assumed	–0.5	Estimated based on the EPA online calculator, including biogenic carbon removals	<0	<0%
Plastic packaging	0.005	kg	Assumed	3.8	Estimated based on EPA online calculator	0.019	4%
Refrigerant (production)	0.00001	kg	Assumed	100	Estimated	0.001	0%
Refrigerant (emissions)	0.00001	kg	Assumed	1000	2010 Defra/DECC GHG guidelines	0.010	2%

(Continued)

Data description	Activity data			Emission factor		$kg\ CO_2e$	% contribution
	Quantity	Unit	Data source	$kg\ CO_2e$/ unit	Data source		
Distribution							
Road transport	0.5	tkm	Estimated based on an assumed distance of 500 km from orange juice production to retail	0.018	2010 Defra/DEC GHG guidelines	0.009	2%
Grid electricity	unknown						
Refrigerant (production)	0.00001	kg	Assumed	100	Estimated	0.001	0%
Refrigerant (emissions)	0.00001	kg	Assumed	1000	2010 Defra/DECC GHG guidelines	0.010	2%
Retail							
Grid electricity	unknown						
Refrigerant (production)	0.00001	kg	Assumed	100	Estimated	0.001	0%
Refrigerant (emissions)	0.00001	kg	Assumed	1000	2010 Defra/DECC GHG guidelines	0.010	2%
Consumer use							
Refrigerant (production)	0.00001	kg	Assumed	100	Estimated	0.001	0%
Refrigerant (emissions)	0.00001	kg	Assumed	1000	2010 Defra/DECC GHG guidelines	0.010	2%
Disposal and recycling							
Landfill of cardboard	0.0134	kg	Assumed based on an average household recycling rate of 33% (Defra municipal waste statistics)	0.55	2010 Defra/DECC GHG guidelines	0.007	2%

(Continued)

Data description	Activity data			Emission factor		kg CO_2e	% contribution
	Quantity	Unit	Data source	kg CO_2e/ unit	Data source		
Landfill of plastic	0.000335	kg	Assumed based on an average household recycling rate of 33% (Defra municipal waste statistics)	0.04	2010 Defra/DECC GHG guidelines	0.00001	0%
Recycling of waste	0.00825	kg	Assumed based on an average household recycling rate of 33% (Defra municipal waste statistics)	0	Recycling emissions allocated to the user of recycled material	0	0%
Waste water treatment	0.2	kg	Assumed based on an estimate of 20% wastage of orange juice	0.00075	2010 Defra/DECC GHG guidelines	0.00015	0%

[a] Ozkan, B., Akcaoz, H. and Karadeniz, F. (2003) *Energy Requirement and Economic Analysis of Citrus Production in Turkey*. Akdeniz: Faculty of Agriculture, Department of Agricultural Economics, University of Akdeniz.

Annex D

Primary data collection tips and templates

PAS 2050 Clauses 7.2, 7.3

Data collection templates: useful tips

- It can be helpful to structure the data collection in a way that is relevant to the supply chain and production process. For example, if it is known that a production process is undertaken as two stages in separate locations, the template should be structured to allow for this. You could seek guidance from whoever will be completing the questionnaire as to the most appropriate structure.
- Use information collated in the scoping exercise to inform questionnaire design – think about which data you need and how you might measure it, including questions referring to use and end-of-life if relevant
- Clearly state what data are being requested and specify what unit reference they should relate to. In other words, the data provider needs to understand what part of the production process the data should relate to and whether it should be provided 'per kg of product', 'per unit of product' or 'per year of production', etc.
- The unit of measurement for a given data point is an important piece of information. To ensure that it is not accidentally missed off, it can be useful to request units in a separate column.
- Remember to include questions on transportations and waste.
- Clearly define what is meant by 'waste.' In some processes, excess material input might be reused or used for a different purpose, and therefore not considered as waste.
- Tailoring the template with as much specific knowledge as possible can be helpful to ensure that the right questions are asked and that the template is completed correctly.
- Remember to ask for the contact details of the person filling out the questionnaire – you will undoubtedly have some questions, and will need to refer back to get them answered.

