Measuring Carbon Footprints of Agri-Food Products

Eight Building Blocks

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EIGHT BUILDING BLOCKS

OECD
BETTER POLICIES FOR BETTER LIVES

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Preface

In pursuit of their net zero objectives, countries are using, or plan to use, a widely varied set of approaches. This richness of policy experiences provides valuable insights on the effects of different tools, which can be adapted to unique national circumstances, but international cooperation will be needed to ensure these tools are as effective as they can be.

Towards this, the Inclusive Forum on Carbon Mitigation Approaches (IFCMA) is the OECD’s flagship initiative, designed to help optimise the global impact of emissions-reduction efforts around the world through better data and information sharing, evidence-based mutual learning and better mutual understanding, and inclusive multilateral dialogue. The IFCMA is taking stock of different approaches, mapping policies to the emissions they cover, and modelling their impacts.

Recent analytical work by the IFCMA highlights the need for sector- and product-level carbon intensity metrics to support the design and evaluation of mitigation policies and enable the development of markets for low-carbon goods. More accurate, timely, and granular product-level carbon intensity metrics could form a foundation on which a wide range of public and private mitigation efforts could be built.

The report Measuring Carbon Footprints of Agri-Food Products is part of our effort to further support this objective by exploring essential building blocks to develop a reliable system to measure carbon footprints in agri-food supply chains. The agri-food sector accounts for one-third of human-made emissions, making it a key focus for reducing global emissions. At the same time, it supports millions of livelihoods, including small-scale farmers and communities in low- and middle-income countries, highlighting the importance of minimising compliance costs for farmers and businesses, and avoiding the unintended creation of trade barriers.

Looking ahead, governments can further enhance transparency in deploying farm-level calculation tools by using the latest scientific evidence, as well as enhancing communication of carbon footprints data along the supply chain. Further support is also needed for farmers, small and medium-sized enterprises, and producers in developing countries to overcome practical barriers in calculating carbon footprints.

The OECD will continue to support globally better coordinated and more effective carbon mitigation approaches, including identifying strategies for governments to enhance the quality and availability of sector- and product-level carbon intensity metrics.

Mathias Cormann
Secretary-General

Foreword

Food systems account for an estimated one-third of global greenhouse gas (GHG) emissions. The 2022 OECD Meeting of Agriculture Ministers therefore committed to increase climate change mitigation efforts by reducing emissions from agriculture and food systems and by increasing carbon sequestration. In 2023, 160 Heads of State and Government similarly affirmed in the COP28 UAE Declaration on Sustainable Agriculture, Resilient Food Systems, and Climate Action, that any path to achieving the goals of the Paris Agreement must include agriculture and food systems.

OECD analysis has long supported governments' efforts to improve the environmental sustainability of the agricultural sector, including GHG emissions. In recent years, OECD analysis has also taken a broader "food systems" lens, looking at the role of food loss and waste, consumer behaviour, and environmental impacts along food supply chains, among other topics.

Reliable data is essential to support efforts to improve environmental sustainability, whether by governments, farmers, businesses, or households. Yet at the moment, it is often difficult to find reliable data on environmental impacts of food products, such as their carbon footprint.

This report asks what it would take to achieve reliable and widespread measurement of carbon footprints of agri-food products, taking into account the specific characteristics of the sector. It identifies eight building blocks and shows that many of the necessary elements are emerging, although more work is needed to further develop and align these. It calls on researchers, farmers, other supply chain actors, governments, and civil society, both at the domestic and international levels, to work together to avoid fragmentation.

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Executive Summary

What would it take to achieve reliable and widespread product carbon footprint information in agri-food supply chains?

This report argues that eight building blocks are essential:

- Reporting standards and guidelines for carbon footprint measurement, to create a shared understanding of what to include in carbon footprint calculations.
- Science-based methods for measuring or estimating emissions.
- Farm level calculation tools, which allow farmers to use primary data on their activities and management practices as inputs to calculate their carbon footprint.
- Databases with secondary data, to be used where primary data is not (yet) available.
- A way of communicating carbon footprint data along the supply chain, so that detailed calculations by producers at one stage of the supply chain can be used as input at the next stage.
- A way to ensure the integrity and quality of the data and calculations.
- A way to scale up carbon footprint calculations while keeping costs low, to ensure widespread adoption by actors with limited capacity, notably farmers, small and medium-sized enterprises (SMEs), and producers in developing countries.
- A way to update these elements as new scientific insights and techniques become available.

If these building blocks were in place, actors in the supply chain would be able to receive product carbon footprint information from suppliers, add their own emissions, and share the result with the next stage of the supply chain, all the way to the point where a consumer buys a food product.

Such a model of “cradle-to-gate” carbon footprints, built up step by step based on primary data, would have the potential to unlock three different levers to reduce emissions in food systems. First, it would allow shifting to products with a lower average carbon footprint (e.g. from animal-based products to plant-based products). Second, within each product category, it would allow shifting to suppliers with a lower carbon footprint (e.g. from higher-emitting dairy producers to lower-emitting ones). Third, it would incentivise producers everywhere to adopt techniques (e.g. farm management practices or technological solutions) to reduce their emissions.

In the absence of primary data, only the first lever is available, based on averages. This would leave important opportunities for emission reductions untapped, as the evidence shows that carbon footprints can vary considerably within the same product category (e.g. wheat) and are influenced by producers’ choices of techniques and practices.

This report explains how the eight building blocks are necessary to achieve a system of reliable and widespread carbon footprints in food systems. For each of the building blocks, the report explains its importance, followed by a first assessment of the current state and gaps or inconsistencies to be addressed.

Across the building blocks, many of the necessary elements are already in place. Some have emerged recently, such as digital solutions to communicate carbon footprints along supply chains. Others were historically developed with different purposes in mind, such as Intergovernmental Panel on Climate Change (IPCC) guidance on science-based methods (originally addressed to governments for National Inventory Reporting) or farm level calculation tools (originally developed to help farmers evaluate total on-farm emissions rather than product carbon footprints). Many building blocks also developed independently of each other. This explains why adjustments will be needed to make all building blocks work well together.

The magnitude of the challenge should not be underestimated: achieving reliable and widespread measurement of carbon footprints in food systems is an ambitious goal. This report identifies many opportunities to improve existing building blocks and create greater alignment. Doing so will require collaboration among researchers, farmers, other supply chain actors, governments, and civil society, both at domestic and international levels.

Working towards product carbon footprint measurement and communication could also help with similar efforts related to other environmental impacts. For example, digital tools for exchanging carbon footprint data could be adjusted to communicate other environmental impacts. The concept of building blocks could therefore be a useful starting point for thinking about other environmental impacts.

1 Introduction

This chapter explains the growing demand for carbon footprint information, and what would be possible if reliable and widespread carbon footprint information were available.

Imagine a world where reliable information on the carbon footprint of firms and products were widely available. In such a world, it would be easy for producers to find out the carbon footprint of their inputs and their production processes, helping them identify ways to reduce their carbon footprint. It would also be easy for them to communicate the result of those efforts to customers. In turn, consumers, other businesses, or governments could compare carbon footprints of different products or different suppliers when making their purchasing decisions. Governments could link financial incentives to carbon footprints, and carbon footprint information could guide investment and R&D decisions.

There is a growing recognition that widespread, reliable carbon footprint information would form a "data infrastructure" on which private and public actors could build a wide range of mitigation strategies – but achieving this data infrastructure will require more accurate, timely, and granular product-level carbon footprint data (OECD, 2024[1]). Important initiatives are underway in the private sector to improve the use of primary data, to ensure greater reliability, and to facilitate digital exchange along supply chains (OECD/BIAC/WEF, 2023[2]). These include cross-sectoral work (PACT, 2023[3]), as well as sectoral initiatives such as Catena-X in the automotive industry or Together for Sustainability in the chemicals sector.

Building on insights from those initiatives, this report asks what it would take to achieve reliable and widespread carbon footprint information in food systems.

Until recently, the idea would have seemed like science fiction. However, the last few years have seen the "fast and furious" rise of environmental impact reporting in food systems, including for carbon footprints (Deconinck, Jansen and Barisone, 2023[4]). There is a growing demand for information from consumers, civil society, investors, and governments. One example is the rise of so-called "Scope 3" reporting, discussed in Box 1.1. The recently revised *OECD Guidelines for Multinational Enterprises on Responsible Business Conduct* also call on enterprises to provide relevant and accurate information on their environmental impacts, for example in terms of greenhouse gas (GHG) emissions (OECD, 2023[5]). In parallel with this growing demand for carbon footprint information, it has also become easier to provide, thanks to the emergence of reporting standards, calculation tools, databases, and platforms for data sharing.

As a result, at least some of the necessary building blocks for reliable and widespread carbon footprints in food systems are falling into place. Of course, some building blocks may not yet be available, while others may not yet be sufficiently mature or developed. In other cases, existing elements may need to be modified to be compatible with others. The aim of this report is to identify the necessary elements, provide a first assessment of what is available and what is not, and identify priority actions for policy makers, stakeholders, and the research community.

This report identifies eight main building blocks for reliable and widespread carbon footprints in food systems. A first assessment shows that many elements are indeed already in place, even if progress is uneven:

- *Reporting standards and guidelines* create a shared understanding of which emissions sources should be included in a carbon footprint calculation, how emissions should be allocated across products in a production process which generates multiple outputs, etc. Reporting standards and guidelines (such as the Greenhouse Gas Protocol reporting standards) are quite well developed in general, although there is a need to ensure greater alignment between standards and guidelines developed by different actors and for different purposes.
- *Science-based methods* for measuring or estimating emissions are essential. Fortunately, guidance developed by the IPCC provides a useful overview of available methods, as well as default options to use when more sophisticated approaches are not feasible. However, there are several areas where investments in better methods are needed, including for measuring soil organic carbon and for measuring emissions in developing countries. In addition, a practical

challenge is that scientific insights continue to evolve, but international guidance is updated only occasionally. Another challenge is that improved scientific insights do not automatically result in improved practical tools for calculating emissions.

- *Farm level calculation tools* allow the use of primary data on farm activities and management practices as inputs to calculate carbon footprints. There is a particular need for primary data at the farm level given the large heterogeneity in carbon footprints even among producers in the same region. Several farm level carbon footprint calculation tools exist already, but further efforts are needed to ensure these tools are aligned with reporting standards and guidelines. These tools also need to provide greater transparency so that users can assess whether their calculation methods are appropriate and based on the latest scientific evidence. In addition, benchmarking exercises may be needed to compare the estimates provided by different tools. In turn, such benchmarking can help determine the most appropriate tool for a given context and identify areas for improvement.
- *Databases with secondary data*, to be used where primary data is not (yet) available. Life Cycle Assessment (LCA) databases are well established and cover a large number of products and geographies. Most are consistent with key standards and updated regularly. However, there is room for improvement. Databases can differ in their methodological choices (which influences the results). There are also data gaps, notably for the developing world. The cost and complexity of LCA databases may also make it hard for smaller supply chain actors to access and use them.
- *A way of communicating carbon footprint data along the supply chain*, so that detailed calculations by producers at one stage of the supply chain can be used as input at the next stage. Several initiatives have emerged to facilitate data exchange, whether between large firms, between farmers and processors, or between farmers and data sources ‘upstream’ from the farm (such as suppliers or government databases). Many of these initiatives are at an early stage but they suggest that at a purely technical level the challenge of communicating carbon footprint data along the food supply chain is largely solved. Yet data exchange depends not only on solving technical questions but also regulatory and governance questions. Many of these are not specific to food systems and will require clarity from policymakers.
- *A way to ensure the integrity and quality of the data and calculations*, for example through third-party verification. Third party verification of product carbon footprints is widespread, but it does not evaluate the methodology itself, merely that whatever methodology was chosen has been followed. The quality of the databases and farm level tools would be considered part of the methodology, and hence outside the scope of third-party verification of product carbon footprints. This leaves important gaps. New approaches may be needed to verify that farm level calculation tools and secondary databases are compliant with widely used reporting standards and use science-based methods that are reliable and relevant to the specific case in which they are applied.
- *A way to scale up carbon footprint calculations while keeping costs low.* Food supply chains involve many smaller producers, who generally lack the capacity to engage in complex carbon footprint calculations. Scaling up carbon footprints in food systems will thus require finding ways to make the collection of primary data at farm level as easy and cost effective as possible. Several options exist, such as private sector engagement with suppliers, public-private awareness campaigns, embedding carbon footprint calculations in existing schemes, and providing technical assistance to low- and middle-income countries.
- *A way to update these elements as new scientific insights and techniques become available*. Reporting standards, calculation tools and databases need to reflect the latest scientific insights. A process is also needed to properly evaluate the impact of new mitigation techniques (e.g. new practices or new technological solutions) and update calculation tools to reflect these new options. Other elements of the “data infrastructure” may also require frequent review to incorporate new insights or techniques. For example, reporting standards may evolve over time to require a greater

degree of primary data. At the moment, there is no deliberate approach to updating the various building blocks. In fact, many initiatives do not have a pre-defined process or timeline for updates. Actors should align on realistic timelines to ensure continuous improvement of the overall system. More generally, embracing the principle of continuous improvement might well prove to be the most impactful action stakeholders can take in the short run. Taking such an iterative approach would acknowledge that initial estimates might come with considerable measurement error, but that stakeholders should work together to reduce this measurement error over time. It would also reassure stakeholders that suggestions for improvement can be discussed and incorporated at regular intervals.

Food systems also contribute to other environmental problems such as eutrophication, acidification, or biodiversity loss, and many initiatives seek to quantify these impacts (Deconinck, Jansen and Barisone, 2023[4]). The concept of building blocks as identified in this report could be useful for these other environmental impacts as well.

The question of measuring and communicating environmental impacts such as carbon footprints is especially important in an international trade context, as inconsistent approaches could create unnecessary trade barriers (WTO, 2022[6]) (Deconinck, Jansen and Barisone, 2023[4]). A detailed discussion of trade implications and potential policy options is beyond the scope of this report although the discussion will touch on some of these aspects.

Box 1.1. Developments in Scope 3 reporting and target setting

An important source of demand for more precise carbon footprint information is the growing expectation for firms to report and reduce their so-called “Scope 3” emissions (Deconinck, Jansen and Barisone, 2023[4]).

Whereas Scope 1 emissions are the emissions of a firm's own activities, and Scope 2 are the emissions of a firm's purchased energy, Scope 3 refers to emissions in the firm's supply chains, both upstream and downstream, as well as other emissions indirectly related to the firm, such as those linked to its investments (GHG Protocol, 2011[7]) (OECD/BIAC/WEF, 2023[2]). As an illustration, emissions from the production of wheat are part of the Scope 3 emissions of the industrial bakery purchasing the wheat, as well as of the Scope 3 emissions of the retailer selling the bread. The growing trend towards reporting and reducing Scope 3 emissions thus indirectly affects agricultural producers, as downstream firms may ask more detailed carbon footprint information from farmers to use in their Scope 3 reporting.

In the European Union, the Corporate Sustainability Reporting Directive (CSRD) makes Scope 3 reporting mandatory for many firms. Eventually, the requirement will cover not just large firms listed on EU financial markets, but also other large firms based in the EU and small and medium-sized enterprises listed on EU financial markets, including EU subsidiaries of foreign firms (European Commission, 2024[8]).

The International Financial Reporting Standards (IFRS) Foundation, which develops widely-used financial accounting standards, has recently developed sustainability reporting standards (known as the International Sustainability Standards Board (ISSB) standards). The climate reporting standard, released in 2023, requires Scope 3 reporting. These standards are voluntary, but are expected to be highly influential. In the United Kingdom, for example, discussions are underway on the creation of a UK Sustainability Disclosure Standard, which will be based on the ISSB standards (UK Department for Business and Trade, 2023[9]). Similarly, Japan has established the Sustainability Standards Board of Japan which is expected to develop sustainability disclosure rules by 2025 based on the ISSB standards (EY, 2023[10]).

Other jurisdictions have been considering Scope 3 reporting requirements. In the United States, the Securities and Exchange Commission (SEC) had initially proposed a climate disclosure rule which would include Scope 3 reporting requirements, although this requirement was dropped in the final proposed rule (SEC, 2024[11]). However, in California the Climate Corporate Data Accountability Act of 2023, which applies to large firms doing business in the state, does include mandatory Scope 3 reporting (Engler, 2023[12]).

Moreover, even before recent mandatory reporting rules, Scope 3 reporting was on the rise globally. Among all publicly listed firms worldwide, about 37% of firms disclosed at least some of their Scope 3 emissions as of May 2023, a doubling in three years' time (MSCI, 2023[13]). Among the 500 largest firms listed in US stock exchanges, 77% disclosed their Scope 3 emissions in 2023, up from 62% in 2021; among the 3000 largest listed firms, 43% now disclose Scope 3 emissions, up from 16% in 2021 (The Conference Board, 2024[14]).

Similarly, a growing number of firms is setting emission reduction targets which include their Scope 3 emissions. The Science Based Targets initiative reported that 4 204 firms had signed up to science-based emission reduction targets at the end of 2023, a doubling compared with one year earlier (SBTi, 2024[15]). For nearly all firms, targets cover Scope 3 emissions (SBTi, 2023[16]). This includes major retailers across OECD countries, such as Aeon (Japan), Ahold Delhaize (Belgium, Netherlands, United States), Aldi (Europe, United States), Carrefour (Europe, Latin America, Middle East and North Africa), ICA (Sweden, Norway, the Baltics), Kesko (Scandinavia, the Baltics), Migros (Switzerland), Tesco (United Kingdom, Europe), Walmart (United States, Canada, Latin America, Asia), and Woolworths (Australia). Food-related emissions tend to be a significant portion of retailers' Scope 3 emissions, which suggests a growing demand for precise quantification of these emissions.

This report is organised as follows. The next chapter provides some background on GHG emissions in food systems, highlighting four important findings from the literature which should inform the design of carbon footprint measurement in food systems. Chapter 3 clarifies the concept of a system of reliable and widespread carbon footprints in food systems as used in this report and presents the eight building blocks. The following chapters introduce each of the building blocks. Each chapter starts by explaining the importance of the element, followed by a first assessment of the current state, and gaps or inconsistencies to be addressed. The final chapter concludes by bringing together the priority actions for policymakers, stakeholders, and the research community.

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2 Background: Four findings about GHG emissions in food systems

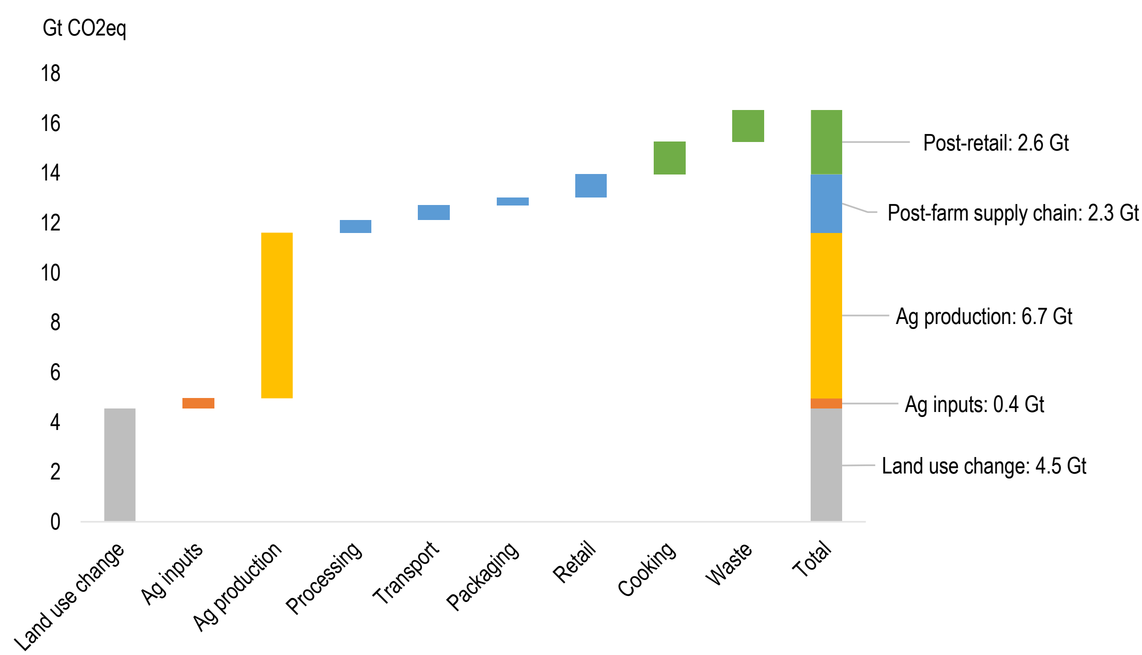
This chapter highlights four main findings about GHG emissions in food systems. First, agricultural production and land use change account for a significant share of the GHG emissions in food systems. Second, food products differ strongly in terms of their carbon footprint. Third, there is large heterogeneity among producers of the same product. Finally, a fourth finding is that many options exist to reduce GHG emissions from food production. The chapter discusses implications for carbon footprint measurement of agri-food products.

Four findings from the scientific literature to date provide important background for carbon footprint measurement in food systems.

First, agricultural production and land use change account for a significant share of the GHG emissions in food systems. Figure 2.1, using data from Tubiello et al. (2021[1]), shows that at the global level these two stages account for most of the GHG emissions.[1] For high-income countries, the role of other stages of the supply chains becomes more important: in Europe and North America, other stages of the supply chain accounted for more than half of domestic food systems emissions in 2019. However, even in these regions, GHG emissions from agricultural production are a significant source of emissions (41% in Europe, 38% in North America).[2] One implication of these findings is that the carbon footprint of a food product as found in a supermarket or restaurant depends heavily on emissions which occurred upstream in the supply chain. In other words, a life-cycle view is essential. Another implication is that any methodology for calculating carbon footprints should take into account the potential impact of emissions from land use change, at least for those commodities where that impact is likely to be significant.

Figure 2.1. Global food systems GHG emissions by supply chain stage, 2019

Gt CO_2eq

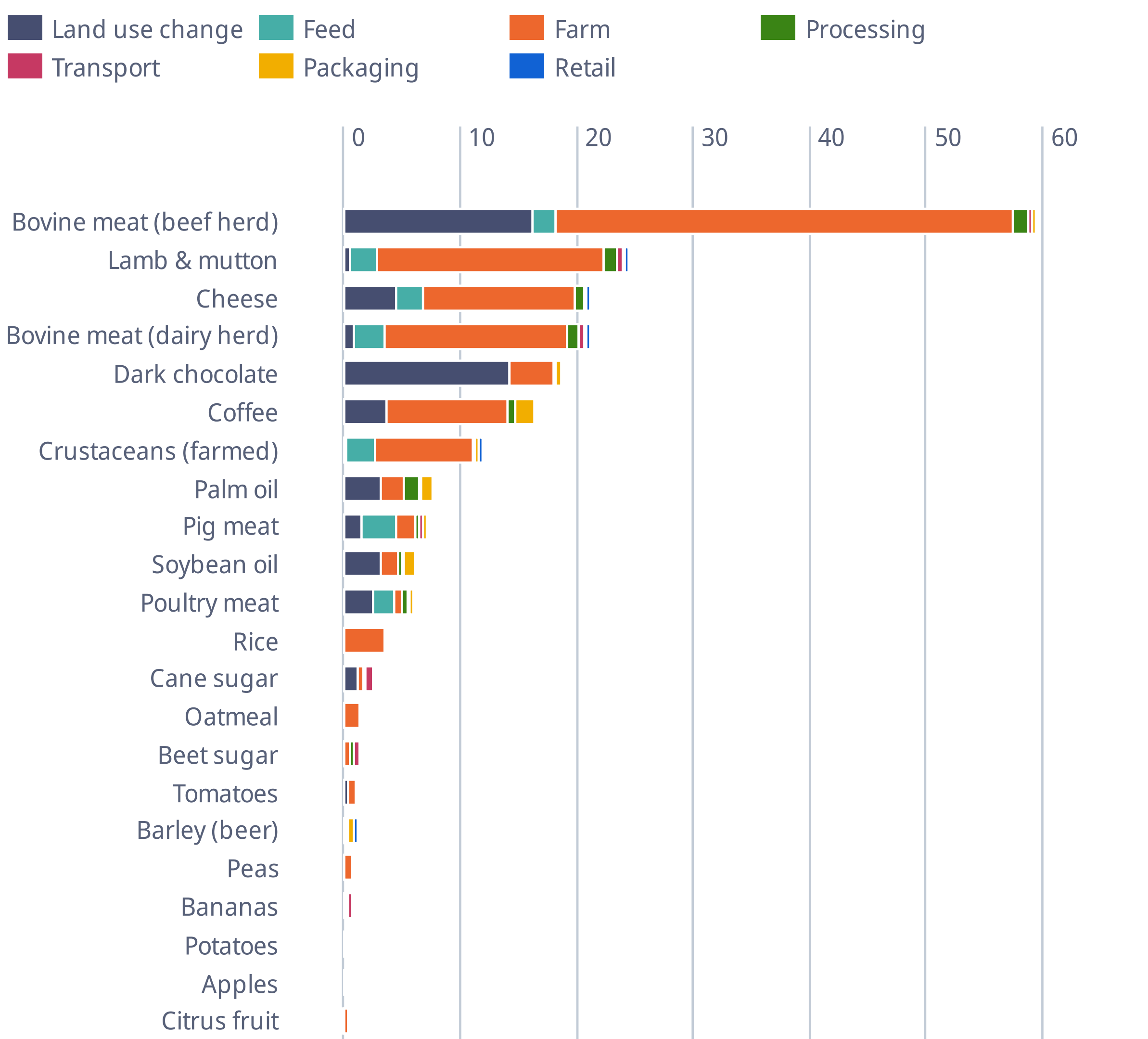


Note: 'Land' includes emissions from net forest conversion, drained organic soils, and fires. "Ag inputs" here refers to emissions related to the production of agricultural inputs; emissions related to their use are included in "Ag production".
Source: Based on Tubiello et al. (2021).

A second finding in the literature is that food products differ strongly in terms of their carbon footprint. Synthesizing 570 studies covering 40 products, nearly 40 000 farms, and 119 countries, Poore and Nemecek (2018[2]) showed large differences between food products in terms of carbon footprints (as well as other environmental impacts). On average, the carbon footprint of food products is higher for animal-based foods than for plant-based foods; within the animal-based foods, carbon footprints are on average higher for ruminant products (beef, lamb, cheese) (Figure 2.2).[3]

Figure 2.2. Estimated average carbon footprint for selected food products

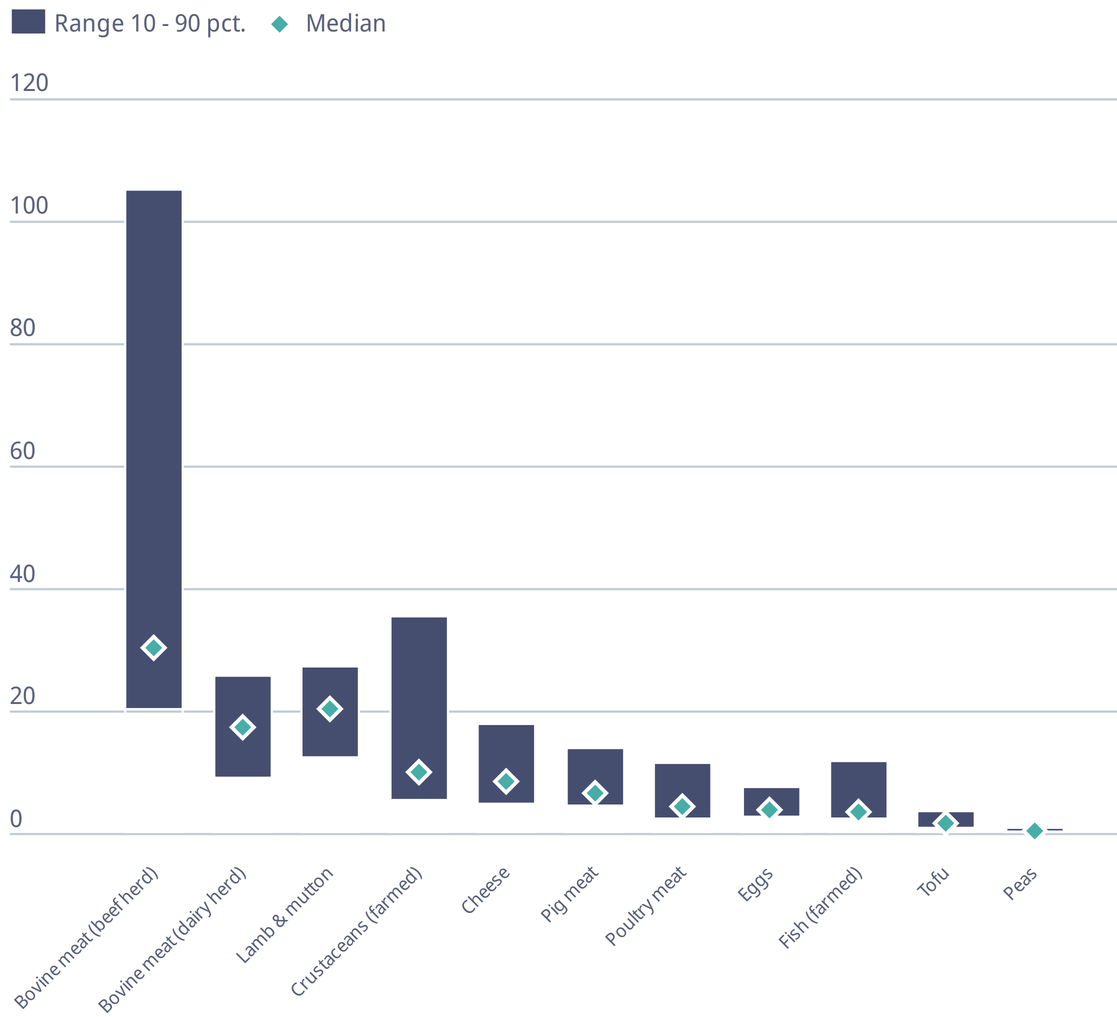
Kg CO2eq per kg of product



Note: Data shows global average GHG emissions (kg CO_2eq) per kg of product (excluding waste). Showing selected food products only.
Source: Poore and Nemecek (2018[2]).

