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The IDF global Carbon Footprint standard for the dairy sector

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The IDF global Carbon Footprint standard for the dairy sector

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FOREWORD

The IDF global Carbon Footprint standard for the dairy sector

We are proud to present this edition of our Bulletin dedicated to Life Cycle Assessment (LCA) methodology: IDF's global standard for assessing Carbon Footprint in the dairy sector. It worth noting that it is the only global dairy standard to measure carbon footprint. The adage says: "We can't reduce, what we can't measure."

The purpose of this bulletin is to assist the dairy sector in its efforts to reduce GHG emissions across all its value chain. It has been developed by IDF to be used by the dairy cattle farming and dairy manufacturing sectors, as well as anyone else committed to assess the Carbon Footprint of their production systems and products by using an LCA approach. This update contains changes in some key areas supported by robust scientific evidence in order to ensure the highest degree of consistency, as well as to allow comparability with the previous version and subsequent revisions.

The first LCA methodology for the dairy sector was developed and published in 2010 by the IDF Standing Committee on Environment (SCENV) with active participation of the Food and Agriculture Organization of the United Nations (FAO) and the Sustainable Agriculture Initiative Platform (SAI Platform), and it was continuously reviewed and revised by our experts to reflect evolving science. Consequently, updated versions of the bulletin were published in 2015 and in 2020. This new edition is then reflecting the evolution of the sector and its practices.

With the IDF being one of the 6 founding partner organizations of the Pathways to Dairy Net Zero initiative, we want to ensure that the IDF plays its part in providing the dairy sector with knowledge and tools in support of the ambitious commitment that was made in September 2021. This guideline is fundamental in helping the dairy sector in quantifying both its impacts and progress, and importantly aligning language around GHG emissions to enable the sharing of mitigation learnings and opportunities with sector peers.

Finally, the IDF would like to thank the Global Dairy Platform for their support in the management provided on the guide.

We are convinced that you will find it useful.

Caroline Emond, Director General
International Dairy Federation Brussels, June 2022

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EXECUTIVE SUMMARY

There is a recognized need to calculate greenhouse gas emissions (that is, the carbon footprint) for both dairy cattle (cows and buffalo) farming operations and dairy manufacturers within the global dairy sector. In 2010, the first edition of 'A Common Carbon Footprint Approach for the Dairy Sector: The IDF Guide to Standard Life Cycle Assessment Methodology' was published. This guide enabled the dairy sector to better understand the carbon footprint of a diverse range of dairy farming systems and through 'talking the same language' approach, explore and identify appropriate mitigation options. The guide was subsequently updated by the IDF in 2015 to capture new LCA and climate science developments and have now again reviewed and revised the guideline to reflect the fast-evolving science and standards in carbon footprint methodology. In addition, the sector is also able to build on the experiences gained through the extensive implementation of the guide over the previous 12 years. This revised version ensures that the guide remains practical for use by the dairy sector globally regardless of their stage of carbon footprinting developments. Several changes have been made, though no fundamental amendments have been necessary. In this 2022 version, for example, the guide now addresses the full value chain from cradle to grave and includes reference to other environmental impact categories. There are several areas that the sector would like to tackle, however the methodologies are not sufficiently developed to make this possible. The IDF has noted these key areas to ensure they remain on the agenda for future revisions. The IDF methodology for carbon footprinting is a dynamic development and will undergo regular revisions capturing the science as it evolves. A dedicated IDF LCA action team consisting of more than 50 LCA and dairy experts from 17 nationalities have committed to continually evaluating LCA and climate science to ensure that the methodology remains at the cutting edge of science providing a valuable resource on which then global dairy sector can evaluate, manage and reduce climate impacts in a responsible way.

Keywords: *Carbon Footprint, Dairy, Dairy Products, Emissions, Environmental Assessment, Greenhouse Gas Emissions, Life Cycle Assessment, Milk, Mitigation*

1 INTRODUCTION

1.1. BACKGROUND

Climate change remains a top priority amongst the myriad global environmental challenges that must be addressed at all levels of society. Most industries have been challenged to both quantify and reduce their emissions of greenhouse gases (GHG) into the atmosphere. Food processors and farming organizations within the international dairy sector have therefore recognized the need to calculate GHG emissions for production systems and products, colloquially known as the carbon footprint (CF). This has led many companies to proactively engage professional bodies or specialist organizations to review and calculate the CF of dairy products.

This guide was developed at the request of the 46 IDF member countries, which together represent more than 75% of the world's milk production, because it has become evident that the wide range of CF figures resulting from differing methodologies and data inputs is leading to considerable inconsistency. This results in potentially confusing and contradictory messages, which could create a false impression that the sector is failing to actively engage with the issue of climate change. Creating consistency and a clear message regarding CF and the importance of addressing climate change is essential for the reputation of the global dairy sector. Furthermore, it's vital to highlight the high level of sector engagement that is already taking place in relation to climate change, and to identify management practices that will further reduce GHG emissions.

1.2. THE DEVELOPMENT OF THIS GUIDE

This guide was first developed and published in 2010 by the IDF Standing Committee on Environment (SCENV) with active participation of the Food and Agriculture Organization of the United Nations (FAO) and the Sustainable Agriculture Initiative Platform (SAI Platform).

At the launch of the IDF Carbon Footprint guide, it was decided that the guide should be continuously reviewed and revised by the IDF SCENV to reflect evolving science and standards in CF methodology, in addition to sector experiences in using the guide. A questionnaire was circulated to IDF National Committees in 2012 and the resulting valuable feedback was used in the SCENV review and revision process. An updated version of the guide was published in 2015.

In 2020, a second revision of the IDF Guide was initiated, as the importance of assessing using CF in the dairy sector has increased exponentially. The use of CF as a monitoring tool to assess and improve individual farm performance has become far more common, and using CF as a basis for commercial purposes, scope 3 corporate reporting and making (comparative) marketing claims has intensified. However, it is important that comparisons are valid, i.e. similar CF scopes and methodology are used and, when food products are being compared, the nutritional value should also be considered.

A more thorough revision has therefore been undertaken, including the following amendments and updates:

- Identifies an approach, based on current best knowledge, for addressing common LCA challenges when calculating the CF of dairy production and dairy products
- Identifies the key areas in which there is currently ambiguity or differing views on the best approach
- Recommends a practical yet scientific approach that can be inserted into existing or developing methodologies
- Adopts an approach that can be applied equally in any dairy system across the globe and which is valid for all, from smallholder farms through to large-scale industrial operations
- Allows users to identify opportunities for mitigating and reducing CF

The updated guide does not:

Re-create knowledge - where the science is available, references have been provided to support existing knowledge. Where a suitable standard or guidance document is already in existence, this has been used.

1.3. PURPOSE OF THE GUIDE

This guide aims to assist the global dairy sector in its journey to reduce GHG emissions across the value chain. The guidelines have been developed by the IDF for use by both the dairy cattle farming and manufacturing sectors, but also others interested in defining the CF of their production systems and products, using a Life Cycle Assessment (LCA) approach. By implementing this standardized approach, the resulting CF of dairy (products) will become more consistent and comparable across different production systems, regions and products. However, CF comparisons should be executed carefully and resulting claims should be nuanced, rather than simplistic. Comparisons between dairy and non-dairy product CF have become increasingly common, as has the tendency to examine changes in CF over time. We recommend that the IDF standard be used to model the CF of dairy products by any party making comparisons between dairy and other food products, or measuring historical changes in CF due to changes in management practices adopted by the sector. We also recommend that, when comparing food products, similar guidelines, inputs and scopes should be used, aligning with the applicable recommendations within this guidelines. For example, the IDF guidelines recommend including changes in carbon stocks in the assessment, therefore these should also be included in the analysis of the food product's CF with which the comparison is made. However, using the IDF guide does not guarantee objective comparison between dairy and other food products, because only dairy products are within the scope of this guidelines – all other food products are consequently out of scope. We also recommend including nutritional value in the functional unit (FU) of both dairy and non-dairy food products when these are being compared, and to only make cradle-to-grave comparisons (see section 4.3.3).

Notwithstanding previous comments that care should be taken in making direct comparisons between footprints produced using different datasets, by using **fat-and-protein-corrected milk** (FPCM) as the functional unit, i.e. standardized milk composition there is good compatibility in comparisons of milk GHG footprints and the nutrition in that milk from different supply chains. In contrast plant-based beverages that claim to be substitutes for milk do not have a standardized composition and the content of added ingredients including protein can vary markedly. Clegg et al. [1] examined the nutritional composition of 299 "plant-based dairy alternatives" and reported that 136 plant-based beverages had reduced concentrations of key nutrients compared to milk. Moreover, for milk to be labelled "milk", many countries have minimum content requirements for key nutrients such as protein or milk solids (MS), for example the standards set in the EU, US, Australia and New Zealand [2,3,4]

This guideline is specifically designed for dairy cattle production and associated product manufacturing, if no alternative approach is identified, the guideline could be applied to other ruminant dairy species (e.g. water buffalo, sheep and goat) to provide an indication of their CF. However, the guide is ***not*** designed to assess the CF of mixed farming systems, e.g. a farm that has a dairy and a pig herd, or a dairy herd and a separate arable cropping operation. This guide sets requirements on minimum standards for CF, yet does not determine requirements for making claims or publishing peer-reviewed papers and does not provide a legal basis. This guide can only make a recommendation to other standards, guidance documents, review panels, accounting and legal bodies to use this guide and its requirements as a reference.

The aim of this guide is to support the dairy sector in mitigating GHG emissions to reduce its potential impact on global climate change. Using this methodology enables:

- Reporting (corporate or product) of GHG emissions from all life cycle stages, i.e. both farming and manufacturing operations within the dairy value chain.
- Monitoring of GHG emissions to demonstrate progress achieved over time.
- Identification of GHG hotspots to focus mitigation actions.
- Determining the impact of different GHG emissions mitigation options.
- Quantifying of the CF of dairy products throughout the life cycle, and communication about CF performance of dairy products to customers and consumers.
- Comparison of CF between dairy and other food products, while including, where appropriate, their nutritional value.

1.4. FUTURE REVIEWS AND ENHANCEMENTS

The environmental impact of food production systems and use of LCA to assess CF is an area of rapidly evolving science and knowledge. The IDF is committed to continually reviewing new science and standards in the field of LCA and CF calculation, in addition to incorporating practical experiences gained by members of the dairy sector using the guide. Relevant outcomes are incorporated into existing guidelines and members informed of advances in specific topics.

The IDF will continue to liaise closely with other organizations working in related fields, with the aim of sharing information, increasing consistency of approach and remaining at the cutting edge of scientific developments.

This guide focuses mainly on CF, but there are other important environmental impact categories that are commonly included in LCA, such as water use, toxicity, eutrophication, acidification, land use and biodiversity. Environmental footprinting (LCA for multiple impact categories) is briefly discussed in section 6.2. However, the available literature relating to many impact categories, such as biodiversity and toxicity, are still evolving, therefore guidance on how to broaden the scope to include a greater number of impact categories will be investigated in following guide updates, or complimentary guidance will be developed. As an example, in 2017, IDF published the LCA guide to Water Footprint methodology for the dairy sector, intended to reach better understanding of water footprint assessment within the dairy sector [5]. The report provided transparent guidelines regarding a dairy product's water profile throughout its life cycle to allow monitoring, quantification and evaluation of the potential environmental impacts related to water use. The IDF water LCA report [5] is compatible with the ISO standard on water footprinting (ISO 14046) [6], the LEAP guidelines for water use that cover all livestock sectors [7] as well as this IDF guide on common CF methodology.

How to account for the nutritional value of foods in a LCA is an area where the science is still evolving. A considerable amount of work is on-going and it is intended that this aspect of CF assessment will be incorporated in the next update of the IDF CF guidelines. Other issues that have been discussed during the 2020 review of the IDF guidelines include the question of how to deal with allocation of manure off-farm. Currently, manure does not have an assigned CF, i.e. there is a cut-off at the farm gate which results in manure being CF-'free' for crop producers, though emissions from application and field use still have to be accounted for. Furthermore, a great deal of debate related to dealing with animal transfers between farms, and assessing the CF of farms with increasing herd sizes has been a challenge. This has been addressed to some extent in the updated version of the guide, but it will be discussed further in future versions. Capital goods and use of animal medicines are two areas where there is insufficient data to include them in LCA. These omissions would be expected to have minor impacts on the result, but from a consistency perspective it would be desirable to have better data on this. Finally, an area of intense scientific focus yet lack of clarity about how to include in LCA, is carbon sequestration. The present update of the IDF guide proposes to include sequestration in the CF analysis, as it can be an important mitigation potential for the dairy sector but it must be reported separately. IDF is also involved in work on developing methodologies on carbon sequestration, and there should be more guidance on how to incorporate carbon sequestration into LCA in a near future. Furthermore, in IDF there are currently two additional Action Teams (AT) working on topics that relate to this guide: an AT developing a framework for assessing ecosystems services, and an AT assessing the opportunities for including nutritional value in environmental assessments. A separate IDF Bulletin may be prepared that provides more detailed information on the use of feed additives and other mitigation technologies, and how these fit within the LCA framework, once a number of these technologies move into widespread commercial use.

2

THE BASICS OF LCA AND CF

2.1. WHAT YOU NEED BEFORE STARTING

As this guide refers to several previously published standards, it would be useful to make sure you have these documents at hand before starting your CF study. The links to the various different documents can be found in Chapter 9 - References. If you have no previous experience in LCA or CF, it may be useful to first read the ISO 14044 and 14067 standards [25,26]. The requirements and guidance for completing a GHG inventory are detailed within the following chapters, including, where appropriate, references to other published guides and standards. To ensure that the IDF recommendations comply with the GHG Protocol Product Standard [27], the term ***shall*** is used in this standard to indicate what is required in order for a GHG inventory, whereas the term ***should*** is used to indicate a recommendation, but not a requirement, and ***may*** indicates an option that is permissible or allowable. Within the guidance sections, the term ***required*** is used to refer to requirements in the standard, whereas ***needs***, ***can***, or ***cannot*** are used to provide guidance on implementing a requirement or to indicate when an action is or is not possible.

2.2. DEFINITION OF A CF

A CF is based on LCA methodology, which was originally used to analyze industrial process chains but has been adapted over the past 20-30 years to assess the environmental impacts of agriculture, including dairy production. An LCA analysis systemically accounts for all inputs and outputs for a specific product or production system across a specified system boundary, e.g. a dairy farm, dairy processing plant or the entire dairy production system. The system boundary is largely dependent on the goal of the study. A CF only accounts for the GHG emissions associated with the product system, but other environmental impacts are commonly included when doing a full LCA (e.g. water use, land use, toxicity, eutrophication or biodiversity). In contrast to a full LCA, the decision to calculate the CF of a product is a conscious decision to focus on climate change as the only environmental indicator

Within the CF, GHG are gases for which the Intergovernmental Panel on Climate Change (IPCC; [8]) has defined a global warming potential (GWP) co-efficient. Each GHG is expressed in terms of its potential to cause global warming by comparison to carbon dioxide (CO2) as the reference gas and thereby measured in CO2 equivalents (CO2-eq or CO2e). The main agricultural GHG are CO2, nitrous oxide (N2O) and methane (CH4). This guidance follows ISO 14067 [26] to use GWP over a 100-year time perspective and to include climate-carbon feedbacks.

The CF is the sum of the impact of all GHG emitted throughout the life cycle of a product within a set of system boundaries, in a specific application and in relation to a defined quantity of a specified product. For example, the CF of one litre of semi-skimmed (2% fat) milk is obtained by calculating and summing all GHG per production unit emitted during all life cycle stages of the product from cradle (the production of production resources) to grave (the consumed and waste-treated product).

The reference unit that denotes the useful output is known as the functional unit (FU) and has a defined quantity and quality, for example a litre of fresh milk of a defined fat and protein content, in a defined packaging type.

The application of LCA to agricultural systems is often complex because, in addition to the main product (e.g. milk), there are usually co-products involved, such as meat, manure or energy. Dairy cattle feed is often derived from crops such as soy, which have oil as a co-product. This requires appropriate partitioning of environmental impacts and resources to each product on the basis of an allocation rule, which can be based on different criteria such as economic value, product properties or system expansion (see section 5.4.).

2.3. THE CHALLENGES OF CF

There are many challenges in calculating a CF, and the analysis for a dairy product is no exception. To date, there have been over 4800 peer-reviewed studies investigating and evaluating CF from dairy [9–19]. However, comparison between these studies is difficult because of methodological differences in, for example, system boundaries, allocation methodology or emission factors. It may also be difficult to identify where meaningful reductions in GHG emissions can be made when differences in results can depend more on the methodological differences than real differences between production systems or management practices [20–22].

The CF for milk and other dairy products is dominated by the dairy farm stage of production, where three-quarters or more of GHG emissions occur [23]. It is therefore crucial to consider the variables in raw (on-farm) milk production that can significantly affect the CF result, for example, herd dynamics and feed composition. For comparison at the level of consumer products, it is also crucial to develop a common approach for allocating the environmental burden from raw milk production between products such as milk, cream, cheese and butter, irrespective of the farm, system, country or region.

2.4. EXISTING INTERNATIONAL STANDARDS AND GUIDANCE

From the outset, the IDF committed to reviewing and aligning with existing standardization work and to collaborate with organizations that were already involved in improving the standardization of LCA methodology. As emphasized in the Introduction, where a suitable standard or guidance document is already in existence, this has been used within these guidelines. Calculation of the CF of a product using LCA methodology should be initially based on the ISO 14000 series, specifically ISO 14040 [24], ISO 14044 [25] and ISO 14067 [26], however, there are multiple standards and guidance documents to take into account when calculating a dairy CF.

As shown in Figure 1, existing CF guidelines can be split into three types:

1. General CF Guidelines such as ISO [25,26], GHG Protocol [27], the general PEF guidance [28] and PAS 2050 [29].
2. Dairy-specific guidelines such as this IDF guide, the dairy PEFCR [30], the LEAP (large ruminant) guidelines [31] and EPD dairy [32].
3. Guidance on specific parts of the CF such as IPCC AR6 [33], other GWP and emission factors for agriculture and the C-Sequ guidance on carbon sequestration [34].

Where relevant, we have checked alignment of these guidance documents with the content of this guide or we refer to using these guidance documents in specific chapters of this IDF Guide.

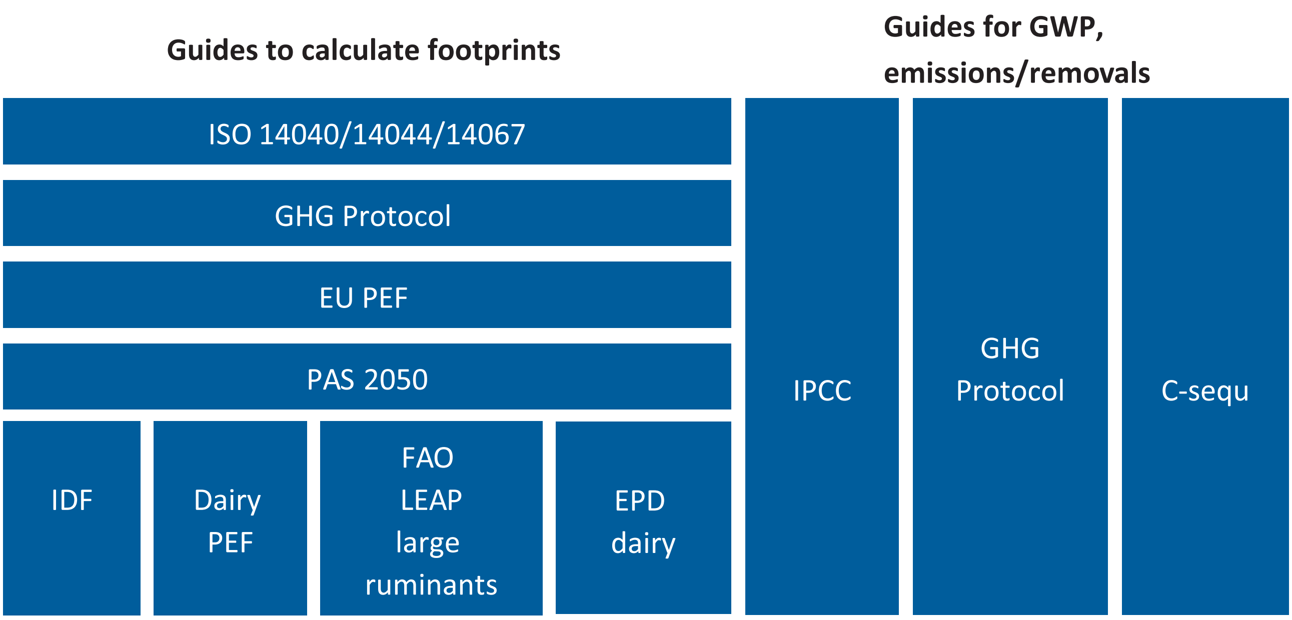

Figure 1. Overview of existing guidelines relevant to LCA or to the calculation of the CF of dairy products.

The overview shown in Figure 1 is not claiming to be exhaustive. For example, the US dairy sector has guides for GHG inventories at the corporate level [35, 36], which are based on the GHG Protocol [27], but it do not make any recommendations on how to quantify the CF of a product (for example, it does not address how to allocate emissions between products) and therefore has not been added to the overview above.

2.4.1. The ISO 14000 series, encompassing ISO 14040, 14044 and 14067

The ISO LCA documents are useful for understanding and applying LCA methodology and its ethical behavioral rules. They do not provide any specific formulas, datasets or technical guidance, but set the ethical framework for how to do an LCA and therefore are very useful background reading for those who are new to LCA. More details on the individual ISO documents follow.

ISO 14040: 2006 'Environmental management - Life cycle assessment - Principles and framework' [24] describes the principles and framework for LCA including: the goal and scope definition of the LCA; the life cycle inventory analysis (LCI) phase; the life cycle impact assessment (LCIA) phase; the life cycle interpretation phase; reporting and critical review of the LCA; limitations of the LCA; relationship between the LCA phases; and conditions for use of value choices and optional elements. It does not describe the LCA technique in detail, nor does it specify methodologies for the individual phases of the LCA.

ISO 14044:2006 'Environmental management - Life cycle assessment - Requirements and guidelines' [25] provides detailed guidance on the four phases of an LCA study: the goal and scope definition phase; the inventory analysis phase; the impact assessment phase; and the interpretation phase. It also gives guidance on how to report results, how to make comparative assertions and how to execute a critical (or ISO) review. An ISO review is a third-party expert evaluation of your LCA study and is particularly suitable when results of a study are to be externally communicated or claimed.

ISO 14067:2018 'Greenhouse Gases - Carbon footprint of products - Requirements and guidelines for quantification' [26]. This document specifies principles, requirements and guidelines for the quantification and reporting of the CF of a product.

Besides these three standards there are other ISO standards that are relevant to some extent. These include ISO 14021 [37], which is useful when making environmental claims and using ecolabels; and ISO 14064 [38], which is useful for reporting organizational footprints.