Example data collection templates are given at the end of this annex.

Checking primary activity data

When reviewing primary activity data, whether relating to your own company's activities or one of your suppliers' activities, how do you know if it is right? The following sets out key areas to check that might indicate an error or inconsistency:

- There is always wastage in a process. If there is none, this should be questioned. It is possible that waste is reused in the process or used for a different purpose, and is therefore not considered as waste in the typical sense.
- Each process step should mass balance: inputs = outputs.

- If a process does not mass balance, have there been any chemical or physical changes in raw materials, such as moisture loss or oxidation, which might account for this? For example, agricultural processes or pulping.
- Are data gaps due to lack of data or because the value is zero?
- Check the units and make sure that they match the emission factor you use to represent them:
  - US units are not the same as UK units – a pint is not a pint, a ton is not a ton or a tonne, a gallon is not a gallon.
  - Always check what unit is being reported, and always record any conversion calculations – the following website provides an online conversion calculator: http://www.onlineconversion.com.
  - LCA data are normally reported in terms of mass (kg) or energy (MJ).
  - Convert volume to mass using density (dry or wet mass as appropriate) – the following sources provide several material densities: http://www.engineeringtoolbox.com/material-properties-t_24.html and http://www.simetric.co.uk.
  - Energy units can often cause problems. For example, kWh is not the same as kW: a 2 kW machine will consume 4 kWh in 2 hours, and 1 kWh = 3.6 MJ (the reason: 1 W = 1 J/second, 1 kW = 1000 J/second, and there are 3,600 seconds in an hour).
- Check that the reference unit is clear. For example, asking for electricity in kWh 'per tonne of material processed, including waste' or 'per tonne of product output excluding waste' could make a difference in the calculations.
- Is there any potential double counting of emissions? For example, if carbon dioxide emissions are reported for a process, is this associated with fuel combustion? If so, this is already included in the fuel emission factor.

Do the numbers look reasonable?

- Are there enough raw materials to make up the mass of the product (including for waste and any co-products)?
- Are energy and fuel inputs reasonable for the type of process considered? Check the literature (e.g. BREF notes, relevant supplementary requirement documents, web search, data from other suppliers).
- Are reported electricity exports achievable? Typically, a 20–30 per cent yield of electricity from burning fuel (1 kWh of fuel = maximum 0.3 kWh of electricity, minus process needs).
- Are the locations of different activities known? Grid electricity factors need to be specific to the country location in calculations and the transport steps.

Example data collection template 1[a]

PRODUCT TYPE				DATA REPRESENTATIVENESS		
SPECIFIC PRODUCT NAME			Orange juice from concentrate – 1 litre	Data collection method	Variability of data point (+/–)	Comments on data
	Unit	Reference	Quantity	[pick from drop-down list]	[pick from drop-down list]	
MATERIAL COMPOSITION						
Please provide information relating to the material inputs to produce 1000 cartons of 1 litre of orange juice from concentrate						
Orange concentrate	kg	per 1000 products				
Others, please add						
Please provide information on chemicals used to produce 1000 cartons of 1 litre of orange juice from concentrate						
Refrigerant (please specify type)	litres	per 1000 products				
Cleaning detergent	litres	per 1000 products				
Others, please add						
Please provide information on water used to produce 1000 cartons of 1 litre of orange juice from concentrate						
Mains water	litres	per 1000 products				
River water	litres	per 1000 products				
Others, please add						
OUTPUTS						
Please provide information relating to solid wastes from the production of 1000 cartons of 1 litre of orange juice from concentrate. *Please also indicate how the wast is disposed of from the drop-down list*						
Waste material 1	kg	per 1000 products				
disposal method [pick from drop-down list]						
Waste material 2	kg	per 1000 products				
disposal method [pick from drop-down list]						
Others, please add						
Please provide information on waste water generated from the production of 1000 cartons of 1 litre of orange juice from concentrate						
Waste water	litres	per 1000 kg paper			5%	
What is the waste water treatment method used?					5%	
Others, please add					5%	
ENERGY AND FUELS						
Please provide information on all purchased energy and fuels used on site to produce 1000 kg of paper.						
Purchased grid electricity	kWh	per 1000 products			5%	
Diesel	litres	per 1000 products			5%	
Natural gas	kWh	per 1000 products			5%	
Heavy fuel oil	litres	per 1000 products			5%	
Light fuel oil	litres	per 1000 products			5%	

[a] Note that it is best to use units familiar to the processing company. This may not be 'per 1000 products' and may be different for different items. For example, refrigerant gas may be per annum, obtained from refrigeration plant maintenance records. The number of products made per year can also be requested so that the amount/1000 products can be calculated later.