However, the same study also shows that there is large heterogeneity among producers of the same product, the third key finding regarding food systems emissions. Figure 2.3 shows this heterogeneity at the global level for selected protein-rich products. The grey bar in the chart shows the range between the 10% best and 10% worst producers globally in terms of carbon footprint, indicating large variation around the median values. Poore and Nemecek (2018[2]) note that their data also shows a large range for wheat, maize, and rice, even within major growing areas (the Australian wheat belt, the US corn belt, and the Yangtze river basin). These differences may be due to different farm management practices and techniques, variations in local climate and soil conditions, and interactions between these.

Figure 2.3. Heterogeneity of carbon footprints for selected products



Note: Figure shows the median and 10th to 90th percentile range of carbon footprints of selected protein-rich products expressed in kg CO_2eq per 100g of protein.
Source: Poore and Nemecek (2018[2])

Finally, a fourth finding is that many options exist to reduce GHG emissions from food production, especially when the full supply chain is considered. For example, the production of nitrogen fertiliser currently relies on the use of natural gas, making it an emissions-intensive production process. It is possible to replace this with a production process based on renewable energy, which would allow for a significant reduction in the carbon footprint of nitrogen fertiliser production. On the farm, a wide range of farm management techniques and existing and future technological options can help reduce emissions. These include for example inputs such as feed additives to reduce methane emissions from enteric fermentation, or enhanced efficiency fertiliser to reduce nitrous oxide emissions; as well as changes in production practices (e.g. to increase soil carbon sequestration). Downstream supply chain actors similarly have many options to reduce emissions, from lower-emission vehicles for road transport to reducing the leakage of refrigerants. Across the food supply chain, reducing food loss and waste would similarly reduce emissions per unit of product delivered to the final consumer.

Taken together, these findings suggest that three levers can be used to reduce emissions of food systems (Deconinck, Jansen and Barisone, 2023[3]):

- *Shifting to products with a lower average carbon footprint*, e.g. from animal-based products to plant-based products. This requires information on the *average* carbon footprint of a product category.
- *Within each product category, shifting to suppliers with a lower carbon footprint*. At the farm stage, this could mean, for example, shifting from higher-emitting dairy producers to lower-emitting ones; but the same logic applies to other stages of the supply chain (e.g. shifting to fertiliser producers with a lower carbon footprint). Such shifts require information on *supplier-specific* carbon footprints.
- Incentivising producers everywhere to adopt techniques (e.g. farm management practices or technological solutions) which reduce their emissions. This requires that producers can access information on which techniques can reduce carbon footprints, not just in general but in their specific business. It also means that when producers are purchasing inputs with lower emissions (e.g. nitrogen fertiliser produced using renewable energy), this should be reflected in the estimated carbon footprint of their products. Again, this applies to the farm stage as well as to other stages of the food supply chain.

Carbon footprints in food systems should ideally be reliable enough to enable all three of these levers. The importance of agriculture in total GHG emissions, as well as the heterogeneity of emission intensities among farmers, argues for using primary data. Calculation methods should also be able to take into account emission reductions through changing techniques (such as farm management practices or new technological solutions) – and carbon footprint estimates should be updated regularly to capture such changes over time. There is a potential tension here between ensuring that methods are able to capture context-specific factors and avoiding trade barriers arising from divergent approaches in different countries.

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Notes

[1] See also Crippa et al. (2021[4]) for a similar analysis.

[2] Moreover, these estimates look only at emissions which take place within national boundaries. Given international trade in agri-food commodities, it is possible that the share of agricultural production and land use change in *consumption*-based emissions would be larger in these regions once trade is taken into account. Better product carbon footprint data could help improve estimates of consumption-based emissions. On consumption-based emission estimates, see Garsous (2021[5]) and Deconinck and Toyama (2022[6]).

[3] The analysis of Poore and Nemecek (2018[2]) results in a greater share of total emissions accounted for by land use change and agricultural production, at around 81% versus 70% in the Tubiello et al. (2021[1]) data. This is partly explained by the use of a different method ("bottom-up" extrapolation from detailed life cycle assessments in the case of Poore and Nemecek; "downscaling" from global cross-sectoral estimates in the case of Tubiello et al) and partly by a different time period, as the data in Tubiello et al. (2021[1]) refers to 2019 while the estimates of Poore and Nemecek (2018[2]) are a synthesis of numerous studies which took place prior to 2018. (The relative contribution of land use change has been falling over time).

3 Towards reliable and widespread carbon footprints in food systems

This chapter clarifies the concept of reliable and widespread carbon footprints as used in this report. It discusses the "cradle-to-gate" logic around which the report is organised, and the challenges of reliability. From these concepts, it is possible to derive the eight building blocks necessary to achieve the ambitious goal of reliable and widespread carbon footprints in food systems.

This report asks what it would take to achieve reliable and widespread carbon footprints in food systems. To clarify this concept, it is useful to go over each of the terms separately, before deriving the necessary building blocks to achieve this outcome.

3.1. Food systems

The focus in this report is mainly on carbon footprints as they occur along the food supply chain up to the point of purchase by consumers (e.g. in shops, restaurants), taking into account the full life cycle of the product up to that point – including land use change and the production of inputs. However, as the term ‘food supply chain’ might be interpreted by some to mean only food processing, distribution, and retail, or starting at the farm rather than taking into account land use change and the production of inputs, the broader term ‘food systems’ will be used here. Most of the discussion will focus on land-based production, although many of the ideas apply to fisheries and aquaculture and novel foods such as meat protein alternatives as well.[1]

3.2. Carbon footprints

As is common in the literature, carbon footprints here refer not just to carbon dioxide (CO2) emissions but to all GHG emissions (which will typically be expressed in CO2-equivalents). This is particularly important in the case of food systems as a large share of emissions consist of methane (CH4) and nitrous oxide (N2O).

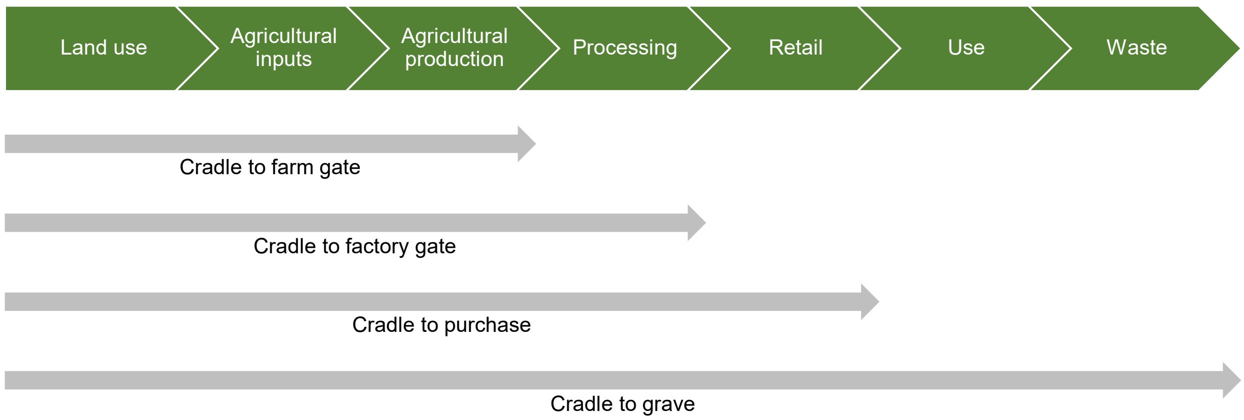
The term ‘carbon footprint’ can refer to different reporting levels, such as countries, sectors, entities (firms, organisations), or products (Deconinck, Jansen and Barisone, 2023[1]).

In this report, the focus is on product carbon footprints. Measuring product carbon footprints requires defining a denominator (e.g. emissions per kg of product). The choice of unit will be discussed in more detail in Chapter 4.

One reason for the focus on product carbon footprints is that quantifying product carbon footprints would also indirectly provide information about carbon footprints at other levels of analysis. Quantifying product carbon footprints requires clarity on how to quantify farm level or firm-level emissions as well, as these are inputs in the calculation. In turn, product carbon footprint information from suppliers can be used to quantify upstream supply chain emissions (which is part of a firm’s Scope 3 emissions).

Product carbon footprints can be defined on a ‘cradle to grave’ basis, covering all stages of the product life cycle including use and waste disposal (Figure 3.1). Other approaches are possible too, such as ‘cradle to farm gate’ or ‘cradle to purchase’.[2] However, the emphasis here is on a ‘cradle to gate’ approach, where each actor in the supply chain focuses on calculating product carbon footprints of the product life cycle up to the point where the product leaves its premises.

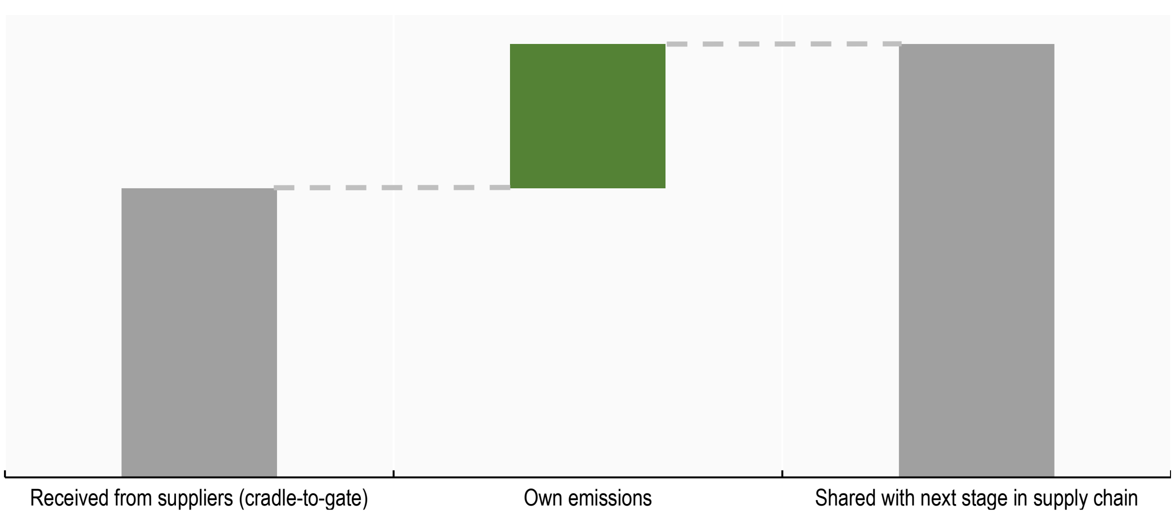
Figure 3.1. Stages of the product life cycle



Note: Simplified representation of the stages of a typical product life cycle for food products. (Transport is not explicitly shown here as it occurs in between each stage but is also in scope).
Source: Adapted from IDF (2022[2]).

A cradle-to-gate approach makes it easier to achieve widespread carbon footprints by "decentralising" the task of calculating carbon footprints. As pointed out by the Partnership for Carbon Transparency (PACT, 2023[3]), if product carbon footprint information on a cradle-to-gate basis is widely available from suppliers, then each actor in the supply chain can focus on calculating its own emissions, adding the carbon footprints of its inputs (provided by suppliers), and allocating the total across its outputs. The resulting product carbon footprint can then be shared with customers. In this way, the carbon footprint of a product can be built up step by step throughout a supply chain, allowing the use of primary data to the maximum extent possible (Figure 3.2).

Figure 3.2. Carbon footprints using the cradle-to-gate principle



Note: Simplified representation of product carbon footprints using a cradle-to-gate principle. A firm receives information from its suppliers on the carbon footprint of its purchased inputs, using a cradle-to-gate principle (i.e. including all upstream emissions). The firm adds its own emissions and shares the resulting cradle-to-gate product carbon footprint with its customers.
Source: OECD analysis.

How would such an approach look like in food supply chains? Starting at the input stage, suppliers of agricultural inputs (such as fertilisers) calculate the carbon footprint of their products using primary data. They in turn provide this information to farmers, either by sharing data directly with the farmer or by making their data publicly available. Farmers then use farm level calculation tools to estimate their on-farm emissions and add this to the emissions embedded in their purchased inputs. They allocate the total emissions across their different outputs (for example, a dairy farmer would need to allocate emissions across milk and meat). The resulting product carbon footprint information is then shared with processors. Processors add their own emissions calculated using primary data (e.g. on energy use, transport), allocate the result across their different outputs (e.g. a dairy processor would need to allocate emissions across cheese, milk powder, fluid milk) and share the resulting product carbon footprint with the next stage in the supply chain (e.g. food manufacturers, traders/wholesalers, retailers).

Each subsequent stage in the supply chain thus takes the 'cradle to gate' information received from its suppliers, adds their own emissions, allocates the result across their different products, and shares it with the next stage. A similar "modular" approach to emissions accounting in supply chains has been proposed by White et al. (2021[4]) and Reeve and Aisbett (2022[5]). Where information is not available for a supplier, firms may need to rely on secondary data, as is currently often the case.

The availability of product carbon footprint information would also help emissions reporting at other scales. For example, as noted in Box 1.1 (Chapter 1) firms are increasingly asked to report not just the total emissions from their own operations (Scope 1 emissions) and from the energy they purchase (Scope 2), but also Scope 3 emissions, which include upstream and downstream supply chain emissions. If product carbon footprint information is widely available on a cradle-to-gate basis, then calculating the upstream supply chain emissions becomes straightforward. This is another motivation for this report's focus on product carbon footprints using a cradle-to-gate basis.[3]

3.3. Widespread

Widespread carbon footprint information ideally means that information is available for all food products, for all producers, at all stages of the supply chain, so that stakeholders can easily take the information into account in their decision making.

Carbon footprints are an application of the life-cycle assessment (LCA) methodology to the specific issue of climate change. Historically, LCAs were conducted as highly customised one-time projects. An expert in LCA would work with a client to map the life cycle of a product and would use a variety of research methods to quantify the various flows. The resulting assessment would be used to identify hotspots (priority areas to be tackled) or to help re-design products and would often remain proprietary information of the client and/or the expert. Thus, originally, an LCA was best thought of as an individual study. Over time, as more life-cycle assessments were conducted, results were increasingly brought together in databases. These made it possible to draw comparisons between different products and processes (as in the synthesis by Poore and Nemecek (2018[6]) mentioned earlier), and to use the data to fill in gaps in LCAs where primary data is unavailable. However, not all products and geographies have been equally well studied (Deconinck and Toyama, 2022[7]).

The concept of *reliable and widespread* carbon footprints studied in this report can be seen as the logical next step. Databases provide valuable information, and further refinements can make them even more useful. But average data as found in a database can hide a considerable degree of heterogeneity and is static. For example, the database might contain information on the average carbon footprint of milk in Switzerland, at farm gate. But the database cannot reflect the efforts an individual farmer has made to reduce emissions, or the changing sourcing decisions made by a processor or retailer in its supply chain. In terms of the "three levers" identified in Chapter 2, databases can help shift purchasing decisions from product categories with higher average carbon footprints to product categories with lower average carbon footprints (the first lever), but they cannot capture individual heterogeneity (the second lever) and cannot identify and incentivise the different actions a producer could take to reduce their footprint (the third lever). Individual studies can do so, but are time consuming and costly, and where practitioners use different methodological choices, results may be hard to compare.

What is needed, therefore, is an approach which captures individual heterogeneity and mitigation efforts as in an individual study, while making data comparable and as easily available as in a database. This is the reasoning behind the proposal by the Partnership for Carbon Transparency (PACT, 2023[3]), as described earlier. However, this logic only works if the available product carbon footprint information is reliable.

3.4. Reliable

The reliability of an estimate or measurement has two components. The first is that it should not be *systematically* over or under the true value – a concept known as “unbiasedness” in statistics, or “trueness” in the ISO 5725-1 terminology. The second is that the *non-systematic* (random) error should be small.[4] For example, if firms do not include some sources of emissions in their estimates, this would lead to a systematic understatement of the carbon footprint. By contrast, if firms use industry averages for the carbon footprint of an input rather than supplier-specific information, the result will be random error, as the true carbon footprint of its suppliers might be higher or lower than the industry average – unless its suppliers *strategically* chose not to disclose their carbon footprint because it is above average, in which case the result would be a systematic understatement of emissions.

There is a strong case for using *primary data* as much as possible in calculating product carbon footprints, rather than *secondary* data.[5] One reason is the large heterogeneity of carbon footprints even among producers in the same region, which means that averages could lead to significant random error, even if there is no systematic over- or underestimation. A second reason is that if a producer adopts mitigation techniques to reduce emissions, this should ideally be reflected in carbon footprint calculations, to provide proper incentives to the producer and other supply chain actors. These arguments apply not just to food systems, but to other sectors as well (PACT, 2023[3]). To be reliable, carbon footprints should therefore be *timely* and *granular* (OECD, 2024[8]).

However, estimates based on primary data may come with their own measurement errors. If primary data from suppliers is used as an input in calculating carbon footprints downstream, any upstream measurement error will affect downstream results. Systematic errors upstream will lead to systematic errors throughout the supply chain. Random errors, by contrast, might end up being ‘averaged out’: for example, if a dairy processor has thousands of farmers supplying milk, a random error leading to an understatement in the carbon footprint estimate of an individual supplier would probably be offset by a random error leading to an *over*statement for another supplier. However, reducing random error is still important for several reasons.

- First, even if random errors of individual suppliers may be ‘averaged out’ in a supply chain, they still lead to uncertainty if the number of suppliers is small. For example, if a processor has only three suppliers, it is possible that all three random errors happen to be positive (leading to an overstatement of the carbon footprints) or negative (leading to an understatement). The smaller the number of suppliers, the higher the chance of such situations occurring, creating uncertainty.[6]
- Second, if the goal is comparability of carbon footprint information (across products, producers, countries, etc.), even random error needs to be avoided or minimised as much as possible, as comparisons might otherwise lead to wrong conclusions. For example, if the dairy processor is selecting its suppliers based on their estimated carbon footprint, random error could mean that farmers are unfairly excluded.

- Third, random error, like systematic error, would send the wrong signals to individual actors about where to focus their mitigation efforts. If a farmer's carbon footprint estimate contains measurement error (whether random or systematic), it becomes harder for the farmer to choose cost-effective mitigation measures.

Both systematic and random error can be reduced by insisting on *completeness* (all relevant emissions sources and sinks should be included) and *consistency* (assumptions, methods, and data should always be used in the same way), as well as on using the most *up-to-date science-based methods*. As science progresses, it seems likely that calculation methods will become more precise, reducing measurement error. In addition, a form of *quality assurance* such as third-party verification can also help improve reliability. Where supplier-specific information is used, data sharing tools can help avoid human error and can provide an 'audit trail' for quality assurance.

The requirements that product carbon footprints should be *reliable and widespread* are closely connected. Since generic averages could be misleading, there is a strong case for incorporating supplier-specific primary data – in other words, widespread product carbon footprints could help with reliability. In turn, achieving widespread carbon footprints is useless if data is of poor quality. However, there may also be trade-offs: increasing the reliability of carbon footprint estimates can increase the cost of calculations, which would make it harder to scale up carbon footprint calculations.

3.5. Building blocks

As the preceding discussion shows, the concept of reliable and widespread carbon footprints in food systems is ambitious and demanding. But it also creates clarity about the necessary building blocks and can create a common vision for how these building blocks should be further developed or adjusted. It seems likely that these efforts would in turn have positive effects in creating a better data infrastructure even if they do not achieve a near-universal system of carbon footprints.

Based on the key findings about food systems emissions and the conceptual discussion above, at least eight distinct building blocks can be distinguished for reliable and widespread carbon footprint measurement in food systems.[7] They are:

- *Reporting standards and guidelines for carbon footprint measurement*, to create a shared understanding of what to include in carbon footprint calculations.
- *Science-based methods* for measuring or estimating emissions.
- *Farm level calculation tools*, which allow different actors along the supply chain to use primary data on their activities and management practices as inputs to calculate their carbon footprint, in line with up-to-date science-based methods.
- *Databases with secondary data*, to be used where primary data is not (yet) available.
- *A way of communicating carbon footprint data along the supply chain*, so that detailed calculations by producers at one stage of the supply chain can be used as input at the next stage.
- *A way to ensure the integrity and quality of the data and calculations*, for example through third-party verification.
- *A way to scale up carbon footprint calculations while keeping costs low*, to ensure widespread adoption by actors with relatively limited administrative capacity, notably farmers, small and medium-sized enterprises (SMEs), and producers in developing countries.
- *A way to update these elements as new scientific insights and techniques become available*.

Again, a detailed discussion of international trade implications is beyond the scope of this report, but it is worth noting some connections between the building blocks identified here and rules designed to avoid trade barriers. The World Trade Organization's Agreement on Technical Barriers to Trade (the TBT

Agreement) incentivises WTO members to align standards and regulations on common international standards and encourages members to accept the results of conformity assessments (verification) performed by other members. The TBT Agreement also recognises the special needs of producers in developing countries and the potential role of technical assistance in helping them meet standards. These principles (on coherence in measurement and standards, on robust verification, and on inclusiveness) are highly relevant to the question of quantifying carbon footprints in an international context (WTO, 2022[9]). Communicating carbon footprint data along supply chains also connects to issues such as trade facilitation (OECD, 2018[10]; Sorescu and Bollig, 2022[11]) and data localisation measures (Del Giovane, Ferencz and López González, 2023[12]).

The following chapters cover each of these building blocks in more detail, assessing what is already in place and which further actions would be needed.

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Notes

[1] On meat protein alternatives, see Frezal et al. (2022[13]).

[2] Yet another possibility, not shown in the figure, is a "cradle-to-cradle" approach. This approach replaces the final step of waste disposal by a reusing or recycling step, so that the 'waste' product effectively becomes the input in another production process, creating a more circular model. See Bjorn and Hauschild (2017[14]) for a discussion.

[3] One shortcoming of a cradle-to-gate approach is that it focuses on activities taking place within companies. This leaves out the activities by households (e.g. emissions from cooking) and waste disposal. In principle, it might be possible to add an estimate for these emissions to the carbon footprint calculation at the retail stage. However, this would necessarily need to involve average data rather than primary data.

[4] The terms "accuracy" and "precision" are often used in this context, but the terms can be confusing. For example, in metrology, the term "accuracy" refers to the systematic error, while "precision" refers to the random error; however, in the ISO 5725-1 standard, "accuracy" describes a combination of low systematic error (high trueness) and low random error (high precision).

[5] Intuitively, the difference between primary and secondary data is that secondary data was collected in other contexts or for different purposes and is used as an approximation instead of collecting primary data on the specific product, firm, or farm being studied. In reality, the distinction is more of a continuum. For example, on a farm, direct measurement of emissions (e.g. using sensors) is often difficult and costly. In practice, primary *activity data* (e.g. on the number of animals, manure management practices, feed rations, use of cover crops) is fed into a model to estimate emissions. While this is one step removed from direct observation of emissions, it still leads to a more specific estimate than using average data (e.g. based on estimates obtained on other farms). In what follows, estimates based on primary activity data will therefore also be referred to as primary data.

[6] This can be seen more formally from the formula for the standard deviation of a sample mean, which is $\sigma/\sqrt{n}$ where σ is the standard deviation in the population (which in this context can be thought of as the standard deviation of the random measurement error) and n is the number of observations (in this context, the number of suppliers). For large numbers of suppliers (high n), this expression becomes small, as random errors are more likely to 'cancel out'. For a small number of suppliers, this is not the case, making it more important to reduce the random error (i.e. a lower σ) to reduce the overall uncertainty.

[7] Recent work by OECD and the International Trade Centre has developed a typology of sustainability initiatives (OECD report) to help establish a common understanding of the characteristics of different sustainability initiatives, and their similarities and differences. The typology looks at features related to an initiative's objective, scope, operations, and governance, each broken down into differentiators, for which potential attributes are defined. The typology is sufficiently flexible that it can be used to organise the

various building blocks covered here. For example, a carbon footprint standard and a farm level calculation tool would both fall under “Scope – sustainability – environmental” and “Scope – performance – outcomes”, but would differ on the objective: where the standard would have “Objective – facilitation – guidance/framework”, the farm level calculation tool would have “Objective – facilitation – tool”. Other building blocks can similarly be classified.

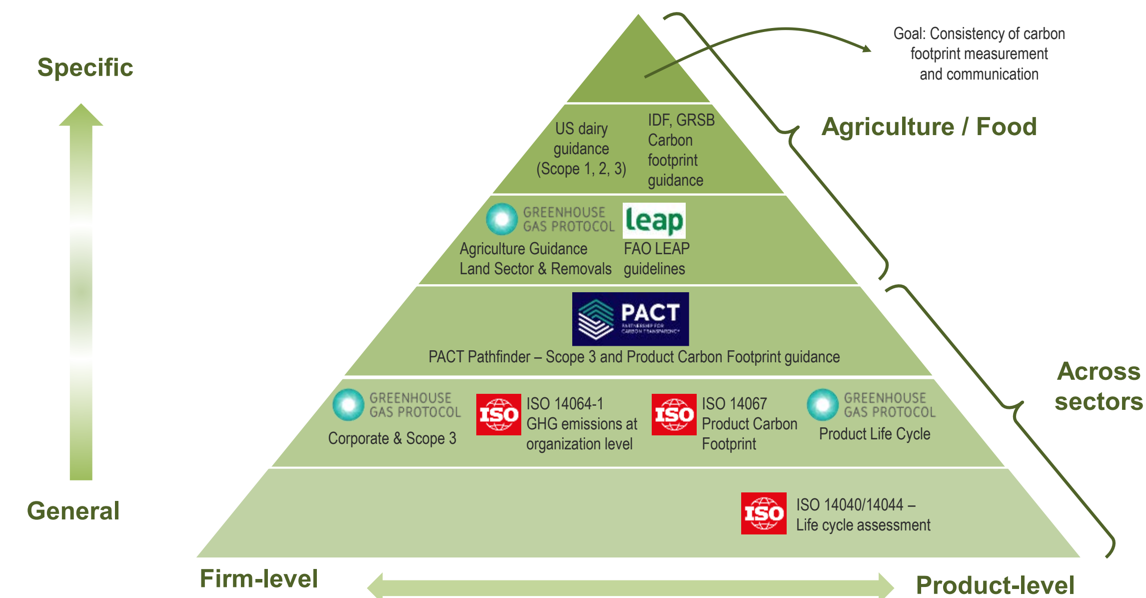
4 Reporting standards and guidelines for carbon footprint measurement

Reporting standards and guidelines are the first building block for carbon footprints. This chapter introduces the landscape of such standards, including product carbon footprint standards, sectoral guidance, as well as product category rules. The chapter also discusses the PACT Pathfinder approach which seeks to integrate these different strands into a coherent whole.

Clear reporting standards and guidelines are essential to coordinate carbon footprint calculations across firms, sectors, and supply chain stages. Standards and guidelines can answer questions such as which activities to include, which methodologies to use, and which numbers to report and at what level of granularity. Without shared answers on these and other questions, each carbon footprint calculation may end up using different definitions or methodological choices, making the resulting numbers difficult to compare.

Over the last two decades, a landscape of standards and guidelines has emerged for measuring carbon footprints, including standards addressing food systems-specific issues. It is easiest to think of this landscape as a pyramid, as shown in Figure 4.1.

Figure 4.1. The landscape of carbon footprint reporting standards and guidelines



Source: OECD analysis.

In this figure, standards and guidelines shown on the left focus mainly on firm-level (or farm level) carbon footprints, while those on the right focus on product-level carbon footprints. Standards and guidelines at the bottom of the pyramid are more general (sector-agnostic) in scope, while those higher in the pyramid are increasingly specific – e.g. focusing on agriculture, or focusing on a specific sub-sector (dairy, beef, horticulture). The ultimate goal of these standards and guidelines is to support consistency in emission measurement and communication, including by ensuring consistency of calculation tools and emission factor databases, as indicated at the top of the pyramid. In the middle of Figure 4.1.

is the PACT Pathfinder initiative which explicitly aims to bridge across the different standards and guidelines, both by connecting product-level carbon footprints to firm-level reporting (for Scope 3 purposes) and by harmonising guidance across different sectors (PACT, 2023[1]).

As is clear from Figure 4.1, the two main standard setters are the Greenhouse Gas Protocol (GHG Protocol) and ISO. Both organisations have standards for firm-level (organization-level) reporting as well as product-level reporting. These standards are fairly similar. In practice, firm-level reporting commonly uses the GHG Protocol Corporate standard (which was the first of its kind when it was published in 2001) while product-level carbon footprints often use the ISO 14067 standard. An older product-level carbon footprint standard, PAS 2050, is also sometimes used.

This chapter asks to what extent existing standards provide sufficient guidance to allow a system of reliable and widespread product carbon footprints. The focus is therefore on product carbon footprint standards, although some of the other standards in Figure 4.1 will be discussed as well, when they provide relevant guidance. For example, sectoral guidance which has been developed originally for firm-level (corporate and Scope 3) emissions can be useful for product-level carbon footprints as well.

4.1. Product carbon footprint standards

Product carbon footprints can be seen as a specialised form of *life cycle assessment* (LCA) (Hauschild, Rosenbaum and Olsen, 2018[2]) (Cucurachi et al., 2019[3]). The basic principles of LCA are defined in the widely used ISO 14040 and 14044 standards. The ISO 14067 standard for product carbon footprints builds on these standards and is designed to be used in conjunction with them.