2.4.2. GHG Protocol of the WRI and WBCSD

The Greenhouse Gas Protocol (GHG Protocol; [27]) is the most widely used international accounting tool, which allows businesses to understand, quantify and manage GHG emissions. It is a nearly 20 year-long partnership between the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) and brings together stakeholders from business, government, non-governmental organizations and academic institutes to develop internationally accepted GHG accounting and reporting standards. The GHG Protocol [27] provides the methodology for nearly every GHG standard and programme in the world, from the International Standards Organisation to the Climate Registry, as well as hundreds of GHG inventories prepared by individual companies. The GHG Protocol [27] offers a number of standards, guidance documents and tools to use in GHG reporting, and is not limited just to CF, but to any type of GHG reporting and accounting. For dairy CF purposes the following standards and guidance documents are most relevant:

1. The Product Life Cycle Accounting and Reporting Standard [39]
2. GHG Protocol Agricultural Guidance [40]
3. Land Sector and Removals Guidance (under development; [41])

2.4.3. PAS 2050:2011 and PAS 2050 dairy

The British Standards Institute, in collaboration with the UK's Department for Environment, Food and Rural Affairs (DEFRA) and the Carbon Trust, has produced a Publicly Available Specification (PAS) 2050 'Specification for the assessment of the life cycle GHG emissions of goods and services' [29] This British pre-standard sets out an initial comprehensive proposal for the methodology of the product CF. The original version of the PAS was published in October 2008 and was largely based on the LCA standard ISO 14040 [24]. The current PAS 2050 [29] (which was updated in 2011) refers to the ISO standard a number of times, but also deviates significantly from it in some areas. PAS 2050 [29] thus represents the first attempt to create a standardized basis for the assessment of GHG emissions arising throughout the product CF.

2.4.4. PEF and PEFCR guidance documents

The Product Environmental Footprint (PEF) is a European standard developed by the European Commission in collaboration with EU industry stakeholders [28]. It aims to set generic (PEF Guidance; [28]) and sector-specific PEF Category Rules (PEFCRs) to apply LCA in the European Union. Two relevant PEFCRs exist for dairy CF, one for dairy [30] and one for feed [42]. The PEF Guide [28] is relatively prescriptive as it aims as much as possible to standardize LCA calculation, and focuses on standardizing green claims in the EU market. The PEFCR Dairy [30] was developed by a Technical Secretariat composed of different industry representatives and was coordinated by the European Dairy Association (EDA). The PEFCR Dairy [30] prescribes the use of specific methods, datasets and default factors to calculate cradle-to-grave (mandatory) dairy LCA for five different dairy product categories (liquid milk, butter, cheese, fermented milk products and dairy ingredients), and includes 18 different environmental impact categories. When applying the PEFCR you are obliged to use a specific set of PEF datasets unless you have primary data available. The PEFCR Dairy [30] can be a useful document when you lack primary data; when several default values are provided; or if you want to make environmental claims in the EU. The

European Commission is currently preparing several legislative proposals with the PEF [28] at their core.

2.4.5. FAO LEAP

The Livestock Environmental Assessment and Performance (LEAP) Partnership is a multi-stakeholder initiative that seeks to improve the environmental sustainability of the livestock sector through harmonized methods, metrics, and datasets. Globally, LEAP leads a coordinated initiative to accelerate the sustainable development of livestock supply chains and to support coherent climate actions, while contributing to the achievement of the 2030 Agenda for Sustainable Development and the Paris Agreement.

The LEAP has published a number of guidelines on sustainable livestock production, of which the following are most relevant to dairy CF:

- Environmental performance of large ruminant supply chains [31]
- Environmental performance of animal feeds supply chains [43]
- Measuring and modelling soil carbon stocks and stock changes in livestock production systems [44]
- Environmental performance of feed additives in livestock supply chains. Guidelines for assessment [45]
- CH_4 emissions in agriculture – sources, quantification, mitigation and metrics [46]

There is also the LEAP guide on nutrient flows and associated environmental impacts in livestock supply chains [47]. This guidance is less relevant to CF but is relevant for dairy LCA studies that include eutrophication as an impact category.

2.4.6. EPD PCR dairy

The International Environmental Product Declaration (EPD®) System is a global programme for environmental declarations. These present transparent, verified and comparable information about the life cycle environmental impact of products and services. The first step in creating an EPD is defining the product, using the appropriate Product Category Rules (PCR). These are specific rules and requirements verified by an independent, third-party panel – for example, a LCI for the LCA must be verified and from reliable sources (for example, from a manufacturing facility). There is a PCR for dairy products [32] within the EPD system.

2.4.7. IPCC

The IPCC is the United Nations body charged with assessing the science related to climate change. The IPCC was created to provide policymakers with regular scientific assessments on climate change, its implications and potential future risks, as well as to put forward adaptation and mitigation options. Through its assessments, the IPCC determines the state of knowledge on climate change; identifying where there is agreement in the scientific community on topics related to climate change; and where further research is needed. The reports are drafted and reviewed in several stages, thus guaranteeing objectivity and transparency. The IPCC does not conduct its own research and its reports are neutral, policy-relevant but not policy-prescriptive. The assessment reports are a key input into the international negotiations to tackle climate change. The most relevant IPCC reports for dairy CF are:

- For GWP coefficients for different GHG: Sixth Assessment report: AR6 (or newer versions once available; [33])
- For emission factors for agriculture and land use change: 2006 IPCC Guidelines For National GHG Inventories [48]
- For emission factors for agriculture and land use change: Refinement to the 2006 IPCC Guidelines for National GHG Inventories; Volume 4 Agriculture, Forestry and Other Land Use [8]
- For emission factors for fuels: 2012 IPCC Emission Factor Database (EFDB) [49]

2.4.8. C-sequ

The C-Sequ methodology [34] is a science-based approach to quantifying both above and below-ground carbon sequestration (in addition to potential emissions) through LCA and CF studies. The method was funded by a number of dairy and beef sector organizations who required a robust and science- based approach to understanding the positive impact their value chains could have through proactive actions by farmers to promote sequestration opportunities. Both the IDF and the Global Round Table for Sustainable Beef (GRSB) were invited into the project as Knowledge Partners. The project began in 2018 and underwent numerous reviews, including public consultation and piloting, benefitting from the input of a large number of global LCA and soil academics. The sustainability consultancy Quantis was contracted as the ‘Technical Lead’ for the project and developed the methodology based on the input of leading specialists who contributed to the transparent development process. The initial aim of the project was to develop a scientifically robust approach that can be easily applied in CF. Ultimately the desired outcome is to assist knowledge development in this complex topic and the provision of advice to farmers on increasing carbon sequestration as a viable approach to minimizing emissions and mitigating climate change.

2.4.9. Review of alignment of standards and guidance documents with this guide

As part of the renewal of this guide, the IDF LCA AT reviewed the alignment of the IDF Guide regarding major CF methodological topics with the following other standards and guidance documents: ISO (14067 [26] and 14044 [25]), PEF (General guidance [28], PEFCR dairy [30], PEFCR feed [42]), LEAP (large ruminants [31], feed [43] and nitrogen [47]), GHG

Protocol [27], PAS 2050 [29], and EPD PCR dairy [32]. The conclusions from this review have been used to improve the IDF guide, for example, if existing standards and guidance were not aligned or were unclear. The review also served in making conscious decisions as to whether the IDF LCA Action Team supported the existing recommendations. Subsequent conscious decisions could be made whether to align, to further elaborate, or whether to deviate from existing standards and guidance documents.

The main conclusions from this review were as follows:

- Purpose: The purpose of different standards and guidance documents varies, but the main focus is on product LCA or CF. Some standards and guidance documents have broader scope, such as corporate reporting or organizational LCA. In the present IDF guide it was decided to broaden the purpose to cover the whole value chain and to give some guidance on how to incorporate the nutritional value of dairy products.
- CF versus environmental footprint: The PEF [28] is the most detailed standard or guidance document with regards to inclusion of other environmental impacts. We decided to keep the main focus on CF in the present IDF guide, but added a paragraph (see section 6.2.) pointing out opportunities to use this guide for other impact categories.
- Scope: The scope of different standards and guidance documents varies. The four main scopes identified and referred to in this guide are: 1) cradle-to-farm gate; 2) cradle-to-factory gate; 3) cradle-to-purchase; and 4) cradle-to-grave. We decided to broaden the scope of this guide from factory gate to end of life and give guidance on when to use which guide and how to set the system boundaries.
- Attributional LCA versus consequential LCA: ISO does not specify the difference between attributional and consequential LCA, whereas all other standards and guidance documents recommend using attributional LCA. We decided to maintain the attributional LCA recommendation in this guide, but gave some context upon when using consequential LCA might be useful.
- Choice of FU: The typical recommended FU is mass-based, e.g. kg of FPCM, although PEFCR dairy [30] proposes to use mass of dry matter (DM) for cheese CF analysis. Nutritional value is not explicitly recommended by any of the standards or guidance documents[1]. For this IDF guide, we decided to discuss both the different possible FU and which one is recommended in which situation. We also recommend how to include nutritional value when food products are compared, though we acknowledge there is not yet consensus on how this should be executed.
- Allocation: Not all standards and guidelines give recommendations on allocation for specific products. For example, ISO only sets the behavioural rules for allocation. For dairy prodiucts, allocation is aligned between the different guidelines. For feed economic allocation is recommended (IDF, PEFCR feed [42], LEAP feed [43]); and for milk production at the farm-level, biophysical allocation is recommended between

1 Though ISO 14040 [24] states: "*The primary purpose of a functional unit is to provide a reference to which the inputs and outputs are related. This reference is necessary to ensure comparability of LCA results.*" Hence, a mass based FU might not ensure comparability of LCA results, and is thus not in line with ISO.

milk and meat (IDF, PEFCR dairy [30], LEAP large ruminants [31], EPD PCR dairy [32]). For manure allocation, most guides (IDF, PEFCR dairy [30], LEAP large ruminants [31]) propose a cut-off if manure is considered a residue from dairy production and economic allocation if it is considered a co-product generating a revenue, while some guides (EPD PCR dairy) do not provide any recommendations for the allocation of manure. For dairy co-products in the dairy site, allocation based on the mass of DM or MS is recommended (IDF, PEFCR dairy [30], LEAP large ruminants [31], EPD PCR dairy [32]).

- Double counting: Double counting is not addressed in detail, but is usually mentioned as an issue to be avoided when biogenic and fossil energy use, or system expansion in energy use are discussed. Further guidance is needed regarding inconsistencies in allocation of biogenic versus fossil energy use and generation in the dairy chain. Further guidance on avoiding double counting is added in the present guide, with a focus on energy use.
- Global Warming Potential (GWP): All standards and guidance documents referred to use a 100-year timeframe for GWP, i.e. GWP_{100}. With regard to climate-carbon feedback (i.e. the effect global warming that has on the carbon cycle) standards and guidance documents are contradictory. PEF [28] and ISO 14067 [26] recommend using GWP that include climate carbon feedback, whereas the values provided by the GHG Protocol [27] refers to GWP excluding climate carbon feedback. The present IDF guide added specific guidance on using the newest (currently AR6 [33]) IPCC GWP on a 100-year basis including carbon feedback and specified the values in this guide.
- Biogenic CH_4 emission: Most standards and guidance documents propose reporting biogenic emissions separately, but only few specifically address the need to use a different GWP for biogenic CH_4. A specific recommendation on the numerical value to use as the GWP for biogenic CH_4 is only specified in the PEF [28] guidance document (i.e. GWP for fossil CH_4 and GWP for biogenic CH_4), but this value is not aligned with the IPCC's AR5 [50] or AR6 [33]. The present guide recommend the AR6 [33], GWP factor for biogenic CH_4.
- Direct (dLUC) versus indirect land use change (iLUC): dLUC is recommended in most standards and guidance documents. Typically iLUC is explicitly excluded or recommended to be considered for inclusion, but documented separately. The present guide recommends to include dLUC, but report it separately and include iLUC in the sensitivity analysis.
- Carbon sequestration: Some standards and guidance documents allow the inclusion of carbon sequestration, provided enough scientific proof is available to support it, but recommend that it be reported separately. However, these standards and guidance documents lack any description of how to determine the scientific proof needed for support, or how to measure, model and incorporate carbon sequestration in a CF. In this guide we recommend using the C-Sequ guidelines [34] for inclusion of carbon sequestration in CF, but to report it separately.
- Peat soil emissions: CO_2 and N_2O emissions from peat soils are either prescribed from inclusion or not mentioned in standards and guidance documents. ISO and PEF [28] recommend reporting CO_2 emissions from peat soils as fossil (not biogenic) CO_2,

but in the PEF, discussions are ongoing and might change this recommendation to biogenic emissions. In this guide we recommend including CO_2 and N_2O emissions from peat soils.

3 THE STEPS IN A CF ASSESSMENT

3.1. SUMMARY OF THE STEPS

The steps involved in undertaking an CF are summarized in Figure 2 and briefly discussed in the following sections, as well as further being elaborated on in the following chapters.

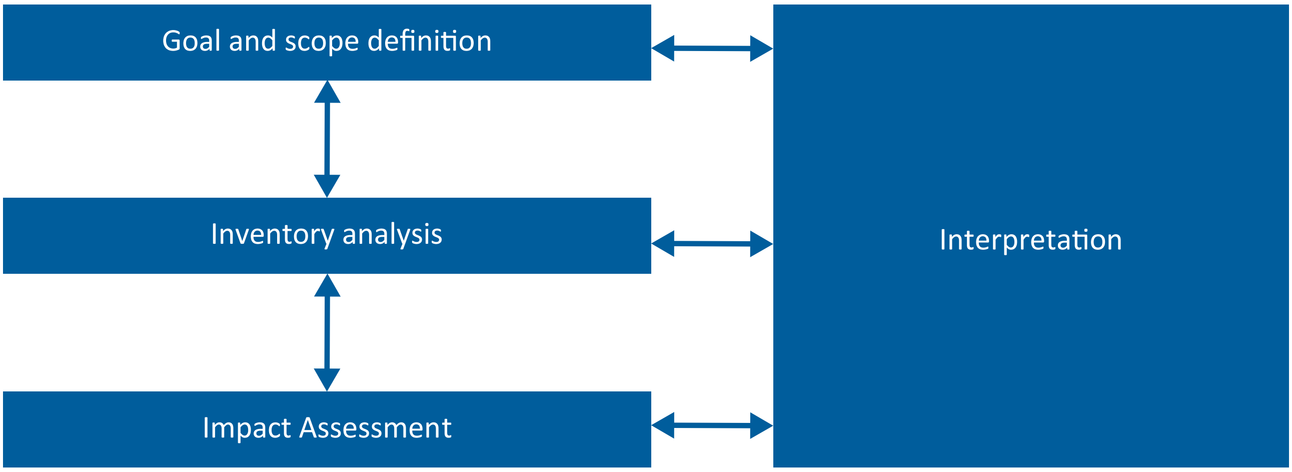

Figure 2. The four steps for conducting an LCA or a CF assessment (based on ISO 14040 [24]).

3.2. STEP 1 – GOAL AND SCOPE DEFINITION

The first step (as shown in Figure 2) of an LCA consists of identifying the goal of the project, i.e. what is the research question to be answered? Establishing the goal at the outset of the analysis is essential to ensure that the aim of the CF is clear; that all parts of the process and product life cycle are included; and that the project does not increase in size, lack data further in the process, or start to expand into areas that are not relevant to the product in question. Based on the goal, the FU that will be the subject of the analysis (e.g. kg of yogurt or tonnes of butter), and all the life cycle stages that need to be included can be identified. Within this stage it is also important to decide which of two possible LCA methodological approaches will be adopted: attributional or consequential. As mentioned in the Introduction, the attributional approach is recommended and described in this guide. The scope setting of the study should also be determined in this phase, depending on the goal of the project. Scope setting includes the decision whether a cradle-to-farm gate, cradle-to-factory gate, cradle-to-purchase or cradle-to-grave study should be done. This also determines in detail which unit processes are within or excluded from in the CF.

These processes allow the system boundaries to be set clearly and in detail, and choices made are motivated based on the end goal.

3.3. STEP 2 – INVENTORY ANALYSIS (DATA COLLECTION)

This phase is typically the most time-consuming step, and involves data collection and modelling of the product's (e.g. liquid milk or cheese) production system. Data collection includes also the referencing, documentation, description and verification of data. All data related to processes within the study boundaries must be verified to ensure that data outputs from the LCA are accurate, defensible, relevant to the context (e.g. regionalized) and evidence-based. The use of assumptions should be minimized at all times. The data must be related back and expressed according to the FU, e.g. kg of FPCM or tonne of cheese. Product mass balances should be complete and consider food losses. The proposed minimum technical data required to calculate GHG emissions and removals are listed in Appendix 10.9.

3.4. STEP 3 – IMPACT ASSESSMENT (CALCULATING THE CF)

The third step involves calculating the CF using the information gathered in the (second) inventory step. All GHG emissions associated with the production processes are converted into mass (g, kg or t) of CO_2e according to the latest IPCC GWP and summed to obtain the total CO_2e, which can then be divided by the total production yield to give the footprint per FU (e.g. kg CO_2e per kg cheese).

3.5. STEP 4 – INTERPRETATION

The fourth step is iterative, meaning that it interprets the information from Steps 1-3. After Step 3, it is therefore important that the information is presented correctly and accurately in order for accurate conclusions to be drawn and benchmarking to occur. The report should include sufficient information to understand the effect of methodology and data choices on the results and the uncertainty within the results, and should be replicated accordingly. To determine the reliability of the results an uncertainty or sensitivity analysis can be done to determine the effect of variability of input data, emission factors and calculation methods on the resulting CF. Depending on the foreseen use of the study, it can be submitted for verification, which may include submitting it for peer-reviewed publication in a scientific journal; executing an ISO (14044) review [25]; having the activity data and method verified by an accountant; or getting the CF verified by a recognized third party certification verifier to determine how many carbon credits would need to be obtained to certify the product for carbon neutrality.

4 GOAL AND SCOPE DEFINITION

As would be the case with any scientific process or calculation, it is important to be clear about the goal of the CF. Knowledge of the goal – in terms of what is being measured (i.e. the CF per FU); why it is being measured; the intended audience; and whether the results are intended for use in for internal business literature, or for publicly available comparisons; will help identify the data, methodology and processes needed to conduct the analysis.

4.1. LCA METHODOLOGY: ATTRIBUTIONAL AND CONSEQUENTIAL

The purpose of these guidelines is to provide an **attributional** approach to calculating the CF of products from dairy farming and manufacturing.

Attributional LCAs focus on describing the environmentally relevant physical flows to and from the product or process; this is in contrast to **consequential** assessments, which describe how relevant environmental flows change in response to, for example, changes in demand. Consequential LCA can also be useful when evaluating reduction or mitigation strategies, because a mitigation strategy (e.g. increasing milk yield) that has a beneficial effect on the GHG emissions of a milk production system might have a negative effect elsewhere, for instance on the emissions of a beef production system. This guide does not advise against using consequential LCA, but equally, guidance is not provided as to how to apply it. When using consequential LCA, care should be taken to avoid double counting as effects outside the value chain are also included in the assessment. This means that using consequential LCA is not fit for the purpose of corporate reporting on GHG emissions or product claims that include offsetting of emissions. For more detail on the use of attributional and consequential LCA modelling approaches, see Appendix 16 of the FAO LEAP guidance [31].

4.2. DEFINING THE PROCESS

Once the goal is defined, it can be determined which life cycle stages (or processes) should be included in the CF. It is a good idea to draw a flow chart to identify what processes should be included (see example of flow chart of a dairy production value chain in Appendix 10.1). The life cycle stages in dairy CF are typically the production of farm resources (e.g. feed), dairy farming (e.g. cattle husbandry and milk production), milk collection (transport), dairy processing, distribution, retail, consumer use and end of life (Figure 3). Often the goal is to compare different dairy products, for example, two different food items (e.g. old and young cheese) or a new product variety (yoghurt with strawberries from the Netherlands versus yoghurt with strawberries from Spain). Alternatively, the goal may be to compare the effect of processing variations on CF, for example different farms, different dairy processing units or different packaging. It should be reiterated that this guide is intended to facilitate calculation of a dairy CF only and should not be used to calculate the CF of whole-operation mixed farms, e.g. a dairy and pig herd or a dairy herd and separate arable operation; nor for factories or other processing operations that produce other non-dairy products (e.g. meat products or baked goods).

Depending on the scope, in some cases life cycle stages may be omitted from the CF study. This should only be done if it is certain that the GHG emissions from the omitted life cycle stages will not be affected by the comparison. When claims are to be made on GHG reductions in only part of the life cycle (for example packaging), care must be taken as partial claims can be perceived as misleading and the claim forbidden by legal authorities. When reporting dairy products CF, the included and excluded life cycle stages should be reported transparently and in detail. Examples would include whether transport after farm, factory or retail gate is included; for which life cycle stages waste is included; and whether food preparation and consumption are included in the analysis.

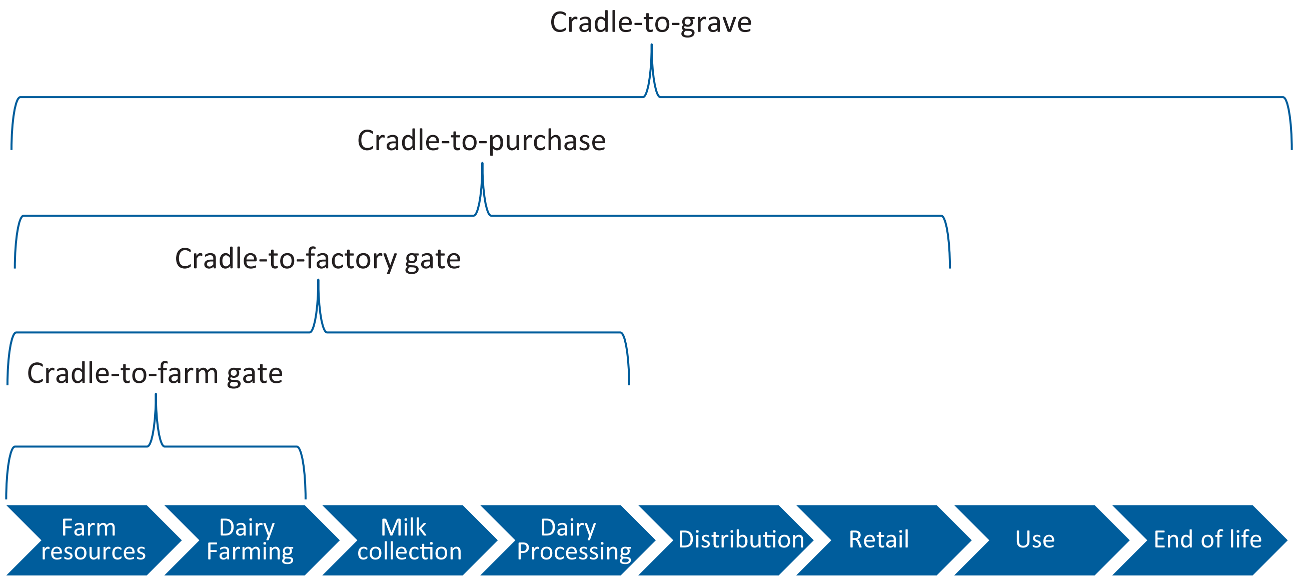

Figure 3. The eight generic life cycle stages for dairy production.