Example data collection template 2[a]

				Products	Transport		Data validity		
				Product 1	**Sourcing location** (city & country)	**Method of transport to site**	**Data collection method**	**Estimated variability of data** (+/-)	**Comments**
General product information									
General	Product manufacturing code	>>							
	Manufacturing site name and location	>>							
	Description of manufacturing process, including different processing stages								
	12 month period that the data represents	>>							
	Average weight of finished product	*kg*							
Inputs		**Units**	**Reference flow**			Drop down menu below	Drop down menu below	Drop down menu below	
Input materials									
		kg	per 1000 products						
		kg	per 1000 products						
		kg	per 1000 products						
		kg	per 1000 products						
		kg	per 1000 products						
		kg	per 1000 products						
		kg	per 1000 products						
		kg	per 1000 products						
			per 1000 products						
Manufacturing energy	Grid electricity - total	kWh	per 1000 products						
	Diesel	litres	per 1000 products						
	Natural gas	m^3	per 1000 products						
	Coal	kg	per 1000 products						
	Heavy fuel oil	litres	per 1000 products						
	Light fuel oil	litres	per 1000 products						
	LPG	litres	per 1000 products						
	Others (please add below)		per 1000 products						

(Continued)

Primary consumer packaging for packed product		kg	per 1000 products				
		kg	per 1000 products				
		kg	per 1000 products				
		kg	per 1000 products				

Processing materials (refrigerants used, water used for cleaning, other materials used for processing but not included in the product)	e.g. refrigerant						
	e.g. water	kg	per 1000 products				
	e.g. cleaning water	litres	per 1000 products				*Specify source (eg drinking water, borehole)*
	e.g. cleaning chemicals	litres	per 1000 products				*Specify source (eg drinking water, borehole)*

Outputs

Waste	Waste to landfill	kg	per 1000 products				
	Waste to recycling	kg	per 1000 products				
	Others (please add below)						

Waste water	Waste water to municipal treatment	litres	per 1000 products				*Describe the wastewater treatment process*
	Waste water to own treatment	litres	per 1000 products				*Describe the wastewater treatment process*
	Others (please add below)						

Air emissions (non-combustion emissions only, e.g. refrigerant leakage)	*Please specify*	*kg*	*per 1000 products*				
		kg	*per 1000 products*				
		kg					

[a] Note that it is best to use units familiar to the processing company. This may not be 'per 1000 products' and may be different for different items. For example, refrigerant gas may be per annum, obtained from refrigeration plant maintenance records. The number of products made per year can also be requested so that the amount/1000 products can be calculated later.

Annex E
Sampling approaches

PAS 2050 Clause 7.7

There are three sampling approaches that are recommended, depending on the situation in each case: (1) complete sampling, (2) random sampling and (3) stratified sampling. This can be a difficult area, and in complex situations it is recommended that a statistician is consulted.

Complete sampling

In some cases it may be practical, or advisable, to sample all sites that produce a product. These cases will likely arise where there are a small number of sites, or when sites are highly variable. For example, produce sourced from sites across multiple geographies.

Random sampling

In the case where there are a large number of sites and these are likely to be very similar in nature, random sampling is appropriate to gain an average dataset; for example, multiple plastic-manufacturing sites producing an injection-moulded product. In the absence of any information on variability, a sample size that is the square root of the population size is a common rule-of-thumb.