In addition to the ISO 14067 standard (originally introduced in 2013, last updated in 2018, and currently undergoing revision), other product carbon footprint standards exist, notably the GHG Protocol Product Life Cycle Accounting and Reporting standard (introduced in 2011) and the PAS 2050 standard (which was the first standard on product carbon footprints, developed by the British Standards Institute in 2008 and last updated in 2011). The standards have many similarities. Whatever differences exist have limited practical relevance nowadays, as the ISO 14067 standard is now the most widely used (see Box 4.1 for a discussion of some differences). The discussion here touches on the main methodological choices and underlying principles in product carbon footprint standards, focusing mostly on the ISO 14067 standard.

A first important distinction is between an *attributional* and *consequential* approach to life cycle assessment (and hence product carbon footprints). Attributional LCA is essentially a "snapshot" at a point in time of the flows that can be ascribed to a given product or system, whereas consequential LCA asks how these would change if for example output was increased by one unit. In the context of land use change, an attributional LCA would ask whether any land use change occurred in the life cycle of the product (a concept known as *direct* land use change), whereas a consequential LCA would ask whether an expansion of output would, through economic and behavioral feedback and substitution effects, lead to land use change (a concept known as *indirect* land use change). The ISO 14067 standard can accommodate both attributional or consequential approaches, but firm-level and product-level carbon footprints typically take an attributional lens (GHG Protocol, 2022[4]); the GHG Protocol Product Standard even requires it (GHG Protocol, 2011[5]).[1]

A second important choice regards the *functional or declared unit* – i.e. the "denominator" of the LCA or carbon footprint. Environmental impacts could be expressed in terms of physical units of output, e.g. per liter of milk at the farm gate; this is referred to as a "declared unit" approach. But impacts could also be expressed in terms of the functions those products or systems fulfill, such as the nutrient content of food, e.g. environmental impacts per 100g of protein. LCAs and carbon footprints are often expressed in terms of such functional units, an approach generally favoured by the ISO 14067 standard to ensure meaningful comparisons. However, such an approach is not ideal if the goal is to transmit carbon footprint data along the supply chain. Since the supply chain involves a transfer of physical products, these should be the relevant denominator. Expressing emissions in terms of declared units also reduces the scope for confusion or incompatibility when the relevant functions of a product can be defined in different ways.[2]

The definition of the *product system and system boundaries* determines which activities (and hence impacts) are in scope of the assessment and which ones are out of scope. For example, in assessing the environmental impacts of milk, this would include a decision on whether the production of fertilisers used in growing animal feed is part of the scope or not. As the term "life cycle assessment" implies, a full LCA (and hence a full product carbon footprint) should include all relevant stages of the life cycle, from raw material extraction to the end-of-life stage (e.g. waste management, landfill); this is also known as a cradle-to-grave approach. But as noted earlier, to scale up the measurement and communication of carbon footprints in supply chains it is often more practical to focus on cradle-to-gate approaches, where each actor accounts for life-cycle emissions up to the point where the product leaves its premises. Existing standards foresee this possibility.

Another aspect of defining the system boundaries is the use of cut-off criteria for excluding certain processes, inputs, or outputs. For example, the ISO 14067 standard notes that emissions related to the production of capital goods (such as the emissions involved in the production of a tractor) can be excluded if this would not significantly change conclusions.[3]

The treatment of *carbon offsets* is another aspect of the definition of system boundaries. A carbon offset or carbon credit is a certificate purchased by an organisation through, for example, an emissions trading scheme or through funding an emissions reduction project unrelated to the life cycle of the product. The ISO 14067 carbon footprint standard (as well as the Greenhouse Gas Protocol's Product Standard and PAS 2050) prohibit the inclusion of carbon offsets in the system boundary: the product carbon footprint should therefore represent *actual* emissions and removals which occurred during the life cycle of the product.

Production processes often involve multiple outputs, and conducting an LCA or product carbon footprint calculation thus requires *allocation rules*. In the context of dairy farming, for example, an allocation rule answers the question of how the total environmental impacts of the farm should be allocated between milk and beef outputs; in dairy processing, allocation rules are needed to allocate impacts between different types of dairy products (butter, skim milk powder, etc.). The ISO standards indicate a preference for avoiding allocation rules whenever possible. For example, an arable farmer with several crops might be able to identify which inputs were used for which crops, avoiding the need to use an allocation rule. Where this is not possible, the ISO 14067 standard stipulates that allocation should be done "in a way that reflects the underlying physical relationships"; and where this is not possible either, allocation should be done "in a way that reflects other relationships," for example in proportion to economic value.[4]

The ISO 14067 carbon footprint standard also defines some overarching principles which should guide practitioners seeking to conduct a carbon footprint assessment using the standard. These include:

- *Relevance*: The selection of data and methods is appropriate to the assessment of the GHG emissions and removals arising from the system under study.
- *Completeness*: All GHG emissions and removals that provide a significant contribution to the product carbon footprint are included.
- *Consistency*: Assumptions, methods and data are applied in the same way throughout the carbon footprint calculation.
- *Coherence*: Methodologies, standards and guidance documents that are already recognised internationally and adopted for product categories are applied, to enhance comparability between product carbon footprints within any specific product category.
- *Accuracy*: Quantification of the carbon footprint should be accurate, verifiable, relevant and not misleading, and bias and uncertainties are reduced as far as is practical.
- *Transparency*: All relevant issues are addressed and documented in an open, comprehensive and understandable presentation of information. Any relevant assumptions are disclosed and methodologies and data sources used are appropriately referenced. Any estimates are clearly explained and bias is avoided.

The GHG Protocol's Product Standard specifies accounting principles similar to these, as does PAS 2050. In all three standards, the principles as well as the more detailed requirements are designed to ensure the reliability of carbon footprint estimates, by reducing the room for both systematic and non-systematic error.

However, by construction the main product carbon footprint standards cannot cover all methodological questions which may arise in calculating product carbon footprints. Further guidance is therefore necessary to avoid methodological inconsistencies. Relevant sources are the PACT Pathfinder Framework, sectoral guidance, and product category rules, which are discussed below.

Box 4.1. Differences between product carbon footprint standards

As noted earlier, the three existing product carbon footprint standards (ISO 14067:2018, the GHG Protocol Product Standard, and PAS 2050:2011) are quite similar. This is partly by construction: for example, GHG Protocol built on the existing PAS 2050 standard when developing its Product Standard, and this standard was in turn taken into account during the revision of the PAS 2050 standard (GHG Protocol, n.d.[6]; BSI, 2011[7]). ISO and GHG Protocol also collaborate to reduce the divergence between their standards. Nevertheless, some differences remain.

Interviews with practitioners reveal that the ISO 14067:2018 standard is currently the most widely used. Its popularity is partly explained by its membership of a broader family of standards such as the ISO 14040/14044 standards for LCA as well as ISO standards explaining how GHG statements can be verified and validated (ISO 14064-3), and standards detailing the competences required for teams which do the verification and validation (ISO 14066). Hence, the differences between ISO 14067 and the GHG Protocol and PAS 2050 standards may often not matter much in practice. However, as will be shown later, some calculation tools are still aligned with the older PAS 2050 standard rather than with the more recent ISO 14067 standard.

One area where standards differ is in the hierarchy of allocation rules proposed. All standards agree that allocation should be avoided where possible, by subdivision or system expansion. But beyond that, the standards diverge. While ISO 14067:2018 and GHG Protocol prioritise physical relationships over economic or other allocation methods, PAS 2050:2011 prioritises supplementary sectoral guidance followed by economic allocation. Physical allocation in PAS 2050:2011 thus is only possible if sectoral guidance for it exists.

Another area where standards differ is in their exclusion criteria. ISO 14067:2018 is not very prescriptive in this regard: activities or life cycle stages can be excluded if this is not expected to “significantly” alter the conclusions. The GHG Protocol standard is similarly flexible: exclusion is allowed if there is a data gap and if an estimation determines that the data would be “insignificant”. PAS 2050:2011, by contrast, provides more concrete guidance: exclusions are allowed for emission sources that would constitute less than 1% of total life cycle emissions as long as at least 95% of total emissions are accounted for.

Some other textual differences between the standards are unlikely to cause differences in the assessment results. As an example, ISO 14067:2018 states that offsets are “not allowed” while PAS 2050 and the GHG Protocol standard states that offsets are “not included”. The latter means that offsets cannot be counted as part of the product carbon footprint but can be reported separately as additional information.

4.2. PACT Pathfinder Framework

Firms are increasingly expected to report and reduce their Scope 3 emissions, but quantifying these emissions is currently challenging partly due to a lack of harmonisation of methodologies and partly due to difficulties in sharing data across complex supply chains (OECD/BIAC/WEF, 2023[8]; OECD, 2024[9]). The Partnership for Carbon Transparency (PACT) Pathfinder initiative aims to tackle both obstacles.

PACT is hosted by the World Business Council for Sustainable Development (WBCSD) and works with stakeholders from different industries, as well as standard-setting bodies, reporting organisations, and industry initiatives. The vision of PACT was outlined earlier: if firms can receive accurate data from suppliers regarding the carbon footprint of purchased inputs on a cradle-to-gate basis, and if firms can add their own emissions, they can in turn provide accurate cradle-to-gate product carbon footprint data to their customers. However, realising this vision requires greater harmonisation of methodologies as well as interoperable technological solutions to transmit data along the supply chain.

To achieve greater harmonisation of methodologies for product-level carbon footprints, PACT has developed the PACT Pathfinder Framework (PACT, 2023[1]).

The PACT Pathfinder Framework first sets out a hierarchy of approaches:

- When product-specific guidelines (so-called product category rules, see below) already exist, firms should prioritise these, as long as they meet certain quality criteria. In particular, product category rules should only be used if they are developed in accordance with ISO standards; if they were developed using a multistakeholder process and independent peer review; if they are applicable to the geography where the product is produced or sold; and if the product category rules are reviewed at least every five years to ensure they are up to date.
- If product-specific guidelines do not exist, firms should use sector-specific rules built on recognised standards, in conjunction with the guidance in the Pathfinder Framework.
- If sector-specific rules do not exist, firms should fall back on cross-sectoral standards such as the ISO 14067 carbon footprint standard, in conjunction with the guidance in the Pathfinder Framework.

Next, the Pathfinder Framework provides guidance on the scope and boundaries of calculations. This guidance explains, for example, the use of a cradle-to-gate approach based on a declared unit rather than a functional unit, as discussed above.

The Pathfinder Framework then provides more detailed guidance on how to calculate product carbon footprints. Firms should include all “attributable processes”, i.e. all processes associated with services, materials, or energy flows that become, make, or carry a product throughout its life cycle. Firms can exclude a process if this would likely represent less than 1% of the total, and if the sum of excluded processes is less than 5% of the total.

For each process, firms should calculate emissions as: Activity data (amount of activity) x Emission factor (kg GHG per unit of activity) x Global Warming Potential (kg CO_2-equivalent per kg of GHG). *Activity data* can include a firm’s material inputs (e.g. purchased fertiliser or feed) expressed in physical quantities; energy inputs (e.g. purchased electricity); or its own production processes. To the maximum extent possible, firms should use primary activity data. For *emission factors*, the Pathfinder Framework similarly prioritises primary data. For purchased inputs, primary data would be obtained from suppliers; if this is not available, firms can use emission factors from secondary databases. For a firm’s own activities primary data would mean, for example, direct on-site measurement. In many contexts this is currently not feasible at scale; in that case, secondary emission factors can be used, as long as these come from high-quality databases (listed in the guidance). The Pathfinder Framework specifies that where emissions are calculated using a model that takes primary data as input (as will often be the case in agriculture), the resulting emissions estimate would also be considered primary data. For *Global Warming Potentials*, the Pathfinder Framework aligns with other standards in referring to the latest information provided by the Intergovernmental Panel on Climate Change (IPCC).

The Pathfinder Framework provides a decision tree on how to allocate emissions in multi-output processes:

- Try to avoid allocation. What looks like a multi-output process may in fact consist of single-output processes; if such “process subdivision” is possible, it should be applied.
- If this is not possible, use the allocation rules outlined in product category rules or sector-specific guidance, if these meet the requirements of the Pathfinder Framework.

- If such guidance is not available, but if there is a dominant, identifiable substitute product, apply "system expansion". This is a procedure where the carbon footprint of the product being studied is calculated by taking the total carbon footprint of the multi-output process and subtracting the carbon footprint of *substitutes* for the co-products (i.e. the other outputs).[5]
- When the above is not possible, the Pathfinder Framework asks what the ratio is of the economic value of the co-products. [6] If this ratio is greater than five, then one co-product can be considered the main driver of the process, and economic allocation can be used – that is, the emissions are allocated proportionally to the economic value (e.g. revenues) associated with the different products.
- If the ratio is equal to or lower than five, the Pathfinder Framework asks whether there exists an underlying physical relationship between the co-products. If so, a physical allocation method should be used.
- If no physical relationship exists, allocation can be done using economic allocation or alternative approaches.

The Pathfinder Framework also contains specific guidance on how to account for emissions from land use change and emissions and removals from "land management" (i.e. agriculture and forestry). However, the Pathfinder Framework notes that this guidance will be updated to reflect the final GHG Protocol Land Sector and Removals Guidance, discussed below.

Finally, the Pathfinder Framework also contains guidance on preferred data sources, as well as requirements regarding assurance and verification and on minimum required data elements to be exchanged alongside product-level carbon footprints. This will be discussed below in the context of facilitating data flows across the supply chain.

4.3. Sectoral guidance

As noted above, the Pathfinder Framework gives priority to product category rules and sectoral guidance, as long as these meet certain quality safeguards. Product category rules are discussed in more detail below; this section discusses sectoral guidance. The Pathfinder Framework prioritises sectoral guidance which is built on cross-sectoral standards such as ISO or the GHG Protocol. For food systems, the relevant guidance here includes the GHG Protocol's Agriculture Guidance and its forthcoming Land Sector and Removals Guidance.[7] These are developed to facilitate implementation of the 'core' GHG Protocol standards for Corporate and Scope 3 reporting.

4.3.1. GHG Protocol's Agricultural Guidance

The Agricultural Guidance (GHG Protocol, 2014[10]) provides guidance on questions which may arise when trying to report GHG fluxes (emissions and removals) from agricultural activities. For example, when a farm's livestock is grazing on land owned by a third party, the Agricultural Guidance clarifies how emissions should be allocated between the owner of the livestock and the owner of the land. The Guidance also discusses common challenges and solutions for the collection of activity data.

The Agricultural Guidance may be subject to change given the forthcoming Land Sector and Removals Guidance (discussed below), and may even be replaced by it. At the time of writing, however, the Land Sector and Removals Guidance was not yet officially published, and hence the Agricultural Guidance remains relevant.

An important element of the Agricultural Guidance is its description of how changes in carbon stocks (in biomass, dead organic matter, soil organic matter, and harvested products) should be accounted for, and how firms should report their GHG fluxes (i.e. emissions and removals). These are summarised in

Table 4.1. The table takes the perspective of an agricultural producer, i.e. Scope 1 here refers to on-farm emissions.

The Agricultural Guidance states that fluxes should be reported for each subcategory in Table 4.1. Importantly, regarding CO_2 fluxes, the Guidance requires that only CO_2 emissions from land use change are reported under Scope 1 emissions, while other CO_2 fluxes (emissions or removals) due to land use management, as well as CO_2 sequestration due to land use change, and CO_2 emissions from biofuel combustion, should be reported under a separate category for "Biogenic carbon". The Guidance does not require firms to report separately on different non-mechanical sources (e.g. enteric fermentation, manure management).

Table 4.1. Reporting agricultural GHG fluxes according to the GHG Protocol Agricultural Guidance

Category of source or sink	Subcategory	Examples
Scope 1	Mechanical sources	Mobile equipment, stationary combustion, refrigeration and air-conditioning systems
	CO_2 emissions from land use change	CO_2 emissions from the conversion of forests into ranchland or the conversion of wetlands into croplands
	Non-mechanical sources	Enteric fermentation, soil N_2O emissions, manure management
Scope 2	Purchased energy	Purchased electricity
Scope 3 (optional)	All other indirect sources	Production of agrochemicals and purchased feed
Biogenic carbon	CO_2 fluxes during land use management	CO_2 fluxes to/from C stocks in soils, above- and below-ground woody biomass, and dead organic matter stocks, and the combustion of crop residues for non-energy purposes
	C sequestration due to land use change	CO_2 removals by soils and biomass following afforestation or reforestation
	Biofuel combustion	Combustion of biofuels in farm machinery
Additional information	• A reference or link to the calculation methodologies used • Description of whether the methodologies are IPCC Tier 1, 2, or 3 • Description of the methodology used to amortise CO_2 fluxes • Assumptions regarding the use of proxy data in calculating the impacts of historical land use change on C stocks	

Note: This table illustrates the requirements and minimum, best practice recommendations for disaggregating agricultural GHG flux data in inventories. Please note that the proposed Land Sector and Removals Guidance would include important changes to these requirements, as discussed below.
Source: GHG Protocol (2014[10]).

4.3.2. GHG Protocol's Land Sector and Removals Guidance

GHG Protocol is currently also preparing a Land Sector and Removals Guidance. A *Draft for Pilot Testing and Review* was published in September 2022 (GHG Protocol, 2022[4]) and, following feedback from pilot testers and stakeholders, is currently being refined. The Guidance would apply to all firms which have "land sector" activities (e.g. agriculture, forestry) in its operations or in its value chain, and would make Scope 3 reporting a requirement for these firms. In addition, the Guidance would also apply to firms reporting removals (including technology-based removals), and to firms that buy or sell carbon credits from land sector or removal activities. The Guidance would notably introduce clear guidelines on when and how removals can be reported (including removals through, for example, soil carbon sequestration).

The Draft Guidance proposes three new principles in addition to the principles of relevance, accuracy, completeness, consistency, and transparency listed in the 'core' GHG Protocol standards. These are:

- *Conservativeness*: Use conservative assumptions, values, and procedures when uncertainty is high. Conservative values and assumptions are those that are more likely to overestimate GHG emissions and underestimate removals.

- *Permanence*: Ensure mechanisms are in place to monitor the continued storage of reported removals, account for reversals, and report emissions from associated carbon pools.
- *Comparability*: Where relevant, firms should apply common methodologies, data sources, assumptions, and reporting formats such that the reported GHG inventories from multiple firms can be compared.

The discussion here focuses on those aspects of the Land Sector and Removals Guidance most relevant to food systems.[8] As in the Agricultural Guidance, the Draft Guidance requires that CO_2 emissions from *land use change* should be reported, but it expands this requirement to also cover methane and nitrous oxide emissions due to land use change (e.g. from burning vegetation or peatland drainage, or from the mineralisation of nitrogen in soil due to losses of soil carbon).

Moreover, the Draft Guidance goes beyond the Agricultural Guidance in requiring that net biogenic CO_2 emissions from *land management* (e.g. loss of soil carbon due to farm management practices) need to be reported in the relevant scope, rather than in a separate "Biogenic carbon" category as is the case in the Agricultural Guidance.

Net biogenic CO_2 *removals* from *land management* (e.g. soil carbon sequestration due to the use of cover crops) as well as from *land use change* (e.g. reforestation) could optionally be reported under the relevant scope, but only if a range of additional criteria are met:

- The calculation of net land carbon stock changes includes at a minimum any changes in carbon stock due to biomass, dead organic matter, and soil carbon.
- There is *ongoing storage monitoring* documented in a land management plan or monitoring plan so that carbon remains stored and any losses can be detected.
- There is *traceability*: when net removals occur in the firm's supply chain, these can only be reported as Scope 3 removals if there is *physical traceability* to the land where carbon is stored or potentially to the first point of collection or processing facility – this requirement was still subject to discussion in the Draft Guidance given the difficulty of achieving traceability in supply chains.
- There is *primary data*: Firms should only include net removals if it can be accounted for using primary data.
- There is *limited uncertainty*: Firms should only include net removals if the estimated increase in the land carbon stock is statistically significant based on uncertainty estimates.
- Moreover, firms would be required to *report any losses* of land carbon stocks either as emissions or reversals. This would also apply if firms lose the ability to monitor land carbon stocks associated with previously reported removals.

The above criteria apply to removals due to land management as well as those due to land use change, although the latter is not always clear from the current text of the Guidance.[9] The Guidance foresees that firms could also optionally report *gross* biogenic land CO_2 removals and gross emissions separately.

The Land Sector and Removals Guidance would also introduce requirements for firms to report an additional "land tracking metric" such as indirect land use change emissions, carbon opportunity costs, and/or land occupation, for Scopes 1, 2, and 3.

Table 4.2 summarises the reporting requirements most relevant to food systems.

Table 4.2. Reporting GHG fluxes according to the GHG Protocol Draft Land Sector and Removals Guidance

Category	Scope 1	Scope 2	Scope 3	Notes
Non-land emissions (e.g. combustion)	Required	Required	Required	
Land management: non-CO_2 emissions (e.g. enteric fermentation)	Required	Required	Required	
Land management: net CO_2 emissions (e.g. net loss of soil carbon)	Required	N/A	Required	
Land management: net CO_2 removals (e.g. net gain in soil carbon)	Optional and subject to additional criteria	N/A	Optional and subject to additional criteria	If included, should be reported separately from emissions
Land use change: net emissions (e.g. due to deforestation, conversion)	Required	Required	Required	
Land use change: net removals (e.g. due to reforestation)	Optional and subject to additional criteria	N/A	Optional and subject to additional criteria	If included, should be reported separately from emissions
Gross biogenic land CO_2 emissions and removals	Optional		Optional	If included, should be reported separately from net emissions
Land tracking metrics Indirect land use change emissions, carbon opportunity costs, and/or land occupation indicator	Required to report one or more metrics	Required to report one or more metrics	Required to report one or more metrics	

Note: Table only shows categories relevant to food supply chains. This is a simplified representation; please refer to the full Guidance for details.
Source: GHG Protocol (2022[4]).

The Draft Guidance also includes an extensive discussion on how best to calculate emissions in each of these categories.

Given the importance of CO_2 removals, it is useful to compare different standards in this regard (Box 4.2).

Box 4.2. The treatment of CO_2 emissions and removals in carbon footprint standards

A unique feature of the land sector (agriculture and forestry and other land management activities) is that the biogenic carbon cycle removes CO_2 from the atmosphere and transfers it to storage in biogenic carbon pools (above- and belowground biomass, dead organic matter, and soil organic matter). Changes in land use (e.g. from cropland to grassland) and changes in land management practices (e.g. use of cover crops) can increase these removals.

The ISO 14067 product carbon footprint standard proposes the following treatment:

- Emissions and removals from direct land use change *shall* be included in the product carbon footprint, and shall be documented separately in the report
- Emissions and removals from land use (land management) *should* be included (a weaker requirement), and if included shall be documented separately

- Emissions and removals resulting from indirect land use change *should be considered for inclusion*, and if included shall be documented separately

The ISO 14067 standard thus treats land-related emissions and removals symmetrically. This is different from the Land Sector and Removals Guidance, which requires reporting of emissions but makes reporting of removals optional and subject to additional criteria.

The ISO 14067 standard also requires that both emissions and removals of the above categories should be documented separately in the carbon footprint study report, whereas the Land Sector and Removals Guidance requires this only for the removals.

The Pathfinder Framework proposes that emissions from direct land use change shall be included, as well as emissions and removals from land management. Emissions from indirect land use change should be reported separately but not included in the carbon footprint. The Pathfinder Framework does not explicitly cover removals from direct land use change. Importantly, the Pathfinder Framework at the moment does not explicitly impose the same criteria for removals as the Land Sector and Removals Guidance, although the relevant section of the Pathfinder Framework will be revisited once the Guidance is finalised. Table 4.3 summarises these requirements.

Table 4.3. The treatment of CO2 emissions and removals in carbon footprint standards

	GHG Protocol Agricultural Guidance	GHG Protocol Draft Land Sector & Removals Guidance	ISO 14067	PACT Pathfinder
Land management: CO2 emissions	Required but in separate “biogenic carbon” category	Required	Should be included	Should be included
Land management: CO2 removals	Required but in separate “biogenic carbon” category	Optional	Should be included	Should be included
(direct) Land use change: CO2 emissions	Required (Scope 1)	Required	Shall be included	Shall be included
(direct) Land use change: CO2 removals	Required but in separate “biogenic carbon” category	Optional	Shall be included	Unclear
Indirect land use change: CO2 emissions	Not covered	One of three additional metrics	Should be considered for inclusion	Shall not be included, but may be calculated separately
Indirect land use change: CO2 removals	Not covered	One of three additional metrics	Should be considered for inclusion	Shall not be included but may be calculated separately

Note: See full text of the carbon footprint standards for additional context and guidance.

4.4. Product category rules and related guidance

The ISO 14040/14044 standards for life-cycle assessment and the ISO 14067 standard for product carbon footprints provide important general guidance, but in calculating a product carbon footprint for a specific product, many additional questions and complexities may arise. Without additional guidance, two analysts could make different methodological choices leading to incomparable results. To prevent this lack of comparability, additional *product category rules* (PCR) can be developed, to provide common answers to common methodological questions in a specific product category.

The importance of these additional rules is recognised in the more general standards: the ISO 14067 standard states that if relevant PCRs exist, these should be used as long as they meet some quality criteria (one of which is that the PCR should have been developed in line with the ISO 14027 standard for the development of PCRs, or a relevant sector-specific international standard that is in line with the ISO 14044 standard for LCA). As noted above, the Pathfinder Framework similarly prioritises the use of PCRs, as long as certain quality criteria are met.

The landscape of product category rules is somewhat fragmented, as anyone can in principle develop a PCR. For food systems, a few PCRs are of particular importance, however.

A first set of PCRs are those developed as part of the EU Product Environmental Footprint (PEF). This initiative aims to set both general guidance and product-specific PEF Category Rules (PEFCR) for life-cycle assessment in the European Union (covering not just carbon footprints but 16 environmental impact categories). Because the goal is to standardise LCA calculations as much as possible, PEFCR guidance tends to be highly prescriptive. For example, the PEFCR for dairy details the specific methods, datasets and default factors to be used in calculating LCAs for five dairy product categories (liquid milk, butter, cheese, fermented milk products, dairy ingredients). The PEFCR requires the use of specific PEF datasets unless primary data is available. In addition to the PEFCR for dairy, PEFCRs exist for beer, animal feed, pet food, and pasta, with work underway on a PEFCR for marine fish.[10] However, practitioners suggest that existing PEFCRs may in some cases introduce new inconsistencies (Foundation Earth, 2023[11]).

A second group of PCRs are carbon footprint standards developed by sector organisations. A prime example here is the International Dairy Federation's Global Carbon Footprint standard for the dairy sector, first published in 2010 and most recently updated in 2022 (see below for a discussion). Other examples include the carbon footprint standard of the Global Roundtable for Sustainable Beef (GRSB, 2022[12]), and the HortiFootprint category rules, which were developed as a precursor for a PEFCR for horticultural products (Helmes et al., 2020[13]).

Finally, while not technically a product category rule, the various guidance documents produced by the Livestock Environmental Assessment and Performance (LEAP) Partnership (a multistakeholder initiative hosted by FAO) play an important role as "fallback option" in cases where a PCR is not available.[11] LEAP guidance takes a life-cycle assessment approach, and is available for large ruminants, small ruminants, poultry, pigs, animal feed, and feed additives. While LEAP guidance documents are less prescriptive than PCRs, they nonetheless provide an important methodological foundation and are cross-referenced in, for example, the IDF and GRSB standards.

4.4.1. An example: IDF guidance on carbon footprints for the dairy sector

The International Dairy Federation (IDF) released its updated "Global Carbon Footprint standard for the dairy sector" in September 2022 (IDF, 2022[14]). [12] A first edition was published in 2010 and subsequently revised in 2015 and 2022. This guidance document can be used for both organisation-level and product-level reporting across the dairy life cycle (i.e. including dairy farming as well as processing).

IDF notes that guidance was necessary to avoid confusing and contradictory messages due to carbon footprint estimates based on differing methodologies and data inputs. For example, more than 4 800 peer-reviewed studies have investigated carbon footprints from dairy, but comparing these studies is difficult because of inconsistent system boundaries, allocation rules, or emission factors.

The IDF guidance is designed to be consistent with existing international standards and guidance documents. IDF distinguishes three sets of relevant standards:

- *General carbon footprint standards and guidelines*, including the ISO standards on LCA (ISO 14040/140444) and carbon footprints (ISO 14067), the GHG Protocol standards as well as the Agricultural Guidance and the proposed Land Sector and Removals Guidance, the general guidance for the EU Product Environmental Footprint (PEF), and the PAS 2050 carbon footprint standard.

- *Dairy-specific guidelines*, including the EU PEF category rules (PEFCR) for dairy, the FAO LEAP guidelines on large ruminants, and the dairy-specific product category rules for Environmental Product Declarations (EPD).
- Guidance on specific aspects of the carbon footprint, such as information on Global Warming Potentials from IPCC reports, guidance by the GHG Protocol on accounting for removals, and guidance on carbon sequestration from the C-sequ initiative.

IDF discusses how its own guidance aligns with these.

Among other aspects, IDF provides guidance on goal, scope and boundaries, on the choice of emission factors, on allocation issues, and on accounting for land use change and carbon sequestration.