Some guidance **follows up**on defining the scope of the life cycle and how to set the system boundaries.

- Cradle-to-farm gate:
- For measuring progress on farm
- For comparing farms, farming systems, co-operatives, regions and countries

When executing a cradle-to-farm gate study, we recommend explicitly stating whether transport of the raw milk to the dairy processor is included or excluded. However, we recommend excluding transport after the farm gate for consistency purposes, not least because some dairy chains may not have distribution to a processor. This also alleviates issues when the dairy product is consumed, processed or sold on the farm.

Cradle-to-factory gate:

- For measuring progress of production and processing of dairy products and ingredients
- For comparing products, processing systems, companies, regions and countries
- For comparing product innovations
- For business-to-business communication on the CF performance of products

When executing a cradle-to-factory gate study **for** business-to-business reporting we recommend excluding transport of the dairy product after the factory gate for both consistency and practical reasons. This reduces comparison issues if products with different routes to market are compared, or when the same product is sold to many different customers, with each different logistics. However, if a dry and liquid variety of a product are compared (e.g. liquid milk and milk powder), then logistics after the factory gate should be accounted for when advising customers on sourcing, because the GHG emissions from drying a product may have an additional impact, but GHG from transport may be greater for the liquid product variety, because of the proportion of water weight. The eventual result of which product variety has the lowest CF will also depends on the transport distance and means of transport between dairy producer and customer.

It is also possible to apply and refer to these guidelines when calculating the CF of different processes or location within the system boundaries. For example, if a dairy is planned to be enlarged or re-built or changes are scheduled to dairy product processing, CF calculations can be performed on a single part of the processing system. However, partial CF analyses should not be used to compare and communicate outside the business regarding the environmental impact of the dairy product, but rather to justify the innovation or investment with regards to climate change. For any innovation or investment CF study, trade-offs with other parts of the life cycle should also be incorporated, for example, if a new process means that greater quantities, different ingredients, or changes in logistics are needed.

Cradle-to-purchase:

- For monitoring and comparing purchase behaviour
- To compare the impact of the entire production chain of dairy products, excluding the impact of consumer use and end of life (from consumption)

Cradle-to-grave:

- To estimate and compare the CF of diets and consumption behaviour, including the impacts of nutritional value and food waste
- For measuring progress in dairy products from a consumer perspective
- For comparing consumer products from different processing systems, brands, companies, regions and countries
- For making claims on products[2]

4.3. THE FU

Using a consistent FU helps to compare results between different studies, yet different FU may be used depend on the purpose of the study. In all CF studies, the FU and corresponding scope and boundaries should be clearly explained, as this can facilitate comparability of results. It is also useful if the study reports additional information that facilitates recalculation into alternative FU such as dairy product density (mass per volume), DM content and nutritional value. It is also important to state where in the value chain the FU is defined, e.g. if it is one litre of purchased milk or one litre of consumed milk. A variety of FU that may be used for different scopes of CF study are discussed in the next paragraphs.

4.3.1. Cradle-to-farm gate

If a study is conducted with the farm gate as the boundary, the FU is one kilogram (kg) of FPCM (i.e. liquid milk corrected to 4% fat and 3.3.% protein), at the farm gate, in the country in which the analysis is taking place. The choice of the farm gate as the boundary indicates that the product is milk ready to leave the farm, as opposed to the actual milk yield of the animal, hence potential milk losses at the farm level (e.g. milk fed to calves) should be included.

Using FPCM as the basis for farm comparisons assures objective comparison between farms with different breeds or feed regimes. FPCM for dairy cattle and buffalo is calculated by multiplying milk production by the ratio of the energy content of the specific farm or region's milk, to the energy content of standard milk with 4% fat and 3.3% true protein content (see Equation 1), with lactose content at a constant 4.85% of milk volume [51].

$$\textbf{FPCM (kg) = milk production (kg)} \times \textbf{[0.1226}\times\textbf{fat\% + 0.0776}\times\textbf{true protein\% + 0.2534]}$$

Equation 1. Formula for calculating the FU (kg FPCM) for cradle-to-farm gate CF studies

If a different milk composition is needed for the standard milk FU, the energy equation (see Appendix 10.2 for more details) can be used to calculate the new standard milk energy and then used to recalculate the coefficients for the FPCM equation.

2 For commercial claims using cradle-to-grave is recommended in several standards (e.g. ISO 14021 [37])

4.3.2. Cradle-to-dairy factory gate

At this level of analysis, the recommended FU is a mass or volume-based quantity of product, packaged or in bulk at dairy factory gate. It is possible to use a FU based on either fresh weight or DM, depending on the product purpose and whether it needs to be compared with others. If, for example the CF of powdered and liquid lactose need to be compared, it is best to do so on a DM basis. If products are compared that differ in DM content and nutritional composition these differences should be regarded and preferably accounted for in the FU. There may also be a difference in products sold versus produced (e.g. inadequate planning may lead to product waste if not all products produced are sold), which should be specified and accounted for.

4.3.3. Cradle-to-purchase and cradle-to-grave

For the CF calculation of dairy end products, different scopes and FU may be used. First of all the CF can be calculated with different system boundaries:

- Until purchase by the consumer. Emissions after purchase are therefore excluded and the FU is the quantity of product purchased. This excludes home transport, storage and preparation, but includes retail and food waste at retail.
- Until end of life. Emissions for transport, storage, preparation, dish washing and food waste between purchase to consumption are included, as well as waste treatment of the product and packaging. The FU is the quantity of product consumed.

At the consumption stage, food waste and changes in food mass and nutritional value resulting from preparation (e.g. cooking) of food products can be substantial. It is therefore very important to explicitly state which of the two scenarios above applies. The CF of a kg of 'mass purchased' product will be lower than the CF of a kg of 'mass consumed' product because of water and nutrient losses – being unaware of the difference between the two will lead to unfair comparisons. For product claims, comparison of food items and carbon neutrality claims we recommend using "mass consumed" as the FU. This FU results in the most equitable comparison of food items, because nutritional value can be incorporated in the comparison, and as all life cycle stages are included, the assessment is both complete and objective.

The following different FU for dairy products are commonly found within CF studies:

- Size (mass, volume, weight, portion, DM)
- Economic value (different currencies)
- Diet (actual or recommended intake per meal/day/month/year)
- Energy (kcal or MJ)
- Nutritional value of a single component (carbohydrate, total protein or protein quality, fat, fiber, vitamins or minerals)
- Integrated nutritional value score

As previously discussed, the chosen FU depends on the goal of the study. If the study does not aim to compare products then any of the aforementioned FU can be applied. However, if dairy products are compared to other dairy products or to non-dairy products an integrated nutritional value score should be used. If comparisons are made on similar food items the food items may be compared on one or more nutritional aspects, but care should be taken that the comparison is not misleading. Comparisons of diets can be very useful in the dairy context, when determining the impact of different diets (e.g. dairy-free, vegetarian or vegan) in the context of their nutritional value and potential impact on climate change. However, it's important to note that comparing single food items that have an entirely different nutritional functionality does not make sense, as these products cannot be substituted even though they may have comparable NRF scores, e.g. comparing oranges to dairy. Although, both food have nutritional benefits (fibre and vitamin C for oranges; protein, essential fatty acids, calcium and vitamin B12 for dairy) they are complementary rather than interchangeable. It is like comparing an energy-inefficient fan heater with an energy-efficient microwave. Although the microwave is more energy efficient, you wouldn't use it to heat the house!

Currently the NRF 9.3 method is the most widely accepted method for comparing the CF of single food items, particularly dairy products [52]. However, it should be noted that debate on the best integrated nutritional score for LCA is ongoing and is likely to be updated in the next version of this guide. One of the topics under debate is whether negative health aspects of nutrition should be included in the FU or rather as an additional health impact category of the LCA study (i.e. comparable to ecotoxicity). Guidance can be found in Appendix 10.12 on how to calculate and collect data for the calculation of the NRF 9.3 score. If this is not feasible, because, for example, nutritional information is not available, the comparison is still more valid on a DM than on a fresh weight basis. However, making comparative assertion claims comparing on a DM basis is not recommended in this instance. Further work on defining a suitable framework for comparing food items is recommended and several initiatives have already been initiated, including, amongst others, FAO [53] and the IDF.

4.4. SCOPE AND BOUNDARIES FOR DATA COLLECTION

We will now describe data collection for each life cycle stage. For comparability and alignment purposes, it is important that the scope and boundaries of different CF studies are comparable. However, it is also important to continue building the body of knowledge relating to dairy CF, therefore flexibility is present to include emission sources and supply chain resources that have not previously been included. It is recommended which data sources should be included in the CF and which additional data sources could be included. Guidance is also given on data sources that do not have to be included, because their impact has been assessed in the past to have a minor impact on the CF. Nevertheless, specific situations may occur in which these emissions may have a greater impact than anticipated. A threshold of 1% has been established to ensure that very minor sources of life cycle GHG emissions do not require the same detailed treatment as more significant sources [8]. From a practical perspective, if any material or energy flow contributes less than 1% of the total emissions it is considered "*de minimus*" and can be excluded, provided the threshold of accounting for 95% of emissions is met [21]. Obviously it is difficult to know the size of an environmental impact before data have been collected, yet this knowledge may be obtained from earlier CF studies or a simple assumption-based calculation. Data collection should be as complete as possible, but it is always possible that data sources that contribute significantly to the CF have not been quantified, in which case we recommend using the 1% threshold rule. Regardless, it is recommended that you clearly report which emission sources have been included in the CF dairy study and in an annex or appendix, report the contribution of each GHG emission source in as much detail as available. This allows for better comparability and correction of results if studies need to be compared. It should be noted that background LCA datasets are not consistent in including or excluding capital goods. Recommendations on the inclusion or exclusion of capital goods therefore is rather based on practical availability of reliable datasets, rather than on the 1% cutoff rule. Nevertheless, the included and excluded processes and data should be reported and associated choices clearly described.

4.4.1. Farm inputs and resources

Farm inputs and resources used for dairy production should always be included in the CF. These inputs and resources represent any "product" (including energy sources and animals) imported to a dairy farm for the purpose of dairy production, including inputs to produce youngstock for dairy production. The following dairy farm resources need to be included in the CF:

- Supplementary feed for the dairy cattle herd, including feed additives
- Bedding materials
- Fertilisers and soil amendments, including, but not limited to: artificial fertilisers, lime, manure, compost, biochar, manure pellets, plant-based fertilizers, food and feed residues. For purchased manure a cut-off rule applies (see section 5.4.1 10.9 section 5.4.1 on farm allocation), meaning that the upstream impact from manure excretion and storage before the dairy farm gate should typically be excluded from the assessment, but the impacts of manure transport to the dairy farm should be included
- Energy, including both fossil and biogenic fuel, heat and electricity for all dairy-related farm practices. If energy is generated on the dairy farm and is used for dairy farming or other operations within the CF system boundaries, then purchased capital goods, auxiliary materials and imported biomass for energy generation need to be included in the CF. If this is not the case, then these farm imports can be excluded.
- Dairy cattle used as dairy herd replacements

- Any dairy production related activities that take place on other farms, e.g. feed production for the dairy cow replacements and youngstock, or cows kept and maintained (temporarily) outside the dairy farm

For any purchased resource, the life cycle stages from cradle-to-dairy farm gate need to be included in the CF, including but not limited to: mining, harvesting or any other type of sourcing, agriculture, transport, processing and packaging, waste and waste treatment during life cycle stages occurring before the dairy farm gate.

Feed production shall be handled in conformance with the requirements from the PEF (General Guidance [28], PEFCR Dairy [30], PEFCR Feed 42) and FAO LEAP [43] guidance. The recipe for compound or concentrate feeds and the country of origin of each feed material should be specified. Land use change emissions for feed production need to be included, but reported separately.

For logistics, the GHG impact from infrastructure and transport vehicles should be included, in addition to energy consumption for transport. Energy use for sourcing and applying irrigation water should be also be included in the CF. Farm inputs classified as capital goods may be excluded from the CF. However, we recommend the development of better environmental footprinting datasets for capital goods, as this is currently a significant knowledge gap. Impacts from other dairy farm inputs may be excluded, but only if the contribution to the CF is expected to be smaller than 1% (see section 4.4). Examples of these smaller impacts include the production of silage plastics, refrigerants, pesticides and water. Dairy medication and veterinarian services can also be excluded from the CF due to a current lack of reliable datasets, although their impact on the CF and environmental impact is unknown and further research on the GHG impacts of antimicrobials and other animal medicines is warranted.

4.4.2. Dairy farming

The system boundaries for dairy farming are limited to all processes that occur during this system, i.e. all farming activities needed to produce milk, including on-farm feed production, dairy cow and youngstock husbandry, and grazing. Other non-dairy-related agricultural production on dairy farms should be excluded from the dairy CF via process subdivision (see section 5.4.2).

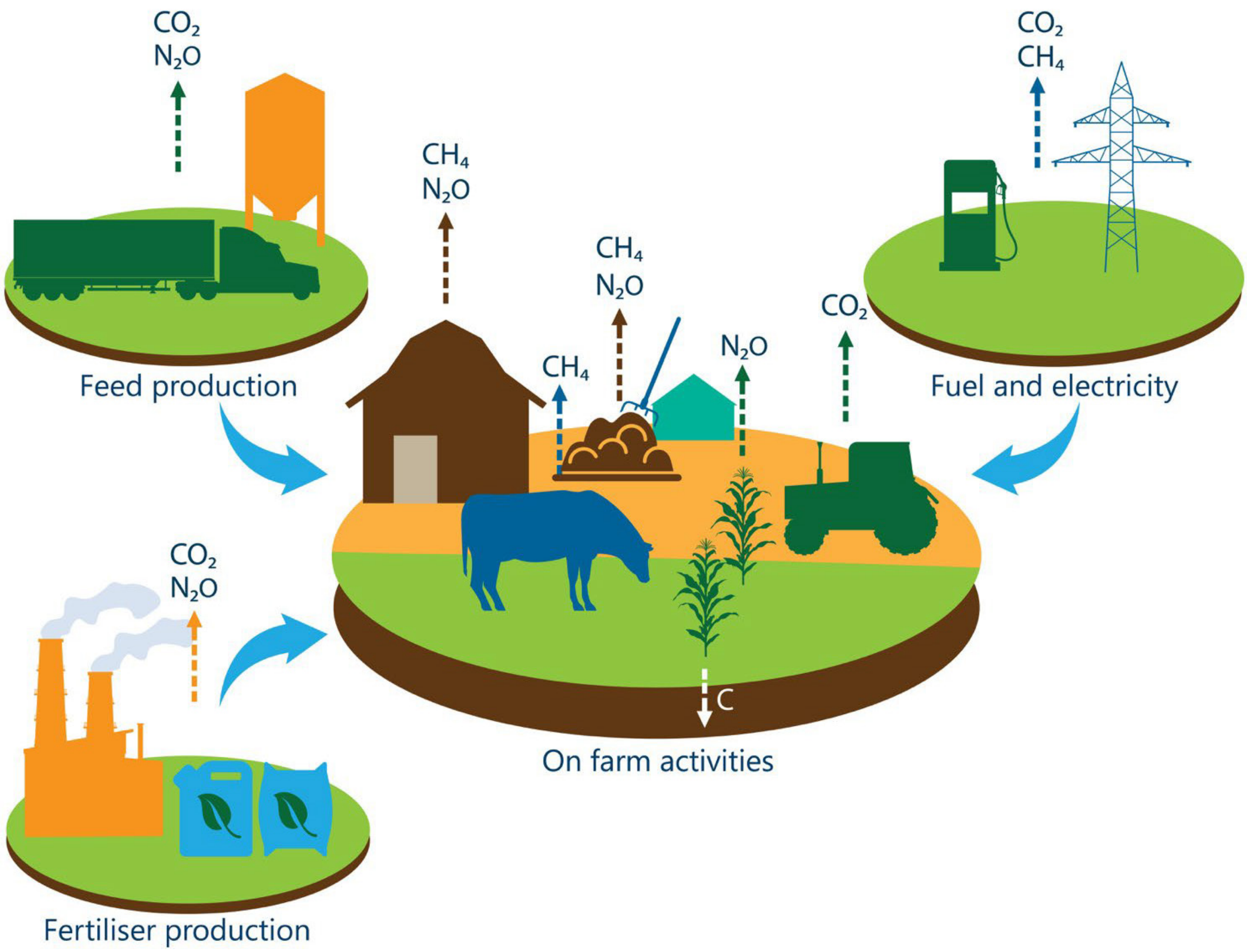

Figure 4. GHG emissions associated with the dairy farm

On-farm GHG emissions that ***should be included*** in the dairy farming CF (as shown in Figure 4):

- All on-farm GHG emissions related to the use of fuels for dairy farming, e.g. natural gas, diesel and other (bio)fuels. Fuel is typically used for fieldwork, grazing management, animal housing and milking. Fossil CO_2 should be included, but CO_2 emissions from combustion of biofuels can be excluded (since there is no net emissions, as the carbon has been sequestrated earlier in the value chain, however emissions from production need to be included as a resource to the dairy farm). Leakage of other GHG emissions from production and use of both biogenic and fossil fuels should be included (e.g. CH_4 from manure digestion and sourcing of natural gas or biogas)
- Enteric CH_4 emission from the dairy cows and replacements/youngstock
- GHG emissions (CH_4 and direct and indirect* N_2O emissions) from manure in cattle housing (including during its storage and treatment) from dairy cows and replacements, including bedding materials
- All GHG emissions from arable land and grassland used to feed the dairy herd. These include, but are not limited to emissions from:

- The application of fertilizers and soil amendments (e.g. direct and indirect[3] N_2O emissions from soil, CO_2 emissions from lime and urea)
- Excreta from dairy cattle and replacements onto pasture (e.g. direct and indirect* N_2O emissions)
- Oxidation and mineralization of peat soils (CO_2 and direct N_2O emissions) and CH_4 emissions from peat soils used for dairy farming
- Harvesting losses and crop residues (direct N_2O emissions)
- Nitrogen in mineral soils (direct and indirect N_2O emissions).
- Carbon sequestration4 (CO2 emissions and CO2 uptake from crop residues and manure 1163 into soil organic matter), although this should be reported separately (see section 5.4.3)
- dLUC due to changes between arable or grassland use and deforestation[4] for dairy farming (biogenic CO_2 emissions) although this should be reported separately

- Any dairy related on-farm processing, including fertilizers, chemicals, feed conservation (silage and hay-making, grain drying) and ingredient production on-farm
- Wastes and their treatment (e.g. waste from feed that is not eaten, waste from plastics from silage making or from packaging materials)
- Refrigerants used on the farm (direct GHG emissions, plus indirect N_2O emissions in cases where NH_3 is used as a refrigerant)
- On-farm dairy processing, although this should be reported separately for comparability purposes

GHG emissions that ***must be excluded*** from the dairy farming CF:

- Emissions that are accounted for in the short (biogenic) carbon cycle (see Figure 5). Carbon absorbed by animals and crops is carbon-neutral because it is re-released quickly (unless, for example, plant materials are preserved for a number of years, e.g. wood being used to build a house) as it is metabolized again into CO_2 and subsequently exhaled or released as biomass (i.e. manure or crop residues) before being degraded. However, carbon in the short carbon cycle that is transformed into biogenic CH_4 should be accounted for
- Nitrogen deposition on dairy farmland from the air can be excluded, as these emissions represent indirect N_2O emissions from production processes other than dairy and therefore should be included in the CF of those production processes and their products

GHG emissions that ***may be excluded*** from the dairy farming CF:

- Pesticides. Their exclusion from the CF is acceptable, but their inclusion in environmental footprinting is recommend, due to ecotoxicity impacts

3 Indirect N2O emissions are emissions from NH3 and leached NO3- emitted from soils, fertilizers and soil amendments and excreta during storage and treatment.

- Water use (i.e. tap water, ground water or surface water). Exclusion from the CF is acceptable, but inclusion in environmental footprinting is recommended, due to the impacts on water scarcity
- Cleaning materials used on the farm

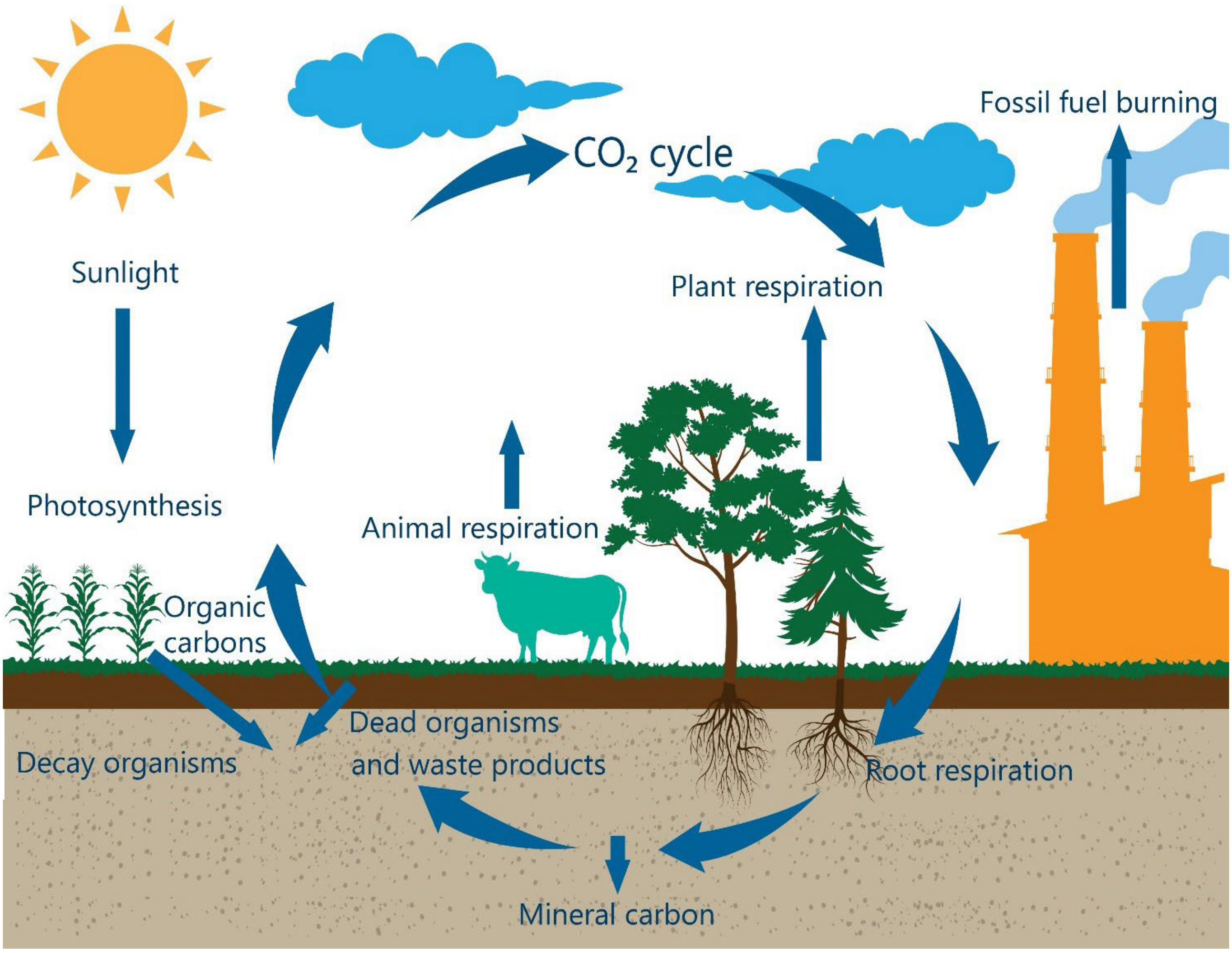

Figure 5. The short carbon cycle on dairy farms

4.4.3. Milk collection and dairy processing

The system boundary encompasses relevant processes within the milk collection and processing system and ***should include***, but is not limited to GHG emissions from:

- The transport of raw milk from the farm gate to processing sites and inter-factory product transport
- Usage of energy that has GHG emissions associated with it
- Consumption of energy carriers that were themselves created using processes that have GHG emissions associated with them (e.g. biobased and fossil electricity, natural gas and biofuel)
- Releases resulting from processes, production, delivery and consumption of operating materials (e.g. refrigerant emissions)

- Freshwater usage on-site
- Wastewater treatment (on and/or off site), including CH_4 and N_2O emissions from wastewater treatment from the milk processing stage
- Waste treatment of packaging, food losses, and auxiliary materials including CH_4 emissions from landfill
- Ingredients, including upstream emissions from production and transport (e.g. salt, sugar, enzymes, fruit)
- Auxiliary materials to produce dairy products, including, but not limited to: chemicals, refrigerants, cleaning agents and packaging materials, although for packaging, it is recommended that primary packaging be included. Impacts from purchased packaging material, the energy, water and waste from the actual packaging of the dairy product and the treatment of wasted packaging materials during processes need to be included in the dairy processing life cycle stage. This stage shall also include any re-packaging that occurs during storage and ripening of dairy products
- Food losses during dairy processes should be included in the mass balance of the CF calculation

GHG emissions that ***must be excluded*** from the milk collection and processing system CF:

- Storage of biogenic carbon in products[4] with a lifetime of less than 100 years should not be included in the CF of dairy products
- CO2 emissions from fossil carbon sources that are not combusted or degraded should not be accounted for, e.g. plastic packaging that ends up in a landfill (since it can take hundreds of years before plastic is degraded).