Stratified sampling

In situations where there are a large number of sites to sample and there is likely to be significant variation in the types of sites, a random sample may miss an important aspect of this variation. In these cases, a stratified approach to sampling is favoured. For this method, initial discussions are required with suppliers to help identify representative sub-groups within the supplier population as a whole. These sub groupings may take into account:

- the geographical location – the nature of the energy used/climate conditions/country-specific regulatory requirements
- the technology type, age, operational status/ operational management – e.g. a mixture of oil, gas, CHP, differences in abatement
- the size of the operation – economies of scale, small/medium/large.

Once these groups have been identified, a random sample should be taken from each group. The size of this sample should reflect the level of proportion of the product supplied by each group to be sampled. Once the data are collected, a weighted average can be computed based on the percentage of the total supply delivered by each group. This weighted average will have less variability than that of a random sample from the population.

For example, a mushroom producer may source from 100 farms of a variety of sizes. These farms can be categorized into three homogeneous sub-groups that reflect their standard operations – small (boiler-based heating), medium (boiler-based heating and automated processing) and large (CHP heating and automated processing) (in practice, there are likely to be more categories than this). The table overleaf shows the percentage of product supplied by each group and the best sampling strategy for data collection.

Type	Number	% of supply	Sites to sample
Large (CHP/automated)	20	60%	12
Medium (boiler/automated)	30	20%	4
Small (boiler/manual)	50	20%	4

(Note – this is an example only)

Note that the sampling effort is based on the proportion of the product supplied, not the number of suppliers for each group. The average dataset will be weighted according to the percentage supplied; therefore, it is best to weight the sampling effort accordingly, to provide the most representative sample.

Annex F

PAS 2050 Clause 7.2

A data quality assessment example

There are many ways in which data quality assessments can be performed, and different scoring approaches could be used in each case. The important thing is that due consideration is given to the quality of the data, and that this done in a transparent way. An example of how data quality can be assessed against the principles of PAS 2050 is presented in this annex. Note that this example outlines only one of the ways in which you could undertake a semi-quantitative assessment to flag areas of uncertainty (and potential need for data improvement).

1. Assessing the quality of primary data

To inform the quality of primary activity data points collected, each data point should be accompanied by additional information that describes what it is and where it has come from. This information will ideally be captured in the data collection template, and requested as part of the data collection exercise (see Annex D for example data collection templates). For example, for each data point, make sure you record:

- the source of the data – the name of the person and the company
- the time period that the data relate to
- how it has been generated, e.g. 'measured', 'calculated', 'estimated' or 'assumed'
- the potential variability – expressed as ±*x* per cent.

By assigning a 'data quality score' to the generation method (measured/calculated/estimated/assumed), it is possible to quantitatively assess the 'quality' of each data point. A scoring system *could be* as follows:

- Measured relates to a directly measured value, such as from an electricity meter or bill. Score = 5
- Calculated relates to one or more calculation required to obtain a value from a starting point of a 'measured' value. An example of 'calculated' data is apportionment of site-wide data to one product. Score = 4
- Estimated relates to the use of professional judgement to obtain a value, such as from process design or from machine energy ratings. Score = 3
- Assumed relates to a guessed value, based on an understanding of the process or a similar process. Score = 1

An example of how this could be used in practice is shown later in this annex.

2. Assessing the quality of secondary data

Using a similar approach, secondary data should also be assessed using scores for key criteria. The objective of a data quality assessment in this case is to ensure that the secondary data used are the most appropriate, and that any areas of uncertainty are identified.

Some suggested criteria and a potential scoring system are as follows (these are based on the key data quality principles outlined in the PAS 2050):