Regarding the scope, IDF explicitly aims to provide guidance for product carbon footprints using different possible scopes: cradle-to-farm gate (covering agricultural inputs and dairy farming emissions), cradle-to-factory gate (which adds emissions from the milk collection and dairy processing stages), cradle-to-purchase (which adds emissions from distribution and retail), and cradle-to-grave (which adds emissions related to use and end-of-life). IDF notes that different scopes will be relevant for different goals. Correspondingly, IDF recommends that carbon footprints should use different functional units (the "denominator" of the carbon footprint). For example, when the life cycle is covered up until the end-of-life stage, the relevant denominator would be the quantity consumed rather than the quantity purchased (to account for food waste). The choice of functional unit is discussed further below.

Regarding the boundaries, IDF provides a detailed overview of the various activities and inputs which should be included. IDF also clarifies that if a farm generates carbon credits/offsets (e.g. by carbon sequestration) and these credits are sold to a different sector, the farm can no longer include the reduction in its carbon footprint as this would lead to double-counting and double-claiming. The IDF standard makes an exception in cases where the carbon credit is maintained within the same value chain (so-called "insets", as opposed to "offsets" traded between different value chains). This particular guidance deviates from the current GHG Protocol guidance, which generally maintains a strict separation between inventory accounting (based on actual emissions) and accounting for credits (see, for example, GHG Protocol (2004[15]), (GHG Protocol, 2011[5]), (GHG Protocol, 2022[4])). However, GHG Protocol is currently studying whether existing guidance needs to be updated in this regard (GHG Protocol, 2023[16]).

Regarding emission factors and calculation methodologies, IDF requires that methodologies be consistent with the IPCC (2019[17]) refinement to the Guidelines for National GHG Inventories, or more recent versions should these become available. In particular, in choosing between Tier 1, Tier 2, and Tier 3 approaches (discussed in more detail below), the IDF standard requires that the highest-possible Tier method must be used, and recommends that at least a Tier 2 approach should be used.

Allocation rules are relevant at several stages of the dairy value chain. At the input stage, animal feed production often generates co-products, for example when oilseeds are crushed, resulting in protein meal and vegetable oil. The farm stage produces milk and meat (from surplus calves and culled dairy cows), as well as manure. The processing stage produces a variety of dairy products (e.g. liquid milk, butter, cheese). IDF provides the following guidance:

- For feed, *economic* allocation is recommended – that is, the allocation takes place on the basis of the relative economic value of the co-products.
- For farm level production, biophysical allocation is recommended between milk and meat. In particular, IDF proposes that where emissions cannot be attributed unambiguously to either milk or meat production, the "milk share" of emissions should reflect the share of net energy for lactation in total net energy requirements.
- For manure, IDF recommends that manure should be considered a "residue" of dairy production, so that a *cut-off* approach can be used whereby no emissions are allocated to manure. However,

IDF notes that where relevant, manure may need to be considered a co-product (in which case economic allocation should be used), or a waste product (in which case emissions from the treatment of manure, potentially including those occurring outside the dairy farm, should be included and allocated between meat and milk products).

- For dairy products, guidelines recommend mass-*based allocation* based on the dry weight of milk solids (fat, protein and lactose) or, less preferred, total dry matter (milk solids as well as minerals).

Regarding land use change, IDF recommends that the GHG emissions arising from changes in carbon stocks (soil carbon and above- and below-ground biomass) due to direct land use change should be included in the carbon footprint. This applies not only to land use change on the dairy farm but also purchased inputs, notably animal feed. All land use change occurring in a 20-year period before the reference year of the carbon footprint assessment should be included. Moreover, IDF recommends that indirect land use change should be included as a sensitivity analysis (to be reported separately).

IDF notes that carbon sequestration can have a significant impact on the carbon footprint of dairy, but that there is currently no consensus on how to quantify and account for it. IDF nevertheless recommends including carbon sequestration but reporting it separately. IDF has in parallel developed the “C-sequ” guidelines for calculating carbon sequestration in cattle production systems (IDF, 2022[18]).

While the IDF standard brings a welcome degree of harmonisation to product carbon footprint calculations in the dairy sector, its definition of the functional unit (i.e. the denominator of the carbon footprint) currently makes it less suitable for facilitating economy-wide emissions accounting. IDF prescribes that cradle-to-farm gate carbon footprints of milk should be calculated not per kg of product, but per kg of fat-and-protein corrected milk (FPCM), i.e. liquid milk with 4% fat and 3.3% protein. The IDF standard argues that this “assures objective comparison between farms with different breeds or feed regimes” (IDF, 2022[14]). However, this practice obscures the actual carbon footprint of the purchased products from the point of view of a buyer, and makes it more complicated to transmit data along the supply chain. For this reason it would be preferable to express emissions by default per kg of actual product, in line with the PACT Pathfinder guidance (PACT, 2023[1]).

IDF also notes several open issues which could be addressed in future revisions of the standard. These include the allocation of manure off-farm. The current version of the standard does not assign any production emissions to manure, so that from the point of view of crop producers, manure is currently produced “emissions-free” (although crop producers of course need to account for emissions from manure application and field use in their own carbon footprint calculations). Other issues include how to account for transfers of animals between farms, or how to account for the use of feed additives and other mitigation technologies. As IDF notes, “Whilst there is not currently enough technical information available to provide a detailed calculation method, it is desirable that we make provision for the inclusion of these technologies as more evidence on their performance becomes available” (IDF, 2022[14]). IDF suggests that a mitigation technology may be included in carbon footprint calculations once it is accepted to be included in a national GHG emissions inventory, as this signals that evidence on emissions reductions is well-substantiated and internationally accepted. IDF itself has initiated the MiLCA project (in collaboration with the Global Research Alliance on Agricultural Greenhouse Gases) to develop a protocol for including mitigation actions in agricultural life cycle assessment (GRA, 2022[19]).

Another major issue is whether carbon sequestration should be included in the carbon footprint assessment, and if so, how. As noted, the current version of the IDF standard proposes to include carbon sequestration as it can be an important mitigation option, but it requires that it be reported separately. IDF notes that in future there should be more guidance in this area. In particular, it is likely that future versions of the IDF standard will also be able to incorporate the GHG Protocol’s Land Sector and Removals Guidance in this regard.

4.5. A first assessment

As the previous discussion shows, there exists a well-developed landscape of carbon footprint reporting standards covering both firm-level (organisation-level) and product-level reporting. Product-level carbon footprint standards are furthermore based on the widely used Life Cycle Assessment methodology. At the level of cross-sectoral guidance, multiple standards co-exist, notably the ISO and GHG Protocol standards as well as the older PAS 2050 standard. Yet, these standards are quite similar.

On top of these cross-sectoral standards, additional sector- and product-specific guidance has been created. For firm-level reporting (including Scope 3 reporting), GHG Protocol provides important additional guidance relevant for food systems. This includes its Agricultural Guidance and its forthcoming Land Sector and Removals Guidance, which is expected to be highly influential. The analysis here shows that there are some inconsistencies between the older Agricultural Guidance and the draft Land Sector and Removals Guidance regarding the treatment of CO_2 emissions and removals from land management, and CO_2 removals from land use change, but this would be irrelevant if the Land Sector and Removals Guidance replaces the older Agricultural Guidance.

For product carbon footprints, additional product category rules and sectoral guidance can be used. These include category rules developed as part of the EU Product Environmental Footprint initiative, as well as sectoral guidance developed for, by example, dairy, beef, and horticulture. The FAO LEAP project also provides methodological guidance for LCA of livestock and feed, which can be used as a fallback in the absence of more detailed guidance.

The PACT Pathfinder Framework provides a bridge between firm-level and Scope 3 reporting on the one hand and product carbon footprints on the other. Its aim is to provide a clear hierarchy of which standards to use. It prioritises well-developed product category rules, followed by sector-specific rules, followed by cross-sectoral standards such as the ISO and GHG Protocol standards. It also provides supplemental guidance to ensure consistency.

Despite these efforts of harmonisation, some areas of ambiguity remain. The treatment of CO_2 emissions and removals from land management and land use change does not appear to be fully streamlined yet between the GHG Protocol Agriculture Guidance, the draft Land Sector and Removals Guidance, the ISO 14067 standard, and the PACT Pathfinder Framework.

In addition, some issues that appear settled in the current standards framework may need to be reviewed over time. One is the question of indirect land use change (ILUC). Existing standards take an “attributional” approach to carbon footprints, which asks whether any land use change occurred in the life cycle of the product. However, as markets are connected, growing demand for commodity A in one region might displace its production of commodity B to a different region, where it might cause land use change. The GHG Protocol draft Land Sector and Removals Guidance and the ISO 14067 standard recognise the importance of this issue, but do not currently require inclusion of ILUC in the ‘regular’ carbon footprint calculation. To provide correct incentives, it may however be desirable to include ILUC, perhaps by providing reference tables with estimates of ILUC effects for major commodities.

Another question concerns allocation rules. Where the same production process creates several co-products (as is often the case in food systems), there is a question of how to allocate emissions across the different products. Existing standards provide guidance on allocation rules. As noted earlier, all standards advocate for avoiding allocation as much as possible. Beyond that, however, the preferred approach differs. Product category rules currently suggest using economic allocation for animal feed (e.g. between protein meal and vegetable oil), biophysical allocation for dairy cows (between milk and meat), and a mass-based allocation for dairy processing (between, for example, butter, skim milk powder). There appears to be a lack of scientific research on how these different allocation rules could impact economic behaviour, and hence on how allocation rules should be designed to provide the correct incentives.

Finally, it must be noted that standards will require continuous updating as scientific insights and techniques evolve. For example, the IDF guidance for carbon footprints in the dairy sector notes a lack of consensus on how to quantify soil carbon sequestration and hence recommends reporting it separately for the time being. Moreover, as standards depend on each other, a modification in a cross-sectoral standard or important guidance document should be reflected in more specialised standards built on top of them. This is one example of the need for continuous improvement, discussed in more detail below.

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Notes

[1] Most LCA databases (discussed in detail further below) are attributional. The "Big Climate Database" created by 2.-0 LCA Consultants and Concito is an exception. See https://lca-net.com/blog/a-bigger-and-better-climate-database-of-540-food-items/ (accessed 16 October 2024).

[2] The ISO 14067 standard gives the example of one tonne of steel: because it can be transformed into many different products, it is difficult to pin down a single functional unit, making it more appropriate to express emissions per tonne of steel (a declared unit).

[3] The treatment of capital goods is ambiguous in existing standards. In contrast with ISO 14067, the ISO 14040 standard (on which the ISO 14067 standard is based) states that capital goods should be taken into account (Kan and Vieira, 2020[22]). PAS 2050 excludes capital goods with a lifespan of over one year, unless supplementary requirements dictate otherwise. The GHG Protocol Product Standard states that capital goods are "non-attributable" processes, i.e. they are '*not directly connected to the studied product during its lifecycle because they do not become the product, make the product, or directly carry the product through its lifecycle*' and are hence not required to be included. For agri-food products, capital goods may in fact contribute a significant amount of emissions, particularly in horticulture, which means their inclusion may be necessary to provide a reliable assessment of carbon footprints. For this reason, the Hortifootprint Category Rules (Helmes et al., 2020[13]), which provide supplementary guidance for the horticulture sector, do require the inclusion of capital goods such as greenhouses.

[4] The recommendation to use an allocation method that reflects underlying physical relationships should not be misinterpreted as favouring a mass-based approach (i.e. allocation based on the relative mass of different co-products). In some cases, allocation by mass could reflect underlying physical relationships (this might for example be the case in allocating emissions of a plane or truck used for transporting different types of goods), but when there is no actual physical relationship, mass-based allocation is not necessarily appropriate.

[5] One downside of the "system expansion" methodology is that it no longer guarantees that carbon footprints of co-products will add up to total emissions of the multi-product process. Imagine a process with three outputs A, B, and C and with total emissions of 60 tonnes of CO_2 equivalent. Imagine that there exist substitute products A', B', and C' where for each substitute the emissions are 30 tonnes of CO_2 equivalent. In that case, calculating the carbon footprint of A by subtracting the carbon footprint of the substitutes B' and C' would result in a carbon footprint of zero – and the same would be true when the procedure is applied to B and C. This could be prevented by stipulating that system expansion can only be used for one product (e.g. A), with carbon footprints for the remaining co-products set equal to their substitutes. But in that case, the resulting carbon footprints are still somewhat arbitrarily dependent on which product is chosen as the 'main' product, and on the emissions of unrelated processes for producing B' and C'.

[6] There is an ambiguity here in the Pathfinder Framework, as the examples in the document seem to suggest that what matters for this calculation is the co-products' price *per unit* rather than their share in total revenues (as would seem more logical).

[7] In addition, there exist other sectoral guidance documents as well. One example is the WRAP Scope 3 Sector Guidance for Food & Drink Businesses (WRAP, 2022[23]). Another example is guidance for the US dairy industry which was explicitly recognised by the GHG Protocol as being in conformance with the

requirements of the GHG Protocol standards. See Innovation Center for US Dairy (2019[20]) (for Scope 1 and 2) and Innovation Center for US Dairy (2019[21]) (for Scope 3).

[8] The Guidance also contains provisions for how to account, for example, the carbon stored in long-lasting products (such as wood products) and how to account for technological carbon removals, which will typically be less relevant in food supply chains.

[9] Section 7.1.1 in Chapter 7 (which deals with land use change) explains that net CO_2 *removals* due to land use change are accounted for as *land management net CO_2 removals* and covered under Chapter 8 (which deals with land management), although Chapter 8 does not explicitly mention removals due to land use change.

[10] In addition to these official PEFCRs, a number of "shadow" PEFCRs exist, developed by industry actors without involvement of the European Commission. These include common wheat flour, food fermentation and soybean, the food and drink sector, fresh products, fruits and vegetables, green coffee, poultry meat, red meat, rice, soft drinks, and vegetable oils and protein meal products.

[11] See https://www.fao.org/partnerships/leap/overview/the-partnership/en/ (accessed 23 February 2024).

[12] IDF refers to its guidance as a standard. While there is no commonly accepted nomenclature, the term "standard" is typically used for documents which provide a framework with broader applicability (e.g. ISO standards, or the GHG Protocol Corporate Standard), whereas the terms "guidelines" and 'guidance' are typically used for additional advice, recommendations or clarifications (e.g. the GHG Protocol's Agricultural Guidance, the PACT Pathfinder Guidance). For consistency, the IDF document is therefore described here as "guidance".

5 Science-based methods

Science-based methods are the second building block for carbon footprints. This chapter introduces the IPCC guidelines for quantifying emissions and related national guidance for quantification at the farm level. The chapter also discusses the challenge of continuous improvement of these methods.

5.1. Overview

Reporting standards and guidelines answer the question of *what* needs to be reported; science-based methods are needed to answer the question of *how* emissions can be quantified.

Ideally, emissions would be measured directly, but this is rarely practical in food systems (at least with current technology). A wide range of methods exist to estimate emissions. An important question is therefore how to choose between the available methods.

Governments face the same question in drawing up their National Greenhouse Gas Inventory Reports under the UN Framework Convention on Climate Change. Important guidance has been developed in this context by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2006[1]). Its 2006 Guidelines consist of five volumes, of which one focuses on Agriculture, Forestry, and Other Land Use. The Guidelines were last refined in 2019 (IPCC, 2019[2]). The Guidelines make a useful distinction between three “tiers” of calculation methods, from least to most detailed.

To illustrate these different tiers, consider the question of how to quantify methane emissions from enteric fermentation in North American dairy farming [adapted from Rotz (2018[3])].

- The simplest approach (known as a “Tier 1” approach) is to multiply the number of dairy cows by a fixed emission factor of 138 kg CH_4 per year, which is the emission factor for North American dairy cattle provided by IPCC (2019[2]).
- A more refined approach (known as “Tier 2”) lets the emission factor vary based on gross energy intake and a methane conversion factor. Countries can develop their own methane conversion factor, but if these are not available, IPCC (2019[2]) provides default values which depend on milk production levels and on feed quantity and quality.
- An even more refined set of approaches are so-called “Tier 3” methods. These consist of a wide range of methods which can provide more accurate estimates, but require more data as input. For example, these could include more detailed statistical models for emission factors, or process-based models. Some of these approaches might be appropriate for research purposes but too cumbersome for other applications (Rotz, 2018[3]).

Specifically for emissions in Agriculture, Forestry and Other Land Use (AFOLU), the IPCC Guidance notes that Tier 3 methods may include process-based models and inventory measurement systems driven by high-resolution activity data and disaggregated at sub-national level, including, for example, comprehensive field sampling. IPCC also provides further guidance on using Tier 3 methods, covering topics such as sampling methods for measurement-based approaches and model selection, calibration, and evaluation for model-based approaches (IPCC, 2019[2]). Box 5.1 discusses such methods in the context of measuring soil organic carbon.

Box 5.1. Soil organic carbon

Three types of Tier 3 approaches exist to measuring and monitoring soil organic carbon. These are direct measurements, remote sensing, and simulation models (Paul et al., 2023[4]). These methods vary in terms of cost and reliability.

- *Direct measurement* (i.e. soil sampling) is the most reliable approach, but is costly and time-consuming when applied to large areas. One reason is that soil characteristics, including the content of organic carbon, can vary considerably even across a single field. Soils also contain a mix of organic and inorganic components, and SOC levels fluctuate with soil depth. All this makes it harder to collect representative samples, and harder to extrapolate accurately from measurements in specific sites to estimates for broader areas. Moreover, to quantify changes over time requires re-sampling at intervals of at least 3-5 years, as it takes several years for soil management measures to create observable impacts (Paul et al., 2023[4]).

- *Remote sensing* offers a potentially cost-effective means of monitoring SOC across large areas in the topsoil, but requires specific conditions such as bare soil, low water content, etc. To date, no studies have successfully detected SOC changes at the field scale using remote sensing methods (Paul et al., 2023[4]).
- *Simulation models* are the most economical and readily available option, and are already widely used for certification schemes (Oldfield et al., 2022[5]). However, currently used simulation models have important shortcomings. A detailed review by Garsia et al. (2023[6]) identified 221 soil organic carbon simulation models. Of these, less than one-third (64) had been validated in line with IPCC guidelines. Of those that had been validated, few were validated for multiple countries and land uses, with large gaps for sub-Saharan Africa and the Middle East.

Given the importance of soil organic carbon sequestration as a potential mitigation option, greater investment is needed in developing and validating soil organic carbon simulation models across a wide range of contexts.

The development of more precise methods to quantify GHG emissions and removals is an active area of research, and further guidance may be useful to help practitioners understand the strengths and weaknesses of different methods. In the United States, for example, the US Department of Agriculture (USDA) in 2014 published a review of relevant methods, updated in 2024 (Hanson, Itle and Edquist, 2024[7]). It informs USDA's own efforts in estimating GHG fluxes and is used as a basis to update USDA's estimation tools (COMET-Planner and COMET-Farm, discussed in the next chapter); the review is also a valuable source of information for farmers and other stakeholders.

In terms of the reporting categories of the GHG Protocol's draft Land Sector and Removals Guidance (Table 4.2), the IPCC Guidance for AFOLU covers land management emissions (both CO_2 and non-CO_2), land management CO_2 removals, and emissions and removals from land use change. So-called "non-land emissions" in agriculture (e.g. combustion of fuels for tractors or heating) and emissions from other segments of the supply chain (e.g. fertiliser production, food processing, and transport) are covered in the IPCC Guidance for other sectors.

5.2. A first assessment

Science-based methods for quantifying emissions in food systems are generally well developed. The IPCC Guidance's Tier 1 and 2 methods provide an internationally accepted baseline, and some countries have developed further guidance on the most appropriate Tier 3 methods. Such country-specific guidance is particularly useful given the important role of local conditions such as soils, climate, or farming approaches in shaping emissions. It is beyond the scope of this report to review the various methods in detail; for example, the USDA review of these methods for the US context alone runs to some 600 pages (Hanson, Itle and Edquist, 2024[7]). But in general, it appears that there exists a foundation of science-based methods covering most of the relevant categories of emissions and removals described in carbon footprint reporting standards. The default methods provided by IPCC (Tier 1 and Tier 2) are designed to be unbiased, i.e. neither systematically above or under the true value; but as these are relatively coarse approximations, there may be considerable non-systematic error in a given application. Tier 3 methods are designed to be more adapted to local circumstances but require more effort (e.g. more precise data). For developing countries (notably sub-Saharan Africa), however, fewer Tier 3 methods have been developed so far. Additional research here would be welcome. As noted above, simulation models for soil organic carbon may similarly be an area where additional research (and especially validation) would be useful.

Scientific insights will continue to evolve, however, and calculation methods can therefore be expected to evolve over time as well. For example, research based on atmospheric measurements suggests that existing calculation methods (which include the Tier 1, 2 and 3 approaches) may in several cases significantly understate true emissions (Miller et al., 2013[8]) (Deng et al., 2022[9]), including methane emissions from animal agriculture (Hayek and Miller, 2021[10]). Improved satellite measurement could similarly provide new insights (Bourke, 2024[11]). These methods can be seen as 'top-down' approaches, starting from measured concentrations of GHGs in the atmosphere and tracing this back to emissions sources. By contrast, Tier 1, 2, and 3 methods are typically 'bottom-up', as they are often based on measuring or modelling individual farms or farm animals. New research findings may lead to updates over time in the Tier 1, 2 and 3 methods to better match 'top-down' estimates.

One practical challenge is in translating these evolving insights into updates of authoritative guidance documents. For example, IPCC Guidance was originally published in 1996, updated in 2006, and subsequently refined in 2019, which means that new methods may take several years before being referenced in updated IPCC Guidance. Similarly, it may take time for improved calculation methods to find their way into practical tools for calculating emissions.

Finally, it is worth noting the important connection here with National Greenhouse Gas Inventory Reports required under the UNFCCC. The national reporting level differs from the product-level view (the focus of this report) in several ways. First, when reporting at a national scale, questions of allocation across products are generally not relevant: it is sufficient to know emissions of dairy cows without having to worry about allocating these emissions across milk, meat, and manure. Second, the product-level view is based on a life cycle perspective, which means that the relevant activities in scope are not constrained by national borders. Thus, emissions from fertiliser production are part of the product-level view for crops even if these emissions occurred in another country. Third, some methods appropriate for national inventories may be either too coarse or too complex for a product-level view. They may be too coarse when some producer-specific differences are not taken into account for national inventories because they would "cancel out" at the national level or when studying these differences would not be a good use of resources (e.g. because the activity is minor for the country as a whole). In other cases, they may be too complex when national inventories rely on sophisticated Tier 3 methods which are not easily reduced to an easy-to-use farm level calculation tool.

Despite these important differences, the science-based methods as originally developed for national inventories form the backbone for measuring emissions at firm-level and product-level, and the methods used in national inventories can be seen as a "default" choice for measurement at these other levels, unless there are good reasons to use alternative methods.

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6 Farm level calculation tools

Farm level calculation tools are the third building block for carbon footprints. This chapter discusses the current landscape of farm level calculation tools in terms of tools' scope, process, methods, alignment with international standards and best practice, and user friendliness and accessibility. The chapter also discusses the reliability of existing tools and how this could be improved.

The availability of science-based methods by itself is not sufficient to scale up carbon footprint measurement in food systems. For example, it may be scientifically feasible to use direct measurement methods for farm level emissions, but these methods are costly and difficult to implement and are therefore at the moment not suitable for widespread use. Similarly, some Tier 3 methods may require many input parameters or powerful computing resources, making them harder to use outside of a research context. For this reason, estimating emissions is often done through calculation tools (also referred to as emission accounting tools), which simplify the necessary data inputs and calculation methods to allow more widespread uptake.

The focus here is on *farm level* tools, in part because a significant share of total emissions in food systems occur on the farm. However, it is worth noting that simplified calculation tools may also be useful in other stages of the supply chain, e.g. to help small- and medium-sized enterprises (SMEs) along the food supply chain estimate their emissions. Even large firms (e.g. firms producing agro-chemical inputs) may use calculation tools to scale up and automate carbon footprint calculations.

Farm level tools play a crucial role in measuring and communicating carbon footprints of food products. As noted earlier, because the farm stage is responsible for a large share of the overall carbon footprint of food products, precise information is important. But carbon footprints can vary considerably from one farm to the next, and various management practices can reduce emissions. Ideally, emissions at the farm stage would therefore be calculated using primary data, including information on management practices. This would make it possible for firms downstream in the supply chain to identify and reward farmers with lower carbon footprints. Farm-level tools can also provide valuable information to farmers on how to reduce their emissions. By contrast, average data from LCA databases make it impossible to shift towards producers with below-average emissions, and remove producers' incentives to lower their emissions (Richards, 2018[1]) (Deconinck, Jansen and Barisone, 2023[2]).

6.1. The current landscape of farm level calculation tools

Farm level calculation tools are widespread. The Greenhouse Gas Protocol, in developing its Land Sector and Removals Guidance, identified 19 farm level calculation tools, while a review conducted for the UK Department for Environment, Food and Rural Affairs (Defra) mentions the existence of 81 farm level calculation tools worldwide (RSK Adas, 2023[3]).

Not all tools are created equal, however. Tools differ on several dimensions:

- *Scope*
    - *Reporting level*: Some tools are designed to calculate product carbon footprints (e.g. the Cool Farm Tool). Most, however, focus on farm level emissions (although tools also often include embedded emissions from feed and fertiliser production). Some tools calculate "whole farm" emissions (i.e. total emissions grouping together all activities on the farm) while others calculate "enterprise" emissions (i.e. emissions of a specific activity on the farm). In some cases emissions are calculated for a user-defined area (i.e. specific fields indicated by the user as belonging to the farm).
    - *Commodity/sector coverage*: Tools differ with respect to their commodity or sector coverage: some cover more commodities than others, and some are specialised in a single commodity. For example, Eggbase is a dedicated tool for the egg laying and poultry sector.
    - *Geographic coverage*: Some tools are tailored to specific countries while others have global coverage. For example, the COMET-Farm tool was developed for the United States, while the Cool Farm Tool and FAO's EX-ACT tool have a global coverage.
    - *Inclusion of other sustainability criteria*: Some tools include sustainability criteria other than GHG emissions. For example, the Cool Farm Tool also evaluates the water use and

biodiversity performance of the farm. The French CAP'2ER tool covers GHG emissions, ammonia emissions, consumption of fossil fuels, water quality, water consumption, erosion, phosphorus consumption and consumption of phytosanitary products.

- *Inclusion of economic criteria:* Some tools include economic information for decision support. In fact, some tools were originally created as economic decision support tools for farmers and subsequently added carbon footprint calculation capabilities. Other tools were created in the first instance as carbon footprint tools; these tend not to cover economic aspects.

- *Process*
  - *Transparency:* Some tools are more transparent about their assumptions and calculation methods than others. For example, the Holos tool provides an open-source version of its core algorithms on GitHub, an open-source software repository.
  - *Governance*: Some tools have an independent scientific advisory board or other mechanisms for quality assurance, while for other tools these governance and quality assurance aspects are less clear.
  - *Updating:* Some tools are regularly updated and clearly indicate their version number and changes made since the previous version, while others are updated irregularly or in less transparent ways.
- *Methods*
  - *System boundaries:* Some tools include only on-farm (Scope 1) emissions. Others include emissions from purchased inputs (e.g. electricity, feed, fertiliser), i.e. Scope 2 and upstream Scope 3 emissions. Downstream Scope 3 emissions are usually not included.
  - *Emissions categories and accounting metrics*: Not all emissions categories are covered in all tools. For example, direct land use change (dLUC) and changes in soil carbon are included in some but not all tools (e.g. included in Farm Carbon Calculator, COMET-Farm, Holos).
  - *IPCC Tier methodology used:* As noted earlier, IPCC distinguishes between three methodological tiers, in increasing order of complexity and accuracy. Some tools may be limited to Tier 1 or 2, whereas others use Tier 3 or a combination of methodologies (e.g. using Tier 3 for some processes but Tier 2 for others – as also happens in National Greenhouse Gas Inventories).
  - *Allocation rules:* For tools which calculate product carbon footprints, there is variation in the allocation methods used. Some use economic allocation while others use a hierarchy of methods.
- *Alignment with international standards and best practice:*
  - *Alignment with reporting standards and guidelines:* Some tools explicitly state that they are aligned with existing standards such as ISO 14067 or the GHG Protocol, but not all do. Several tools claim compliance with the older PAS 2050 product carbon footprint standard (which was last updated in 2011). Interestingly, this includes tools which do not actually calculate product carbon footprints but which use the other prescriptions of the PAS 2050 standard as guidance for farm level carbon footprint calculations.
  - *Alignment with up-to-date scientific best practice:* Some tools are aligned with the latest IPCC guidance and metrics, in particular the IPCC 2019 Guidance and the Global Warming Potential (GWP) values of the latest IPCC Assessment Report, while others are not. Similarly, some tools (such as the ECOGAN tool, developed by the Spanish Ministry of Agriculture, Food and Fisheries) use the same methods used in the National Inventory Reports of the countries in their geographic scope, while others do not.

- *User friendliness and accessibility*
    - *Cost:* Publicly available tools (e.g. Holos, COMET-Farm) are free, while others may have a free version in addition to one or more paid versions (which may come with additional support). For example, Cool Farm Tool and Farm Carbon Calculator both offer free versions for farmers but paid versions for other commercial users.
    - *Languages:* Some tools are available in multiple languages (notably the Cool Farm Tool, which is available in 13 languages).
    - *Time requirements*: Tools with a broader scope, more emission categories and higher-Tier methodologies tend to have higher data requirements and hence take longer to complete. Reported time requirements vary from 30 minutes to 160 minutes.
    - *API:* Some tools provide an Application Programming Interface (API) to allow users to upload data to the tool directly from other software applications.
    - *Exporting results:* Some tools allow users to easily export results (e.g. as Excel files).
    - Some other aspects of user friendliness could include whether tools report results in line with reporting requirements of international standards, or whether tools also provide suggestions to farmers on how they can reduce their emissions.