GHG emissions that ***may be excluded*** from the milk collection and processing system CF:

- Secondary and tertiary packaging, unless they are the primary focus of the CF study
- Any ingredients that contribute less than 1% to the CF, such as production and distribution to the dairy processing unit of, for example, lactic ferments, rennet or yeast; and solid waste at the dairy unit
- The dairy processing unit's capital goods

In some regions or countries, milk from two different species (e.g. cattle, buffalo, sheep or goat milk) is mixed and transported to the processing unit. In this instance, it is good practice to know the CF and proportion of milk from each species within the total mixed milk received at the processing unit.

4.4.4. Distribution and retail

The following GHG emissions and associated activities ***should be included*** in the distribution and retail CF:

4 In some cases the biogenic carbon content might be relevant to include, e.g. for comparison of bioplastic and fossil plastic packaging, but then it needs to be accounted for correctly in the different life cycle stages and reported clearly and transparently.

- Transportation from processor to retail distribution centre and to retailer. This may include international transport for exported dairy products
- Storage and related emissions (energy, refrigerants) across transportation and distribution steps
- Food losses during distribution and retail – these need to be included in the mass balance.
- If retail involves food service (e.g. a take away, coffee machine or restaurant), food preparation needs to be included, but reported separately, and conform to the scope and boundaries of the consumer use life cycle stage (section 4.4.5)
- In the case of composite food products containing dairy (e.g. a pizza), product processing needs to be included, but reported separately, and conform to scope and boundaries of the dairy processing life cycle stage (section 4.4.3)
- Wastes and their treatment during distribution and retail

GHG emissions that ***may be excluded***:

- Capital goods at the distribution centre and retailer

It is recommended that modelling of the retail and distribution stages conforms to the principles of the PEFCR dairy guidance [30]. Defaults from PEFCR dairy [30] may be used if they are representative for the dairy retail and distribution stage.

4.4.5. Use

The various activities and emissions that ***should be included*** in the consumer use CF:

- Energy use for travelling to the point of purchase and back (allocated to the products purchased)
- Home energy use for refrigeration or freezing of food items (allocated to the products stored)
- Food preparation including cooking and changes in mass and nutritional value of the food item during preparation (allocated to the products prepared)
- Cleaning of utensils, plates (water heating, dishwashing; allocated to the products prepared)
- All avoidable and unavoidable food waste including packaging residues

GHG emissions that ***may be excluded*** from the consumer use CF:

- Ambient storage by the consumer
- Capital goods associated with the consumer
- Cutlery for consuming dairy products

It is recommended that modelling of the consumer use stage conforms to the principles of the PEFCR dairy guidance [30]. Defaults from PEFCR dairy [30] may be used if they are representative for the dairy retail and distribution stage.

4.4.6. End of life

Activities and GHG emissions that ***should be included*** in the end of life stage CF:

- Wastes from food losses, food waste and packaging throughout the life cycle of the dairy product, with respect to the scope of the CF study. Specific CF accounting for end-of-life such as landfill, incineration, recycling or composting should be taken into account
- Transport of waste to treatment site

Wastes and waste treatment should be modelled separately for each life cycle stage included in the CF study and preferably reported in the results as part of each individual life cycle stage so that it is clear how much waste occurs in each stage.

4.5. REDUCING THE CF OF RAW MILK

The purpose of this CF guide is to help the global dairy sector reduce its GHG emissions. Therefore, some guidance on the different options to reduce the CF of dairy products is suitable for inclusion within the guide. An extensive list of GHG mitigation options is listed in Appendix 10.11. This list is intended to inspire dairy farmers, companies and other stakeholders to consider the different options to reduce the CF of their dairy products and is therefore neither prioritized nor based on impact or effectiveness. This is because each dairy supply chain is different and therefore the effectiveness, adoptability and applicability of mitigation options varies considerably across the globe, whether because of physical criteria such as geography (e.g. weather, soil type), political considerations (e.g. prohibitions and subsidies) or consumer preferences. The degree to which farmers may further reduce their CF also depends on whether specific life cycle stages are included in the CF study, and to what extent GHG emissions from the dairy supply chain have already been optimized. For example:

- If there are no peat soils present in your supply chain, then increasing water levels will not have a beneficial environmental impact
- If a feed additive is prohibited from being used in the country from where you source your raw milk, there is no GHG benefit from using it in your supply chain
- The potential to increase milk yield per cow varies between regions, countries and individual farms, not least because it depends on the baseline and how much improvement has already taken place. It also depends on farmers' knowledge and understand of dairy production, and their ability to make economic investments
- If dairy is sold or consumed on the farm it does not make sense to optimize logistics within off-farm transportation

When considering the application of GHG mitigation practices in the dairy supply chain, the framework in the feasibility matrix shown in Appendix 10.11 may be helpful to determine the feasibility of different mitigation options in your supply chain and CF model. The impact of the different mitigation options on other environmental issues, economics and animal welfare should also be considered to avoid negative trade-offs. For more guidance on different mitigation options for dairy we refer to publications [31] and [54-56].

4.5.1. New GHG mitigation technologies

Over the lifetime of this IDF guide, several new technologies may become available that mitigate part of the GHG emissions associated with dairy cattle (or other ruminant) systems. This raises the question about how to accommodate these within the CF method described here. Making provision for the use of new mitigation techniques will support the longevity of the guide and help to encourage the adoption of scientifically proven technologies. 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. Such technologies include feed additives, vaccines, wearable devices, and nitrification inhibitors.

The inclusion of new mitigation options in CF is recommended in order to assess their impact on the CF in an early stage of the innovation process, however, making claims around practical implementation should be done carefully and only based on sufficient scientific evidence and after sectoral alignment on their effectivity (e.g. via platforms such as IDF, LEAP and the Global Research Alliance for dairy). At the point where a mitigation technology is accepted to be included within the national GHG emissions inventory it may also be claimed for in CF, because this provides a suitable level of scientific rigor around the mitigation performance, enabling CF to include well-substantiated and internationally accepted claims of emissions reductions. This also ensures that the CF remains consistent with both national GHG inventories, and an overall assessment of global emissions from the sum of national GHG reports. The benefit of a mitigation technology in the CF should be calculated using the same equations, or more situation-specific ones, as used for the national GHG inventory in the country in which it is applied. The extent of use is to be based on the documented level of use within the system boundary. This assures the CF considers any local factors that impact on effectiveness of the mitigation technology.

4.5.2. Offsetting in relation to CF calculations

There is an increasing focus on carbon credits and offsetting schemes to 'balance out' the CF of a product, i.e. to claim carbon neutrality. Hence, carbon credits or offsetting cannot be used to <u>reduce</u> the CF, only to compensate for it, and it is therefore important to distinguish between carbon "reductions" versus "compensations". Within the dairy sector, debate continues on the role of the sector in generating carbon credits. These could be generated, for example, through carbon sequestration or the use of feed additives to reduce enteric CH_4 emissions. A caveat exists however: let's imagine that a farm is generating carbon credits by, for example, carbon sequestration, and these are sold (i.e., leaving the farm) to another sector, which will also account for these “negative emissions”. The farm therefore cannot include the reduction in their CF as this will lead to double counting and double claiming, i.e. the mitigation is accounted for both the farm as a carbon reduction within the life cycle, and by the other sector as a compensation of the CF of a different life cycle, and thus is counted and claimed twice by different parties. Reduction of the CF in combination with a carbon credit can only take place if the carbon credit is maintained within the value chain. Of course, reductions on the (same) farm that have not been certified for offsetting (e.g. increased efficiency, reduced emissions or purchasing inputs with a lower CF) can be included in the farm’s CF.

5 INVENTORY ANALYSIS

5.1. DATA QUALITY

One of the most important issues in LCA calculations is transparency and correct reporting of the data used in the study. The IDF recommends that data sourcing and utilization are aligned with ISO 14044 [25] and ISO 14067 [26], which should be referred to for further details.

It should be clearly stated whether data used is primary (from individual farms and sites), which is preferable; secondary (e.g. generic databases, articles, reports, national statistics); or based on assumptions and default data (therefore less specific to the product being studied) are used. For all data, the source must be documented (e.g. the reference, the company, or the site the data is collected from; or from which database, article or report it is taken) and the temporal, geographical and technological coverage should be clearly stated, as well as how representative this data is for the study purpose. Average data over a long period may be used, or data from a specific year, yet for agricultural products it is important to consider that seasonal variations may affect the CF. The period for which the data are collected should therefore be appropriate for the study and in line with the goal. For example, if the goal is to measure annual progress and variations in CF, then data collection and reporting for individual years is most suitable. By contrast, if the goal is to inform the consumer of the current CF of a product and the claim needs to be maintained for a couple of years, then calculating the average CF of the last three years may be more suitable, and the study may be updated three years later to limit administrative burden.

The data should be as representative as possible of the region for which the CF is calculated, although the regional scope can vary depending on the goal of the CF study, i.e. farm-specific, regional, national, continental or global. The data collected should also represent the technical characteristics of the production system. For example, whether the data represent a modern or older dairy processing factory; a local supply chain or international dairy trade; a large-scale or small-scale dairy farm; whether dairy farming is organic or conventional; and whether cows are grazing or confined. It should be obvious that, for example, data for milk produced in the USA cannot be seen as representative for farms in sub-Saharan Africa, as the climate and production system are completely different.

No rounding should be applied during data collection and life cycle inventory modelling. The methodology and level of detail throughout the study should be consistent, high-quality, appropriate and feasible. Detailed data collection on farm is of the utmost importance as dairy farming contributes much to the CF of dairy products and because only with detailed data it is possible to measure mitigation on farms and assess progress in reducing the CF. For farm-specific data collection, a balance therefore must be found between ensuring data accuracy and completeness, and the time and effort involved by farmers supplying data. Automated data collection through access to existing data sources can help to enhance data quality and lower the administrative burden for farmers.

Finally, the variation and uncertainty within CF study data should be discussed, even if only qualitatively. A quantitative approach is preferred however, for example, through sensitivity analysis. The dairy PEF guidance document and PEFCRs provide a standardized method called the data quality rating, which is recommended for use when making CF or PEF [28] claims within the EU market. For example, N_2O emissions vary considerably over time and as a result of weather conditions even within in one field and measuring and N_2O directly is expensive and therefore accurate data are not often available. Data precision can also vary, especially if it is a parameter that is difficult to estimate, e.g. feed intake or conserved feed and harvesting losses. Therefore, it is important to conduct a sensitivity analysis of critical parameters, especially those for which it is difficult to get a precise estimate.

5.2. EMISSION FACTORS

Emission factors provide an indication of the amount of GHG emitted from a particular source or activity. There are various methods and sources for determining emissions, which are tiered according to their accuracy and detail. The simplest approach is described as Tier 1, and more detailed approaches where country-specific information is available are described as Tier 2. Individual data, that account for local circumstances and conditions, are described as Tier 3. For example, the 2006 IPCC Guidelines for National GHG Inventories [48] and its subsequent refinement in 2019 [8] described all three tiers for estimating CH_4 emissions from enteric fermentation. On a Tier 1 basis, the emissions are calculated using standard emission factors from the literature. The Tier 2 level calculation require detailed country-specific data on gross energy intake and CH_4 conversion factors for specific livestock categories. Tier 3 requires even more accurate and scientifically accepted data from direct experimental measurements concerning, for example, detailed diet composition, concentration of products arising from ruminal fermentation, seasonal variation in animal population or feed quality and availability, and possible CH_4 mitigation strategies.

The highest possible tier method available, adoptable and applicable to the study must always be used, as this improves accuracy and representativeness, and enables effectiveness of mitigation strategies to reduce the CF. For the purposes of achieving consistency in dairy CF, it is recommended to use at least a Tier 2 approach. When making product claims and for peer-reviewed publication, we recommend that only Tier 2 or 3 emission factors are used. When making comparative claims between CF's that use different Tier levels, these differences must be addressed explicitly and their impact on the result must be estimated by means of an uncertainty analysis.

Information on emission factors and calculations of Tier 1, Tier 2 and Tier 3 methodology are given in:

- 2006 IPCC Guidelines for National GHG Inventories, Volume 4: Agriculture, Forestry and Other Land Use [48]
- 2019 Refinement to the 2006 IPCC Guidelines for National GHG Inventories, Volume 4: Agriculture, Forestland and Other Land Use [8]
- United Nations Framework Convention on Climate Change (UNFCCC) Training Package on GHG Inventories [57]
- IPCC Emission Factor Database for fuels [49]

The IPCC 2019 refinement [8] report or any update published subsequent to that report should always be used instead of outdated methodologies from older IPCC reports. The refined report includes the latest scientific information on emission factors; has improved relationships between productivity and emissions; focuses on differentiation between commercial production systems and subsistence systems; and the consistency of methods and emission sources has been improved. In sections 5.2.1 to 5.2.3 we give specific guidance on the use of emission factors for dairy farming, as this is a major contributor to the CF of dairy products. Section 5.2.4 provides guidance on the use of emission factors and equations for other life cycle stages.

5.2.1. CH_4 emission factors from enteric fermentation

In addition to existing Tier 1 methodology, the IPCC 2019 refinement [8] introduced more advanced Tier 1a methodology for those countries that have differentiated production systems into low- and high-productivity systems and those countries that are transitioning from low- to high-productivity systems. We recommend that separate enteric fermentation CH_4 conversion (Ym) and CH_4 emission factors are used when applying Tier 1 and 1a methodology.

In Tier 2 methodology, enteric CH_4 emission factors are estimated based on the gross energy intake and Ym for each livestock category. In this methodology we recommend using separate Ym on the basis of annual milk production (low/medium/high) and feed quality (digestibility and neutral detergent fibre or NDF content). However, care must be taken that data on milk yield, digestibility and NDF are of sufficient quality. Alternatively, a simplified Tier 2 approach is also suggested in the IPCC 2019 refinement, wherein enteric CH_4 emission factors are calculated using pre-defined CH_4 yield per unit of feed DM intake.

If feasible, it is recommended to use Tier 3 method and incorporate additional country-specific information in enteric emission estimates. Tier 1 and Tier 2 methods rely on gross energy intake through feed and proportion of gross energy loss as CH_4 (Ym). However, feed intake and Ym may be influenced by changes in feed digestibility and energy content; increasing levels of feed intake; ration composition; breed and individual cow variation; environmental stressors; rumen microbiome characteristics; and fermentation kinetics. For instance, the IPCC 2019 refinement [8] has shown that a 10% change in feed digestibility will affect enteric CH_4 emissions by between 12-20% depending on dietary characteristics. We therefore recommend using Tier 3 methodology improvements to estimate digestibility are encouraged. As an example, equations proposed by INRA [58] may be useful to take into account the effect of feeding level and the proportion of concentrates fed on reduced diet digestibility, as described in Appendix 10.3.

5.2.2. CH_4 emission factors from manure management

The IPCC 2019 refinement [8] recommends using separate volatile solids (VS) excretion rates for low-and high-productivity systems. In Tier 1 methodology, CH_4 emissions should be estimated per unit of volatile solids excreted in the manure (g CH_4 per kg VS) rather than per head. By contrast, in Tier 2 methodology, CH_4 conversion factors (MCFs) should be derived from monthly temperatures in climatic zones (rather than annual average temperature) and the duration of manure storage should be taken into account. It is also recommended that the new anaerobic digestion MCFs developed for different qualities of digesters, which also consider the storage of digestate, should be used as per the IPCC 2019 refinement [8]. In Tier 3 methodology, it is recommended that the effects of diet interactions (such as level of consumption and concentrate proportion) on VS excretion should be accounted for using actual data from experiments.

5.2.3. Overview of N_2O emissions

As a minimum requirement, the following N_2O emissions should be included in the CF:

- Direct and indirect N_2O emissions from the production of artificial fertilizer. Considerable differences in N_2O emissions occur depending on the artificial fertilizer production process and the local legislation. Therefore, we recommend that you determine the region/source of the artificial fertilizer used if possible and use datasets that model N_2O emissions accordingly
- Direct and indirect N_2O emissions from excreta in the cattle housing, storage and treatment from dairy cows and replacements, including bedding materials
- All N_2O emissions from arable land and grassland used to feed the dairy herd (both on and off-farm). This includes, but is not limited to N_2O emissions from:
    - Direct and indirect emissions of N_2O from soil application of fertilizers and soil amendments
    - Direct and indirect emissions of N_2O from excreta from dairy cattle and replacements on pasture

  - Direct N_2O emissions from peat soils if applicable (for more guidance see section 5.5.4)
  - Direct emissions of N_2O from harvesting losses and crop residues
  - Direct and indirect N_2O from nitrogen in mineral soils that is mineralized
- Indirect N_2O from refrigerant use throughout the life cycle (e.g. if NH_3 is used as a refrigerant)

To model N_2O emissions we refer to IPCC 2019 [8] and recommend using country-specific emission factors if available. However, it should be noted that N_2O emission measurements from dairy farming are scarce. The data that do exist are often outdated, variable and based on inconsistent methodology. Therefore, considerable differences are observed between studies and country-specific emission factors, and their uncertainty and region specificity should be accounted for. Further research on N_2O emissions, the factors that affect them and potential mitigation measures is encouraged.

5.2.4. Emission factors in other life cycle stages

For feed emissions we recommend using the PEFCR Feed [42] and the LEAP guidance on feed [43] as a basis for calculating emissions. The emission of refrigerants is best calculated based on the quantity of refrigerants consumed at farm or factory, or retail. For fuels and logistics, it is best to use existing databases and IPCC fuel factors or, if not suitable, other reliable country-specific energy content and combustion factors for the fuel used [48]. For modelling emissions from recycling, we recommend using the circular footprint formula of the PEF guidance document [28].

5.3. USE OF LCI DATASETS

Different LCI databases exist that can be used to model the background data in dairy CF, however care should be taken to consider their methodology. For example, some databases are specifically intended to be used for consequential LCA and are not suitable for attributional LCA; some databases are region-specific; and databases may or may not include specific emission sources, e.g. LUC, carbon sequestration, capital goods or peat soils. Allocation and cut-off rules may also vary between LCI databases. At the results level, emission sources may be registered differently between databases, which results in a variable level of granularity. It is important to make sure that the LCI dataset used complies with the methodological recommendations in this guide. For developed and industrialized production systems LCI database coverage is generally good, yet it is clearly lacking for developing regions and less developed systems. When LCI databases do not deliver background data of sufficient quality for the dairy product being studied, you may collect primary data, rely on data from peer-reviewed studies, or use less-representative datasets. If you choose the latter option, this must be noted when discussing the results. Furthermore, making product claims is not recommended if less than representative background datasets contribute much to the CF (e.g. dairy compound feed). Datasets that enable measurement of CF improvement over time would be useful, yet this is currently a knowledge gap that warrants filling in order to correctly track and claim progress in dairy CF over time.

A non-exhaustive list of LCI databases that are often used in dairy CF:

- Eco-invent (Swiss database; [59])
- EF 3.0 datasets (only intended for PEF studies, to be released end of 2022; [60])
- GFLI (database for feed ingredients Home – The Global Feed LCA Institute; [61])
- Agrifootprint (Dutch database for food and agricultural products; [62])
- Agribalyse (French database for food and agricultural products; [63])
- USDA (US database; [64])

An overview of LCI databases may also be found online [65].

5.3.1. Electricity modelling

For electricity, we recommend using supplier-specific electricity data if available (e.g. if electricity from windmills is used, the associated CF should also be for electricity from windmills). If this is not available, the country-specific residual grid mix (including grid losses) for the country where the product is produced should be used, accounting for import and export. The residual grid mix refers to the unclaimed or untracked electricity. This prevents double counting when using supplier-specific electricity (typically referred to as green electricity). If the residual electricity mix is not available, then the average electricity mix (including grid losses) used in the country, in which the life cycle stage takes place, is proposed (also accounting for import and export).

5.4. ALLOCATION

Methodology for handling co-products often has a significant impact on the results of the CF. Various ways exist to handle co-products, varying according to scientific versus practical application, but there is no single, common or established method. The allocation procedure described by ISO 14044 [25] is as follows:

Step 1: Wherever possible, allocation should be avoided by:

a) dividing the multifunctional process into two or more sub-processes and collecting the input and output data related to each of the sub-processes, or
b) expanding the production system (known as system expansion) to include the additional functions related to the co-products.