- Criteria 1: time-related representativeness – the age of the data.
  - <5 years old. Score = 5
  - 5–10 years old. Score = 3
  - 10–15 years old. Score = 2
  - >15 years old. Score = 1
- Criteria 2: geographical representativeness – the degree to which data reflect the geographic context of the subject, i.e. given the location, region, country and continent.
  - Match. Score = 5
  - Within one position, e.g. requires the regional value but the data are for a country average. Score = 3
  - Within two positions, e.g. requires the regional value but the data are for a global average. Score = 1
- Criteria 3: technological representativeness – the degree to which data reflect the technology of the subject and its operation.
  - Match. Score = 5
  - Industry average. Score = 3
  - Substitute. Score = 1
- Criteria 4: precision/accuracy – a measure of the potential variability of each data point.
  - Variability is described in the secondary data source as 'low'. Score = 5
  - Variability is described in the secondary data source as 'high'. Score = 2
  - Variability is not described, but considered 'low'. Score = 3
  - Variability is not described, but considered 'high'. Score = 1
- Criteria 5: method appropriateness and consistency.
  - PAS 2050/supplementary requirement prescribed emission factor. Score = 5
  - Government/international government organizations/ industry-published emission factor (using IPCC, 2007 global warming potentials (GWPs)). Score = 4
  - Government/international government organizations/ industry-published emission factor (using other GWPs). Score = 2
  - Company/other published emission factor (using IPCC, 2007 GWPs). Score = 2
  - Company/other published emission factor (using other GWPs). Score = 1

An example of how this could be used in practice is shown below.

Example data quality scoring approach

During the product carbon footprint calculation process (see Step 3 of this Guide), each primary and secondary data point should be assigned a score, based on a scoring system described above, or other means.

For example, the electricity consumption for pasteurizing orange juice prior to filling into a carton is provided by the orange juice manufacturer. The total site-wide electricity consumption is available, which has been apportioned to 1 litre of orange juice. The manufacturer is located in the UK, and a UK grid electricity emission factor for GHG emissions has been sourced from Defra/DECC reporting factors. The resulting GHG emissions from electricity used for pasteurizing orange juice account for 1 per cent of the total carbon footprint.

The data quality assessment and scoring is shown on the next page.

These scores can either be judged individually (e.g. against a target data quality score of 3–4) or can be multiplied by the proportion of the total carbon footprint that is attributable to a given data point (e.g. the total score for primary and secondary data multiplied by a 1 per cent contribution), to generate an overall score for the product footprint.

Alternative approaches

As noted, this is only one example. The important thing is that you use a systematic approach to assessing your

Primary data quality scoring

Primary data point	Time period of data	Source/publication	Collection method	Variability of data point (+/−)	Primary data quality score
Electricity	Jan. to Dec. 2010	John Smith, Superdrinks	Calculated	15%	3.4

Collection method: Score = 4

Primary data quality score: Collection method × (1 − Variability of data point) = 4 × 85%

Secondary data quality scoring

Chemistry	Technology	Geography	Age	Source	Variability	Secondary data quality score
Surrogate	Match	Country data required Country data provided	Less than 5 years	Peer reviewed life cycle inventories	Variability described as 'high'	4.4

Chemistry: Score = 1
Technology: Score = 5
Geography: Score = 5
Age: Score = 5
Source: Score = 5
Variability: Score = 2

Secondary data quality score: Sum of all scores ÷ Number of criteria = 22 ÷ 6

data – the 'scoring' system within can be made to fit your needs. An alternative, for example, is shown in the table on the next page.

Documenting data quality

The data quality assessment, along with any accompanying assumptions or calculations, should be recorded with the product carbon footprint calculations. When documenting assumptions and recording data, it might be helpful to think about whether the data and calculations will be clear in a year's time or if someone with no knowledge were to review it. This is useful when considering that some period of time might pass between performing the carbon footprint calculations and looking at them again. Clear documentation of data will mean that any updates in future years can be undertaken with significantly less effort.

An alternative data quality scoring approach

Score	1	2	3	4	5
Reliability of the source	Verified data based on measurements	Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on assumptions	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate
Precision	Data collection method allows for replication that will yield identical data	Data collection method allows for replication that will yield data very close to but not identical to data previously collected	Data collection method allows for replication that will yield data close to but not identical to data previously collected	Data collection method allows for replication, however data will not be close to that previously collected	Method of data collection does not allow replication of data as the variance is too large
Completeness	Representative data from sufficient sample of sites over an adequate period to even out normal fluctuations	Representative data from a smaller number of sites but for adequate periods	Representative data from an adequate number of sites but from shorter periods	Representative data but from a smaller number of sites and shorter periods or incomplete data from an adequate number of sites and periods	Representativeness unknown or incomplete data from a smaller number of sites and/or from shorter periods
Temporal correlation	Less than 3 years of difference to year of study	Less than 6 years difference	Less than 10 years of difference	Less than 15 years of difference	Age of the data is unknown or more than 15 years of difference
Geographical correlation	Data from area under study	Average data from a larger area in which the area under study is included	Data from area with similar production conditions	Data from an area with slightly similar production conditions	Data from an unknown area or an area with very different production conditions
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials but the same technology	Data on related processes or materials but different technology