It is important to note that not all of these differences are problematic. Since farm level tools have many potential uses, tools can differentiate themselves by focusing on, for example, a specific scope (such as a specific commodity or geography), or by making a different trade-off between precision and simplicity. For users to make an informed choice requires that tools be clear about these aspects, and about their limitations.

It is out of the scope of this report to present a full review of existing farm level tools on each of the above dimensions. However, a closer look at some tools can help illustrate differences and similarities. For this purpose, six tools were selected from a list of resources provided by the GHG Protocol in the context of its draft Land Sector and Removals Guidance (inclusion on this list does not imply that these tools are necessarily endorsed by the GHG Protocol). Tools were chosen based on their prominence in the literature and to ensure geographic diversity. However, many other tools exist.[1]

Table 6.1 compares these six tools on a number of the criteria listed above.

Table 6.1. Key characteristics of selected farm level calculation tools

	Agrecalc	COMET-Farm	Cool Farm Tool	Farm Carbon Calculator (Farm Carbon Toolkit)	Holos	OverseerFM
First created	2007	2005	2011	2009	2004	2003
Reporting level	Whole farm; enterprise; product	Enterprise	Product	Whole farm; product	Whole farm	Whole farm; enterprise
Commodity/sector coverage	Multiple types of crops and livestock	Multiple types of crops and livestock	Multiple types of crops and livestock	Multiple types of crops and livestock	Multiple types of crops and livestock	Multiple types of crops and livestock
Geographic coverage	United Kingdom	United States	Global	United Kingdom	Canada	New Zealand
Inclusion of other sustainability criteria	No	No	Water (blue, green); Biodiversity (farm level only)	No	N losses	N and P losses

	Agrecalc	COMET-Farm	Cool Farm Tool	Farm Carbon Calculator (Farm Carbon Toolkit)	Holos	OverseerFM
Full transparency of methods and/or code	No	Yes (based on USDA methods report and DayCent model)	Yes (methods)	Yes (methods)	Yes (complete algorithm available on GitHub)	Yes (methods)
Latest update	2023	2023	2024	2023	2024	2024
IPCC Tier methodology	1, 2	1, 2, 3	1, 2, 3	1, 2	2	2
Allocation rules	Economic	Not applicable	Economic (crops) Biophysical (dairy co-products)	Unclear	Not applicable	Not applicable
Alignment on international carbon footprint reporting standards and guidance	"Broadly aligned" with PAS 2050; ISO 14044; GHG Protocol Ag Guidance draft; FLAG SBTi; moving towards full alignment with ISO14064 and ISO14067 in 2024	No	Broadly aligned with major standards and IDF dairy standard	PAS 2050; considering alignment with other standards	No	No
Alignment on IPCC 2019 and most recent GWP	Yes	Yes (aligned on US National Inventory)	Yes	Yes	Yes	Unclear
Cost	Free option 3 paid options	Free	Free for farmers Paid options for other businesses	Free for farmers Paid options for other commercial users	Free	Paid annual subscription
Languages	English, French, Spanish	English (Spanish available for Comet Planner tool)	More than 13 languages including English	English	English, French	English
Time to complete	160 min (1)	Not available	150 min (1)	30 min – 120 min (2)	10-30 min (2)	Not available
API	Under development	Yes (cropland)	Yes	No	Yes	No
Export of results	No	JSON, XML	Paying members can provide code to farmer to share results	PDF, CSV, JSON	CSV	PDF

Note: (1) from Brake (2021[4]) (2) from tool provider.
Source: Analysis by the authors using publicly available information on each of the tools. Analysis refers to the version of each tool available in February 2024.

Table 6.2 provides additional detail on the system boundaries used by different tools, and the different emission categories covered. While tools again differ, there are some systematic patterns which can be discerned.

In terms of on-farm emissions, tools generally cover the main sources of emissions such as enteric fermentation, manure management, fertiliser application, and fuel combustion, with some exceptions. Most of the tools cover soil organic carbon sequestration. By contrast, residue management, feed loss and the use of organic fertiliser inputs is not included in most of the tools surveyed here.

Table 6.2. System boundaries of selected farm level calculation tools

	Agrecalc	COMET-Farm	Cool Farm Tool	Farm Carbon Calculator	FarmGAS	Holos	OverseerFM
On-farm emissions (Scope 1)							
Residue management	Maybe	Yes	Yes	Maybe	Maybe	Yes	Maybe
On-farm feed production	Yes	Yes	Yes	Yes	Maybe	Yes	Yes
Liming	Maybe	Yes	Yes	Yes	Yes	Maybe	Yes
Synthetic fertiliser management	Yes	Yes	Yes	Yes	No	Yes	Yes
Manure management	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Organic fertiliser inputs	Yes	Yes	Yes	Yes	Maybe	Maybe	Maybe
Grazing (manure and urine)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Enteric fermentation	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bedding	Yes	Yes	Yes	Yes	Maybe	Yes	Maybe
Soil organic carbon sequestration	Yes	Yes	Yes	Yes	No	Yes	No
Tillage	Yes	Yes	Yes	Maybe	No	Yes	Maybe
Fuel combustion	Yes	Yes	Yes	Yes	No	Yes	Yes
Purchased energy (Scope 2)							
Purchased fuels and electricity	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Purchased steam, heating and cooling for farm use	Yes	No	Yes	Yes	Maybe	Yes	Yes
Purchased inputs (upstream Scope 3)							
Physical capital	No	No	Maybe	Yes	No	No	Maybe
Embedded livestock emissions	No	No	No	Yes	No	Maybe	Yes
Feed	Yes	No	Yes	Yes	Yes	Yes	Yes
Bedding	Yes	No	Yes	Yes	Maybe	No	Maybe
Fertiliser	Yes	No	Yes	Yes	Yes	Yes	Yes
Lime	Yes	No	Yes	Yes	Maybe	Maybe	Yes
Pesticides	Yes	No	Yes	Yes	Maybe	Yes	Yes
Seed and/or young plant material production	Maybe	No	Maybe	Maybe	Maybe	Maybe	Maybe
Services	Maybe	No	Maybe	Maybe	Maybe	Maybe	Maybe
Transport of farm inputs to farm	Maybe	No	Maybe	Maybe	Maybe	Maybe	Yes

Note: Following the similar approach used by the GHG Protocol Land Sector and Removals Guidance, “Yes” means “High confidence that the resource supports calculation of this metric or accounting category”, “No” means “High confidence that the resource does not support calculation of this metric or accounting category”, and “Maybe” means “Lack of explicit publicly available information on whether or not the resource supports calculation of this metric or accounting category”. The overview here refers to the version of each tool available in February 2024; the year of the latest update of each tool is provided in the previous table.
Source: Analysis by the authors using publicly available information on each of the tools.

Most tools cover emissions from purchased energy (Scope 2), but tools differ in their treatment of embedded emissions related to the production of purchased inputs (upstream Scope 3 emissions from the point of view of the farm). The COMET-Farm tool explicitly excludes all purchased inputs except energy, while other tools generally try to include embedded emissions in purchased feed and fertiliser. Tools also differ in their treatment of embedded emissions in physical capital and in purchased livestock. The Farm Carbon Calculator is most complete in this regard as it includes vehicles, machinery and agricultural buildings, as well as materials used on farm such as metal, wood and plastic. Cool Farm Tool is planning to include capital items in its calculations as well. It is less clear how existing tools account for some other purchased inputs such as seed, services, or transport of farm inputs to the farm.

It is worth noting that emissions from purchased energy (Scope 2) and purchased inputs (upstream Scope 3) are almost by definition not where farm level calculation tools have a comparative advantage.

The main promise of farm level calculation tools is to use primary data (e.g. information on management practices) to create a more precise estimate of on-farm emissions than would be possible from secondary LCA databases. However, many tools try to provide a more complete picture by adding an estimate of Scope 2 and upstream Scope 3 emissions. This is typically done by multiplying a relevant measure (e.g. purchased synthetic nitrogen fertiliser) with emission factors from secondary LCA databases (e.g. average production emissions of synthetic nitrogen fertiliser). It would however be preferable if also for these emission sources more precise information were used, such as supplier-specific data on the carbon footprint of the exact fertiliser products purchased by the farmer. Emission factors could then be used whenever such supplier-specific information is not available. Some tools allow for this, but not all.

It is also worth noting that even where tools cover similar emission categories, they may differ in terms of their underlying methodology (e.g. Tier 1, 2, or 3 methods – or different kinds of Tier 3 methods).

Another way of looking at similarities and differences among tools is in terms of alignment with the accounting metrics listed in the draft Land Sector and Removals Guidance of the GHG Protocol. GHG Protocol itself has provided a preliminary assessment of which accounting metrics are covered by which tools. Table 6.3 summarises this information for the tools considered here. (See Chapter 4 on reporting standards and guidelines for an overview of which of the metrics are required and which are optional under the draft Guidance).

Tools are generally able to account for non-land emissions (e.g. combustion) and non-CO_2 emissions from land management (e.g. enteric fermentation). Some tools calculate CO_2 emissions and removals from land management and from land use change, while others do not (Under the draft Land Sector and Removals Guidance, reporting emissions in these categories is required while reporting removals is optional but subject to additional criteria). Tools similarly differ in their ability to report on the (optional) metric of gross biogenic land CO_2 emissions and removals. The largest gaps are found for the land tracking metrics, where it is unclear whether any of the tools covered here can report on at least one of the metrics (as required in the draft Guidance).

Table 6.3. Emission accounting metrics included in selected farm level calculation tools

	Agrecalc	COMET-Farm	Cool Farm Tool	Farm Carbon Calculator	FarmGAS	Holos	OverseerFM
Non-land emissions							
On-site energy use GHG emissions	Maybe	No (separate tool available)	Yes	Yes	Maybe	Yes	Yes
Land management: non-CO2 emissions							
Enteric fermentation CH4 emissions	Maybe	Yes	Yes	Yes	Yes	Yes	Yes
Manure management CH4 and N2O emissions	Maybe	Yes	Yes	Yes	Yes	Yes	Yes
Managed soils N2O emissions	Maybe	Yes	Yes	Yes	Yes	Yes	Yes
Biomass burning CH4 and N2O emissions	Maybe	Yes	No	No	Yes	Yes	Yes
Rice cultivation or flooded land CH4 emissions	Maybe	Yes	Yes	No	Maybe	No	Maybe
Land management: CO2 emissions and removals							
Biomass carbon stocks	Maybe	Yes	Yes	Yes	Maybe	Yes	Yes
Dead organic matter carbon stocks	Maybe	Yes	Yes	Maybe	Maybe	Yes	Maybe
Soil carbon stocks	Maybe	Yes	Yes	Yes	Maybe	Yes	Maybe
Biomass carbon stock changes	Maybe	Yes	Yes	Maybe	Maybe	Yes	No

	Agrecalc	COMET-Farm	Cool Farm Tool	Farm Carbon Calculator	FarmGAS	Holos	OverseerFM
Dead organic matter carbon stock changes	Maybe	Yes	Yes	Maybe	Maybe	Yes	No
Soil carbon stock changes	Maybe	Yes	Yes	Yes	Maybe	Yes	No
Land use change: emissions and removals							
Direct land use change emissions (dLUC)	Maybe	Yes	Maybe	Yes	No	Yes	No
Statistical land use change emissions (sLUC)	Maybe	No	No	No	No	Yes	No
Gross biogenic land CO2 emissions and removals							
Gross biogenic land CO2 removals	Maybe	Yes	Maybe	No	Maybe	Maybe	No
Gross biogenic land CO2 emissions	Maybe	Yes	Maybe	No	Maybe	Maybe	No
Land tracking metrics							
Indirect land use change emissions (iLUC)	Maybe	No	No	No	No	No	No
Land occupation (LO)	Maybe	No	Maybe	No	No	No	No
Carbon opportunity cost (COC)	Maybe	No	No	No	No	No	No

Note: Table shows indicative assessment by GHG Protocol for emission accounting categories listed in the draft Land Sector and Removals Guidance. Not all of the listed categories are required under the draft Guidance (see discussion in main text). "Yes" means "High confidence that the resource supports calculation of this metric or accounting category", "No" means "High confidence that the resource does not support calculation of this metric or accounting category", and "Maybe" means "Lack of explicit publicly available information on whether or not the resource supports calculation of this metric or accounting category". Not showing three accounting categories with limited relevance for agriculture and food (product carbon stock changes, temporary product carbon storage, and gross biogenic product CO_2 emissions from end of life treatment) and one accounting category relevant only for bioenergy (gross biogenic product CO_2 emissions from combustion).
Source: GHG Protocol.

6.2. How reliable are existing farm level tools?

Given the differences between tools, it is unsurprising that tools can provide different emission estimates for the same farm, as several studies have found (RSK Adas, 2023[3]; Bonasia et al., 2022[5]; Brake, 2021[4]; Grain Growers, 2020[6]; Leinonen et al., 2019[7]; Lewis et al., 2012[8]; Richards, 2018[1]; Sykes et al., 2017[9]; Whittaker, McManus and Smith, 2013[10]).

Two studies for Australia illustrate this. Brake (2021[4]) compared four tools suitable for assessing mixed farming enterprises in Western Australia. The tools varied in their level of detail and generated different results, both at the level of the whole farm and by type of enterprise (crops and sheep). Compared to the average estimate, results varied from 70% below to 62% above the average estimate (or a ratio of 540% between the highest and lowest estimate). Similarly, a Grain Growers (2020[6]) study compared five tools suitable for cereal, pulse and oilseed production in Australia. Using data from two sample farms from opposite sides of Australia (New South Wales and Western Australia), the various tools again produced results ranging from 61% below to 67% above the average estimate (a ratio of 428%). The report concluded that there is a need for a more harmonised approach to emissions accounting.

A recent study commissioned by the UK Department for Environment, Food, and Rural Affairs (Defra) similarly found large variation in results from farm level calculation tools (RSK Adas, 2023[3]). The study used data for a set of 20 "typical" UK farms covering cereals, general cropping, horticulture, mixed farming, pigs, poultry, dairy, grazing livestock in less favoured areas, grazing livestock in lowlands, and two additional farms to test tools' ability to represent anaerobic digestion and agroforestry (silvopasture) practices in dairy systems. Table 6.4 summarises the findings, showing the ratio between the highest and lowest emission estimate across the different tools tested. These ranges are generally smaller than the ones found by Brake (2021[4]) and Grain Growers (2020[6]) for Australia, but are still considerable.

Table 6.4. Variation in results of farm level calculation tools for emissions in UK agriculture

Model farm	Number of tools	Ratio of highest to lowest estimate
Cereals 1	5	175%
Cereals 1 with carbon stock change	5	220%
Cereals 2	4	128%
General cropping 1	5	171%
General cropping 1 with carbon stock change	5	1093%
Horticulture 1	3	157%
Horticulture 2	3	238%
Pigs 1	4	133%
Pigs 2	4	250%
Poultry 1	6	355%
Poultry 2	5	448%
Dairy 1	5	129%
Dairy 1 with carbon stock change	5	155%
Dairy 2	4	123%
Dairy 3	4	141%
Dairy 4	4	143%
Grazing in less favoured areas 1	4	196%
Grazing in less favoured areas 2	4	109%
Grazing in lowland 1	4	281%
Grazing in lowland 2	4	238%
Mixed farming 1	4	179%
Mixed farming 2	4	217%

Note: For farms where carbon stock changes are included, emissions are net emissions.
Source: RSK Adas (2023[3]).

In general, tools were most aligned for dairy, and least aligned for poultry, grazing in lowland, and cereals when carbon stock changes were included. In some cases, the variation is caused by a single outlier result, but in other cases there was not much agreement between the tools. In some cases, a single factor drove the variation (e.g. embedded emissions of animal feed in the poultry assessments) while in other cases a range of factors was responsible (e.g. for lowland grazing, calculators differed on emissions from enteric fermentation, manure management, nitrous oxide soil emissions, and embedded feed emissions). In some cases, tools agreed on the overall emissions but estimated different contributions of emissions sources. Tools also differed strongly on carbon stock changes. However, it was not the case that one tool systematically delivered higher or lower estimates than others.

Overall, the study identified divergence in the following emission sources:

- *Carbon stock changes*: Calculators showed a large variation in which aspects are included (e.g. land use change, emissions and removals from above ground biomass, emissions and removals from below ground carbon stocks) and how they were modelled.
- *Crop residues*: Calculators varied in their assumptions on the quantity produced and quantity remaining on the field.
- *Enteric fermentation*: Tools differed in how they accounted for livestock numbers and the amount and type of feed, leading to different results.
- *Manure*: Calculators varied in how they accounted for manure quantity and management practices.

- *Embedded emissions from feed and fertilisers*: Tools relied on emission factors from secondary data sources for these emissions, but the numbers used varied considerably. For feed, this was particularly true for land use change emissions from soy-based feed. For fertilisers, two calculators were using out-of-date emission factors.

The study also analysed the underlying reasons for the divergence in estimates for these emission sources:

- Calculators applied a range of different *system boundaries* in their tools. For example, should forested land be included as part of the farm business or not? Different default answers to these questions (or a lack of guidance to users on what should be included) led to different results.[2]
- Developers of calculation tools *must balance precision with user friendliness, which means tools differed in terms of the amount of data they asked users to input (and correspondingly*, where tools used assumptions rather than user-provided data).
- For purchased inputs, tools did not always use the best available *emission factors from secondary data sources*. The study notes that in the UK context, relevant datasets exist for energy (from the UK government), animal feed (from the Global Feed LCA Initiative), and fertilisers (from Fertilizers Europe); but not all tools relied on these sources. It is worth noting that some tools allowed using actual emission factors for feed or fertiliser provided by the manufacturers.
- Not all calculators were aligned on the *IPCC 2019 guidelines*; some were still relying on the 2006 edition. Even where tools follow the latest IPCC guidelines, tools differ in whether they are using Tier 1, 2, or 3 approaches.
- Tools did not take a consistent approach to *carbon removals and emissions from land use change and land management*. The study notes that some tools used the IPCC Tier 1 methodology for carbon stock change in mineral soils, even though this approach was not designed to assess effects at farm scale.
- Tools also differed in the extent to which they could account for the use of *mitigation options* such as nitrification inhibitors for nitrogen fertilisers.

While the assessment thus found major shortcomings to existing tools, the study also notes that several tools have gone through updates in the meantime, which may have reduced divergence. To improve the harmonisation of farm level calculation tools, the study recommends among other things that calculation tools should align with the latest standards and guidelines (e.g. ISO, GHG Protocol), the latest IPCC guidance, and the latest version of emission factor databases. Tools should be regularly reviewed and updated; they should present outputs in accordance with the latest standards; and there should be transparency and third-party verification of the alignment of calculators to minimum standards to build user confidence (RSK Adas, 2023[3]).

6.3. How reliable should tools be?

As noted earlier, a reliable estimate is one with a low *systematic* error (i.e. a low level of bias) and a low *non-systematic* error (i.e. a low level of random error).

Farm level tools can be used for various purposes, such as raising awareness, reporting emissions, evaluating projects, and making product claims (Colomb et al., 2012[11]). Not all of these purposes require the same degree of reliability.

For example, where farm level measurement is used by a farmer to *track changes over time,* potential errors might be less problematic: even if the estimated emissions are systematically above or below the true value, the tool might still provide a reasonable approximation of the changes over time.

Similarly, where farm level tools are used by a downstream firm to estimate the *average* carbon footprint of a large number of suppliers (e.g. with the goal of reporting its Scope 3 emissions), *non-systematic error* may be less problematic: with a large enough sample size, non-systematic errors would tend to average out.

However, where the aim is to *compare different farms*, or where decisions over awarding a contract or providing market access depend on measurement outcomes, a greater level of reliability is needed, both in terms of systematic and non-systematic errors. This is also true where tools are used to estimate the amount of emissions avoided or sequestered through a project or action, and especially where results of such an estimate are the basis for generating carbon credits or offsets.[3] As these use cases are becoming more common, the level of reliability expected of farm level tools is increasing as well. It might therefore be useful for tool providers to explicitly adopt a philosophy of continuous improvement, whereby each new iteration of the tool aims to reduce systematic and non-systematic error. Governments could provide an enabling environment, e.g. by regularly engaging in benchmarking exercises such as the one conducted in the United Kingdom (RSK Adas, 2023[3]). These could form the starting point for constructive engagement with tool providers to identify areas for improvement.

The issue of comparability is particularly important where different agro-ecological conditions are concerned. Some methods may have a wide applicability but are relatively coarse. This is the case for IPCC Tier 1 methodologies: the default values are designed to be systematically neither above nor below the true value – but there may be a significant difference between the true value and the estimated value on a particular farm. By contrast, other methodologies may be highly precise for a specific context but less reliable outside of it. This may be the case for certain Tier 3 methodologies: a complex model may have been designed and validated for a specific agro-ecological context, where it may have low systematic and non-systematic error – but outside of this context, the model may not be appropriate. In other words, there is a potential trade-off between reliability and geographic coverage. It might be useful for tools to clearly indicate the geographies (or agro-ecological conditions) for which they work best.

A second trade-off was hinted at earlier: more sophisticated Tier 3 methods may yield more reliable answers than Tier 1 or Tier 2 methods but may require more data from the user. For example, tools to model soil carbon dynamics may require users to provide information on land use for the past ten or twenty years. Not all farmers will have such detailed information readily available, and even if they did, inputting information into the tool can be a time-consuming process (and runs the risk of data entry errors). A tool can always be simplified by substituting assumptions and default values for user-provided data, but this will reduce its reliability. One possible path forward is to explore ways to make data entry as easy as possible for farmers, for example by pre-populating a tool using data from administrative sources or farm management systems, or by providing assistance (e.g. through extension services).

Still, it is likely that estimates for an individual farm will have a considerable random (non-systematic) error. This raises the question of whether tools should report this uncertainty (e.g. by displaying confidence intervals). On the one hand, doing so could create more transparency about the level of precision of estimates. This could be especially relevant in comparing different tools or methods. On the other hand, there may be a pragmatic argument against providing uncertainty ranges to users. For example, the exact emission reduction from using a new feed additive may be highly uncertain on an individual farm because of the intrinsic variability of biological systems. At the level of a region or an entire country, however, it may be clear that the new feed additive is highly likely to reduce emissions (as random errors are "averaged out" across large numbers of farms). If farmers are presented with large uncertainty ranges around the expected emission reduction from the new feed additive, uptake may remain low. It might therefore be more opportune to present users with the average effect only, to provide the right incentives to reduce emissions for the sector as a whole. This would also have the benefit of not penalising farmers for factors which are outside of their control. However, more research is needed on this question.

6.4. A first assessment

Farm level tools could play a crucial role in creating reliable and widespread measurement of carbon footprints, as well as in driving emission reductions. Several tools exist, but as the discussion in this chapter has shown, at present the tools can give widely divergent answers for the same farm. This is due among other factors to differences in system boundaries and emission categories covered; differences in calculation methods; and differences in emission factors used for purchased inputs. Some tools are aligned on relevant standards and are transparent about their methods, but not all. It is currently difficult for users to understand the relative strengths and weaknesses of the available tools and to make an informed choice. However, there appear to be several options to remedy this situation.

To realise the potential of farm level data, more must be done to improve the reliability of existing tools, and to create greater transparency about their performance. A combination of minimum requirements and benchmarking exercises could help. For example, it appears that many differences between the tools would be resolved if tools were all aligned on the latest international standards (notably ISO and GHG Protocol), followed the latest scientific guidance (notably the IPCC 2019 guidelines), and were updated regularly to ensure emission factors for purchased inputs were taken from up-to-date sources. In parallel, benchmarking exercises (where data for the same farm is submitted to different tools to compare estimates) could be useful to help tool developers identify areas for improvement and to inform users.

In addition to the above, two important weaknesses in the current landscape of farm level tools concern geographic coverage and the treatment of soil organic carbon. Most tools have been developed for use in high-income economies. While some tools provide global coverage, in general there are fewer Tier 3 methods available for developing countries which limits the possibilities for developing farm level tools adapted to those contexts.

Many farm level tools calculate soil organic carbon stocks and/or changes. However, as the UK review showed, tools differ widely in how they model this. Some tools use the IPCC Tier 1 method, which was developed for national reporting and may be unreliable for farm level calculations. Other tools are more sophisticated. The Holos and COMET-Farm tools use the precise coordinates of a user's fields to link to detailed soil maps and weather data, which are then fed into a simulation model. But as noted in Chapter 5 on Science-based methods, properly validated simulation models are not available for all contexts (Garsia et al., 2023[12]).

Finally, most of the existing farm level tools were not originally designed for calculating product carbon footprints. Moving from a farm level assessment to a product-level assessment requires at least two changes. First, since a product carbon footprint takes a life cycle perspective, emissions from other stages need to be added to the farm level emissions. For a cradle-to-farm gate assessment, this means including emissions from purchased energy (Scope 2) and purchased inputs (upstream Scope 3). Second, these emissions must be expressed on a per-product basis. For farms, this will typically require allocating emissions across multiple outputs. Both steps could be done inside a farm level tool, or could be done in a subsequent step. As noted, several tools draw on emission factor databases to include an estimate of emissions from purchased energy and inputs, and some tools (e.g. the Cool Farm Tool) allocate emissions to calculate product carbon footprints. When these steps are embedded in a farm level tool, it is important to ensure that up-to-date emission factor databases are used, and that allocation rules are consistent with reporting standards and guidelines. Moreover, tools should ideally allow using supplier-specific information (from fertiliser firms, feed manufacturers, etc.) to be used in calculations, with emission factors as a fallback option when supplier-specific information is not available.

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Notes

[1] One prominent tool, FAO's EX-ACT tool, is not included here as it was mainly designed for evaluating impacts of projects rather than calculating attributional carbon footprints.

[2] The answer to this particular question is no, from the point of view of product carbon footprint standards, if the forest is not part of the process for producing the agricultural product. For firm level reporting, the answer is more complicated; see the discussion of the Draft Land Sector and Removals Guidance above.

[3] Such "project accounting", which underlies carbon credits and carbon offset schemes, is different from the attributional carbon footprint accounting view which is the focus in this paper. Rather than asking which activities and products account for existing levels of emissions, a project-based approach compares emissions against a *counterfactual* (e.g. to calculate by how much an initiative has reduced emissions relative to a baseline). See GHG Protocol (2005[13]) for a discussion of project accounting. However, many of the issues regarding measurement and communication are common across the approaches.

7 Databases with secondary data

Databases with secondary data are the fourth building block for carbon footprints. This chapter discusses the landscape of Life Cycle Assessment (LCA) databases, and where the data in those databases come from. The chapter also discusses the geographic specifity of existing LCA databases, and the scope to improve their interoperability.

A recurring theme in this report is the importance of primary data. However, this should not obscure the role of secondary data, such as data on average emissions of agri-food products or inputs. Given the challenges in collecting primary data, calculations will initially need to rely mostly on secondary data.

One use of secondary data was already discussed in the previous chapter: some farm level calculation tools rely on secondary data to include an estimate of ‘embedded’ emissions of farm inputs such as fertilisers, feed, or electricity. The lens taken in this report, of a system of reliable and widespread carbon footprints in food systems, suggests that this should be a temporary workaround until supplier-specific carbon footprint estimates can be obtained directly from input suppliers. The next chapter discusses how such information could be efficiently communicated through the supply chain and easily incorporated in carbon footprint calculations, using the cradle-to-gate principle. But even when the use of primary data is scaled up, secondary data may continue to play an important role, for example in providing a ‘default’ value in the absence of primary data.

7.1. The landscape of LCA databases

Secondary data are typically found in Life Cycle Assessment (LCA) databases, sometimes also referred to as Life Cycle Inventory (LCI) databases.[1] These databases provide estimates of carbon footprints (and other environmental impacts) of a wide range of products, based on the LCA methodology (discussed in Chapter 4). The estimates themselves could be based on a range of sources, such as direct measurement, modelling based on direct measurement of proxy variables, data taken from other LCA databases, expert judgment, or a combination of these sources (Hauschild, Rosenbaum and Olsen, 2018[1]). This is discussed further in the next section.

The landscape of LCA databases is vast and interlinked. The GHG Protocol lists at least 53 third-party LCA databases that can be used for constructing product life cycle or corporate value chain GHG inventories.[2] These include industry specific databases (e.g. Worldsteel Association, ICE for building materials, BUWAL for packaging materials), country specific databases that may feature specific industries (e.g. US Lifecycle Inventory Database, Canadian Raw Materials Database, Australian Life Cycle Inventory Database, Chinese Life Cycle Database), and other multisector databases that provide access to multiple databases and datasets at once, such as Ecoinvent. There also exist LCA software tools that help users combine data from different databases, calculate environmental impacts, and generate reports. They vary in complexity and features, ranging from free tools such as OpenLCA to commercial tools such as SimaPro.

Among the many LCA databases relevant for food systems, a few stand out because of their size, widespread use, or specialisation. Table 7.1 presents key characteristics of six of these databases: Agri-footprint, Agribalyse, Ecoinvent, Sphera (formerly known as GaBi), the Global Feed LCA Institute database (GFLI), and the World Food LCA database (WFLDB).