Step 2: Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them (i.e., they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system).

Step 3: Where physical relationships alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.

Throughout the entire life cycle of milk and dairy products, from farm to manufacturing gate, there are several processes that involve multiple co-products, including, for example:

- Feed production of feed (e.g. soy meal and soy oil)
- Production of milk and meat on-farm (i.e. meat and calves are co-products when exported from the farm)
- Manufacture of dairy products at the processing site (e.g. skim milk and cream; or cheese and whey)
- Energy generation (e.g. on-farm biogas production or electricity produced at the dairy manufacturing site where surplus electricity can be exported to the grid).
- The impacts of transporting, chilling and preparing multiple foods simultaneously in the use phase (e.g. buying milk and several other foods and transporting them to the consumer's home)

It should be noted that since this IDF guide uses attributional LCA methodology, system expansion is not applicable and can typically not be used due to double counting, hence the bullet point 1b in the ISO allocation procedure described above is irrelevant.

5.4.1. Allocation for farm resources: Imported feed and bedding materials

Many feed ingredients are co-products from a production system that generates more than one product, therefore the environmental burden should be distributed between the co-products. Some of the more commonly used feed ingredients for dairy cows where such allocation situations occur include:

- Soy meal or expeller and hulls (co-product of soy oil and soy hull, produced from soy beans)
- Rapeseed meal or expeller (co-product of rapeseed oil, produced from rapeseed)
- Palm kernel expeller (co-product of palm kernel oil, produced from palm kernels, which is a co-product of palm oil, produced from oil palm)
- Maize gluten meal or expeller (co-product of maize gluten feed, maize germ meal and maize starch, produced from maize)
- Sunflower meal or expeller (co-product of sunflower oil, produced from sunflowers)
- Dried distillers' grains with solubles (co-product of corn ethanol, produced from corn grain)
- Molasses and vinasse (co-product of sugar and ethanol production)

- Beet and citrus pulp (co-products of sugar production and citrus juice production)
- Wheat bran (co-product of wheat flour, produced from grain)
- Grain and straw
- Waste streams from the human food sectors (e.g. whey, bone meal, fish meal)

Some commonly used bedding materials for dairy cattle where allocation situations occur are:

- Straw (by-product from grain production)
- Sawdust (by-product from the forest industry)

The present guide uses economic allocation for co-products in feed production, as well as for bedding materials, which are often a by-product from feed or agricultural/forestry sector. This is identified as the most feasible allocation method to use at this stage because:

- System subdivision is not typically possible for feed products or bedding materials
- It is difficult to find a physical relationship that reflects the relation between inputs and outputs. For example, soy meal is typically used for its protein content, whereas soy oil is used for its energy content, hence applying allocation based on protein content or energy does not give an allocation factor that is relevant for both products

In consequence, economic allocation is the recommended method for farm inputs. As many feed ingredients are produced regionally or locally, five-year averages of prices are recommended to minimize fluctuations between years. If a feed is coming from a specific regional supplier, we recommend using those specific prices, whereas if it is a global commodity, global market prices are recommended. A calculation example for feed allocation is found in Appendix 10.4.

5.4.2. Allocation for dairy farming

For dairy farms, where the focus is on milk production, meat generated from surplus calves and culled dairy cows is an important co-product. It is therefore necessary to determine total emissions and to allocate emissions between milk and other co-products. In some cases, manure can also be exported off-farm, and if so, this too needs to be considered as a co-product.

We recommend using an allocation method based on an underlying physical relationship. Although the 2020 amendment to the ISO 14044 guidelines [66] indicates that the use of underlying physical relationships is applicable for combined production, where products can be independently produced, we argue that the approach provided in these guidelines is aligned with step 2 in ISO 14044 [25] because it is based on the animals' utilization of feed net energy to produce milk and meat. Regardless of ISO alignment, the approach recommended in these guidelines is more stable and universally applicable than a revenue-based approach to allocation between the main products of a dairy operation.

Furthermore, animal feed consumption is the main determinant of enteric CH4 emissions and of N2O and CH4 emissions from animal excreta, which together may contribute up to 80% of total on-farm GHG emissions. This supports the application of this methodology due to the direct correlation between the animals' physiological net energy requirements, feed consumption and GHG emissions.

Although the recommended methodology assumes that all dairy farm activities are intermingled and provides a mechanism for allocating cumulative emissions among multiple products***, in situations where data are readily available it is preferable, under the ISO guidelines, to employ system separation***. An example where system separation may be feasible would be if a dairy keeps bull calves for fattening and has separate records of feed consumption and manure management. The fattening operation can then be considered separate from the dairy operation and no allocation is needed for fattened calves.

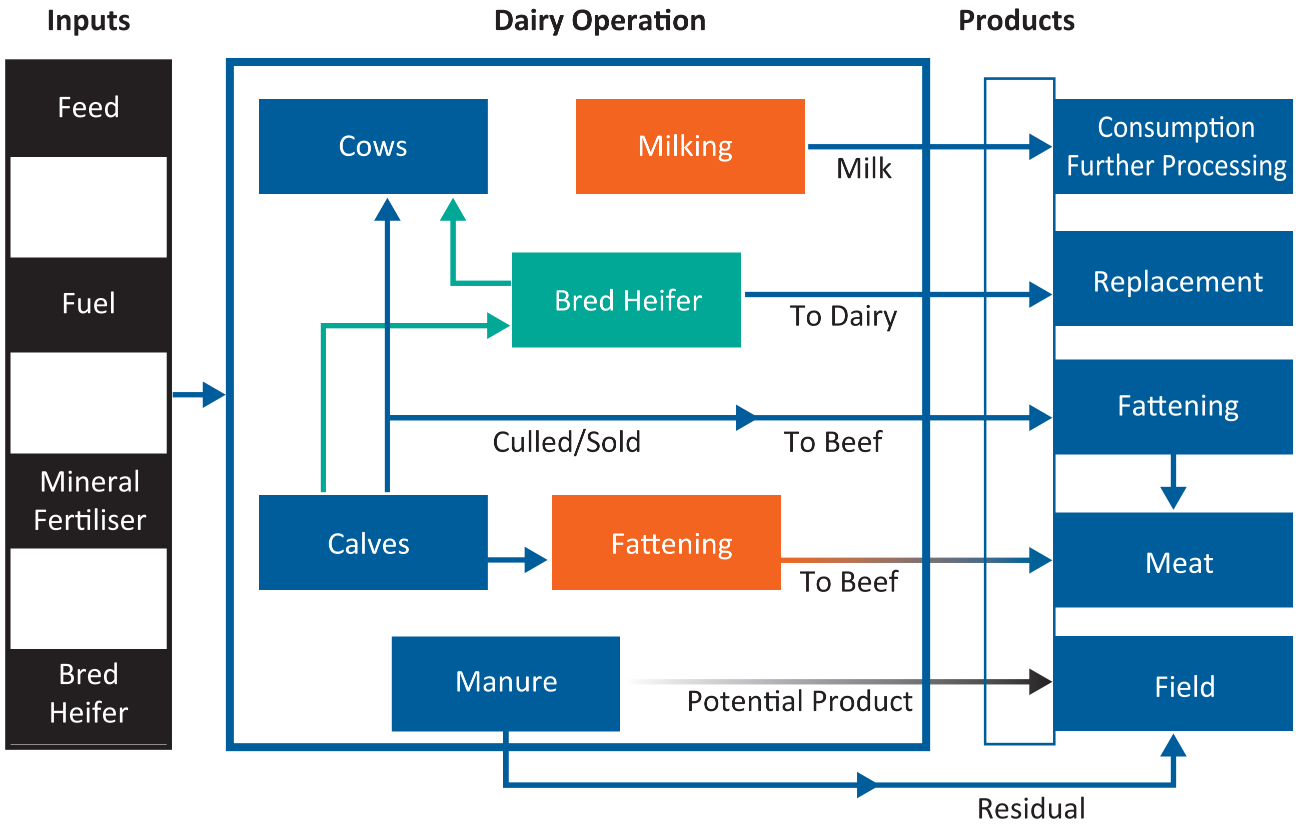

Figure 6. Flows and products from dairy operations. Orange colored boxes are activities that are potentially separable, following the ISO hierarchy step 1. The fattening animals sold to beef are subject to allocation if not separately accounted for. The allocation of emissions arising from both purchases (upstream, embedded emissions) and on-dairy direct emissions among potential co-products is based on the feed net energy consumed to produce the respective products (except manure, which may be an exception under some circumstances). Green arrows represent internal flows that do not affect allocation calculations.

Animal transfers can notably skew the calculations, particularly when herd size is significantly changing during the course of a reporting period, because these situations represent a non-steady state condition for the dairy operation. LCA is fundamentally constructed to provide an accounting framework for steady-state operations. Therefore, under these circumstances we do not recommend using these guidelines for CF accounting because they will lead to non-representative results. For example, if a dairy herd is expanding through the purchase of bred heifers, then the incoming burden of these purchased animals will be included in the accounting of the milk CF even though these animals may not be productive, resulting in an increased CF compared to the situation if the herd size is approximately constant.

Allocation factors for milk and meat in the previous 2015 IDF guidelines were calculated following the approach of Thoma et al. [67]. However, this approach was tested in a variety of dairy production situations and was found to be lacking in both specificity and range [68]. Specifically, the previous approach does not differentiate between the type of animal leaving the farm (e.g. calf or cull cow). More importantly the range of the validity of the regression is limited to situations within a narrow range of beef to milk ratios (ratio M_{meat} / M_{milk}), ranging from zero to approximately 3%. The current update to the IDF guidelines provides an improved algorithm for estimating an allocation fraction among the potential coproducts; however, allocation to manure has not yet been implemented. The general recommendation in the present guide is to treat manure as a residual and use a cut-off approach (further details are given later in this chapter).

Numerous alternative approaches to solve the issue of multifunctionality in dairy production were discussed during a series of meetings of the IDF LCA allocation AT. The ultimate consensus regarding the conceptual basis for allocation among multiple products at a dairy farm operation was to adopt an improved computational approach that based on a biophysical evaluation of the system following Nemecek and Thoma [69]. This method is based on the known relationships between net energy for lactation (NE_L) and net energy for growth (NE_G) and the production of milk and body mass. The determination of the allocation factor is straightforward and involves the following steps:

Step 1a: Collect/determine the total kg of live weight sold per year [M_{meat}]. In the implementation of this approach, M_{meat} includes the live weight of animals leaving the farm, regardless of their destination. It does not include any animals which die and are subject to mortality management on the farm.

Step 1b: Collect/determine the total kg of FPCM produced per year [M_{milk}]. M_{milk} is the sum of milk sold corrected to 4% fat and 3.3% protein (FPCM) using equation 10 shown in Appendix 10.2.

$$AF_{milk} = \frac{NE_L * M_{milk}}{NE_L * M_{milk} + NE_G * M_{meat}}$$

Step 2: Use the simple calculation for milk (NE values have units of MJ/kg)

Equation 2: Formula for the dairy farm milk allocation factor (AF_{milk}) based on farm sales of milk

Step 3: Use the simple calculation for meat:

$$FA_{meat} = 1 - AF_{milk}$$

Equation 3. Formula for the dairy farm meat allocation factor (AF_{meat}) based on farm sales of cattle liveweight

Alternate calculation: in some situations, it may be desirable to differentiate between the different classes of animals which are sold from the enterprise. In this case, the individual net energy for growth requirements at each animal class must be known. For these calculations the following relationship can be used:

$$AF_{milk} = \frac{NE_L * M_{milk}}{NE_L * M_{milk} + \sum_i NE_{G_i} * M_{class_i}}$$

Equation 4. Alternate formula for the dairy farm milk allocation factor (AF_{milk}) based on farm sales of different classes of cattle liveweight

In this equation, Mclass is the mass of animal classi that is sold. The net energy for growth can be estimated from the animal's age at sale from Figure 7. According to Nemecek and Thoma [69], reasonable approximations for the net energy requirements for growth are 27.5 MJ/kg for calves sold at birth; 15 MJ/kg LW for mature animals; 11 MJ/kg LW for bred heifers and fattened calves; and 3.1 MJ/kg FPCM. There is relatively small variation in the NEG relationship to age among different breeds although the age to weight relationship will be different, so allocation will be different. Whether the animal is sold into the beef sector or into another dairy does not affect the calculation of the allocation factor. In this situation, the allocation factor for each animal class is calculated by replacing the numerator in the equation above with the following expression: $NE_{G_i} * M_{class_i}$. Note that this allocation factor should only be applied to emission sources that cannot be attributed unequivocally to either a specific animal class or milk production. Energy use by milking equipment, for example, should be attributed entirely to milk production and not be allocated to meat. Similarly, if separate accounting for fattening calves or bred heifers sold from the farm is available for the enterprise, then this activity can be separated and is neither subject to allocation, nor contributes to the calculation of the allocation factor. A calculation example is provided in Appendix 10.5. For a detailed explanation of this approach, including more refined estimates for the net energy requirements of animals at different stages which may be sold from the farm, refer to Appendix 10.6.

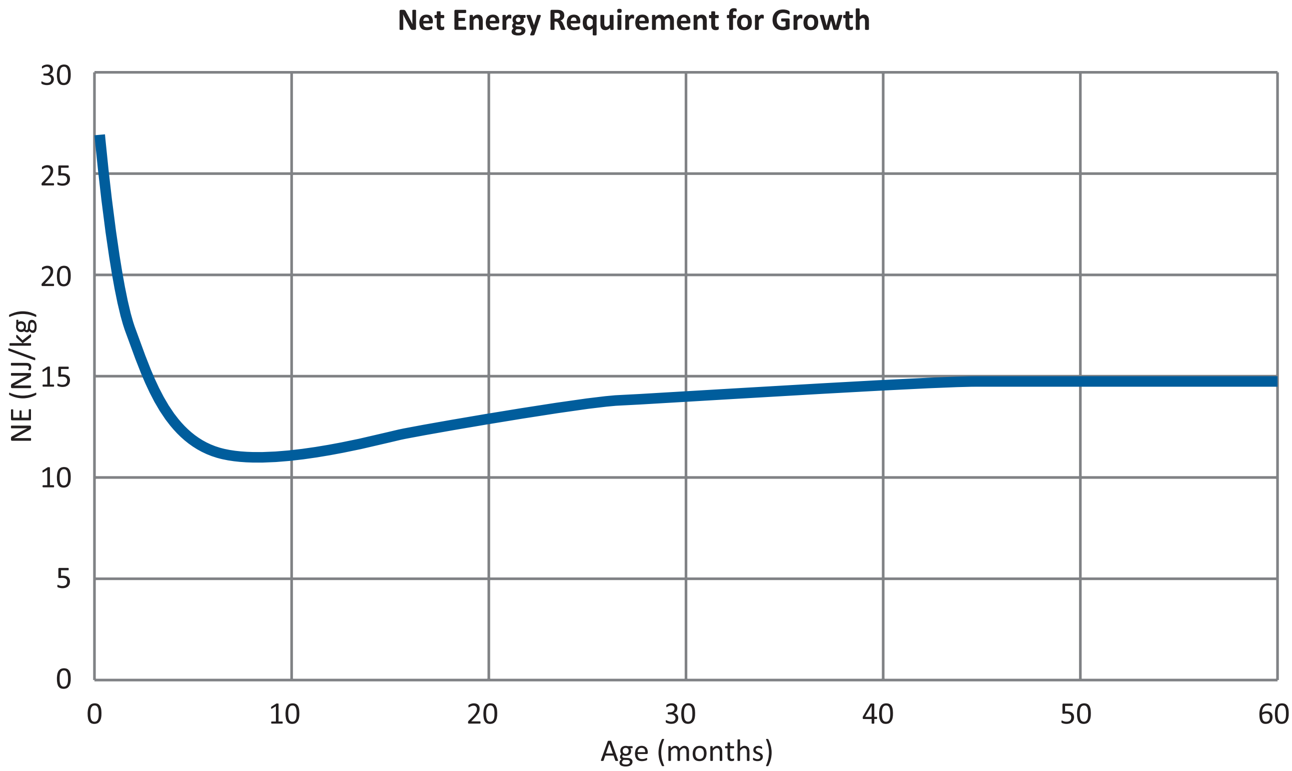

Figure 7. Net energy for growth as a function of animal age. The relationship shown is approximately valid across a range of breeds.

For manure exported from the farm, we recommend treating the manure as a residue for allocation purposes, and using a cut-off approach. For situations in which practitioners feel this approach is not appropriate given the specific goal and scope of a study, and where it is determined that the manure should be classified as a co-product or waste, economic allocation or no allocation should be applied respectively. This is aligned with the guidance from the FAO LEAP guidance on large ruminant supply chains [31], and also follows the previous IDF guidance. When manure is classified as a residue, as stated in the FAO LEAP guidance on large ruminant supply chains in Section 9.3.1(f) [31], "Manure has essentially no value at the system boundary. This is equivalent to system separation by cut-off, in that activities associated with conversion of the residual to a useful product (e.g., energy or fertilizer) occur outside of the production system boundary system." In this approach, emissions associated with manure management up to the point of field application are assigned to the animal system, and emissions from the field are assigned to the crop production system. For guidance on allocation of manure classified as a co-product or waste, see Section 9.3.1(f) of the FAO LEAP guidance [31].

In summary, when manure is classified as:

- Waste – no allocation should take place, hence all emissions from the treatment of manure (potentially also those falling outside the dairy farm boundaries) should be part of the dairy farm and be allocated between all products (e.g. milk and meat)
- A residue – a cut-off approach should be applied
- A co-product – economic allocation should be applied

The use of shadow prices for economic allocation, as described in the FAO guidelines on nutrient cycling [47], are not recommended due to the potentially significant variations in allocation factors based as a result of local markets and price volatility. Hence, economic allocation based on the revenue from manure in relation to other co-products should be used.

Other multifactorial functions of dairy cattle may be appropriate to include, depending on the goal of the study (e.g. draught power). These are not included in this revision of the IDF guidelines, but further guidance can be found in the LEAP Guidance [31] .

5.4.3. Allocation for dairy product manufacture

Dairy manufacturing plants usually produce more than one product because the fat content in raw milk exceeds the product specification for milk powders or fresh milk products (e.g. liquid milk, yoghurt or dairy desserts), therefore the excess milk fat can be further processed into butter or anhydrous milk fat (AMF). Another typical example of co-production in the dairy sector is the production of cheese, alongside the co-product whey. These co-products necessitate the environmental impact of production and transport of raw milk and processing, plus other inputs and outputs, to be allocated to different dairy co-products.

The data collection for each process unit within the plant is resource-intensive, and sometimes impossible, as a result of insufficient metering on a process unit level. In many cases allocation is necessary since several products result from one process (e.g. the separation of skim milk and cream). Often resource use or emission data are only available on a whole factory basis and use of aggregated data (i.e. company or site level) results in lower accuracy of the CF for a specific product, as opposed to detailed data for specific unit processes within a site. We therefore recommend obtaining the highest level of detailed data as possible, given the goal and timeframe of the study.

5.4.4. Definition of milk solids for allocation

Milk mainly consists of three different solids: fat, protein and lactose, plus a small amount of minerals, also referred to as ash. It is primary the fat, protein and lactose that have an economic value and is therefore appropriate to allocate based on these MS. The data available at a dairy processing facility differs and it is recommended to use the data with the highest accuracy: if data is available for fat, protein and lactose, but amount of minerals is not known, it is recommended to allocate based on fat, protein and lactose, but if total DM is known and this information is of higher accuracy it is recommended to use that for allocation. Whether allocation based on the MS (fat, protein and lactose) or the total DM is considered to have estimated a minor impact on the CF results. The most important consideration is to be consistent in allocation and ensure that no emissions are “lost” in accounting.

5.4.5. Allocation of raw milk and transport from farm to processing plant

Allocation of the CF embodied in the raw milk as it comes into the processing plant (including transportation from farm to processing plant) should be carried out on the basis of the MS content of fat, protein and lactose[5] in the final product, i.e. mass allocation using dry weight of the three MS components (see section 5.4.4).

The allocation factor (AF) can be calculated for each product (i) using the following equation:

$$AF_i = \frac{MS_i \cdot Q_i}{\sum_i^n = 1\,(MS_i \cdot Q_i)}$$

Equation 5. Formula for the processing plant allocation factor (AF_i) based on milk solids content in the final product

In this equation, AF_i is the allocation factor for product I; MS_i is milk solid content of product i (expressed as percentage milk solids or as weight by mass of milk solids/weight by mass of product i); and Q_i is the quantity of product i output at the production site or from the unit operation (in kg of product i).

It may sometimes be difficult to know the total milk solid content (sum of milk solids) of all products produced from the site. If more reliable information on milk solids into the site exists, then that may be used instead. The same equation (Equation 5) is then used, only accounting for total MS in product i into the site divided by total MS into the site. Hence, allocation should be executed on either MS coming into the site or out from the site for consistency – it is not possible to divide MS in products from the site with total MS into the site, as some emissions then are not accounted for. If data is available on total MS into and out of the processing site, it is important to account for any losses (e.g. from cleaning) that occur during the production process. Figure 8 is a simplified illustration of the milk balance (MS in and out) for a dairy processing plant, where MS in raw milk for product i is the sum of MS in product i and milk losses for product i.

Figure 8. Simplified illustration of the milk balance of a dairy processing site

5 Ash is also present in small proportions in milk, however, this is typically of no economic value, and therefore the guide proposes to only include the MS fat, protein and lactose.

5.4.6. Allocation of other inputs and outputs to dairy products

Besides raw milk, there are several other inputs to a dairy processing plant (e.g. electricity, heat, water), as well as outputs (e.g. solid waste, product waste, waste water, emissions from cooling agents), as shown in Figure 9. All these inputs and outputs must be considered in the CF. If possible, energy and other inputs, as well as emissions and other outputs, should be assigned wherever possible to specific processing stages and product flows (step 1 in ISO 14044 [25]). For example, if milk is first pasteurized and separated into skim milk and cream, and the skim milk is then dried to produce skim milk powder, we recommend allocating the energy for pasteurization and separation between the milk and the cream, while the energy for drying should be assigned to the skim milk powder only. This can be done relatively easily if specific meter readings exist, or if any product-differentiated information is available for the site[6]. Some inputs are easy to assign to a specific product (e.g. packaging materials or ingredients) and no allocation is needed, while others are more complex (e.g. energy use or waste water treatment). If no differentiated information exists for different processing stages or product flows such that it is not possible to ascribe it to a specific product, we recommend to allocating all inputs and outputs based on the MS content of the product, as described in Equation 5. In the majority of processing scenarios, energy is primarily used for heating, cooling and drying processes, which mean that the MS content (in DM) of the final products adequately reflects the share of energy use[7] (for more information see [57]). No distinction is made regarding the type of MS present (i.e. fat, protein or lactose) as these do not change with heating, cooling and drying, therefore only the quantity of MS in the product is altered by processing. Other inputs (e.g. water, chemicals) and outputs (e.g. waste, waste water) typically have a minor contribution to the CF, allocating based on MS content is therefore regarded as the best option. Some dairy products also contain non-dairy ingredients (e.g. a spread where butter and vegetable oil is mixed, or a fruit yoghurt containing fruit or fruit mixes), yet it is assumed that the majority of the energy used at a dairy site is used for heating and cooling. We therefore recommend that allocation is again executed based on MS content and not on a DM basis, i.e. no energy is allocated to vegetable oil, fruit, sugar etc.