PAS 2050 Clauses 5.1, 5.2, 5.5

Annex G

Biogenic carbon accounting

This annex provides a worked example of biogenic carbon accounting for a paper-based product. It sets out one of many ways in which these flows and emissions might be calculated and recorded. When undertaking

Mass of CO_2 relative to C = 1 × (44/12) = 3.67 × GWP of 1

0.5 kg C remains in the system within the paper. It is assumed that the remainder is combusted on site and oxidized

Removals

Emissions

In			Out			
C in (kg)	Biogenic CO_2e (kg)	Life cycle step	C out (kg)	C out as CO_2 (kg)	C out as CH_4 (kg)	Biogenic CO_2e (kg)
		Forestry				
–1	–3.67	*2 kg wood in, 50% biogenic C content (average moisture content)*				
		Paper production				
		1 kg paper produced, 50% C content (average moisture content)	0.5	0.5		1.83
		50% recycled at end of life				
		Post-consumer paper recycling	0.25			0.92
		40% disposed to landfill				
		90% of biogenic C is released over 100 years, 90% as CH_4, 50% captured for electricity generation	0.18	0.02	0.16	3.06
		10% disposed to incineration				
		Incineration with electricity export to grid	0.05	0.05		0.2
		Results				
		Emission balance	–0.02			2.33

Mass of CO_2 relative to C = 0.5 × (44/12) = 1.83 × GWP of 1

This carbon leaves the system to be passed on to the next user (allocated to the recyclate as a removal). Must be accounted for to balance the original removal. Expressed as mass of CO_2 relative to C

See further details below

Leaves the system as allocated to energy co-product. Expressed as mass of CO_2 relative to C

Some not re-emitted within 100 years

10% released as CO_2 over the period and 90% as methane

Sum of removals and emissions

Further details on the landfill calculation:

- **0.02 kg C released as CO_2 from landfill in 100 years = 0.02 × (44/12) × 1 = 0.07 kg CO_2e**
- **0.16 × 50% kg C released as CH_4 from landfill in 100 years = 0.08 × (16/12) × 25 = 2.7 kg CO_2e**
- **0.16 × 50% kg C released as CH_4 from landfill but burnt on site to generate energy – the resultant CO_2 from combustion is allocated to the energy co-product, leaves the system and is accounted for to balance the original removal = 0.08 × (44/12) × 1 = 0.3 kg CO_2e**
- **Total = 3.06 kg CO_2e**

any approach, it is recommended that both carbon flows and subsequent emissions are fully traced through the system and a carbon balance is drawn up.

Note that, alongside biogenic carbon removals and emissions, there will also be fossil CO_2e emissions at each stage.

Note also that this example is based on a series of hypothetical assumptions, and should not be taken as specific data to represent any elements of this system.

Annex H
Worked CHP example

A coal-fired boiler is used to produce both heat and power. The CHP plant has an overall efficiency of 75 per cent, producing 30 MJ of electricity and 45 MJ of heat for every 100 MJe of fuel input.

Coal (for electricity generation) has a gross calorific value of 25 MJ/kg, therefore 100 MJe fuel input = 4 kg coal. Using the 'all scopes' value for emissions from the Defra/DECC GHG conversion factors gives emissions of 10.5 kg CO_2e for the combustion of this 4 kg coal.

According to PAS 2050 requirements (clause 8.5), these emissions must be allocated in the ratio of 2.5:1 per MJ electricity:heat (as it is a boiler-based CHP system).

Electricity and heat are produced in the ratio 30 MJ:45 MJ by the CHP process.