As this overview shows, databases differ in terms of geographical coverage, specialisation, and other characteristics. While Agribalyse covers a single country (France) and Agri-footprint covers 63 countries, other databases claim global coverage. The number of products varies too, from some 130 products for WFLDB to thousands for some of the other databases. However, not all of the possible datasets (that is, “country x product” combinations) exist in the databases; the number of datasets varies from some 1 800 for GFLI to more than 20 000 for Ecoinvent.[3]

Table 7.1. Key characteristics of selected LCA databases relevant for food systems

	Agri-footprint	Agribalyse	Ecoinvent	Sphera (GaBi)	GFLI database	World Food LCA Database (WFLDB)
Developer	Blonk Consultants (private)	French Environment and Energy Management Agency (public)	Ecoinvent (non-profit)	Sphera (private)	The Global Feed LCA Institute (non-profit)	Quantis (private)
Sector / products	Food, feed and agricultural intermediate products	Agri-food products	General (all sectors)	General (all sectors)	Feed ingredients	Agri-food products
Created	2014	2010	2003	1989	2020	2012
Latest version (as of June 2024)	v6.3 Aug 2022	v 3.1.1 June 2023	v3.10 Jan 2024	v2022.2 Nov 2022	v2.1 Oct 2023	v3.9 Oct 2023
Datasets	Unclear	Unclear	20 000+	18 000+	1 800+	2 600+
Products	5 000 products and processes	2 517 products	3 500 products and services	Unclear	Unclear	130+
Geographic scope	63 countries	France	Global	Global	Global	150+ countries
Impact categories	19	14	23	13	16 to 19	Unclear
Allocation approach	Economic, mass, energy	Economic (biophysical for dairy, mass for cheese)	Economic	Physical, economic	Economic, mass, energy	Physical, economic (but may differ for different supply chain stages)
Alignment on standards	ISO 14040; ISO 14044; PEF (2021); PEFCR (2018); SBTi's Forest Land and Agriculture Guidance (FLAG)	ISO 14040; LEAP and PEF	ISO 14040; ISO 14044; ISO/TS 14048	GHG Protocol, ISO 14040/44, EN 15804+A2, ILCD DN entry level, subset of data: EF 2.0 and 3.0	FAO LEAP feed guidelines (2016), LEAP feed additives guidelines (2020), Feed PEF database methodology (2017), and Feed PEFCR (2018)	ISO 14040; ISO 14044; ILCD; PEF
Alignment on IPCC 2019 and most recent GWP	Yes	Yes	Yes	Yes	Yes	Yes
Cost	Three different pricing options (Research, Commercial, Developer) + through SimaPro and OpenLCA	Full version through SimaPro, openLCA and Brightway; Simplified version as Excel files	Four different pricing options + through other dataset initiatives and software tools (e.g SimaPro)	Partly free, partly with a license fee	Four different pricing options (Membership, Commercial, Developer, Per project)	Only through SimaPro subscription with five different pricing options available
Languages	English + SimaPro provides 13 different languages	English, French	English, German + SimaPro provides 13 different languages	English, German	English	English + SimaPro provides 13 different languages

Note: "Unclear" means information not found in online documentation of the databases.
Source: OECD analysis based on online database documentation.

While the focus in this report is on carbon footprints, LCA databases typically include more than a dozen different impact categories, often including land use, water use, eutrophication, and acidification, which are of particular relevance to food systems. All LCA databases comply with the ISO standards 14040 and 14044, which define the LCA methodology. Some also comply with data documentation standards (ISO/TS 14048), data standards (the EU's ILCD) as well as sector or product specific standards such as FAO's LEAP or the EU Product Environmental Footprint rules (Chapter 4). All LCA databases seem to align with the latest IPCC (2019) recommendations.

A preliminary assessment by GHG Protocol shows that WFLDB, Ecoinvent and Sphera (GaBi) include most of the emission accounting metrics relevant for the GHG Protocol Land Sector and Removals Guidance, with the exception of land use-related variables such as direct and indirect land use change or carbon opportunity costs.

Databases typically see frequent updates; as of June 2024, all databases had been updated within the last two years. Some LCA databases, WFLDB for example, can be accessed exclusively through paid-for software such as SimaPro. OpenLCA is open source software and hence free, and its developer provides access to datasets formatted for use in openLCA (some free, some paid).[4] Sphera (GaBi) is both a dataset and a software tool.

Databases also vary in terms of cost. The publicly funded Agribalyse database is free while others have different pricing options. A perpetual commercial license to the ecoinvent database costs EUR 3 800 for a single user; a commercial license for Agrifootprint starts at EUR 1 160 per year. Alternatively, some LCA software packages are bundled with licenses to LCA databases. For example, a SimaPro commercial license starts at EUR 5 900 per year but includes access to the ecoinvent and Agri-footprint databases (among others).

7.2. Where do the data in an LCA database come from?

As noted earlier, data sources can include direct measurement, modelling based on direct measurement of proxy variables, data taken from other LCA databases, or expert judgment, or a combination of these (Hauschild, Rosenbaum and Olsen, 2018[1]).

As an example, consider an estimate for the carbon footprint of fluid milk at farm gate in Switzerland. This estimate could be based on observations from a sample of dairy farmers in the country. On-farm GHG emissions could be modelled based on farm level data, as with the farm level tools discussed in the previous chapter. Embedded emissions of feed and fertiliser could be calculated by combining input use observed on those farms with average emission factors from existing LCA databases. Transparency on assumptions and methods is important: ideally, underlying activity data are stored so that results can be re-calculated when improved models become available.[5]

Estimates in a secondary database could therefore be based on primary data. What makes it nevertheless a secondary database is that the estimates will be *used as a substitute* for primary data in another context. To continue the example of milk in Switzerland, if a Swiss dairy processor wants to calculate the carbon footprint of its cheese, it might decide not to collect primary data from the farmers that supply the milk, but instead use the estimate for fluid milk at farm gate in Switzerland.

As noted in Chapter 4, important parameters for an LCA are the definition of the relevant system boundaries, and the allocation rules used. LCA databases differ in their methodological choices, which are typically documented in guidelines. For example, Nemecek et al. (2019[2]) provide guidelines for the World Food LCA Database (version 3.5), including general principles around the structure of the database, naming conventions, system boundaries, required representativeness of the data in terms of geographical, temporal, and technological coverage, and allocation rules. The guidelines also cover principles for data collection (e.g. how to identify the most appropriate data source) and specifies which emission models are used to translate activity data into Life Cycle Inventory data. For example, the guidelines specify that the IPCC Tier 2 approach is used to estimate methane emissions from livestock.

Because LCA databases make different methodological choices, their results will usually differ. For example, Pauer et al. (2020) found that the Ecoinvent 3.6 database led to higher environmental impacts compared to GaBi (now Sphera), because Ecoinvent datasets often include more background processes. LCA databases may also make different modelling choices, for example on whether to use Tier 2 or Tier 3 models, and if Tier 3, which ones.

As with farm level calculation tools, different choices lead to different results. Such differences have been documented for other sectors (Herrmann and Moltesen, 2015[3]; Kalverkamp, Helmers and Pehlken, 2020[4]; Speck et al., 2015[5]; Lopes Silva et al., 2019[6]; Säynäjoki et al., 2017[7]) although this kind of comparison has apparently not yet been undertaken for agri-food products.

Some LCA databases also allow the user a choice between different options, e.g. between physical and economic allocation across co-products.

7.3. Geographic specificity of LCA databases

LCA databases by construction contain average data rather than producer-specific information. However, databases may differ in the level of granularity. For example, data could represent a global average, a regional average, a national average, or a sub-national average. Similarly, average data could distinguish different production methods or practices. Geographic specificity and distinctions between production methods are important for agri-food products, given the variability of biological processes (Notarnicola et al., 2017[8]).

In this regard, there are important evidence gaps for some products and regions, particularly in the developing world (Deconinck and Toyama, 2022[9]) (Edelen et al., 2017[10]). Practical challenges in the developing world include a diversity of production systems, a lack of reliable data, and highly diverse natural contexts (Basset-Mens et al., 2021[11]). The problem here is not merely about a lack of activity data (e.g. farm level data), but also gaps regarding the models used to estimate emissions: available models have often been developed and validated for countries with more temperate climates and may not be appropriate, for example, for tropical agriculture. In terms of the "building blocks" identified in this report, this corresponds to a lack of suitable Tier 3 science-based methods (Chapter 5).

In response, global initiatives have emerged to provide greater "regionalisation" of LCA databases. The UNEP-led Life Cycle Initiative is a global, public-private multi-stakeholder initiative that promotes the establishment of regionally representative databases for LCA studies.[6] It focuses on creating national LCA databases that can better reflect local conditions and cover sectors and products most critical for each country, using methodologies, data quality assurance mechanisms, and data format requirements in accordance with widely adopted standards. One concrete project under this initiative was a cooperation between Ecoinvent and the Brazilian Agricultural Research Corporation (Embrapa), which resulted in the creation of more regionalised Brazilian land use change data. Research using this granular sub-national level data demonstrated the importance of going beyond national-level data, particularly for large and heterogenous countries like Brazil: national-level data misrepresents direct land use change emissions for many agricultural products (Donke et al., 2020[12]; Novaes et al., 2017[13]). Similar initiatives to improve LCA databases in low- and middle-income countries should be encouraged.

Populating an LCA database ideally happens based on primary research rather than extrapolation from other data points. There may be data gaps when some activities in some regions have not been studied. The data actually available in LCA databases are often the cumulative result of many *ad hoc* research projects, rather than a deliberately planned effort to fill in data gaps. It would be helpful to have a more explicit strategy to identifying and addressing data gaps in LCA databases. Publicly funded research (e.g. by agricultural research institutes) can play an important role here.

Data quality ratings can be a useful tool in prioritising new research. LCA databases often compute a data quality rating reflecting how representative an estimate is in terms of geography, technology, time, and precision. The Ecoinvent data quality guidelines (Weidema et al., 2013[14]) are used as a reference across many databases. Some databases also rely on supplementary requirements and product rules for their data quality ratings. For example, Agri-footprint's data quality ratings for feed materials follow the EU Product Environmental Footprint methodology.

7.4. Interconnectedness and interoperability of LCA databases

Because they take a life-cycle perspective, LCA databases are often built on a "modular" principle, where results from one LCA (e.g. fertiliser) become an input in another LCA (e.g. wheat), which may in turn be an input for yet other LCAs (e.g. bread). In many cases, information originally came from a different LCA database. This leads to a certain level of interconnectedness. For example, both Agri-footprint and the World Food LCA database (WFLDB) use Ecoinvent as a background database for fuel and energy. Similarly, the Australian National Life Cycle Inventory Database (AusLCI) combines Australian data with selected emissions factors adapted from the Ecoinvent database.

The interconnectedness of LCA databases could create problems such as a lack of clarity on where data comes from, inconsistencies in methods and data collection, and difficulties in translating and converting across different sources, possibly leading to a loss of information and incorrect interpretations (Edelen et al., 2017[10]). Such difficulties are particularly likely when underlying databases are updated. For example, in the Australian case AusLCI is based on version 2.2 of the Ecoinvent database, even though Ecoinvent version 3.10 is currently available. As with other elements of the building blocks, this example suggests the importance of regular updates to incorporate new versions of underlying datasets (Chapter 11). However, it also highlights the importance of ensuring interoperability between various LCA databases. For example, databases may use different nomenclatures, making it hard to match data across databases. Edelen et al. (2017[10]), looking at four databases commonly used in the United States, found that when the original nomenclature of the different databases was used, automatic name-to-name matching was typically difficult. In the United States, the Federal LCA Commons (an initiative to harmonise public LCA research) created a Federal Elementary Flow List (FEDEFL) as a common nomenclature; Edelen et al. (2022[15]) found that this greatly facilitated automatic matching.

An important tool in creating interoperability is adopting a common data format. The International Life Cycle Data System (ILCD) is a data format developed by the European Union which is increasingly used in the LCA community (Pré Sustainability, 2019[16]).

Specifically for agri-food products, the HESTIA project (https://www.hestia.earth/) has also developed a standardised data format that can be used to represent not only LCA data but also other agri-environmental data, including data from farms, farm surveys, and experimental field trials. The HESTIA format is discussed in more detail in Box 8.1 in Chapter 8.

Other actions can be taken to improve access and interoperability. For example, governments may have LCA data and models which could be made available to the public. In the United States, the Federal LCA Commons initiative mentioned earlier is a collaboration between several federal agencies (including the US Department of Agriculture) to make LCA datasets freely available through an online platform.[7]

7.5. A first assessment

LCA databases are well established and cover a large number of products and geographies. Most are consistent with key standards (notably ISO standards), and updated regularly. Databases also often cross-reference each other, for example as a source of information for “background” processes.

However, there is room for improvement. First, databases differ in their methodological choices, which influences the results. While databases tend to document their choices, differences still make it hard to compare and combine data. This goes beyond interoperability of data formats, as it concerns more fundamental choices around system boundaries, allocation rules, and the like. One option would be for existing databases to harmonise their methodological guidelines, taking into account not only general standards such as ISO 14040/14044 and ISO 14067 but also more detailed product category rules. Another option is for databases to provide users with the flexibility to adjust methodological parameters, perhaps using “presets” corresponding to different standards or product category rules. More research on how methodological choices influence carbon footprint results for agri-food products would be welcome, too.

Second, there exist data gaps. Not all products, activities and geographies are equally well covered by existing databases. It would be valuable to develop a deliberate strategy to identify and address data gaps as part of an ongoing process of continuous improvement. Data quality ratings can be a useful tool in prioritising areas where new research is needed. Actually addressing the data gaps may require in-depth scientific research (e.g. to create new science-based methods) and farm surveys to collect the necessary activity data. It is a task which LCA database providers may not be able to undertake by themselves and where collaboration with, for example, agricultural research institutes may be important.

Third, the existence of databases does not mean all supply chain actors can easily access and use them. The cost of commercial databases and commercial LCA software is one element, but correctly using the data also requires specialised skills. It is possible that consultants will be able to provide an integrated service to firms that lack the means and capabilities to do everything in-house. But the financial cost of accessing and analysing secondary data should be kept in mind as a potential barrier to widespread carbon footprints (see also Chapter 10, which discusses other possible barriers and ways to address them).

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Notes

[1] In the LCA methodology, a Life Cycle Inventory (LCI) can be thought of as a flowchart containing all emissions and material flows, including resources extracted from the environment and waste products. In a carbon footprint context, this would include estimates of GHG emissions. In the LCA methodology, the LCI stage is then followed by the Life Cycle Impact Assessment phase, where LCI numbers (such as GHG emissions) are translated into impacts in terms of human or environmental health. For the purposes of this report, the LCI phase is the more relevant one.

[2] These databases are not necessarily endorsed by the GHG Protocol.

[3] As an example, the documentation for WFLDB lists as some of the datasets "Broiler husbandry, poultry industrial broiler systems, at farm, Brazil", "Broiler husbandry, poultry industrial broiler systems, at farm, Canada", and so on. In some cases there is a separate global dataset too.

[4] The LCA models made available through the US Federal LCA Commons mentioned earlier are free, and also formatted for use in openLCA.

[5] This is an example of a process-based approach. An alternative approach is environmentally extended input-output analysis (EEIO). An input-output table captures how the output of one sector is used as input in another sector. If information is available on emissions related to the production of inputs, it is then possible to use input-output tables to follow how these 'embedded' emissions flow through the economy until the final product. For a discussion in the context of environmental impacts in food supply chains, see Deconinck and Toyama (2022[9]).

[6] See https://www.lifecycleinitiative.org (accessed 4 June 2024).

[7] See https://www.lcacommons.gov/about-us (accessed 16 October 2024).

8 Communicating carbon footprint data along the supply chain

The "cradle to gate" approach adopted in this report foresees that firms will share carbon footprint data with their customers. Communicating carbon footprint data along the supply chain is therefore the fifth building block for carbon footprints. This will require interoperability of software solutions, not only for the exchange of data between large firms, and for the exchange of data between farmers and their buyers, but also between various data sources (e.g. government databases, suppliers, smart farm equipment) and farm level calculation tools. This chapter also discusses the importance of a harmonised data format as a tool for interoperability.

According to the “cradle-to-gate” principle explored in this report, each firm receives carbon footprint data from its suppliers, adds its own emissions, allocates the resulting emissions among its products, and shares the resulting carbon footprint with its customers. Communicating product carbon footprint data along the supply chain is thus an essential building block.

The starting point is the assumption that actors along the supply chain use digital tools for carbon footprint calculations and emissions accounting. Many large firms already use specialised software for firm-level emissions reporting and in some cases for calculating product carbon footprints for internal use, and the past decade has seen strong growth in the number of technological solutions available for these purposes. One overview of the market counted 88 such solutions as of June 2024 (Verdantix, 2024[1]). As discussed in Chapter 6, there are also several farm level tools for calculating carbon footprints. Communicating carbon footprint data along a supply chain is then a matter of connecting the different software solutions. The question is not unique to food systems, and the discussion here will draw on insights from cross-sectoral initiatives as well as initiatives in other industries. But there are some specific features of food systems which require attention, notably the large number of small primary producers with limited capacity for complex data management tasks.

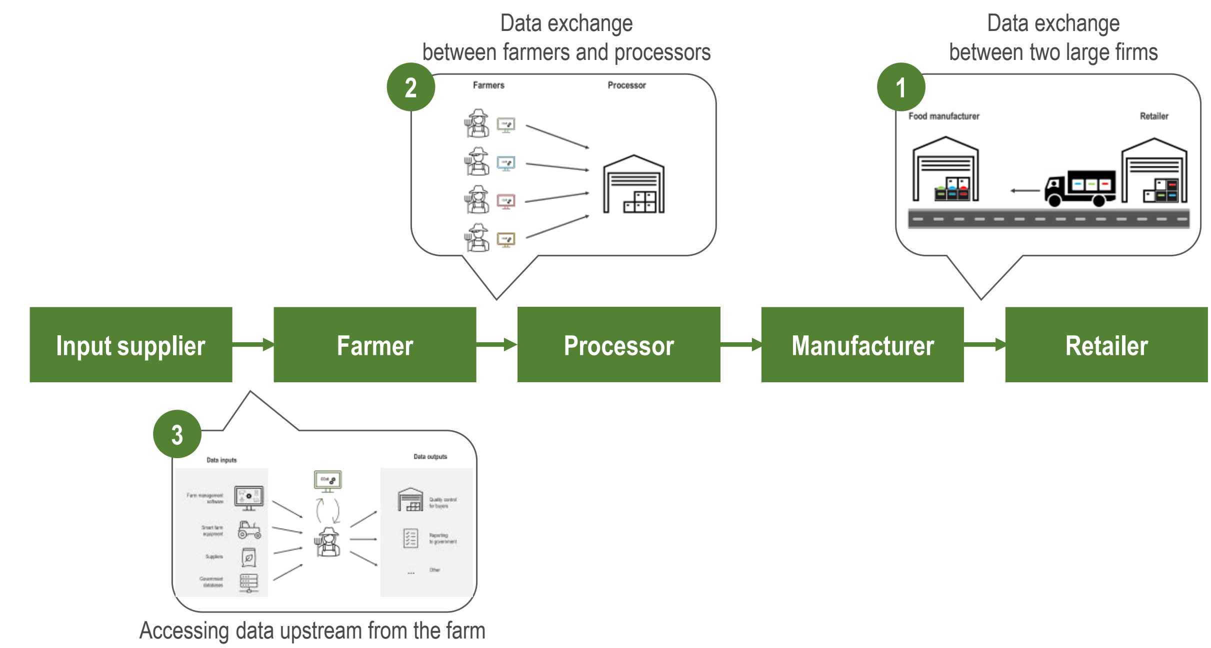
A recurring theme in this chapter is the importance of *interoperability*, understood as the technical capability of two or more heterogenous systems to exchange and use information effectively, enabling the connection of diverse digital structures within a larger workflow (Jouanjean et al., 2020[2]). The question of interoperability is broader than just the exchange of product carbon footprint data along the supply chain: it already came up in the previous chapter in the context of exchanging data between LCA databases, and will also make an appearance in the context of other building blocks. For example, a lack of interoperability means that data may need to be manually entered, stored, and converted. This not only requires more effort but also increases the likelihood of errors and reduces traceability; interoperability therefore also matters for ensuring data quality (Chapter 9) and for scaling up carbon footprints while keeping costs low (Chapter 10).

There are several possible obstacles to interoperability. For example, data could be stored in different data formats, using different variable names, using different definitions or calculation methods, expressed in different units, or using different levels of (dis)aggregation. Some of these are actual technical obstacles which prevent data exchange. Others, such as the use of different calculation methods, do not necessarily prevent data exchange but might mean that the resulting data is not meaningfully comparable. Because calculation methods and the like were discussed earlier, the focus in this chapter is on technical aspects of interoperability. Some regulatory and governance aspects are discussed as well.

There are at least three distinct steps in the agri-food supply chain where technical interoperability matters (Figure 8.1). Working backwards through the supply chain, they are:

- The exchange of product carbon footprint data between large firms, e.g. between food manufacturers and retailers (or between primary processors and manufacturers, between wholesalers and retailers, and so on). The technical interoperability challenge here is similar to that in other industries.
- The exchange of product carbon footprint data between farmers and primary processors, based on the output of farm level calculation tools.
- At the farm level, the collection of various data inputs necessary to calculate product carbon footprints. These can include product carbon footprint data from suppliers (e.g. for fertilisers, feed, or electricity), data from farm management software, data from smart farming equipment, and data from government databases.

Figure 8.1. Three interoperability challenges along the supply chain



Note: Transport is not explicitly shown in the supply chain diagram as it occurs in between each stage, but is also in scope.
Source: OECD analysis.

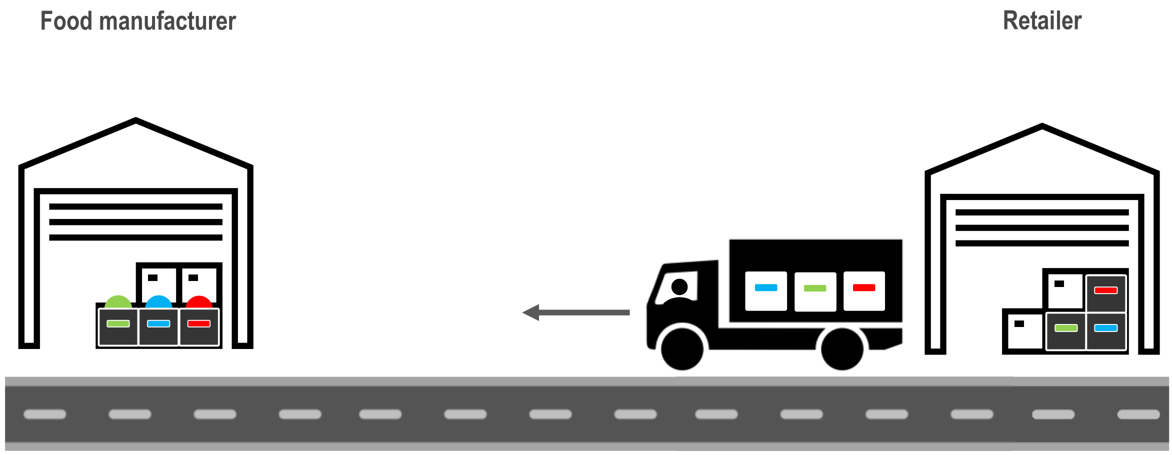
For each of these three cases, several initiatives have made important progress, as discussed below. Some solutions build a specific data exchange platform, while others focus on allowing different solutions to exchange data peer-to-peer; some approaches are sector-agnostic, whereas others are specifically tailored to food systems. An important next step is to ensure that various initiatives are aligned to avoid the emergence of parallel but incompatible ecosystems. In addition, each of the three cases could involve cross-border data exchange and could hence be restricted by data localisation measures, as discussed below.

8.1. Data exchange between two large firms

Consider a retailer calculating the carbon footprint of its products using data from a food manufacturer. Rather than manually exchange data, the two firms seek to automate their data transfer. However, the firms use different emissions accounting software. To automate data transfer, the retailer and the food manufacturer need to make their software systems “talk to each other”.

To understand the technical requirements for this, an analogy can help. Imagine the food manufacturer’s data as consisting of physical components which are stored in its warehouse and need to be transferred to the retailer’s warehouse (Figure 8.2). The retailer sends a data request to the food manufacturer, in the form of a truck with empty boxes labelled with the various data elements needed. Upon arrival, a worker in the warehouse of the food manufacturer verifies the identity of the truck driver, and then takes the requested data elements from the warehouse and places them in the proper boxes on the truck. The truck drives back to the retailer’s warehouse, where a worker in the retailer’s warehouse unloads the truck and stores the data elements internally.

Figure 8.2. Data exchange between two large firms



Source: OECD analysis.

In this analogy, the food manufacturer and the retailer could have completely different ways of organising their warehouses. What matters is merely that they agree on which data elements go in which boxes, and under which labels. The food manufacturer and the retailer are not even required to use these labels in their own warehouse, as long as the warehouse workers have a clear “dictionary” to translate the common label into the corresponding term used internally. However, some degree of standardisation of the data elements themselves may be needed, to avoid elements which are too big or the wrong shape to fit into their boxes.

This analogy describes the essence of Application Programming Interfaces (APIs), a widely used type of software code which allows for communication between different systems. APIs typically include instructions for how to access a system (similar to directions to the warehouse of the food manufacturer), security features (similar to the verification of the identity of the truck driver), and information on the agreed variable names and type of content found in those variables (similar to the labels and boxes on the truck). Such an API can allow for data exchange between the food manufacturer and the retailer despite their use of different emissions accounting software.

The Partnership for Carbon Transparency (PACT) has developed technical specifications for APIs to exchange carbon footprint data (WBCSD, 2022[3]). To enable both cross-industry interoperability and industry-specific requirements, PACT provides a core data model common to all industries but also allows for industry-specific “data model extensions.” At the time of writing, PACT is exploring such extensions for the agri-food sector, e.g. to address the reporting requirements of the GHG Protocol Land Sector and Removals Guidance (discussed in Chapter 4).

The PACT approach is already in use by major firms across a range of sectors, including Unilever, Dow, Colgate-Palmolive, and Schneider Electric, and also underlies other sector-specific initiatives, including in the chemicals industry (Box 8.1).

Box 8.1. Exchanging carbon footprint data in the chemicals industry

Together for Sustainability (TfS) is an initiative of the chemicals industry which has made significant progress in enabling the automated exchange of product carbon footprint data.

TfS currently counts 53 member firms, including agrochemical firms such as BASF, Bayer, Corteva, SABIC, Syngenta, and Yara, as well as other major firms such as AkzoNobel, Dow, Henkel, Merck, and Solvay. TfS members represent annual sales of more than EUR 800 billion.

Building upon the PACT Pathfinder Framework as well as the ISO and GHG Protocol standards, TfS first developed a product category rule for chemical products. More specific product category rules (e.g. for particular types of chemical compounds) can be built on top of this. The goal is to ensure that all firms in the chemicals sector calculate carbon footprints in a comparable way.

TfS subsequently set up the data exchange platform siGREEN, developed by Siemens, to automate data exchange of product carbon footprints between member firms. The technical aspects of this platform are consistent with the PACT specifications. At the time of writing, this platform is in a pilot phase.

These developments build on initiatives by individual firms in the industry to automate their carbon footprint calculations. BASF was the first firm to develop large-scale automated product carbon footprint calculations, covering its portfolio of 45 000 distinct products through the use of tailor-made carbon accounting software. The underlying methodology aligns with the carbon footprint standards of ISO, GHG Protocol, and TfS, and relies on primary data instead of industry averages. Since this data is already TfS compliant, it can be seamlessly integrated with the siGREEN platform and shared with BASF's customers.

The work of TfS is relevant to food systems for two reasons. First, many TfS members are major suppliers of agrochemicals, so that product carbon footprint data from the industry are a relevant input in carbon footprint calculations for food systems. This is especially the case for synthetic nitrogen (two major producers, Yara and SABIC, are TfS members). Second, while food systems face some unique challenges, the TfS example carries lessons on the importance of simultaneously harmonising reporting standards and methodologies while building technological solutions for automated data sharing.

Source: Together for Sustainability, "Scope 3 GHG emissions programme", https://www.tfs-initiative.com/how-we-do-it/scope-3-ghg-emissions (accessed 5 June 2024); interview with Alessandro Pistillo (BASF/TfS).

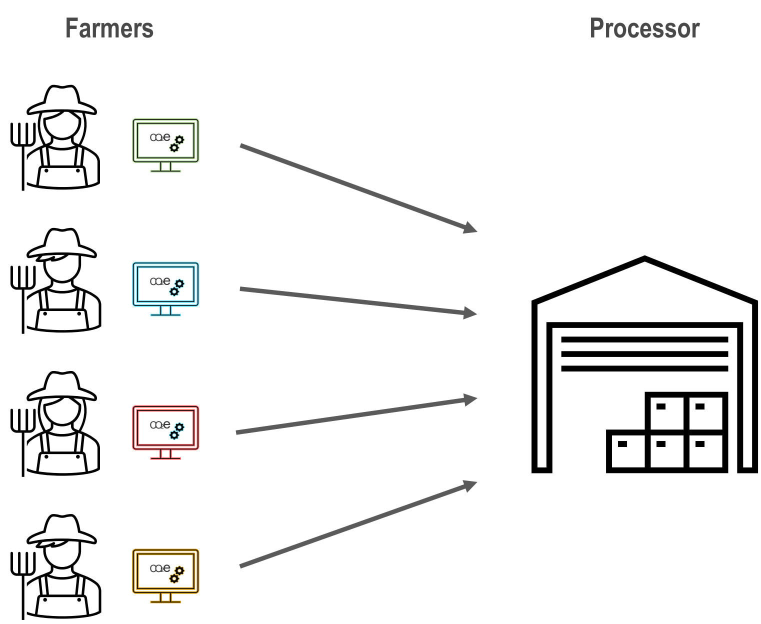
8.2. Data exchange between farmers and processors

The previous example illustrated data exchange between two large firms. But a key characteristic of agri-food supply chains is the presence of many small producers: farmers (Figure 8.3). These will typically have a lower capacity to deal with complex data or software issues. They are also less likely to use the same carbon accounting software solutions used by large firms. However, farmers may be using a farm level calculation tool as discussed in Chapter 6. It can be challenging to collect the activity data needed to calculate a carbon footprint using such a tool; the next section discusses this in more detail. Assuming that farmers are able to calculate a carbon footprint, however, how could data be exchanged between farmers and processors?