6 If a specific allocation matrix for different inputs and outputs exists that would be applicable to a particular site or study, then that can also be applied.

7 The true drivers of energy use in thermal processes would be the water content of the ingoing product and the difference in DM content between the initial and final product, but all products generally derive from the same raw milk and therefore are reflected by the final MS content.

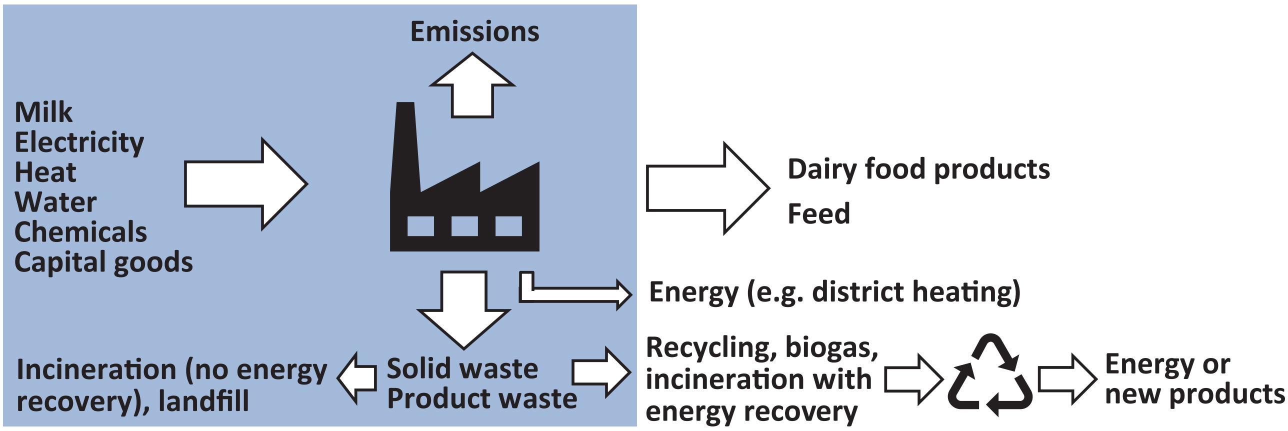

Figure 9. Overview of inputs and outputs to a dairy processing site. The shaded area illustrates all the activities that shall be allocated to the various products

The allocation procedure at the dairy manufacturing site level is therefore summarized as follows:

Step 1: Sub-divide the system and assign inputs and outputs to specific processes, either by detailed, differentiated information (e.g. meter readings) or best possible knowledge

Step 2: Subtract any inputs or outputs from Step 1 (if relevant) and allocate the remaining inputs and outputs between the products based on the MS content as described in Equation 5.

5.4.7. Allocation between various by-products from the dairy processing plant

As previously discussed, a dairy processing plant typically produces several dairy products, but also generates several by-products and/or waste streams. As described in the previous section, allocation of inputs and outputs at a dairy processing site should be allocated based on differences in MS content between dairy products. In some cases there may be an economic loss when a product is downgraded (e.g. cheese cut-offs for graded cheese), but since it is still suitable as food for human consumption (i.e. a high quality product) allocation should executed based on MS content. Yet by-products of milk and whey of non-food quality may also be produced, being used, for example, for animal feed. In these cases, we recommend economic allocation, which is done in two steps.

First, allocation is executed based on the economic value of the main products for human consumption and the economic value of the by-products going to animal feed. The environmental impact (and all flows) is therefore split between the main products and the by-products, and the total impact (and all flows) related to all the main products can then be allocated between the products to human consumption based on MS content (as previously described). Often the economic value of the by-product is relatively low, and it can be difficult to find sufficient data to conduct an allocation, so a cut-off may be appropriate. A low quality (i.e. non-food quality) by-product will therefore not have the same environmental burden as the food products.

Other by-products may also exist, e.g. excess heat going to district heating to the local community, or food waste being converted biogas. The preferred way to allocate to these by-products is via sub-division, or, if this is not possible, to use a cut-off[8]. In order to handle waste streams correctly, it is important to know what will happen with these streams. If the waste is used for a new product, e.g. solid waste going to recycling, we recommend applying cut-off (i.e. the new product will absorb the environmental impact associated with upgrading). If the waste goes to landfill or incineration with no heat recovery, allocation is not relevant, since all emissions from waste treatment should be allocated between the products. An overview of allocation between various outputs, inspired by the food waste hierarchy, is shown in Figure 10.

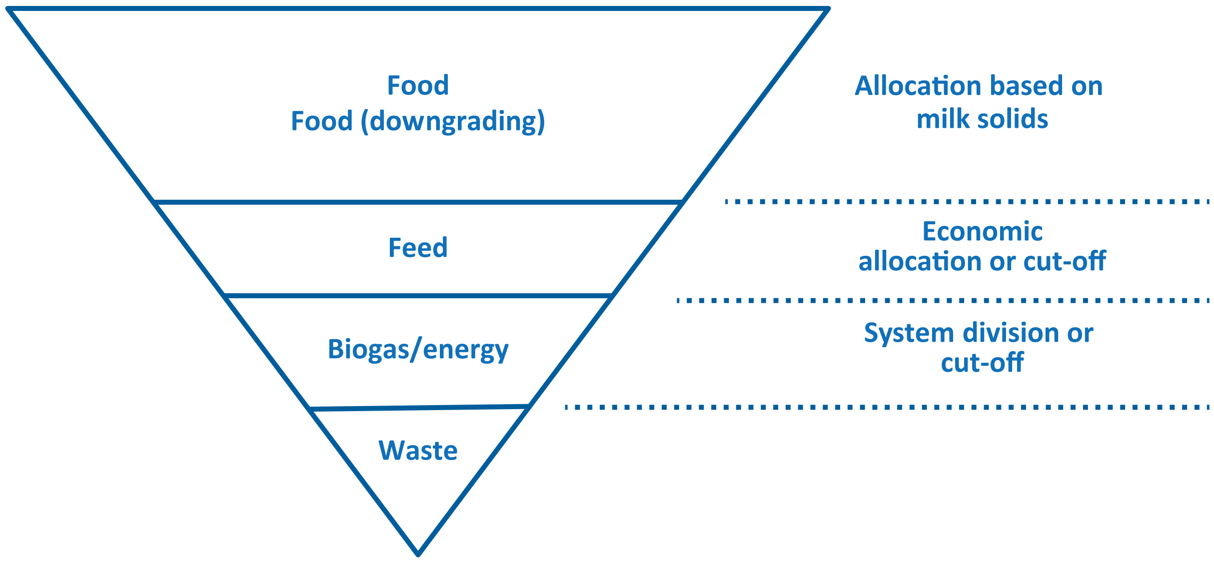

Figure 10. Overview of allocation between various outputs at the dairy processing stage

5.4.8. Ex-factory gate

This may be categorized into four main stages: distribution, retail, home transport and consumer refrigeration. For distribution of dairy products to wholesale or retail outlets (or intermediate transport between sites/distribution centres), allocation based on the mass of the product shall be applied. For storage of dairy products at retail, allocation based on dairy product volume shall be used. If primary data is not available, default data is available in table 43 in the PEFCR for dairy products [30]. In terms of transport from the retail stage to the consumer, allocation shall be based on dairy product mass (for further information see PEFCR [30]). Finally, if the dairy product requires refrigeration by the consumer, allocation based on dairy product volume shall be used (for further information see PEFCR [30]).

8 Often system expansion is applied in situations of excess heat (e.g. a site is delivering district heating and substituting for natural gas), but when doing so there is a risk of double counting since the site would then get a credit when substituting natural gas and the ones using the district heating would likely apply a very low (or no) CF of the heat.

5.4.9. Summary of co-product handling

Table 1 provides an overview of the recommended allocation approaches for the life cycle stages imported feed, dairy farm, and dairy product manufacture. Different main products, by-products and waste streams are generated from each of these stages. Obviously feed is the main product from production of imported feed, and, if the feed is a by-product from the food sector, also food is a main product. Other by-products of lower economic value may be crop residues (e.g. straw) for feed, bedding or energy use. Economic allocation is recommended for this life cycle stage. For dairy farm operations, the main products are milk and meat (the latter also includes hides and other carcass products as it is expressed as live animals leaving the farm), and in some cases, manure is a high value product used for biogas and/or fertilizer. Biophysical allocation is recommended between milk and meat, while a cut-off at farm gate is recommended as the default allocation for manure. The dairy farm may also produce crops that are exported from the farm, and in this case sub-division is recommended. Sub-division is also recommended in situations where energy is generated, for example from biogas. Allocation based on MS content is proposed between dairy products for human consumption in the manufacturing stage. If whey and milk losses are used for animal feed then economic allocation or cut-off is recommended and, as for the dairy farm level, sub-division or cut-off is recommended for energy generation at the manufacturing site level.

Table 1. Overview of recommended allocation approaches for products leaving the system

Outputs: / Life-cycle stage	Food	Feed	Fertiliser	Fuel/energy/heat	Waste
Production of imported feed	Economic	Economic	Not relevant	Economic	No allocation, i.e. all emissions are allocated to the other products.
Dairy farm operations	Milk/Meat*: biophysical ('physical causality')	Crops: sub-division	Cut-off or economic	Sub-division of cut-of	No allocation, i.e. all emissions are allocated to the other products.
Manufacturing af dairy products	Food products: mass (milk solids)	Whey or milk losses: Economic of cut-off	Not relevant	Sub-division of cut-of	No allocation, i.e. all emissions are allocated to the other products.

* Liveweight of animals leaving the farm, i.e. also includes hides etc

In the previous IDF guide (2015), system expansion was recommended for energy generation at farm and manufacturing sites, but due to the risk of double counting this has been changed in the present revision. The user of the green energy (e.g. biogas or electricity from windmills) usually takes credit for the green energy, i.e. uses a lower CF for the gas or electricity compared to a residual mix; therefore and if the farm or site used system expansion (i.e. also get a credit for this green energy) it would be double counted.

5.5. LAND USE AND LAND USE CHANGE (LUC)

Emissions from land use and land use change (LUC) can have significant impacts on the CF of dairy products, but their inclusion is variable between studies and is not always clearly reported. In the following sections, dLUC; iLUC; carbon sequestration and emissions from land use; and drained organic soils are described in greater detail.

5.5.1. Direct land use change (dLUC)

This is an extremely challenging and complex area of the LCA process, not least because it has a significant impact on the CF contribution of specific feed ingredients that are sourced from countries with a high land use change risk, such as soy and palm-based ingredients. After careful review, the IDF, for the purposes of this document, has decided to adopt the guidance provided in Section 5.5 and Annex E of PAS 2050:2011 [29] and annex B of PAS 2050-1:2012 [70].

In summary, the guidance states that GHG emissions arising from changes in carbon stocks due to dLUC should be assessed for any input to the life cycle of a product originating from agricultural activities, and that the GHG emissions arising from changes in carbon stocks due to the dLUC should be included in the assessment of GHG emissions of the product. In this instance, “changes in carbon stocks” refers to changes in soil carbon and changes in above- and below-ground biomass over time.

The assessment of the impact of LUC should include all dLUC occurring within a period of 20 years from the reference year of the assessment. Primary information on previous land use transformation relating to the sourced ingredient should be used, if available. One-twentieth (5%) of the total emissions arising from the land use change should be included in the GHG emissions of these products in each year over the 20 years following the change in land use. Emissions shall be subsequently calculated following guidance from the relevant sections of the IPCC Guidelines for National GHG Inventories [8, 26] and included in the CF. It should be noted that dLUC refers to the conversion of non-agricultural land to agricultural land, either as a consequence of producing an agricultural product or input to a product on that land. By contrast, iLUC refers to the conversion of non-agricultural land to agricultural land as a consequence of changes in agricultural practice elsewhere. Because of large uncertainties associated with the calculation of LUC emissions, we recommend that they are reported separately for greater transparency.

Further guidance about how to calculate dLUC is provided in Appendix 10.8 with examples of how to perform the calculations of dLUC when it is either known or unknown. More information can also be found in the FAO LEAP guidance for feeds [43]

5.5.2. Indirect land use change (iLUC)

This concept is used to capture the responsibility for LUC outside the immediate dairy product system being evaluated. Theoretically, all actual LUC would be accounted for via dLUC in the product systems that directly use the recently transformed land, but this does not necessarily track the full cause and effect chain. Suggested frameworks for including iLUC range from attributing a share in LUC to all land-based production, to evaluating in more detail how increased demand for certain products or functions may cause land transformation via compensation, as discussed by Brandão et al. [71]. The former approach provides a way to include iLUC in an attributional LCA [72], or rather to attribute LUC to all product LCA regardless of whether there is dLUC in the specific supply chain. However, one should consider that this can or does lead to double counting, given that dLUC for one crop or region is iLUC for another crop or region [72]. The latter approach is therefore more common, and typically associated with consequential LCA because of the inherent assumption that the iLUC is related to changes in supply or demand. For example, it is often highlighted as an issue in increased demand for feedstock for biofuels, which may compete with demand for food. The recent Commission Delegated Regulation (EU) 2019/807 supplementing Directive 2018/2001 [73] identified feedstocks as having a high indirect land-use-change risk when:

- The average annual expansion of the global production area of the feedstock since 2008 is higher than 1% and affects more than 100,000 hectares; and
- The share of such expansion into land with high-carbon stock is higher than 10% according to a prescribed formula

The standard ISO 14067:2018 [26] for product CF acknowledges that no internationally agreed procedure exists around iLUC. It states that iLUC should be considered for inclusion but shall be documented separately if calculated. Since iLUC can provide important insights about the studied system, in order to also address the indirect effects, we recommend including iLUC as a sensitivity analysis. If assessed, it needs to be reported separately and it is not possible to aggregate emissions from dLUC and iLUC due to double counting.

5.5.3. Carbon sequestration and emissions from land use

Grasslands and other agricultural vegetation cover a considerable amount of the Earth's land surface and span a range of soil types and climatic zones. Agricultural ecosystems hold large carbon reserves [74], mostly in soil organic matter. Soil carbon sequestration (enhanced sinks) is therefore regarded as an important mitigation opportunity in the agriculture sector, with an estimated potential of 0.3-6.8 Gt CO2 per year [75] There is considerable potential to sequester carbon in soils and vegetation, but also a risk of losing carbon cropland tillage and management. Hence, it is important to both increase carbon sequestration, and to maintain current carbon stocks, thereby avoiding potential emissions.

Carbon stock changes in agricultural land are closely tied to management practices, which may either enhance or deplete carbon stocks. The greenhouse effect can be limited by both maintaining and increasing existing stocks. Practices that raise the photosynthetic input of carbon and/or slow the release of stored carbon (e.g. through respiration or depletion) will increase carbon stocks [76]. Carbon accumulation and losses occur mostly below ground – these carbon 'pools' (aggregate carbon stored) have slower rates of turnover than above-ground pools because most of the organic carbon in soils comes from the conversion of plant litter into more persistent organic compounds [77]. Carbon storage is not a linear process however; it occurs rapidly for the first 20 years before slowing down. Storage depends on the kinetics of organic matter decomposition by the soil microbial community – in the long-term it tends to move towards an equilibrium in which inputs and outputs balance. However, there is no time-limit placed upon carbon storage – some very old global rangelands are still adding to their carbon stocks. The geospatial and climatic conditions also have an impact on the turnover of carbon in soils and how long time it takes to reach an equilibrium. In cooler climates the turnover is slower, and it takes longer time to reach equilibrium, compared to warmer climates. This factor must be accounted for when assessing changes in carbon stocks.

Maintaining grassland area or converting arable land to grassland makes it possible to store more carbon in the soil. However, it must be remembered that this process is both vulnerable and reversible. Soil carbon dynamics depend on grassland management practices, and some practices may affect both the physico-chemical conditions of the soil environment and the physical protection of organic matter in the soil [78]. The lack of a globally consistent and regionally detailed set of net CO_2 flux estimates makes it difficult to quantify these potential emission sources and sinks by region, although there are some relevant studies that provide useful estimates of the net fluxes for specific regions. For example, based on research on temperate grasslands in Western Europe, Soussana et al. [79] estimated that grassland sequestration rates average 5±30 g carbon per square meter per year. In a later publication, Soussana et al. [78] conceded that the uncertainties associated with CO2 stock changes following changes in management are very high.

Above ground carbon sequestration (e.g. trees and hedges) may also play a role in mitigating climate change. In some production systems, hedges are planted between fields to reduce erosion/protect crops from wind, or provide shade for grazing livestock. This above ground biomass is also important for biodiversity and other eco-system services. Regardless of whether carbon is stored below or above ground, carbon stocks are vulnerable to disturbances including tillage, fire, erosion and droughts that can lead to rapid reversals of accumulated stocks. Hence, if carbon sequestration is accounted for, CO_2 losses must also be quantified.

To date there is no consensus on how to account for carbon sequestration in LCA studies. Few studies have included carbon sequestration for dairy, although Knudsen et al. [80] is an exception. There are several ongoing projects developing methods on how to quantify GHG carbon sequestration, for example the C-Sequ project [34] and the GHG Protocol on Land Use and Removals Guidance [41]. The former project should be finalized during 2022 and the latter in 2023, both providing appropriate approaches for incorporating carbon sequestration into CF assessments, enabling farmers who are taking proactive sequestration actions to be credited. The aforementioned guides do not address how to take soil measurements – for further information on this and modelling soil carbon stocks and stock changes, see LEAP guidance on soil carbon stocks [44].

As carbon sequestration can have a significant impact on the CF of dairy, we recommend including carbon sequestration in any CF calculation, but reporting it separately. This approach is aligned with ISO14067 [26] in which it states that GHG emissions and removals from land use should be included, but shall be documented separately.

5.5.4. Drained organic soils

GHG emissions from drained organic soils (peat) shall be included in the LCI, following IPCC [50] or later if an update is available), and country-specific Tier 3 modelling should be used. If this is not available, the modelling summarized in sections 2.2.1.1 (CO_2), 2.2.2.1 (CH_4) and 2.2.2.2 (N_2O) of the 2014 supplement to IPCC [81] can be applied. Emissions should be calculated for both farm-produced and purchased feeds. In all GHG emissions calculations from drained organic soils, the calculation is based on the factor A, which for each crop-country combination is defined as the share of agricultural land area on organic soils and estimated via Equation 6:

$$A = \frac{\text{area of crop on drained organic soils}}{\text{total area of crop}}$$

Equation 6. Formula for calculating the proportion of drained organic soils in the total crop area (factor A)

Organic soils are generally identified on the basis of criteria 1 and 2, or 1 and 3 listed below:

1. Thickness of organic horizon greater than or equal to 10 cm. A horizon of less than 20 cm must have 12% or more organic carbon when mixed to a depth of 20 cm

2. Soils that are never saturated with water for more than a few days must contain more than 20% organic carbon by weight (i.e., about 35% organic matter)

3. Soils are subject to water saturation episodes and have either:
   a) At least 12% organic carbon by weight (i.e., about 20% organic matter) if the soil has no clay; or

b) At least 18% organic carbon by weight (i.e., about 30% organic matter) if the soil has 60% or more clay; or

c) An intermediate proportional amount of organic carbon for intermediate amounts of clay

Once A is determined per crop and country (or per farm, in case of farm-level assessment), GHG emissions can be calculated by using GHG-specific emission factors ($CO_{2,soil,organic}$, $CH_{4,soil,organic}$ and $N_2O_{soil,organic}$). These parameters should be based on primary data, or on national surveys (Tier 2). If these are not available, secondary data sources may be used (Tier 1, e.g. National Inventory Reports or FAOstat [82]).

For CO_2 emissions, Equation 7 shall be used:

$$CO_{2,soil,organic} = \sum_{c,n,d} (A \cdot EF_{CO_2,organic})_{c,n,d} \cdot \frac{44}{12}$$

Equation 7. Formula for calculating the CO_2-specific emission factor from drained organic soils

where:

$CO_{2,soil,organic}$ is the annual on-site CO_2 emissions/removals from drained organic soils in a land-use category (kg per year); The sum is calculated over different climate domains (subscript c), nutrient statuses (subscript n) and drainage classes (subscript d);

$A_{c,n,d}$ is the share of cultivated area on organic soils for climate domain c, nutrient status n and drainage class d (ha), which shall be provided by the practitioner;

$CF_{CO_2,organic\ c,n,d}$ is the emission factor for drained organic soils, for climate domain c, nutrient status n and drainage class d (kg per ha per year). This can be based on default values from Table 2.1 of (IPCC [50]); Tier 1). If country-specific emission factors are available (Tier 2), they shall be used.

For CH_4 emissions, Equation 8 shall be used:

$$CH_{4,soil,organic} = \sum_{c,n,d} \left(A_{c,n,d} \cdot \left((1 - Frac_{ditch}) \cdot EF_{CH_4,land_{c,n,d}} + Frac_{ditch} \cdot EF_{CH_4,ditch_{c,d}}\right)\right)$$

Equation 8. Formula for calculating the CH_4-specific emission factor from drained organic soils

where:

$CH_{4,soil,organic}$ is the annual CH_4 loss from drained organic soils (kg per year);

$A_{c,n,d}$ is the share of cultivated area on organic soils for climate domain c, nutrient status n and drainage class d (ha), which shall be provided by the practitioner;

$EF_{CH_4,land_{c,n,d}}$ is the emission factor for direct CH_4 emissions from drained organic soils, for climate zone c and nutrient status n, and drainage class d (kg per ha per year). This can be based on default values from Table 2.3 of (IPCC, [50]; Tier 1). If country-specific emission factors are available (Tier 2), they **shall** be used.

$EF_{CH_4,ditch_{c,d}}$ is the emission factor for direct CH_4 emissions from drainage ditches, for climate zone c and drainage class d (kg per ha per year). This can be based on default values from Table 2.4 of (IPCC, [50]; Tier 1). If country-specific emission factors are available (Tier 2), they shall be used.

$Frac_{ditch}$ is the fraction of the total area of drained organic soil which is occupied by ditches, where "ditches" are considered to be any area of manmade channel cut into the peatland (dimensionless). The ditch area may be calculated as the width of ditches multiplied by their total length. Where ditches are cut vertically, ditch width can be calculated as the average distance from bank to bank. Where ditch banks are sloping, ditch width should be calculated as the average width of open water plus any saturated fringing vegetation. This can be based on default values from Table 2.4 and Table 2A.1 of (IPCC, [50]; Tier 1). If country-specific emission factors are available (Tier 2), they shall be used.