To calculate the ratio of emissions, these two ratios are multiplied together:

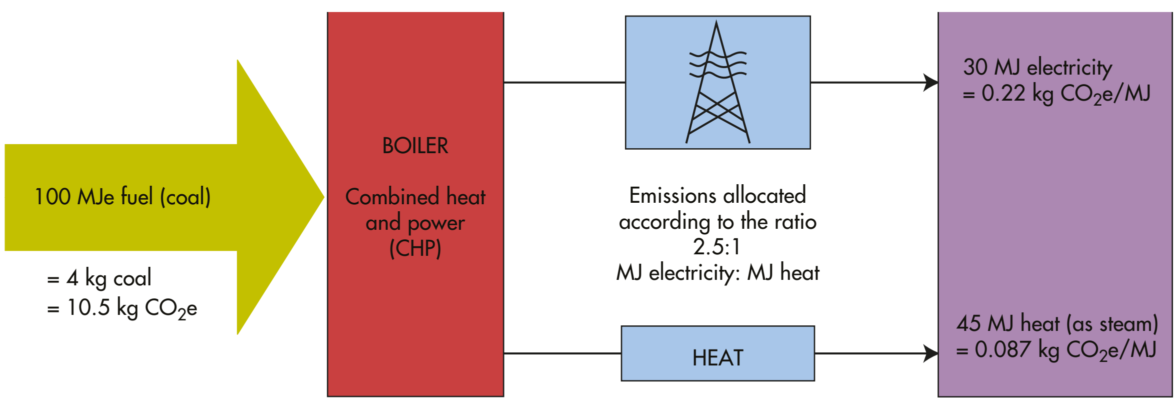
$$(2.5 \times 30):(1 \times 45)$$
$$= 75:45$$
$$= 1:0.6$$

So, for every 1 kg CO_2e allocated to electricity, 0.6 kg CO_2e is allocated to heat.

We know that 10.5 kg CO_2e is produced from the process described above. To calculate the fraction of emissions associated with electricity and heat, we need to divide each side of the ratio by the sum of both sides. The sum of both sides is 1.6. Therefore, the fraction of emissions allocated to electricity is $1/1.6 = 0.625$, and the fraction of emissions allocated to heat is $0.6/1.6 = 0.375$.

Emissions allocated to electricity: $0.625 \times 10.5 =$ 6.7 kg CO_2e allocated to 30 MJ of electricity.

Emissions allocated to heat: $0.375 \times 10.5 =$ 3.9 kg CO_2e allocated to 45 MJ of heat.



The final step is to divide by the amount of electricity and heat energy produced to calculate a figure per MJ.

Electricity: 6.7 kg CO_2e/30 MJ = 0.22 kg CO_2e per MJ (0.78 kg CO_2e per kWh).

Heat: 3.9 kg CO_2e/45 MJ = 0.087 kg CO_2e per MJ (0.31 kg CO_2e per kWh).

A quick way to check whether your calculations are correct is to check that the 2.5:1 (or 2:1) ratio still applies to the calculated figures for kg CO_2e per MJ. In this case, $0.087 \times 2.5 = 0.22$, so the calculation is correct.

Annex I

Supplementary requirements

PAS 2050 Clause 4.3

There are some specific elements of the PAS 2050 method that allow for the provisions within supplementary requirements:

- functional unit/unit of analysis definition
- system boundary development
- co-product allocation
- carbon storage
- land use change
- soil carbon
- capital goods
- transport and storage
- recycling
- use phase and final disposal profiles.

Supplementary requirements might also usefully provide information to support in the scoping and data collection stages of a footprint calculation.

Currently, PAS 2050 (Clause 4.3) provides a series of principles to guide the development of supplementary requirements, ensuring that they are:

- compatible with PAS 2050 itself and not in conflict with its provisions
- broadly recognized and developed through an inclusive process
- publicly available and up-to-date
- harmonized with regard to any other existing product sector or category rules/guidance updates (e.g. taking account of existing product category rules and updating them where necessary).

Independent verification is envisaged in order to achieve this, and is recommended alongside the principles set out in PAS 2050. It is anticipated that there will be a common registration facility for verified supplementary requirements. The BSI PAS 2050 website will provide updates on developments in these areas.