Farmers have several options for sharing their product carbon footprint with processors.

- A first option involves sending their activity data to processors, who would then calculate the emissions score. However, farmers might not agree to this due to concerns about data ownership and privacy.
- A second option is for farmers to calculate their emissions themselves (or with the help of, for example, a farm advisor) and send only the final product carbon footprint to processors using a data sharing function integrated in the farm level calculation tool. For example, the Cool Farm Tool allows farmers to share their final footprint with third parties using a share code.
- A third option is for farmers to use a farm level calculation tool, export the data from the tool in a specific format and share it with processors themselves.

Figure 8.3. Data exchange between farmers and processors



Source: OECD analysis.

All of these options require the data format to be compatible with other formats and software tools, such as those promoted by PACT, and all require a digital platform for data sharing. But product carbon footprints are just one area where farmers may be asked to share data with other firms in food systems. Such data exchanges are essential to unlock the promise of the digital transformation of agriculture, but farmers have often been reluctant to share their data (McFadden, Casalini and Antón, 2022[4]) (McFadden et al., 2022[5]). Causes include concerns around data privacy, ownership, and security, as well as perceived risks of lock-in (where data is 'stuck' with one solution provider, limiting farmers' ability to switch providers). In other cases, farmers are already required or willing to share data (e.g. for mandatory reporting, or in the context of subsidy schemes, quality assurance, etc) but have no easy or secure way of doing so. For example, farmers may be asked to report the same data in different formats to different entities.

One initiative to address these problems is DjustConnect (https://www.djustconnect.be/en), a platform to facilitate secure and transparent data sharing in the agri-food sector. DjustConnect was developed by the Flanders Research Institute for Agriculture, Fisheries and Food (ILVO), an independent scientific research institute of the government of Flanders (Belgium). It connects farmers with firms interested in using their data. Firms can request data via DjustConnect, but the platform only delivers the data upon the farmer's explicit consent, maintaining data privacy and security. The platform uses standardised data exchange contracts designed to be consistent with EU data sharing rules as well as the "Code of conduct on agricultural data sharing by contractual agreement" agreed by 11 major stakeholder organisations in EU agriculture (including farm unions, the farm machinery industry, and input suppliers). Analogous to a truck on a highway, DjustConnect securely transports data between parties without viewing or storing it.

The DjustConnect platform can be used by farmers to share any kind of data, including potentially the output of farm level calculation tools. An interesting example is the Klimrek tool, a farm level carbon footprint calculator built explicitly on top of the DjustConnect platform. Farmers can easily share the resulting carbon footprint with processors or retailers.

So far, this discussion of DjustConnect has focused on data sharing downstream from the farmer. However, the platform also makes it easier for farmers to access data upstream, e.g. from input suppliers, smart farm machinery, or government databases. This is discussed in more detail below. Recently, DjustConnect has begun connecting with similar farm data sharing platforms across Europe (Agdatahub in France and Tritom in Finland), to facilitate transnational data exchange. There are several other initiatives underway to facilitate data sharing in agriculture, such as the EU initiative to create a "European data space for agriculture" (https://agridataspace-csa.eu/).

8.3. Accessing data upstream from the farm

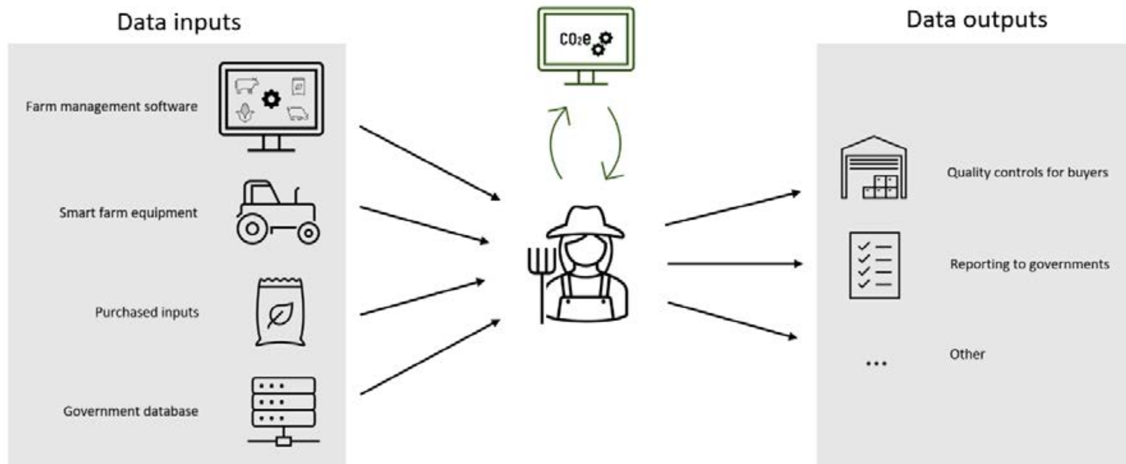
To realise a full "cradle to gate" carbon footprint calculation at farm level requires two types of information. The first type is detailed data on farm activities, to calculate the "on farm" component of the carbon footprint. These serve as inputs for farm level calculation tools. Relevant data here may be stored in, for example, farm management software, farm accounting software, government databases, or data from smart farming equipment. The second type is data on the carbon footprint of purchased inputs (feed, fertiliser, electricity, etc.). Some farm level tools already include an estimate of these emissions based on secondary data. However, ideally primary data would be used here. In both cases, the question is how these data could be accessed by farmers.

Again, carbon footprint calculations are merely one example here of a broader problem (Figure 8.4). Farmers are often asked to report data which requires them to collect, combine and forward data from many different sources, resulting in substantial manual work and room for error. A potential solution is software that automates data collection from various sources and formats it appropriately so it can be easily used to respond to various data requests or to feed into farm level calculation tools. This approach would significantly reduce the manual burden on farmers and improve data security and ownership.

The DjustConnect platform mentioned earlier is one example of such a solution. In addition to facilitating the sharing of farm data with actors downstream from the farm, the platform also allows farmers to access data relevant to their farm from a variety of sources, such as government data on agricultural parcels, lab data on water and soil analyses, or data from smart farming equipment (e.g. on applications of fertiliser). In response to a data request, farmers can therefore easily share relevant data from these sources with other actors. Moreover, the Klimrek farm level calculation tool mentioned earlier was explicitly built on the DjustConnect platform. Farmers can give permission to share relevant data with the tool to calculate their carbon footprint and can separately decide whether to share the resulting carbon footprint with others.[1]

This is not the only possible model for using supplier data in a farm level calculation tool. For example, the UK-based Farm Carbon Calculator tool already uses primary data on the carbon footprint of fertilisers in its calculations. Farmers can select the specific type of fertiliser use, e.g. YaraVera Urea produced by Yara International, and the tool will use the corresponding product carbon footprint provided by Yara to the Farm Carbon Calculator. In this case, data upstream from the farmer "bypasses" the farmer and is fed directly into the calculation tool.

Figure 8.4. Finding, combining, and sharing data relevant to the farm



Source: OECD analysis.

In addition to the initiatives mentioned here, another possible tool for facilitating data sharing and addressing broader interoperability issues in food systems is the adoption of a harmonised data format (Box 8.2).

Box 8.2. HESTIA: A harmonised data format as a tool for interoperability

HESTIA (https://www.hestia.earth/), a joint initiative of Oxford University, WWF, and the Login5 foundation, has developed a harmonised data format which can be used to represent a wide range of agri-environmental data, including data from farms, Life Cycle Assessments, and experimental field trials. The data format includes a glossary of terms, minimum data requirements, and basic validation standards. In addition, HESTIA has created a library of models typically used to quantify environmental impacts in LCA, and has set these up so that they can be run automatically on any data in the HESTIA data format.

In a context of carbon footprint calculations, the HESTIA format could be used by farm level calculation tools to ensure a common way of requesting and representing farm activity data. The format could also be used for storing the output of a farm level calculation. For example, tools could provide farmers with the option of exporting in the HESTIA format not only the final result of the calculation but also all the detailed activity data they provided. This would make it easier for farmers to switch between different tools or recalculate impacts. The HESTIA format was initially built on the openLCA data format for LCA databases, and can hence also be used to store or exchange LCA data.

The potential for a harmonised data format goes beyond that, and conceivably touches on each of the building blocks identified in this report. For example, the calibration and validation of sophisticated science-based models requires experimental field trials. Data from such trials can also be represented in the HESTIA format, potentially creating a large set of training data which could be used by researchers to build better models. As another example, the use of a common data format would greatly facilitate quality assurance, by making it easier for a third party to understand which data was used to generate a carbon footprint calculation. As a third example, the detailed representation of activity data in the HESTIA format could help deal with the need for regular updates of methods and standards. Farmers might for example be able to store their historical farm level data in the HESTIA format, so that they can easily re-calculate historical carbon footprints if new calculation methods are introduced.

Moreover, because the HESTIA format was designed to capture a wide range of agri-environmental data consistent with LCA databases and models, the format can be used not only for carbon footprint data but also for other environmental impacts.

The HESTIA format can also be used to unlock existing data from various sources. Valuable agri-environmental research findings are currently hard to access as results are stored in research reports, scientific papers, or databases using different formats and nomenclature. HESTIA is transforming such data into its own format, to allow other researchers to build on previous findings. At the time of writing, data from some 800 peer-reviewed studies and reports had already been digitised in the HESTIA format. This includes most of the studies synthesised in Poore and Nemecek (2018[6]). The HESTIA format has also been used to store data from thousands of farms surveyed by CGIAR, CIRAD, and other international organisations, showing how such information can be brought together in a harmonised way.

Source: Interview with Joseph Poore (University of Oxford/HESTIA).

8.4. Data governance and restrictions on sharing sensitive data

In addition to the technical aspects discussed so far, data exchange along the supply chain also raises multiple legal and regulatory questions concerning data ownership and security, and possible restrictions on sharing data (Stenzel and Waichman, 2023[7]).

For example, detailed product-level data might be competitively sensitive information, in particular when underlying activity data is included. If a supplier provides this information to a customer, the customer might be able to “reverse engineer” the supplier’s cost structure and use this information to renegotiate pricing. Competitors of the supplier, too, could use this information to uncover trade secrets. If product carbon footprint data is too detailed, it could thus threaten firms’ competitiveness, which in turn would make those firms unwilling to share data in the first place.

A different concern is that indirectly unveiling information on costs could lead to tacit collusion, whereby firms in an industry keep prices above the levels that would otherwise obtain, without any explicit coordination. For this reason, competition law often restricts the exchange of information on pricing and costs.[2] If detailed product carbon footprint data would achieve the same effect, exchanging this information might similarly violate competition rules. In July 2024, the French competition authority was asked by organisations in the animal feed industry whether they would be allowed to share information with the goal of creating a harmonised method for calculating environmental footprints. The competition authority allowed this but reminded actors of the need to limit the exchange of sensitive information between competitors (Autorité de la concurrence, 2024[8]).[3]

One possible solution to both concerns is to limit the level of detail in the product carbon footprint data. For example, rather than sharing a carbon footprint which distinguishes different GHGs (methane, nitrous oxide, etc), the exchange of data could be limited to CO_2-equivalent emissions. In addition, if each supply chain actor uses a cradle-to-gate approach and shares only the resulting total (including not only its own emissions but also emissions from upstream in the supply chain), this would go some way towards “masking” the cost structure.

Another potential regulatory issue relates to cross-border data flows. Countries are increasingly implementing data localization measures, which often restrict cross-border data flows (Stenzel and Waichman, 2023[7]; OECD, 2024[9]; Del Giovane, Ferencz and López González, 2023[10]). These might restrict firms’ ability to exchange product carbon footprint data.

Yet another set of issues concerns data governance – including questions of who owns the data, who has access to it, and how the value derived from that data is distributed (Jouanjean et al., 2020[2]). Failing to address these questions is an obstacle to the digital transformation of agriculture, as farmers may be unwilling to share data. Some of the initiatives mentioned above were designed explicitly to address such concerns. OECD work has identified other options to build trust, such as voluntary standards to enhance transparency and fairness in data contracts (Jouanjean et al., 2020[2]).

Generally, then, the smooth exchange of product carbon footprint data across supply chains depends not only on the technical infrastructure, but also on regulatory and governance issues (OECD, 2024[9]). Many of these issues are not specific to food systems but apply to other sectors as well, necessitating close cross-sectoral cooperation. Clear governance frameworks would allow for responsible and secure sharing of product level data.

8.5. A first assessment

There are three main points along the food supply chain where data exchange needs to be improved to allow sharing of carbon footprint data. These are data exchange between two large firms (such as between food manufacturers and retailers), between farmers and processors, and between the many sources of information relevant to farmers (e.g. government databases, farm management software, data from smart farming equipment, etc.) and farm level calculation tools. For each of these scenarios, initiatives have emerged to facilitate data exchange.

While many of these initiatives are at an early stage, they provide a powerful “proof of concept”, suggesting that at a purely technical level, the challenge of communicating carbon footprint data along the food supply chain is largely solved. The flow of data between different data sources and software solutions is technically feasible, with necessary APIs developed and often available through open-source formats. An important point of attention now is that various initiatives should collaborate closely and build on each other's work to create compatible systems for data exchange. This includes not just initiatives working on data exchange itself, but also other actors, such as farm level calculation tools, LCA databases, and standard setters such as the GHG Protocol.

Data exchange depends not only on solving technical questions but also regulatory and governance questions. Many of these are not specific to food systems and will require clarity from policymakers.

Finally, as noted, the concept of *interoperability* is not only relevant for exchanging data along the supply chain, but for ensuring that the various building blocks described in this report can work together smoothly. Efforts to facilitate the flow of data can also bring important benefits in terms of other building blocks.

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Notes

[1] Another possibility is to create interoperability directly between different systems, e.g. through the use of APIs. The EU-funded ATLAS project (https://www.atlas-h2020.eu/) is an example. The initiative developed an open-source system to make digital tools in agriculture interoperable. This includes all data-generating farm equipment (in-field sensors, livestock behaviour analysis, on-board machine processing) as well as existing farm management software. Each of the participating systems continues to operate independently on its own technical infrastructure, but with interconnections and standardised data exchange made possible through the technical specifications provided by the ATLAS project. In contrast with the DjustConnect platform, there is no central "hub", but data is exchanged peer-to-peer. However, to ensure data quality and reliability, a trusted directory of ATLAS participants oversees the membership in the network. Farmers must also give consent to whom their data is shared with.

[2] See, for example, the European Commission's 2023 Guidelines on horizontal co-operation agreements (2023/C 259/01), in particular Chapter 6 on information exchange; also see the US FTC and Department of Justice's Competitor Collaboration Guidelines (2000), Section 3.34e on the likelihood of anticompetitive information sharing.

[3] Interestingly, the competition authority also underlined the importance of allowing firms to use firm-specific data rather than industry averages: since firms partly compete on their environmental impacts, allowing only industry averages would amount to an agreement to restrict competition.

9 Ensuring the integrity and quality of the data

The sixth building block for carbon footprints is ensuring the integrity and quality of the data. This chapter explains how assurance can be used to ensure that a product carbon footprint calculation is the result of applying the appropriate methodology to the right data. The chapter also discusses some gaps in the current landscape and how these could be addressed.

A firm shares its product carbon footprint estimate with a customer. How can the customer be confident that the estimate is reliable?

Part of the answer lies in the building blocks discussed earlier. A product carbon footprint estimate is more likely to be reliable if it was calculated following clear reporting standards and validated science-based methods embedded in farm level tools or databases with secondary data.

But this is not the full answer. After all, even if the methods used are in principle sound, and the firm provided the correct information as inputs in the calculation, how would the customer know? If the firm used information provided by its suppliers, the customer's challenge in verifying the calculations becomes even more daunting.

Reliable and widespread carbon footprints in food systems thus require a way of ensuring the integrity and quality of the data. To be more precise, what is needed is *a way to guarantee that a product carbon footprint calculation is the result of applying the appropriate methodology to the right data.*

A few examples can clarify what this means in practice. First, consider a food manufacturer who combines several ingredients into a final product, with minimal processing (e.g. muesli). If the food manufacturer does not have primary data from its suppliers, the product carbon footprint can be calculated by multiplying the amounts of each ingredient (the activity data) with a product carbon footprint from a secondary database (the emission factor). Checking the product carbon footprint calculation here means checking whether the activity data are correct (did the manufacturer not omit or understate the amounts of each ingredient?), whether the emission factor comes from a relevant and reliable database, and whether the calculation did not contain any errors.

Second, consider a farmer using a farm level calculation tool. The farmer enters activity data into the tool, and receives an estimate for farm level emissions. Checking the calculation here means checking the activity data (did the farmer not omit or understate anything?), checking whether the calculation tool used is good, and checking whether the tool indeed returns the same estimate when fed the activity data.

Third, consider a farmer calculating product carbon footprints using the cradle-to-gate approach, using primary data for on-farm emissions and some data from suppliers (e.g. from the fertiliser company) and from secondary databases for emissions embedded in inputs. The farmer then uses allocation rules to arrive at product carbon footprints for the different outputs. In this scenario, there are additional items to be checked. How reliable is the data provided by the supplier? Did the farmer use the correct allocation rules? Was the overall calculation consistent with the relevant standards (e.g. in terms of system boundaries)?

These examples illustrate the questions which must be answered to ensure the quality and integrity of product carbon footprint data in food systems. Fortunately, *assurance* (in particular, third-party verification) is generally well developed, including for carbon footprints. But the current system still leaves some important gaps.

9.1. How assurance works

Assurance refers to the "demonstration that specified requirements relating to a product, process, system, person or entity are fulfilled." The terms "conformity assessment", "certification" and "verification" are also used (ISEAL, 2023[1]).

Assurance is widespread in food systems. Examples include assessing whether a firm or product meets organic standards, ISO 9000 quality management standards, HACCP food safety standards, and more.

The details of how assurance is organised depend on the context.

- In some cases "first party" assurance (i.e. a self-declared claim) is accepted. For example, a "Supplier Declaration of Conformity" is a document where a supplier declares that a product, process, or service conforms to certain requirements (von Lampe, Deconinck and Bastien, 2016[2]).
- In other cases "second party assurance" (by, for example, a supplier, customer, or contractor) could be appropriate. For example, a buyer could inspect a product to make sure it meets its own requirements.
- In yet other cases, assurance is performed through an independent third party (also known as a conformity assessment body, a validation or verification body, or a certifier).

These different types of assurance could each be appropriate depending on the circumstances. In general, first-party assurance is cheaper and easier but also provides less confidence than third-party assurance. This may create a trade-off, especially in dealing with smaller producers and producers based in developing countries. While the remainder of this chapter discusses third-party assurance, it is useful to consider whether first-party or second-party assurance might be an appropriate alternative (Chapter 10).

The ISO 17029:2019 standard lays out general principles and requirements for validation and verification bodies. ISO 14065:2020 takes these general requirements and provides further detail related to validating and verifying environmental information, while ISO 14064-3:2019 is a standard that provides guidelines for the validation and verification of GHG assertions specifically. The latter standard is part of the ISO 14064 standards, which outline the principles and requirements for the quantification, monitoring, reporting, and verification of GHG emissions and removals.

National Accreditation Bodies such as ANAB in the United States, JAB in Japan, UKAS in the United Kingdom, ONAC in Colombia or DAkkS in Germany can accredit organisations to perform third-party verification and certification services. In Germany, for example, there are 90 organisations accredited in accordance with ISO 17029 or ISO 14065 in the agriculture, food, and sustainability category.

Third-party verification of a product carbon footprint claim consists of two steps. First, the verification body checks whether the calculation followed the methodology it claims to use (for example the ISO 14067 product carbon footprint standard). Second, the verification body checks the activity data used in the calculation (e.g. whether the data can be traced back to reliable sources or records, whether there are possible errors, and what their impact would be).

9.2. A first assessment

Third party verification of product carbon footprints is widespread, but it does not evaluate the methodology itself, merely that whatever methodology chosen has been followed. Where emission factors from a secondary database are used the verification body would check whether the database is relevant and up to date, but it would typically not evaluate the quality of the data in the database. Similarly, where a farm level calculation tool is used the verification body would not evaluate the tool itself. The quality of the databases and farm level tools would be considered part of the methodology, and hence outside the scope of third-party verification of product carbon footprints.

This leaves important gaps. First, farm level tools and secondary databases should ideally follow widely used reporting standards. Second, even if tools and databases follow the relevant standards, there are many methodological questions which can influence results (such as the choice of specific emissions models). Neither of these two important questions are addressed in a third-party verification of a firm's product carbon footprint calculations.

Other types of third-party verification can be used to address some of these gaps. For example, farm level calculation tools often state that they are compliant with reporting standards such as ISO 14067, GHG Protocol, or even sectoral guidelines such as the IDF product carbon footprint guidelines for the dairy sector (Chapter 6). It is possible for tools to seek explicit third-party verification of their alignment with these standards. In the chemicals industry, for example, BASF developed a digital tool to calculate cradle-to-gate product carbon footprints for its own product portfolio (Box 8.1 in Chapter 8). A third-party verification confirmed that the tool is aligned with ISO 14067:2018 and the GHG Protocol Product Standard. Farm-level tools could follow a similar approach. Another possibility would be for standard setters themselves to list the tools and databases which are consistent with their requirements. In the past, the GHG Protocol did so through its "Built on GHG Protocol" programme, and providers of product category rules and sectoral guidelines could similarly indicate which tools and databases are consistent.

This still leaves the question of how to decide which tools and databases are the most suitable in a given context. Two farm-level tools or databases could both follow the same standards but make different modelling choices, leading to different results. Moreover, not every tool or database is well adapted to every geographic or technological context. Different options exist. For example, where governments have provided guidance on science-based methods (Chapter 5), third-party verification could confirm that a tool is indeed following these methods. Another option is an independent scientific assessment process which validates tools and databases best suited for specific contexts (e.g. a list of farm level tools most appropriate for crop farming in Canada). This process could function similarly to proficiency tests (Box 9.1).

A third option is to define minimum quality criteria for farm level tools (e.g. in terms of governance, transparency, independent scientific oversight) and assess tools based on those criteria.

Hence, while assurance is widespread, there are some important gaps that need to be addressed in order to guarantee that a product carbon footprint calculation is the result of applying the appropriate methodology to the right data.

Box 9.1. Proficiency testing

The question of how to evaluate the reliability of farm-level tools is similar to the question of how to evaluate the reliability of different laboratories, conformity assessment bodies, or measurement devices. Proficiency testing (also sometimes referred to as "ring trials") are frequently used in that context (Johnson and Cabuang, 2021[3]) and could be a useful model for farm-level tools. The discussion here will use laboratories as example, although similar ideas apply to conformity assessment bodies or measurement devices.

Proficiency testing refers to an ongoing periodic assessment of test performance of different laboratories, where results are compared to the results of other participants and/or reference standards. Typically, this involves laboratories performing the same test on the same samples. The process of proficiency testing is organised by an independent provider (the ISO/IEC 17043 standard sets out the requirements for such providers).

Proficiency testing is not only useful to assess the performance of different laboratories, but can also be a powerful tool to improve performance over time. Johnson and Cabuang (2021[3]) provide several examples in the context of animal disease testing.

Comparing tests results from different laboratories against a known reference has the advantage of being able to detect and reduce both systematic errors (bias) and non-systematic errors (noise). In the context of agricultural emissions, knowing the "true" emissions may be difficult. However, even when the true value is unknown, a comparison of different results could be useful in identifying and reducing noise. Counterintuitively, reducing noise can improve performance even if the true value is unknown (Kahneman, Sunstein and Sibony, 2021[4]).

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10 Scaling up carbon footprints while keeping costs low

The seventh building block for carbon footprints consists of ways to scale up carbon footprints while keeping costs low. This chapter discusses several ways in which this can be achieved, with particular attention to removing barriers faced by farmers, small and medium-sized enterprises, and producers in the developing world.

To achieve widespread carbon footprints, it is not sufficient to design an approach feasible only in theory, or feasible only for the most sophisticated and largest firms: the approach must be feasible for all actors. If calculating and sharing carbon footprints is costly, difficult, or time consuming, progress will be slow.

In a sense, all building blocks discussed so far tackle a particular barrier to scaling up: it would be hard for farmers to calculate their carbon footprints if farm level calculation tools are not available, for example. But real-world efforts to scale up carbon footprint calculations will probably encounter other barriers too.

At the moment, no systematic overview exists of the barriers to scaling up carbon footprints. But it seems plausible that farmers, small and medium-sized enterprises (SMEs), and producers in the developing world may face barriers related to the cost and complexity of calculating and sharing carbon footprints (WEF, OECD and BIAC, 2023[1]). One concern is that this may lead to their exclusion from supply chains (Deconinck, Jansen and Barisone, 2023[2]; WTO, 2022[3]). This chapter discusses several approaches to overcome such barriers.

10.1. Using default values as a starting point

Design choices can help prevent or reduce some of the barriers. For example, one way to keep costs and complexity down is to use default values as a starting point. Retailers, food manufacturers and others along the supply chain could start from product carbon footprint estimates based on secondary data but with the possibility of replacing this with an estimate based on primary data where feasible.

Because secondary data is already widely available (cfr. Chapter 7), this approach would make it possible to quickly arrive at a first approximation of product carbon footprints in food supply chains. For example, Clark et al. (2022[4]) showed that it is possible to combine product ingredient lists and publicly available LCA information on agri-food commodities to create first estimates of the environmental impact of more than 57 000 food products available for sale in supermarkets in the United Kingdom and Ireland. Likewise, the BRC Mondra Coalition (https://www.mondra.com/coalition) in the United Kingdom is using detailed product recipe data from private-label manufacturers to quickly generate a first estimate of carbon footprints and other environmental impacts for thousands of products, while allowing manufacturers to update these estimates using primary data.

Firms would have an incentive to replace default values with estimates based on primary data if their suppliers' operations and their own have relatively low emissions and if gathering primary data is not too costly. Increasing the share of primary data could be done by increasing the default value over time (to gradually increase the incentive for firms to collect primary data) and by investing in other initiatives to reduce the cost of collecting primary data over time.

10.2. Private sector engagement with suppliers

Downstream supply chain actors are increasingly asking suppliers for carbon footprint information, for example to refine their Scope 3 reporting (Box 1.1 in Chapter 1). It often makes sense for larger firms to support their suppliers in providing this information.

One example is Unilever.[1] In developing its strategy for reducing emissions, the firm discovered that upstream suppliers accounted for two-thirds of Unilever's total emissions, yet many suppliers lacked climate targets or even detailed emissions data. In response, Unilever launched a supplier engagement programme in 2021. The programme aims to eventually support suppliers of all sizes, industries, and geographies in measuring and reducing their emissions.

Recognising that suppliers were at various stages of their carbon reduction journeys, Unilever categorised them into three maturity levels: "Low maturity" suppliers with limited to no knowledge about their emissions, "Medium maturity" suppliers that had started their emissions reporting, and "High maturity" suppliers with fully defined Scope 1, 2, and 3 targets and capabilities to calculate product carbon footprints. Based on this categorization, Unilever provided tailored assistance. Low maturity suppliers were asked to simply get started with quantifying emissions. Medium maturity suppliers were asked to transition towards product carbon footprint reporting. High maturity suppliers were asked to provide product carbon footprint data in line with the PACT approach (Chapter 8).

Unilever's assistance to suppliers includes one-on-one engagements, e-learning tools and capacity development trainings. Initially, suppliers' biggest challenge was the lack of resources to monitor emissions. But in Unilever's experience once tools were in place many suppliers were keen to move from the e-learning phase to actual data gathering.

In addition to this engagement tailored to suppliers' maturity level, a second element in Unilever's approach was to align its own requests with emerging industry standards, notably PACT. Suppliers will be more willing to invest in data gathering and reporting if they know that the same numbers will be accepted by multiple clients.

Private actors along the supply chain can thus play an important role by engaging their own suppliers and assisting them in scaling up product carbon footprint calculations. Cooperatives can play a similar role.

10.3. Public-private awareness campaigns

The public sector and industry groups can also work together to drive the adoption of carbon footprint calculations in the agricultural sector.

In New Zealand, an estimated 84% of farmers had by 2023 calculated their on-farm GHG emissions. Following the Climate Change Response Act 2002, the government established the *He Waka Eke Noa* partnership between industry, Māori agribusiness interests, and the Ministries for Primary Industries and the Environment. They developed a practical framework to measure, manage and reduce agricultural GHG emissions, including step-by-step guidance documents.

As part of *He Waka Eke Noa*, the Ministry for Primary Industries launched the awareness campaign "Know Your Numbers".[2] The initiative offered an overview of the available farm level calculation tools, and guidance for farmers. Farmers could choose between three options for calculating their on-farm emissions:

- Use a calculation tool themselves
- Ask farm advisors which tool(s) they use and what services they can offer
- Ask their processor or industry organisation for advice.

Industry associations also supported farmers in calculating emissions. For example, the farmer levy body Beef+LambNZ published user guides, easy-access open-source GHG calculators, Q&A documents, and links to GHG calculators and Excel sheets where farmers can collect their emission data. These efforts helped scale up calculations of on-farm emissions. A remaining challenge is the use of different calculation tools by farmers, which could limit the comparability of results. To address this, the New Zealand government is currently working to align the methods used by calculation tools on those used in the national inventory.

10.4. Embedding carbon footprint calculations in existing schemes

Another option for scaling up carbon footprints is to embed them into existing schemes. The Irish *Origin Green* initiative has in this way been able to achieve widespread carbon footprint calculations for Irish agriculture, covering more than 90% of beef farms and 95% of dairy farms.[3] At the time of writing, some 367 000 carbon footprints had been calculated since 2013.