For N_2O emissions, Equation 9 shall be used:

$$\boldsymbol{N_2O_{soil,organic} = \sum_{c,n,d} \left(A_{c,n,d} \cdot EF_{N_2O,organic\ c,n,d}\right. \cdot \frac{44}{12}}$$

Equation 9. Formula for calculating the N_2O-specific emission factor from drained organic soils

where:

$N_2O_{soil,organic}$ is the total direct N_2O emission from managed soils (kg per year);

$A_{c,n,d}$ is the share of cultivated area on organic soils for climate domain c, nutrient status n and drainage class d (ha), which shall be provided by the practitioner;

$EF_{N_2O,organic\ c,n,d}$) is the emission factor for drained organic soils, for climate domain c, nutrient status n and drainage class d (kg per ha per year). This can be based on default values from Table 2.5 of (IPCC, [50]; Tier 1). If country-specific emission factors are available (Tier 2), they shall be used.

5.5.5. Summary of land use change, carbon sequestration and organic (peat) soils

Table 2 provides an overview of recommendations to be included in CF calculations of dairy products as per the current revision of the IDF guidelines, and how these emissions or sequestration should be documented (the table is inspired by ISO 14067 [26]).

Table 2: Overview of the revised IDF guidelines of what to include in CF calculations for dairy products

	Treatment in calculations			Documentation	
	Shall be included	***Should be included***	***Should be considered for inclusion as a sensitivity assessment***	***Shall be documented separately***	***Shall be documented separately, if calculated***
*GHG emissions from **dLUC***	X			X	
*GHG emissions from **iLUC***			X		X
*GHG emissions from **peat soils***	X			X	
*GHG removals from **carbon sequestration***		X			X

6
IMPACT ASSESSMENT

By contrast to the various steps that have to be executed before this stage, the calculation of the CF is relatively simple, although the aforementioned caveats as to accuracy, representative data, transparency and justifying methodologies and assumptions still hold.

6.1. THE CF CALCULATION

The following procedure is used to calculate the CF for a FU of dairy product:

1. Assess the GHG emissions of each activity involved in the life cycle of your product by multiplying all materials, energy and waste within an activity by their GHG emission factors. Then add the direct GHG emissions produced from the activity and sum the GHG emissions for the separate substances (e.g., CH_4, N_2O or CO_2) across all activities.

2 Emissions data of the different GHG substances are then converted into **CO2e** by **multiplying** the emissions of the individual GHG substances (e.g., kg CH_4) by the relevant impact characterization factor (see below). Summing the CO_2e from all GHG substances results in the total CF, which needs to be divided by the total number of FU provided by the system (e.g. total kg FPCM milk sold or total litres of milk consumed) to give the CF per FU. It is also recommended that you provide results split by life cycle stages as well as per emission substance.

The recommended impact characterization factor is the 100-year global warming potential (GWP_{100}). Because the GWP factors have changed over time, it is recommended to always apply the most recent IPCC GWP factors when undertaking a product CF calculation using this methodology. The currently most recent factors can be found in Chapter 7.6 of 'The Physical Science Basis' volume of the IPCC 2021 report on climate change [33]. For GWP_{100}, the following factors (including carbon cycle responses) are reported:

- 1 kg of fossil CH_4 (CH_4 fossil) = 29.8 kg of CO_2e
- 1 kg of non-fossil CH_4 (CH_4 non-fossil) = 27.0 kg of CO_2e
- 1 kg of N_2O (N_2O) = 273 kg of CO_2e

GWP factors for different refrigerants are available from the same reference document as the factors listed above. The choice of GWP factors used in a CF study can have significant impacts on the result, and if the purpose is to compare emissions in a specific context where other GWP factors are used (e.g., to be PEF [28] compliant the GWP factors from IPCC 2013 including carbon-climate feedbacks shall be used), then obviously the most appropriate GWP must be chosen.

6.2. CALCULATING THE ENVIRONMENTAL FOOTPRINT

In LCA it is possible to include other environmental impacts (e.g. acidification or eutrophication) in addition to climate change. This revision of the IDF guide does not give detailed guidance on how to calculate these impact categories. However, once data have been collected to calculate the CF, additional calculations for other environmental impacts does not require too much additional effort, although some exceptions occur (e.g. toxicity). Calculating additional environmental impact categories may be useful to understand more about possible negative side effects of mitigation options for climate change. **They may** also help to nuance the impact of dairy products compared with other food products. For example, almond drinks that contains almonds from water-scarce regions may have a low CF, but a higher water footprint than liquid milk.

Environmental impact categories that may be assessed in an LCA include: climate change, acidification, land use, water use, photochemical ozone formation, ionizing radiation, particulate matter emission, eutrophication (marine, freshwater and terrestrial), resource use (fossil metals and minerals) and ecotoxicity (human, cancer, non-cancer). There are different environmental impact assessment (EIA) methods to determine the LCA results. Examples of widely applied EIA's include ILCD [83], ReCiPE [84] and PEF [28]. An optional step is to aggregate results from individual impact categories into a single score, i.e., one number that determines the overall environmental impact of a product. This is done through a process of normalization which means recalculating impacts into the same unit and weighting the relative damage or importance of the different impact categories. Different EIA may use different characterization, normalization and weighting factors which may affect the result, therefore comparing studies using different EIA's should be executed with care. Furthermore, data throughout the life cycle for some of the additional impact categories for dairy may be scarce, e.g. data on fine dust or heavy metal losses to soils in agriculture. We recommend these insecurities be taken into account when drawing conclusions.

The list of impact categories is quite exhaustive and not all environmental issues are equally relevant to dairy or the food sector. In the PEFCR Dairy [30], a hotspot identification based on the PEF EIA method has revealed that the most relevant impact categories for dairy are: climate change, particulate matter, acidification, eutrophication, land use, water use and resource use (fossil). This may help to narrow down the scope. However, there are still several environmental impact categories and environmental issues that are important from a sustainability perspective, but are not typically included in LCA (e.g. biodiversity or plastic pollution). In the interests of understanding the full picture of dairy's environmental impacts, it is recommended that these issues receive greater research interest than they currently command.

7 INTERPRETATION

A CF study always includes some uncertainties, therefore evaluating and reporting the results is a critical step within the study. The majority share of GHG emissions from dairy products are represented by the biogenic emissions CH_4 and N_2O which are impossible to measure absolutely accurately, therefore a certain degree of uncertainty will always be related to these emissions. In addition, as a biological system, considerable natural variation occurs in, for example, crop yields due to weather conditions. These factors must be accounted for within the discussion of the results and according to the goal of the study (section 3.2).

7.1. REPORT EVALUATION AND SENSITIVITY ANALYSIS

The results reported and associated sensitivity analyses depend on the goal of the study. In general, we recommend that any dairy product CF report includes a section identifying ways in which emissions could be reduced. This demonstrates that the exercise has a purpose (i.e. continual emissions mitigation), and that the knowledge gained from the study will lead to improvements, even if it these are minor or gained through the "quick-win" solutions. It may also be important to conduct a sensitivity analysis to understand the impact of various environmental parameters and process choices within the dairy product life cycle, for example, choosing road or rail transport, or the impact of different milk yields. Whether a sensitivity assessment is necessary, and how detailed it should be, depends on the purpose of the study and how detailed data has been used (see next section). A sensitivity analysis is especially important if doing a comparative assessment.

7.2. REPORTING

How detailed the reporting should be also depends on the purpose of the study (for example, corporate reporting or a product LCA). For corporate reporting, emissions should be reported in terms of scopes 1, 2, and 3, while for a product LCA results are typically reported according to the different life cycle stages (farm, site, transport, packaging, and retail/consumer). However, the principles listed below are derived from financial accounting and reporting principles, which are also applicable to this situation. These principles also reflect the outcome of a collaborative process involving stakeholders from a wide range of technical, environmental, and accounting disciplines. Thus, GHG accounting and reporting should be based on the following principles, as described in the WRI and WBCSD GHG Protocol Product Life Cycle Standard [39]

- Relevance – Ensure that the GHG inventory reflects the GHG emissions of the company or industry and serves the decision-making needs of both internal and external users
- Completeness – Ensure that the inventory report covers all product life cycle GHG emissions and removals within the specified boundaries; disclose and justify any significant GHG emissions and removals that have been excluded
- Consistency – Choose methodologies, data, and assumptions that allow for meaningful comparisons of a GHG inventory over time
- Transparency – Address and document all relevant issues in a factual and coherent manner, based on a clear audit trail. Disclose any relevant assumptions and make appropriate references to the methodologies and data sources used in the inventory report. Clearly explain any estimates and avoid bias so that the report faithfully represents what it purports to represent
- Accuracy – Ensure that reported GHG emissions and removals are not systematically greater than or less than actual emissions and removals and that uncertainties are reduced as far as practicable. Achieve sufficient accuracy to enable intended users to make decisions with reasonable assurance as to the reliability of the reported information

As discussed in section 5.1, the source of all data should be documented (e.g. the reference, the company, or the site the data is collected from; or from which database, article or report it is taken); and the temporal, geographical and technological range should be clearly stated.

7.3. KEY PARAMETERS OF THE CF REPORT

To obtain a better understanding of the studied dairy product system it is beneficial for the following 'key parameters' to be included in the report:

- Total CF, divided into:
  - Fossil and biogenic CH_4
  - N_2O
  - Fossil CO_2
  - Biogenic CO_2 (biogenic carbon in packaging and carbon emissions from LUC should be reported separately)
  - CO_2 and N_2O from organic (peat) soils
  - Carbon sequestration (if assessed)
- FU used
- Percentage of emissions attributed to milk (i.e. allocation factor between milk and meat/animals (and potentially manure), and the method used to determine the allocation factor)
- Milk yield per cow and milk composition

- DM intake per cow and body weight per animal class
- DM intake divided into different feed types (as a minimum, the share of forage versus concentrate feed)
- Manure management system
- All emission factors and GWP factors used and their sources
- Allocation factors applied in the dairy manufacturing plant and all other applicable life cycle stages

8 GLOSSARY AND ABBREVIATIONS

Action Team (AT)
IDF committee set up to advise on specific topics and, if necessary, produce guides and reports

Allocation
Partitioning the inputs or emissions from a shared process or a product system between the product system under study and one or more other product systems.

Allocation Factor (AF)
Factor used in allocation calculations to partition resources or emissions between systems or products

Anhydrous milk fat (AMF)
Anhydrous milk fat is a concentrated butter with a milk fat content of 99.8% and a maximum water content is 0.1%

Attributional
LCA assessments that describe the environmentally relevant physical flows to and from the product or process.

Biogenic
Derived from biomass, but not fossilized or from fossil sources.

Biomass
Material of biological origin, excluding material embedded in geological formations or transformed to fossil.

Boundary
Set of criteria specifying which unit processes are part of a product system (life cycle).

By-Product
Side-product associated with a main product process or system, of lower value than a co-product

Capital goods
Goods, such as machinery, equipment and buildings, used in the life cycle of products

Carbon dioxide (CO_2)
An important heat-trapping (greenhouse) odourless and colourless gas, which is released through human activities such as deforestation and burning fossil fuels, as well as natural processes such as respiration and volcanic eruptions

Carbon dioxide equivalent (CO2e)
Unit for comparing the radiative forcing (global warming impact) of a GHG expressed in terms of the amount of carbon dioxide that would have an equivalent impact.

Carbon footprint (CF)
The total quantity of GHG emissions that come from the production, use and end-of-life of a product or service, usually expressed in carbon dioxide equivalents (CO_2e).

Cattle
Cattle (within this document) refers to both cows and buffalo and includes all animals at their different stages of life, including calves, heifers, dry and lactating cows.

Combined heat and power (CHP)
Simultaneous generation in one process of useable thermal energy and electrical and/or mechanical energy.

Carbon storage/sequestration
Retention of carbon from biogenic or fossil sources of atmospheric origin in a form other than as an atmospheric gas. e.g. in soils or vegetation

Consequential
LCA assessments that describe how relevant environmental flows will change in response to different decisions, e.g. changes in demand.

Co-products
Any of two or more products from the same unit process or product system

Data quality
The reliability and uncertainty of data used to calculate the carbon footprint

Default data
Predefined data in a standard or guidance which can be used when no primary data is available

Direct land use change (dLUC)
The concept used to capture a responsibility for land use change inside the immediate product system boundary, e.g. on the land used to cultivate the feedstock.

Dry matter (DM)
The quantity of material remaining after all the water has been evaporated off – the non-water component of a product (e.g. feed, forage)

Emission factor
Quantity of GHG emissions expressed per unit (e.g. CO_2 per kWh electricity or NH_3 per kg manure). Emission factors are typically obtained from secondary data sources.

Emissions
Releases to air that result in GHG entering the atmosphere. The main GHG emissions from agriculture are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4).

Enteric fermentation
A natural part of the digestive process for most ruminant animals, whereby anaerobic microbes, called methanogens, decompose and ferment feed present in the digestive tract producing compounds that are then absorbed by the host animal.

Environmental impact assessment (EIA)
A tool used to assess the significant effects of a project or development proposal on the environment.

Environmental product declaration (EPD)
An EPD tells the life cycle story of a product in a single, comprehensive report. The EPD provides information about a product's impact upon the environment, such as carbon footprint, smog creation, ozone depletion and water pollution.

Fat-and-protein-corrected milk (FPCM)
A volume of milk standardized according to set fat (4.0%) and protein (3.3%) contents, which can therefore be used to compare yields, resource use or efficiencies across production systems.

Functional unit (FU)
This expresses the function of a studied product or service in quantitative terms and serves as a basis of calculations. It is the reference flow to which all other flows in the CF model are related. It also serves as a unit for comparison.

Global warming potential (GWP)
Developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2).

Greenhouse gas (GHG)
Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. Note that GHGs include among

others carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride (SF_6).

Indirect land use change (iLUC)
The concept used to capture a responsibility for land use change outside the immediate product system boundary.

Input
Product, material, resource or energy flow that enters a unit process.

Land use (LU)
The total arrangements, activities and inputs applied to a parcel of land. The term land use is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction). Land use is classified according to the IPCC land use categories of forest land, cropland (annual and perennial), grassland, wetlands, settlements, other lands.

Land use change (LUC)
The change from one land use category to another.

Life cycle
Consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to end of life, inclusive of any recycling or recovery activity, for example the cradle-to-grave life cycle of a dairy product.

Life cycle assessment (LCA)
An integral method to evaluate the potential environmental impacts of a product system throughout its life cycle based on the inputs and outputs of the system

Life cycle GHG emissions
Sum of GHG emissions resulting from all stages of the life cycle of a product and within the specified system boundaries of the product.

Life cycle impact assessment (LCIA)
Life cycle impact assessment (LCIA) is the phase of an LCA where the evaluation takes place of the potential environmental impacts stemming from the elementary flows (environmental resources and releases) obtained in the LCI.

Life cycle inventory (LCI)
The phase of an LCA that involves creating an inventory of input and output flows for a product system. Such flows include inputs of water, energy, and raw materials, and releases to air, land, and water.

Methane (CH_4)
A colourless, odourless gas that occurs abundantly in nature under anaerobic circumstances and as a product of certain human activities (ruminant animal farming (enteric digestion and manure) fossil fuel extraction and landfill). Methane is the simplest member of the paraffin series of hydrocarbons and is among the most potent of the greenhouse gases. Methane has a global warming potential of 27.0 (biogenic) and 29.8 (fossil) kg CO_2e per kg CH_4 [33].

(Biogenic) Methane
Produced from biological process (e.g. in plant, soil or animal). This is carbon within the short carbon cycle.

(Fossil) Methane
These emissions return geological carbon back to the atmosphere that has typically been stored underground for millions of years. Releasing fossil methane adds to the atmospheric concentrations of carbon dioxice, thus causing additional warming as methane.

Methane conversion factors (MCF)
Country-specific values for the provision of precise enteric methane emissions inventory reports. Used in conjunction with “Ym” – a factor for the proportion of dietary energy lost as methane.

Material contribution
Contribution from any one source of GHG emissions to a product of more than 1% of the anticipated life cycle total GHG emissions associated with the product being assessed. Note that a materiality threshold of 1% has been established to ensure that very minor sources of life cycle GHG emissions do not require the same treatment as more significant sources.

Milk solids (MS)
The sum of the three different solids found in milk: fat, protein and lactose. A small amount of minerals, also referred to as ash, are also contained in milk, however, these are usually disregarded when calculating the MS.

Net energy (NE)
The amount of energy in the feed minus the energy lost in the feeces, urine, and in heat production through digestive and metabolic processes.

Nitrous oxide (N_2O)
An odorless and colorless GHG resulting from nitrification and denitrification from soils and industrial processes. Nitrous oxide has the global warming potential of 273 kg CO_2e per kg N_2O [33].

Offsetting
A mechanism for balancing out GHG emissions associated with a process or product through the removal of, or preventing the release of GHG emissions in a process unrelated to the life cycle of the product being assessed.

Organic soils
In this document, these refer to drained peat soils with a significant content of organic matter.

Output
Product, material, resource or energy flow that leaves a unit process.

Peat soils
Drained soils with a significant content of organic matter.

Primary activity data
Quantitative measurement of activity from a product's life cycle that, when multiplied by an emission factor, determines the GHG emissions arising from a process. Examples include the amount of energy used, material produced, service provided or area of land affected.

Product
Any good or service.

Publicly available specification (PAS)
A standardization document that closely resembles a formal standard in structure and format but which has a different development model.

Product category rules (PCR)

A set of rules, requirements and guidelines for developing Environmental Product Declarations (EPD) for one or more product categories.

Product environmental footprint (PEF)
A methodology that measures the environmental performance of any service or product throughout its life cycle, taking into account all the supply chain activities.

Product environmental footprint category rules (PEFCR)
A set of rules on how to measure the life cycle environmental performance of the product in scope.

Raw material
Primary or secondary material used to produce a product

Secondary data
Data obtained from sources other than direct measurement of the emissions from processes included in the life cycle of the product. Note that secondary data is used when primary activity data is not available or it is impractical to obtain primary activity data. In some case, such as emission factors, secondary data may be preferred.

Short carbon cycle
Carbon recently derived from carbon dioxide in the atmosphere, i.e. through photosynthesis, respiration and biogenic decay.

System boundary
Set of criteria specifying which unit processes are part of a product system (life cycle).

System expansion
Expanding the product system to include the additional functions related to the co-products or subtracting the system with the additional function of an alternative system.

Unit process
Smallest element considered in the life cycle inventory analysis for which input and output data are quantified

Volatile solid (VS)
Substances that can easily transform from their solid phase to their vapour phase, without going through a liquid phase.

Waste
Substances or objects which the holder intends or is required to dispose of.

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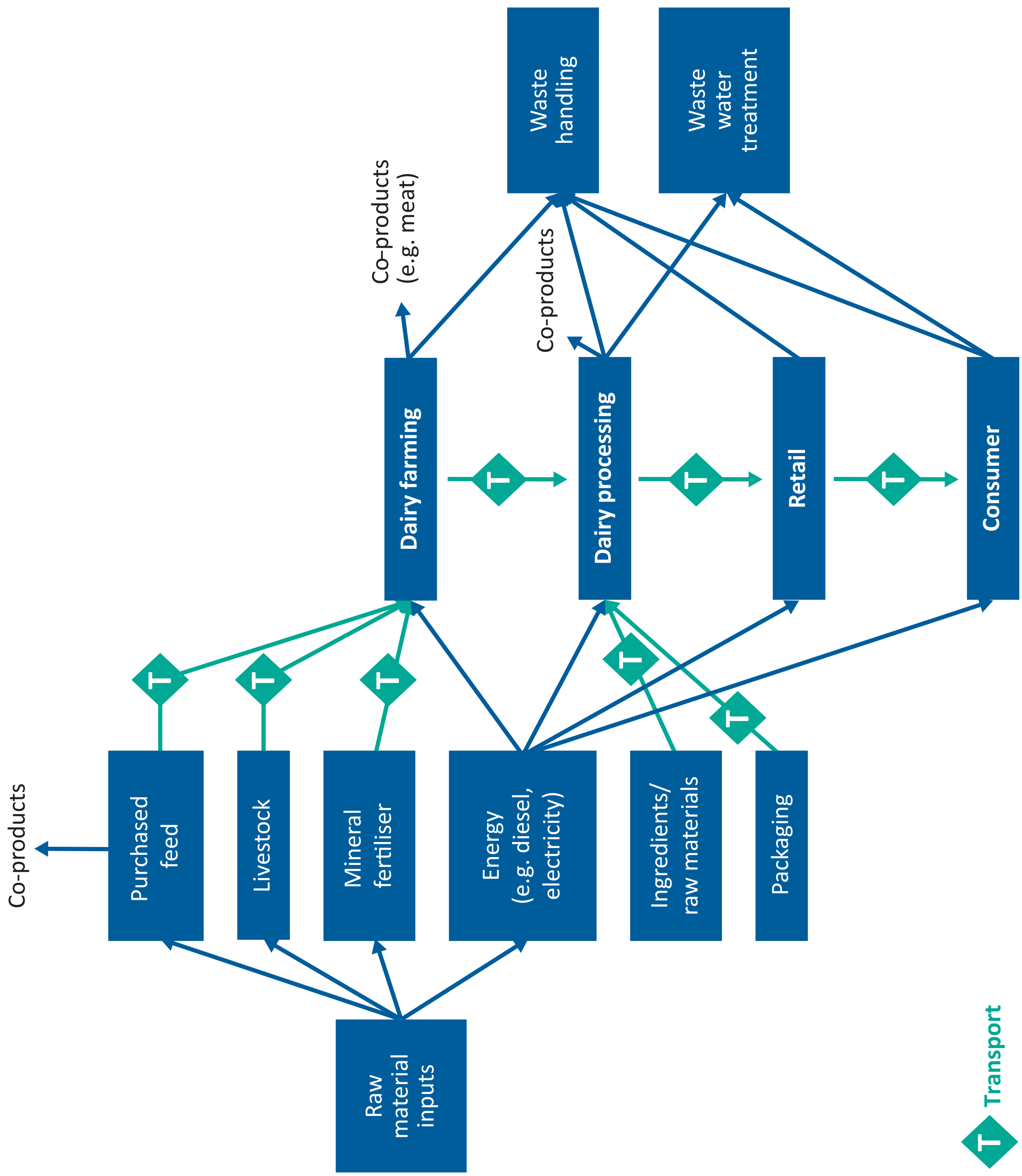
10 APPENDICES

10.1. FLOW CHART OF A DAIRY PRODUCT VALUE CHAIN



10.2. CALCULATING THE FU FOR MILK PRODUCTION AT THE FARM LEVEL

The energy content of milk with known fat and protein content is calculated by:

$NE_L = 0.0929 * Fat\% + 0.0563 * TP\% + 0.0395 * Lactose\%$ (Mcal/kg)[9]

Equation 10. Formula for calculating the energy content of milk with known fat and protein content

Where: TP is true protein content. Which for standard milk (4% fat; 3.3% TP) is 0.748965 Mcal/kg or 3.13 MJ/kg. This simplifies the equation to[10]:

$$\boldsymbol{NE_L = 0.0929 * Fat\% + 0.0563 * TP\% + 0.192}$$

Equation 11. Simplified formula for calculating the energy content of milk with known fat and protein content

Where: lactose content is assumed to be 4.85%, which is typical in dairy cattle, but may vary for other species. Note that if crude protein, as opposed to true protein is used, the protein coefficient should be changed to from 0.0563 to 0.0547. Most modern dairy testing results report true protein.