Origin Green is a voluntary programme created by Bord Bia, the Irish government agency for trade, development, and food. A key component of Origin Green is on-farm assessments conducted through Bord Bia's Sustainable Assurance Schemes. Independent auditors visit farms to assess practices and record data on a wide range of sustainability issues. Bord Bia then uses this data to assess the farm's environmental performance, including its carbon footprint. The collected data is stored in Bord Bia's database, which is also connected to LCA databases to fill any gaps with secondary data. Bord Bia generates a feedback report for farmers, illustrating how their farm inputs and activities contribute to emissions and suggesting ways to mitigate these emissions and improve production efficiencies.

The rollout of carbon footprint calculations was accelerated by Bord Bia's pre-existing Quality Assurance infrastructure, which has been in place for over 20 years. The necessary information for carbon footprint calculations is collected as part of regular audits, and the calculations themselves are done by Bord Bia, which reduces the burden for farmers. Audits are free for farmers, as the programme is funded by the government.

Several other assurance schemes require producers to estimate GHG emissions. This includes Rainforest Alliance, the Roundtable on Sustainable Palm Oil, and Bonsucro.[4] Working with existing assurance schemes to scale up carbon footprint calculations holds significant potential, since farmers already know the scheme and an infrastructure for audits and quality assurance is already in place.[5]

10.5. Using first-party or second-party assurance where appropriate

As noted in Chapter 9, cheaper alternatives to third-party assurance are first-party assurance (i.e. a self-declared claim) or second-party assurance (where, for example, a buyer verifies whether a product meets requirements). Although these are generally seen as providing less confidence, these approaches are also easier and cheaper. Where the use of these alternatives is considered appropriate, they could thus help scale up carbon footprints by lowering barriers for producers.

An example of using first-party assurance to allow faster scale-up is the "visualisation" initiative in Japan, which is part of the Japanese government's MIDORI Strategy for Sustainable Food Systems. Under the initiative, farmers' efforts to reduce environmental burdens (including GHG emissions) are displayed on a product label. The scheme is self-declared. Farmers evaluate their GHG emissions reduction efforts by themselves, by entering their primary data in a calculation tool developed by the Japanese Ministry of Agriculture, Forestry and Fisheries (MAFF). The approach is self-declared to lower barriers for producers to join the initiative. However, the government requires farmers to submit their calculation result to MAFF, which allows checking for suspicious data.[6]

10.6. Technical assistance to low- and middle-income countries

Small producers and SMEs in low- and middle-income countries are likely to face even greater barriers in calculating and sharing carbon footprints than their counterparts in high-income countries. Various forms of technical assistance can help reduce the burden of cost and complexity.

One form of technical assistance, that provided by private actors to their suppliers, was noted earlier. In a context of global supply chains, it can be an important channel for transferring know-how and technology from high-income countries to low- and middle-income countries (Swinnen and Kuijpers, 2019[5]).

Other forms could include technical assistance provided by development banks, development co-operation agencies or initiatives such as the International Trade Centre. This could be aimed at improving the capabilities of specific firms in low- and middle-income countries. But assistance could also aim to improve a country's capabilities in terms of the various building blocks, e.g. developing science-based methods, farm level tools, and LCA databases which take into account a country's climate and production conditions, or helping the country develop its system of standards, accreditation, assurance, etc., known as its "national quality infrastructure" (WTO, 2022[3]). This could take the form of technology transfer, for example by sharing know-how and source code for farm-level tools.

10.7. A first assessment

Many barriers could hamper or slow down the calculation and exchange of carbon footprints in food systems. This chapter discussed some likely barriers faced by farmers, SMEs, and producers in the developing world as well as possible solutions, without aiming to be exhaustive. Private actors, assurance schemes, and public-private collaborations could play important roles, as could the provision of technical assistance. While the practical challenges should not be downplayed, the examples in this chapter do show how existing approaches could be expanded or adapted to scale up carbon footprints in food systems.

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Notes

[1] The discussion in this chapter is based on an interview with Giulia Saladino and Katy Armstrong of Unilever.

[2] See https://www.agmatters.nz/goals/know-your-number/ (accessed 26 June 2024).

[3] See Origin Green, Progress Update Report 2023 (https://www.origingreen.ie/globalassets/bb-progress-report-2023-002.pdf) (accessed 26 June 2024) and https://www.origingreen.ie/who-is-involved/producers/carbon-footprint-assessments/ (accessed 26 June 2024).

[4] See Cool Farm Alliance, “Certification Standards and the Cool Farm Tool”, 8 December 2022, available at https://coolfarm.org/certification-standards-and-the-cool-farm-tool/ (accessed 16 October 2024).

[5] For an introduction to consumer-oriented assurance schemes in agriculture and food, see Deconinck and Hobeika (2023[6]).

[6] Information provided by Japan’s Ministry of Agriculture, Forestry and Fisheries (MAFF).

11 Updating as new scientific insights and techniques become available

Scientific insights as well as technologies and practices will continue to evolve. The eighth building block for carbon footprints is therefore that all other building blocks should be able to adapt over time, incorporating new scientific insights and techniques. This chapter discusses the tension between the need for flexibility and the need for stability, and argues that existing initiatives should adopt an explicit process for reviews and updates.

Science and technology are continuously evolving. The building blocks for measuring carbon footprints will therefore need frequent updates as well. But frequent updates could create additional costs and uncertainty. A deliberate approach should strike a balance between the need for change and the need for stability.

Some examples can illustrate the need for updates.

- *Reporting standards.* Current reporting standards are a compromise between what is desirable and what is feasible. For example, the IDF guidance for carbon footprints in the dairy sector (Chapter 4, Section 4.1.1) notes that soil carbon sequestration is important but that there is a lack of consensus on methodology. The current version of the guidance therefore recommends reporting sequestration separately rather than making it part of the carbon footprint calculation itself. It makes sense that such guidance would be revised once methods are sufficiently mature. Reporting standards could also be relaxed if it turns out that some requirements are not feasible or not as important as previously thought.
- *Science-based methods*. Scientific research is continuously refining the most sophisticated (Tier 3) models for quantifying GHG emissions. But even the less sophisticated (Tiers 1 and 2) methods are subject to change. As noted earlier, research using atmospheric inversion techniques suggests that methane emissions from livestock might in some cases be greater than currently thought. If confirmed, such insights should be reflected in emission factors. As another example, if new mitigation options are available to farmers, science-based methods should be developed to quantify their reduction potential.
- *Farm-level tools*. A smoother connection between farm management software, smart farming equipment, government databases, and the like would make it possible to use more detailed data for farm-level carbon footprint calculations while reducing the reporting burden for farmers. In turn, this means more sophisticated calculation methods could be used. The availability of new mitigation options should also be reflected in farm-level tools, once it is clear how reductions should be quantified.
- *Secondary databases*. As firms and farmers start to reduce their emissions, LCA databases should be updated to reflect this new reality. For example, lower emissions in fertiliser production should lead to lower life-cycle emissions for wheat, and hence also for bread. Moreover, as science-based methods change, LCA databases should re-calculate emissions, too. As noted earlier there is also a need for further “regionalisation” of LCA databases, using new data and models to create more fine-grained emission factors. More precise estimates could over time replace extrapolations.

Changes in one building block may require changes in several others. For example, an update to the reporting requirements of the GHG Protocol or new science-based methods would trigger changes in farm-level tools and LCA databases and potentially in digital tools used to share data along the supply chain.

11.1. The tension between change and stability

While these examples illustrate the need for updates, there is a tension between change and stability.

On the one hand, if standards, methods, and numbers are not sufficiently updated all three of the levers to reduce emissions in food systems would be weakened.

- *Shifting across product categories:* If product categories manage to reduce their average emissions this should be reflected in the numbers. Otherwise consumers and supply chain actors would be relying on the wrong signals, and sectors would not be rewarded for reducing their emissions.
- *Shifting between suppliers*: If suppliers manage to reduce their emissions this should similarly be reflected in the numbers. Otherwise customers would not have the right information to allow them

to switch to lower-emission suppliers, and suppliers would not be rewarded for reducing their emissions.

- *Reducing emissions through mitigation options*: If new mitigation options are not included in calculation methods for carbon footprints, producers would not be rewarded for lowering their emissions. This weakens the incentive to adopt new mitigation techniques – which in turn would weaken the incentive for developing them in the first place.

A lack of regular updates would thus weaken the signals needed to help consumers, producers, and other actors work towards lower emissions in food systems. In addition, a lack of regular updates would mean that any inconsistencies would take a long time to resolve. Discussions over revisions of the building blocks might also become more tense as stakeholders feel that it is “now or never” to introduce or resist a change.

Such a lack of flexibility could be the unintended by-product of rules to create greater reliability. For example, to avoid greenwashing or fragmentation, governments or standard setters might decide to prescribe certain methods and exclude others. While this creates more clarity and comparability today, there is a risk that doing so would effectively halt innovation unless a process exists to revise these decisions.

But there are good reasons to keep changes to a minimum. Frequent changes (especially ones which “cascade” through the different building blocks) create costs, and make it harder to interpret numbers. For example, if farm level tools changed their calculation method every year, it would be difficult for farmers and other actors to understand whether fluctuations in carbon footprint estimates are due to their own actions or to changing methods. The same applies to changes in LCA databases or reporting standards. Ideally, historical data would be recalculated using the new methods, but this is not always feasible and does not fully remove risks of misinterpretation or confusion. Comparisons between products, firms, and countries will be complicated if it is unclear whether numbers were all derived using the same standards and methods. The carbon footprint of fertiliser is an input in the calculation of the carbon footprint of wheat, bread, and so on: in this case there may be confusion over whether all relevant calculations were updated. In short, frequent updates could create uncertainty and a feeling that carbon footprint estimates are arbitrary. These problems would be compounded if there is no clear indication of which version of a standard, method, or database was used, and if it is unclear for how long the current version of a standard, tool, or database will remain valid before another update occurs.

11.2. A first assessment

At the moment, there is no deliberate approach to updating the various building blocks. In fact, many initiatives do not have a pre-defined process or timeline for updates. One notable exception is provided by the ISO standards: all ISO standards must undergo a review at the latest every five years. As the overview of LCA databases showed, LCA databases are also commonly updated, although databases differ in how often this happens. But most initiatives reviewed here are updated infrequently. The IPCC guidance, which is a benchmark for science-based methods, was last updated in 2019; its previous version dated from 2006. The USDA guidance on methods was updated in 2024, with its previous version dating from 2014. The assessment on farm level tools in the United Kingdom (discussed in Chapter 6) concluded that many tools were not aligned on the most recent reporting standards and guidance. Strikingly, the GHG Protocol standards which underpin much emissions reporting do not carry version numbers, and for some of the older standards (e.g. the Agriculture Guidance) even the publication date is not provided in the standards document.

To reconcile the need for change and the need for stability, a deliberate approach to updating the building blocks is needed. Important steps can be taken by initiatives in each building block separately, whereas others require coordination.

Reporting standards, overviews of science-based methods, farm-level tools, and secondary databases could all adopt an explicit policy about how changes will be made. This policy could stipulate a regular timeline for review, and could define how the scientific community, stakeholders, and other initiatives will be involved. Clear version numbers would allow users to specify which version was used, while change logs (i.e. overviews of changes made between two versions) would help users understand how results may differ because of the updates. Third-party verification of carbon footprints could then also mention the version numbers of standards and tools used.

It would be helpful if documents which take stock of science-based methods were updated more frequently. One possibility is to update chapters or sections of chapters separately rather than updating an entire document (as is currently done). Another possibility is to separate discussions of the "state of the art" (which could be updated more frequently) and "recommended" methods (which could be based on feasibility and the need for stability and could hence be updated less frequently). There is a particular need for a process to decide when there is sufficient evidence for a new mitigation technique (e.g. a new practice or new technological solution) to be included in models, and by how much it reduces emissions.

Farm-level tools could adopt clear version numbers and change logs. The tools could clearly state which standards (and which version) they are consistent with, and which version of the relevant scientific guidance they follow. This information could also be part of the output of the tool. Farm-level tools could consider adopting a standardised data format such as the HESTIA format (Chapter 8). Such a standardised data format would make it easier for farmers to store historical activity data, so that historical baselines can be easily recalculated when methods are updated.

These practices could easily be adopted by individual initiatives, but some coordination may be required to align the different processes. For example, it might be helpful for the various initiatives (standards, tools, database providers) to agree on a regular update cycle (e.g. every five years) and on a clear sequence for updating the various building blocks within that cycle (e.g. reporting standards reviewed and updated in year 1, farm-level tools and LCA databases updated in year 2).

It could be useful to have a forum where various initiatives can gather to discuss possible updates. Involving stakeholders in these discussions is important, as these can then communicate to their members what is changing and why (e.g. farm organisations could inform farmers about why estimated carbon footprint numbers will be revised).

One advantage of being explicit about future updates is that it sends a clear message to all stakeholders that the building blocks for carbon footprints will keep evolving but will do so on a predictable timeline. New insights, new techniques, or new concerns of stakeholders could be taken on board in future iterations. This makes innovation and adaptation possible. At the same time, a clear timeline would provide clarity to users about when new changes might be expected.

An explicit process for updates would also help acknowledge that at least initially carbon footprints in food systems may come with considerable error margins, but that stakeholders can work together to reduce these errors over time. As part of the updating process, stakeholders could assess the reliability of carbon footprint estimates, identify the main sources of divergence, and work to improve estimates. For example, an analysis such as that done for farm level tools in the United Kingdom (RSK Adas, 2023[1]) could be done regularly and could form the basis for a discussion with tool providers on how to improve accuracy. As another example, a regular analysis could assess data quality in secondary databases and identify the main activities or products where further research is needed. It could also be used to track progress in scaling up carbon footprints, assessing the main barriers, and developing action plans.

Such a "continuous improvement" approach is common in the fields of quality management and environmental management and underlies modern software development techniques.[1] The approach could be a useful way to organise collaboration on the building blocks needed for reliable and widespread carbon footprints in food systems.

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Note

[1] See, for example, Sutherland (2014[2]) and Ries (2011[3]).

12 Conclusion

This chapter brings together the findings from earlier chapters on the eight building blocks and draws out the implications for policymakers, researchers, and stakeholders.

Making carbon footprints visible all along the food supply chain could be a powerful tool in reducing emissions. In line with initiatives in other industries this report has explored the potential for a “cradle to gate” approach where each firm along the supply chain receives carbon footprint information from suppliers, adds an estimate of its own emissions, allocates the total across its products, and shares the resulting carbon footprint with its customers. This approach would decentralise the calculation of product carbon footprints, and allow each firm or farm to focus on quantifying its own emissions.

Within this setup, the report identified eight building blocks for achieving reliable and widespread carbon footprints in food systems. They are:

- Reporting standards and guidelines for carbon footprint measurement, to create a shared understanding of what to include in carbon footprint calculations.
- Science-based methods for measuring or estimating emissions.
- Farm level calculation tools, which allow farmers to use primary data on their activities and management practices as inputs to calculate their carbon footprint.
- Databases with secondary data, to be used where primary data is not (yet) available.
- A way of communicating carbon footprint data along the supply chain, so that detailed calculations by producers at one stage of the supply chain can be used as input at the next stage.
- A way to ensure the integrity and quality of the data and calculations.
- A way to scale up carbon footprint calculations while keeping costs low, to ensure widespread adoption by actors with limited capacity, notably farmers, small and medium-sized enterprises (SMEs), and producers in developing countries.
- A way to update these elements as new scientific insights and techniques (such as farm management practices or technological options) become available.

Across the eight building blocks this report has provided a first assessment of what is available, what would need to be added, and what would need to be modified to achieve reliable and widespread product carbon footprints on a cradle-to-gate basis. Table 12.1 summarises the findings by building block.

Table 12.1. Building blocks: A first assessment

Building block	Current state	Next steps
Reporting standards and guidelines	Well-developed landscape of standards at firm and product level Additional sector and product guidance often available But some inconsistencies and ambiguities remain, and some ‘settled’ issues may need to be revisited	Continue to improve alignment of existing standards and guidelines Investigate the impact of different standards on calculated impacts Streamline treatment of CO2 emissions and removals from land management and land use change Consider including indirect land use change (ILUC) Investigate impact of different allocation rules and whether these can be streamlined Adopt clear processes for reviewing and updating standards
Science-based methods	Methods generally well-developed, with IPCC providing authoritative guidance on Tier 1 and 2 methods and some countries providing national recommendations on methods But some gaps (e.g. for developing countries and for soil organic carbon), including validation of models	Fund additional research and validation in areas with gaps, in particular in low- and middle-income countries Consider developing national guidance on most appropriate methods for farm-level emissions (cfr. United States), taking into account alignment with National Inventory methods Adopt a process for faster update of guidance documents
Farm level calculation tools	Several tools exist, but these differ in methodology, which can lead to very different answers for same farm Not all tools transparent about methods and alignment to standards	Create greater transparency on methods, assumptions, and performance, e.g. through minimum requirements and/or benchmarking exercises Ensure tools are regularly updated to reflect latest science, reporting standards, and secondary data (e.g. emission factors), while striking a balance with the need for stability Improve coverage of developing countries and of soil organic carbon as improved science-based methods become

Building block	Current state	Next steps
		available Where necessary, adapt farm level assessment tools to perform product level assessment. Improve interoperability of tools and databases through a harmonised data format (e.g. HESTIA)
Databases with secondary data	Databases are well established and cover large number of products and geographies; databases usually consistent with key standards Databases differ in methodological choices Data gaps for some products, activities, and geographies Cost and complexity may pose a barrier to accessing and using databases	Consider harmonizing methodological guidelines to a greater extent (e.g. incorporating product category rules) or provide "pre-sets" so users can easily adjust calculations to different standards Develop a deliberate strategy to address data gaps, using data quality ratings to prioritise areas for new research
Communicating carbon footprints along the supply chain	While at an early stage, several initiatives exist to enable digital sharing of carbon footprint data along food supply chains, and technical aspects are well developed Several open regulatory and governance questions (e.g. data ownership, competition rules)	Collaborate to create compatible systems, including working with farm level calculation tools, LCA databases, and standard setters Consider adopting harmonised data format (e.g. HESTIA) as basis to create interoperability between farm-level tools, databases, and initiatives to transmit data along supply chain Create clarity on regulatory and governance issues (often cross-sectoral)
Ensuring integrity and quality of the data	There are three models of assurance (i.e. a demonstration that requirements have been fulfilled): first party (i.e. self-declared claims), second party (e.g. when buyers evaluate whether a product meets requirements), and third party (with an independent body). The most appropriate choice depends on the context; in general, third-party assurance provides more confidence but is also more expensive. Third party verification of carbon footprints is widespread However, verification does not evaluate underlying methodology, only that the methodology has been followed – i.e. no process for ensuring quality of LCA databases and farm level tools	Consider whether first-party, second-party or third-party assurance is most appropriate in a given setting. Consider third-party verification of farm level tools' compliance with reporting standards Consider possibility of standard setters listing the tools consistent with their requirements Consider third-party verification that farm level tools follow relevant science-based methods (e.g. based on national guidance) Consider independent assessment processes for validating tools and databases most suitable for specific contexts Consider proficiency tests for farm-level tools Consider minimum quality criteria (e.g. on governance, transparency, independent scientific oversight) for farm-level tools
Scaling up while keeping costs low	Farmers, SMEs, and producers in the developing world are likely to face barriers in calculating carbon footprints Several approaches exist already, including private sector engagement with suppliers, public-private collaborations, or the provision of technical assistance	Extend or adapt existing approaches to help farmers, SMEs, and producers in developing countries overcome practical barriers in calculating carbon footprints Consider the possibility of first-party or second-party assurance for farm activity data where appropriate. Consider how governments could strengthen confidence, e.g. by operating the self-declared scheme (cfr the visualisation initiative in Japan's MIDORI Strategy)
Updating all elements as new scientific insights and techniques become available	Currently no deliberate approach for updating various building blocks; many initiatives lack a process for updates or revisions Tension between the need for change and the need for stability	Consider adopting an explicit policy for revisions and updates (for reporting standards, overviews of science-based methods, farm-level tools, databases) Introduce clear version numbers and change logs (for reporting standards, overviews of science-based methods, farm-level tools, databases) Consider adopting harmonised data format (e.g. HESTIA) for storing historical data to facilitate updates and re-statements of historical baselines if new methods become available Across all building blocks, consider aligning on a common multi-year update cycle Across all building blocks, consider creating a multi-stakeholder forum for discussion on possible updates Across all building blocks, adopt a "continuous improvement" mindset

Note: See main text for more detailed assessments and recommendations.

What is remarkable is how many of the necessary building blocks are already in place. Some have emerged only recently, such as digital solutions to communicate carbon footprints along supply chains. Several other building blocks were historically developed with different purposes in mind, such as IPCC guidance on science-based methods (originally addressed to governments for National Inventory Reporting) or farm level calculation tools (originally developed to help farmers evaluate total on-farm emissions rather than product carbon footprints). Most building blocks have also developed independently of each other. This explains why adjustments will be needed to make all building blocks work well together.

An important question is how to avoid fragmentation and unnecessary transaction costs in the context of international trade. The World Trade Organization's Agreement on Technical Barriers to Trade encourages the use of common international standards, acceptance by members of conformity assessments performed by other members, and special attention to the needs of producers in developing countries; these principles are highly relevant for carbon footprints (WTO, 2022[1]). In terms of the "building blocks" framing used here, international standards would be most relevant in the context of reporting standards and guidelines, and science-based methods. More broadly, however, each building block could benefit from an international exchange of experiences and (where relevant) alignment.

The suggested next steps listed in Table 12.1 involve a wide range of actors. Some involve international civil society and potentially governments and international organisations (e.g. on reporting standards), some involve the international scientific community (e.g. IPCC guidance), some involve database and tool providers (which may be national or international, and may be private sector, non-profit, or public), some involve governments and stakeholders at the national level (e.g. public-private awareness campaigns), and so on. To avoid fragmentation and to coordinate this diverse group of actors, international organisations could play an important role as conveners. For example, as suggested in the context of mechanisms to update the building blocks, it might be useful to create multi-stakeholder forums to allow cooperation and coordination between these different communities around the shared goal of carbon footprints for food systems. The OECD could be a venue for such conversations. For example, ongoing work under the OECD Inclusive Forum for Carbon Mitigation Approaches (IFCMA) is exploring carbon footprints with a focus on emissions-intensive and trade-exposed sectors (OECD, 2024[2]) while the OECD together with the International Energy Agency is providing the interim secretariat for the Climate Club (https://climate-club.org/), an intergovernmental forum for exchange on industry decarbonisation. In 2023-2024, the OECD Food Chain Analysis Network brought together experts from diverse backgrounds to discuss carbon footprints of food systems; insights from these discussions informed the writing of this report ().

Box 12.1. The OECD Food Chain Analysis Network on carbon footprints of food systems

The OECD Food Chain Analysis Network (FCAN) is an OECD expert group specialised in food systems analysis. In previous years, the FCAN has contributed to OECD work on issues such as simplified nutrition labelling policies or food insecurity in OECD countries. FCAN experts are nominated by OECD countries. The OECD can invite other experts or stakeholders as observers. FCAN members participate in annual meetings and ad hoc virtual events (facilitated by the OECD) to share insights, data, and best practices on topical food systems issues related to ongoing OECD projects. In this way, FCAN informs the work of the OECD, while also enabling peer learning and dialogue among OECD member countries.

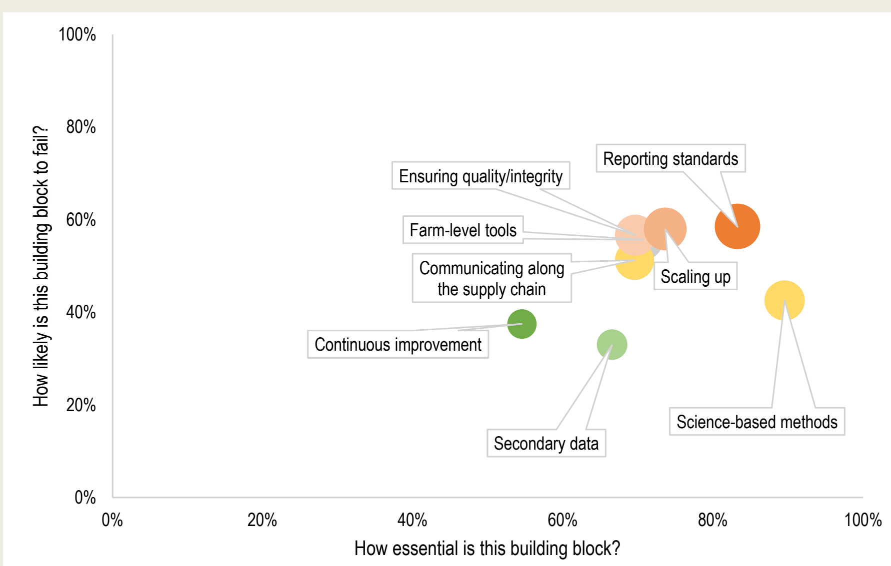
In 2023 and 2024, the FCAN studied initiatives to measure and communicate environmental impacts of food products. The first hybrid meeting was organised in Paris on 22-23 June 2023. Participants shared experiences on initiatives to measure and/or communicate environmental impacts, and discussed governance issues. A series of virtual workshops then looked in more detail at farm-level calculation tools, simplified environmental labelling schemes, carbon footprint standards, consumer behaviour, secondary databases, and interoperability and data sharing issues.

On 10-11 October 2024, the FCAN met again in hybrid format in Paris, this time with a focus on measuring carbon footprints in food systems. Participants included experts and delegates from Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Croatia, Denmark, Estonia, the European Commission, Finland, France, Germany, Ireland, Israel, Japan, Korea, Latvia, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, Türkiye, the United Kingdom, and the United States, as well as representatives from Business at OECD, FAO, WWF, UNEP, the World Farmers Organisation, the World Business Council for Sustainable Development, the International Dairy Federation, the Global Roundtable on Sustainable Beef, and many initiatives and actors working on carbon footprints in food systems, including HESTIA/Oxford University, the Cool Farm Tool, and the Global Feed LCA Institute.

Discussions were structured around the eight building blocks covered in this report. Participants were asked how essential each building block is, and how likely to fail (in the absence of deliberate effort), and discussed this question through a mix of individual work, breakout sessions, interviews with experts, and plenary discussions. Figure 12.1 shows the average scores across five breakout groups. Multiplying the score for how essential a building block is, with its score for how much it is considered at risk, gives a rough prioritisation. Overall, reporting standards (Chapter 4), scaling up (Chapter 10), ensuring the integrity and quality of the data (Chapter 9), and farm level tools (Chapter 6) scored highest in terms of this combined score, although science-based methods (Chapter 5) and communicating data along the supply chain (Chapter 8) were close behind.

These scores should not be interpreted in a strict quantitative sense, as the main purpose of the exercise was to stimulate discussions among experts, but they do confirm the relevance of the building blocks covered in this report.

Figure 12.1. Expert judgment on the eight building blocks



Note: Chart shows average scores across five expert discussion groups at the OECD Food Chain Analysis Network meeting on 10-11 October 2024.
Source: OECD analysis.

Experts were also asked if they saw any additional building blocks to be added. Some major themes which emerged from these discussions were:

- The importance of harmonisation not only within specific building blocks (e.g. within reporting standards), but across the building blocks (e.g. alignment of farm-level tools and LCA databases on reporting standards). Participants expressed a clear need for greater harmonisation.
- The role of government. Several participants noted that successful initiatives often had the implicit or explicit support of government, whether as convener of stakeholders, funder of initiatives, or direct provider of tools or services.
- The importance of taking an inclusive approach, mindful of the circumstances of small producers, small and medium-sized enterprises, and producers in developing countries.

These could be seen as additional building blocks, or alternatively as 'enablers' which apply across the building blocks covered in this report.

While many elements are therefore in place, the magnitude of the challenges should not be downplayed: achieving reliable and widespread carbon footprints in food systems is an ambitious goal. A particular challenge is how to achieve comparability of carbon footprint estimates referring to very different geographies and production systems, and calculated using different methodologies. A "continuous improvement" approach is helpful here, as it acknowledges that estimates will initially come with significant error margins but that stakeholders can work together over time to reduce these uncertainties. And as noted in the introduction, investments in the building blocks would anyway generate important benefits such as improved databases and methods even if in the end the goal of reliable and widespread product carbon footprints remains out of reach.

Working towards product carbon footprints could also help with efforts to quantify other environmental impacts. For example, digital tools for exchanging carbon footprint data could easily be adjusted to communicate other environmental impacts. In other cases, building blocks for carbon footprints could inspire or inform similar work for other environmental impacts. For example, there is currently no equivalent to IPCC guidance and Tiers 1 and 2 methods for quantifying other environmental impacts, and most farm level tools quantify only GHG emissions. The concept of building blocks could therefore be a useful starting point for thinking about other environmental impacts as well.

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Measuring Carbon Footprints of Agri-Food Products

Eight Building Blocks

What would it take to achieve widespread and reliable information on carbon footprints of agri-food products? This report argues that eight building blocks are essential. Reporting standards, science-based methods, farm-level calculation tools, and databases with secondary data are needed to calculate carbon footprints, but these must be complemented with ways to communicate carbon footprint data along the supply chain, ensure the integrity and quality of the data and calculations, scale up carbon footprint calculations while keeping costs low, and to update all these elements as scientific insights and technologies evolve. Although the magnitude of the challenge should not be underestimated, this report shows that many of the building blocks are falling into place and can be improved and aligned through collaboration between researchers, farmers, other supply chain actors, governments, and civil society, both at domestic and international levels.

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