To correct the production from an individual operation to the fat and protein standard, first select the standard composition and then multiply the annual production of the operation by the ratio of the energy content of the standard milk (typically 4% fat and 3.3% crude protein and 4.85% lactose but can be varied if desired).

An example is shown in Table 3 of the relative FPCM for cow, buffalo and standard milk.

9 Equation 2-15 from National Research Council (U.S.), Subcommittee on Dairy Cattle Nutrition, 2001. Nutrient requirements of dairy cattle. National Academy Press, Washington, D.C. [51]

10 Equation 2-16. (Ibid.)

Table 3. Example calculation of FPCM production

	Operation A (cow)	Operation B (buffalo)	Standard Milk
Production	1000 Mg	1800 Mg	n/a
Fat content	4.5%	7.36%	4.0%
Protein content	3.1%	4.19%	3.3%
Lactose content	4.85%	5.08%	4.85%
Energy content (Mcal/kg)*	0.784155	1.120301	0.748965
FPCM factor§	1.0470	1.4958	
FPCM production§§	1047 Mg	2692 Mg	n/a

* Calculated using equation 11, above.
§ Ratio of calculated energy content to energy content of standard milk.
§§ Milk production multiplied by FPCM factor.

10.3. EXAMPLE OF CALCULATING TIER 3 ENTERIC CH_4 EMISSIONS CONFORMING TO INRA

$$\Delta OMd\_FL = -2.74 \times (FL - FLref)$$

Equation 12. Digestive interaction related to feeding level for forages and concentrates and by products.

Where: ΔOMd_FL (% unit of organic matter digestibility) is the digestive interaction

FL is the feeding level of the diet (DM intake, % B W (body weight)),

FLref is the reference FL of a given feedstuff (DM intake, % BW).

For forages, the FLref corresponds to FL measured *in vivo* on standard sheep for determining the tabulated OM digestibility. For concentrates and byproducts FLref is fixed at 2, which corresponds approximately to the mean of the FLref of forages in tables published in Sauvant [85].

$$\Delta OMd\_CO = -6.5 / (1 + (0.35/PCO)^3)$$

Equation 13: Digestive interaction related to variation in the proportion of concentrate fed in the diet

where ΔOMd_CO is the digestive interaction related to variation in proportion of concentrate (% units of OM digestibility)

PCO is the dietary proportion of concentrate ($0 \leq PCO < 1$).

Calculation Example

If a lactating cow fed with a diet having FLref = 2.0% BW and OMd = 79.0%, based on tabulated values, and experienced an actual FL = 3.5% BW and PCO = 0.4, the total reduction in digestibility would be:

ΔOMd_FL = -2.74 x (3.5 – 2.0)

ΔOMd__FL = - 4.1%, and

ΔOMd_CO = -6.5 / (1 + (0.35/0.4)^3)

ΔOMd_CO = -3.9%

total ΔOMd = ΔOMd__FL + ΔOMd_ CO

total ΔOMd = - 8.0%

Thus, OM digestibility would be 71% instead of 79%.

10.4. EXAMPLE OF CALCULATING ALLOCATION BETWEEN CO-PRODUCTS FOR DAIRY COW FEEDS

If meal and oil are co-products, and meal is used for feed as part of the LCA, the economic allocation factor (AF) is the value of the output of meal divided by the value of the combined output, as calculated using the equation below. The output from the process is X kg meal (with the price of A $/kg meal) and Y kg oil (with the price of B $/kg oil). Therefore:

$$\mathbf{Af_{meal} = (X*A) / (X*A + y*B)}$$

Equation 14: Formula for calculating the allocation factor for meal – a co-product used for cattle feed

The allocation factor is then multiplied by the environmental impact from the process (e.g. emissions associated with cultivating and transporting the raw material, energy used for processing), and then divided by X to get the CF for one kg of meal. Please, note that the specific currency considered is irrelevant, as long all the co-product prices are expressed in the same currency. This is typically, the currency of the country in which the process occurs.

In the example shown in Figure 12, for a hypothetical production of 1000 kg of rapeseed yielding 520 kg of rapeseed meal and 430 kg of rapeseed oil (50 kg of the initial weight are lost in the waste stream), and market prices of 0.18 $/ kg rapeseed meal and 0.85 $/ kg rapeseed oil, applying the equation above, the allocation factor for the production of rapeseed meal is (520*0.18) / (520*0.18 + 430*0.85) = 0.2039. To avoid errors, we suggest rounding at 4 significant figures.

Figure 12 Example of allocation of co-products for feed

10.5. EXAMPLE OF CALCULATING ALLOCATION BETWEEN MILK AND MEAT

The example shown in Figure 13 demonstrates the calculation of the allocation between milk and meat for a hypothetical farm with 650 Milking Shorthorn (mature weight of 568 kg) lactating animals each producing 8500 kg FPCM per year for a total of 5525 Mg FPCM per year. If the replacement rate is 25%, and excess heifers and bull calves (assumed 35.6 kg each at birth) are fattened on-site to the age of 12 months prior to sale to the beef sector. For the purposes of this simple example, it is assumed that the fattening operation is not separated from the dairy operation, and therefore allocation among the three main product is needed. For purposes of this example, we assume that the total unallocated CF for this example is 1.4 kg CO2e/kg FPCM giving an unallocated total emission for the operation of 7735Mg CO_{2e}.

Cull cows: 568 kg/head * 163 head = 92.3 Mg; Assuming 1 calf/cow/year and even sex distribution and ignoring mortality: 162 heifers*300 kg/head + 325 bull calves*300kg = 146Mg; here we assume calves are fattened for 12 months and reach 300 kg each.

Approximations for the net energy requirements for growth are assumed to be 27.5 MJ/kg for calves sold at birth; 15 MJ/kg LW for mature animals; 11 MJ/kg LW for bred heifers and fattened calves; and 3.1 MJ/kg FPCM (following Nemecek and Thoma [69]).

Using the equation for allocation (step 2 above), the allocation to milk is:

$$AF_{milk} = \frac{3.1\ MJ/kg * 5525000\ kg}{3.1\frac{MJ}{kg} * 5525000\ kg + 11\frac{MJ}{kg} * 146000\ kg + 15\frac{MJ}{kg} * 92300\ kg} = 0.851$$

Thus 85.1% of the unallocated footprint is allocated to milk, yielding a farm-gate footprint of 1.19 kg CO_2e/kg FPCM.

To calculate the allocation to fattened calves, simply replace the numerator of the equation with the contribution from fattened calves (the middle term in the denominator):

$$AF_{fattened} = \frac{11\ MJ/kg * 146000\ kg}{3.1\frac{MJ}{kg} * 5525000\ kg + 11\frac{MJ}{kg} * 146000\ kg + 15\frac{MJ}{kg} * 92300\ kg} = 0.08$$

Similarly for culled cows, the allocation fraction is calculated by replacing the numerator with the third term in the denominator.

8% is allocated to fattened calves and 6.9% to culled cows. Thus, the footprint for fattened calves is:

$$\frac{AF_{fattened} * \text{Total Emission}}{LW\ production} = \frac{0.08 * 7735000\ (kg\ CO_{2e})}{146000\ (kg\ LW)} = \frac{4.24\ kg\ CO_{2e}}{kg\ LW}$$

And for culled cows the allocation fraction is 0.069, leading to a footprint of 5.78 kg CO_2e/kg LW.

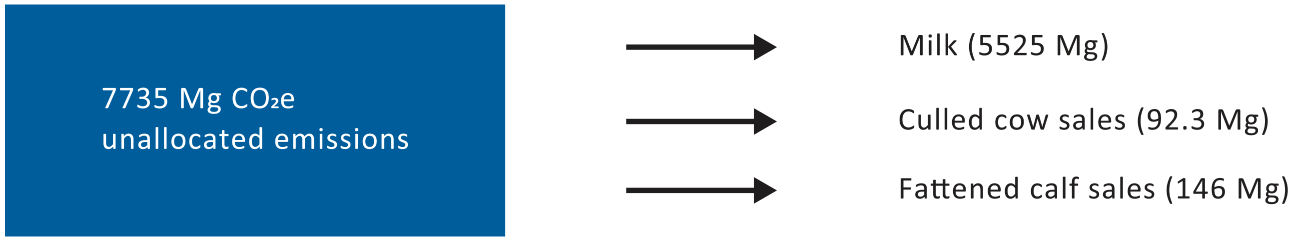


Figure 13 Example of allocation between milk and meat as a co-product

10.6. THE SCIENTIFIC BASIS FOR THE APPROACH OF ALLOCATION BETWEEN MILK AND MEAT

A large study that included collection of detailed farm-level data from 536 US farms was completed in 2012 by Thoma et al. (2013) [67]. In that study a causal relationship between the energy content in the animal ration and milk and beef production was developed. However, since implementation of the regression equation presented in work, it has become clear that limitations to its applicability need to be addressed. Specifically, differences the allocation to different animal classes which may be sold from the farm and the observation that the relationship has a limited range of applicability and that there are frequently systems which operate outside of valid range of the relationship.

The current guidelines expand the approach proposed by Nemecek and Thoma [69] based on the principle of net energy utilization for growth versus milk production on a dairy operation. This approach is based on application of the IPCC 2019 revised Guidelines for National Greenhouse Gas Inventories [8] combined with NRC 2001 pregnancy relationships. The following relationships are adopted (equation numbers refer to IPCC):

$$NE_p = \int_{179}^{270} (0.00318 * t - 0.0352) \left(\frac{CBW}{45}\right) dt \qquad \text{(EQ: 2.19, [51])}$$

$$NE_G = 22.02 \left(\frac{BW}{c\ (MBV)}\right)^{0.75} (ADG^{1.097}) \qquad \text{(EQ: 10.6, [8])}$$

Where NE_P is net energy for pregnancy (MJ/day) and NE_G is net energy for growth (MJ/day). CBW is calf birth weight (kg); BW is body weight (kg); BW is body weight (kg); and ADG is average daily gain (kg/day). The constant '**c**' in the net energy for growth relationship is 0.8 for heifers, 1.0 for steers, and 1.2 for bulls.

Nemecek and Thoma [69] performed integrations on equation 10.6 and demonstrated that a reasonable average value for NE_G falls in the range of 11-15 MJ/kg (except for calves sold immediately). A mathematically more rigorous approach to calculating animal class specific estimates for NE_G is to estimate the net energy from the following integral:

$$NE_g(\text{age}) = \int_{o}^{age} 22.02 \left(\frac{BW(t)}{c\ (MBV)}\right)^{0.75} (ADG^{1.097})dt$$

Where t is the animal age in days. This calculation is straightforward if the growth curve the animal is known. A common and simple growth model can be adapted to enable calculations. The von Bertalanffy relationship expressing weight as a function of age is used for predicting the growth of numerous species, and specifically evaluated for cattle [86].

$$BW(t) = MBW(1 - Be^{-kt})^3$$

$$ADG(t) = 3k\ \mathrm{BW(t)} \left[\frac{Be^{-kt}}{1 - Be^{-kt}}\right]$$

Based on the NRC [51] recommendations that dairy animals' weight at first breeding should be approximately 0.55MBW allows the growth constant, k, to be estimated from the following relationship, where AFC is the age at first calving (in days):

$$\mathbf{k = \frac{-1.2045685065}{\mathit{AFC} - 280}}$$

and the constant, B, can be calculated from the calf birth weight, typically 0.06275MBW (at age =0):

$$\mathbf{B = 0.6026213}$$

A spreadsheet is available for these calculations.

The process for calculating the allocation therefore can be summarized as follows:

Step 1a: Collect/determine the live weight of animals each weight class sold per year [kg meat] total kg/year.

Step 1b: Collect/determine the total kg of milk (4% fat and 3.3% protein equivalent) produced per year.

Step 2: Calculate the Net Energy for growth for each animal class from the integral formula

Step 3: Calculate the allocation factors

The approach outlined here avoids some of the shortcomings of economic or fixed allocation algorithms. Specifically, it prevents the allocation fraction from changing due to variation in the economics of the milk and meat sectors, and it provides an accounting of differences in relative production between milk and meat at scales from single farms to regions.

Note that the net energy required for use in the calculations is strictly for growth and lactation; maintenance energy is not included in the calculation of the allocation fraction but is later allocated between the co-products. Furthermore, questions regarding purchased animals, for example bred heifers purchased as replacements, do not affect the allocation calculations because these animals are considered input resources to the farm, similar to feed or electricity, and when these animals are sold, they will be included in calculation of the allocation fraction as well as receiving an allocated burden from the operation.

10.7. EXAMPLE OF CALCULATING ALLOCATION BETWEEN PRODUCTS AT THE DAIRY PROCESSING SITE

Allocation of raw materials and energy, between different products, is based on the milk solid (MS) content of fat, protein and lactose[11]. The following example uses fictitious numbers.

A dairy site produces cheese and whey as a by-product. The annual total raw milk intake is 1000 tonnes of raw milk (12.7% MS), and the production of cheese (59% MS) is 105 tonnes. In addition, 875 tonnes of whey (7% MS) are produced as a by-product from the cheese making. There is a loss of dairy raw material at the site of 2% (20% MS – see Figure 14).

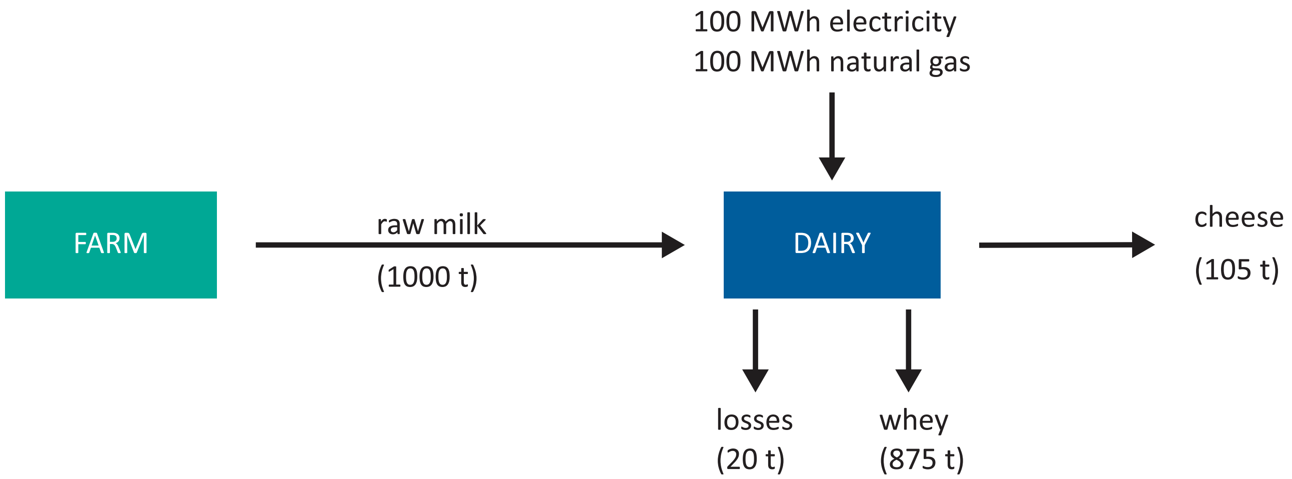


Figure 14: Simplified overview of inputs and outputs to the dairy site for cheese production

The CF of raw milk is 1.5 kg CO_2e per kg FPCM (12.15% MS). Since there is a different MS content in raw milk and FPCM, this needs to be adjusted for, hence the total raw milk intake of 1000 tonnes corresponds to 1045 tonnes FPCM (1000 tonnes*12.7%/12.15%). So the total CF for raw milk intake is 1568 tonnes CO_2e.

The CF for the energy use at the dairy site is 100 MWh electricity and 100 MWh natural gas. The emission factor for electricity is 0.5 tonnes CO_2e per MWh and 0.2 CO_2e per MWh for natural gas. The total CF for the energy use 70 tonnes CO_2e (100*0.5+100*0.2).

If the whey is used (further processed to whey powder) the emissions need to be allocated between cheese and whey. The total MS in the products are 62 tonnes MS for the cheese (105 tonnes*59%) and 61 tonnes MS for the whey (875 tonnes*7%). Using equation 5 (see section 5.4.3) then gives the allocation factor of 50% to cheese.

The cheese CF, if all whey is utilized for human consumption, is 823 tonnes CO_2e in total ((1568 tonnes CO_2e + 70 tonnes CO2e)*0.5) and 7.8 kg CO_2e per kg cheese (826 000 kg CO2e/105 000 kg).

11 The total MS content, also including ash, is slightly higher.

If the whey is not utilized for human products, but is used for pig feed, no emission shall be allocated to the whey, which means that the cheese shall take the whole environmental burden. The CF for the cheese is then 1638 tonnes CO_2e (1568 tonnes CO_2e + 70 tonnes CO_2e) and 15.6 kg CO_2e per kg cheese (1638 000 kg CO_2e/105 000 kg).

10.8. EXAMPLE OF CALCULATING DIRECT LUC

When LUC is known:

In Guatemala, 10 years ago, 1 ha of tropical mountain forest with high activity (HAC) soils and in a wet tropical climate has been converted into a sugar cane cultivation with medium level of inputs and a full tillage intensity. The presented definitions are based on IPCC [8] terminology and maps on soil and climate are provided by the JRC [87]. These various parameters can be used to estimate:

- Soil carbon stock of expanding crop (SOCa): 44.4 ton C/ha. This is the soil carbon stock of the cropland system, dependent on climate, soil type, crop type, tillage management and inputs level, based on IPCC [48].
- Vegetation carbon stock of expanding crop (CVEGa): 34.4 ton C/ha. This is the vegetation carbon stock of the expanding crop dependent on crop type and climate, based on EC [88].
- Reference soil carbon stock (SOCr): 44.0 ton C/ha. As previously, but for the reference land use, previous to the change.
- Reference vegetation carbon stock (CVEGr): 94.0 ton C/ha. As previously, but for the reference land use, previous to the change.
- Reference dead organic matter stock, forest only (CDOMr): 7.4 ton C/ha. Only valid in case of change from forest, available from the FAO [74].
- The sum of the first two calculated parameters (SOCa+CVEGa) give the total carbon stock of expanding crop (CSa = 78.7 ton C/ha), while the sum of the other three parameters (SOCr+cvegR+CDOMr) results in the total carbon stock of reference (CSr = 145.4 ton C/ha).

These two parameters are ultimately used to assess the LUC impact of the conversion of 1 ha of tropical mountain forest into sugar cane in Guatemala. This value should be applied equally for the year from 2010, up to 2030 (20 years amortization after the conversion):

$$\mathbf{LUC = (CSr - CSa) * 44 / 12 * 1 / 20 = 12.21\ tonne\ CO_2e/ha*year}$$

Where: 44/12 is conversion from CO_2-C to CO_2, 1/20 amortization over 20 years.

Where it can be demonstrated that the land use change occurred more than 20 years before the assessment being carried out, no emissions from land use change should be included in the assessment because all emissions resulting from the land use change would be assumed to have occurred prior to the application of the PAS.

When the previous land use is unknown, practitioner shall refer to the method detailed in Annex B of PAS 2050-1: 2012 [70].

When LUC is unknown:

If we, again, look at the production of sugar cane in Guatemala, these parameters need to be calculated to estimate the extent and type of conversion in this specific crop-country combination For all the following parameters, the expansions and contraction data can be extrapolated from FAOstat [82] and should be based on a three-year average. As an example:

- Share of area expansion of the assessed crop in relation to total current area of the assessed crop (REC): 34%. So, in this case we have a current are of 250083 ha (2016-2018 average), while 20 years prior there was a 170860 ha (1996-1998 average). (250083 – 170860) / 250083 = 34%.

- The share of area expansion at the expense of grassland and forest (SEF&G): 96%. It is calculated as 1 minus the sum of all crop area contractions (39407 ha) divided by the sum of all crop area expansions (995352 ha).

- The share of area expansion at the expense of forest land (SEF): 50%. It is calculated as SEF&G times the contraction forest (-818 ha) divided by the contraction forest and grassland (sum of -757 ha and -818 ha).

- The share of area expansion at the expense of grassland (SEG): 46%. It is calculated as SEF&G minus the contraction grassland (-757 ha) divided by the contraction forest and grassland (sum of -757 ha and -818 ha).

- The share of area expansion at the expense of perennial tree cropland (SEP): 0.1%. It is calculated as (1 – SEF&G) times the sum contractions perennial crops (1309 ha) divided by the sum contractions all crops (sum of 1309 ha and 38098 ha).

- The share of area expansion at the expense of annual cropland (SEA): 3.8%. It is calculated as (1 – SEF&G) times the sum contractions annual crops (38098 ha) divided by the sum contractions all crops (sum of 1309 ha and 38098 ha).

As in the previous example, the practitioner should now calculate the land use change emissions (amortized over 20 years) for each different scenario (conversion from forest, average, perennial crop and annual crop) by using the known climate, soil type, tillage intensity and input level. In case this information is also unknown, the practitioner may use the indicated source to estimate a country average as approximations.

In this example, by using average information we would calculate emissions factors of 14.5, 0.4, 0.0 and -3.2 tonne CO_2e/ha*year for forest (LUCf), grassland (LUCg), perennial cropland (LUCp) and annual cropland (LUCa), respectively.

Each share (SEF, SEG, SEP and SEA) needs to be multiplied by the relative expansion (REC), and an average impact can be then calculated. Two average impacts need to be calculated:

Weighted average = SEF*REC*LUCf+ SEF*REC*LUCg+ SEP*REC*LUCp+ SEA*REC*LUCa = 50%*34%*14.5+46%*34%*0.4+0.1%*34%*0+3.8%*34%*(-3.2) = 2.5 tonne CO_2e/ha*year

Average = SEF*REC*33%+ SEF*REC*33%+ SEP*REC*0%+ SEA*REC*33% = 33%*34%*14.5+33%*34%*0.4+0%*34%*0+33%*34%*(-3.2) = 1.3 tonne CO_2e/ha*year

The average LUC can be calculated by considering the transformation from land use equivalent to the current land use as 0%. The worst-case scenario needs to be selected. In this case, the weighted average LUC of 2.5 tonne CO_2e/ha*year.

Data over average land use transformation for a country-cultivation combination can be derived from publicly available database (e.g., FAOstat [82]). Limitations and possible data gaps of the data used should be considered and clearly described when reporting. Examples of limitations are lack of data for some specific crops (e.g., roughages), uncertain distribution of relevant land uses and differences in annual variability and reporting around mixed farming systems. Also, should be noted that the methodology as detailed in PAS 2050-1: 2012 [70] does not indicate how to estimate the impact of conversion to pastureland.

10.9. TECHNICAL DATA REQUIRED TO CALCULATE GHG EMISSIONS

Table 4: List of technical data required to calculate GHG emissions

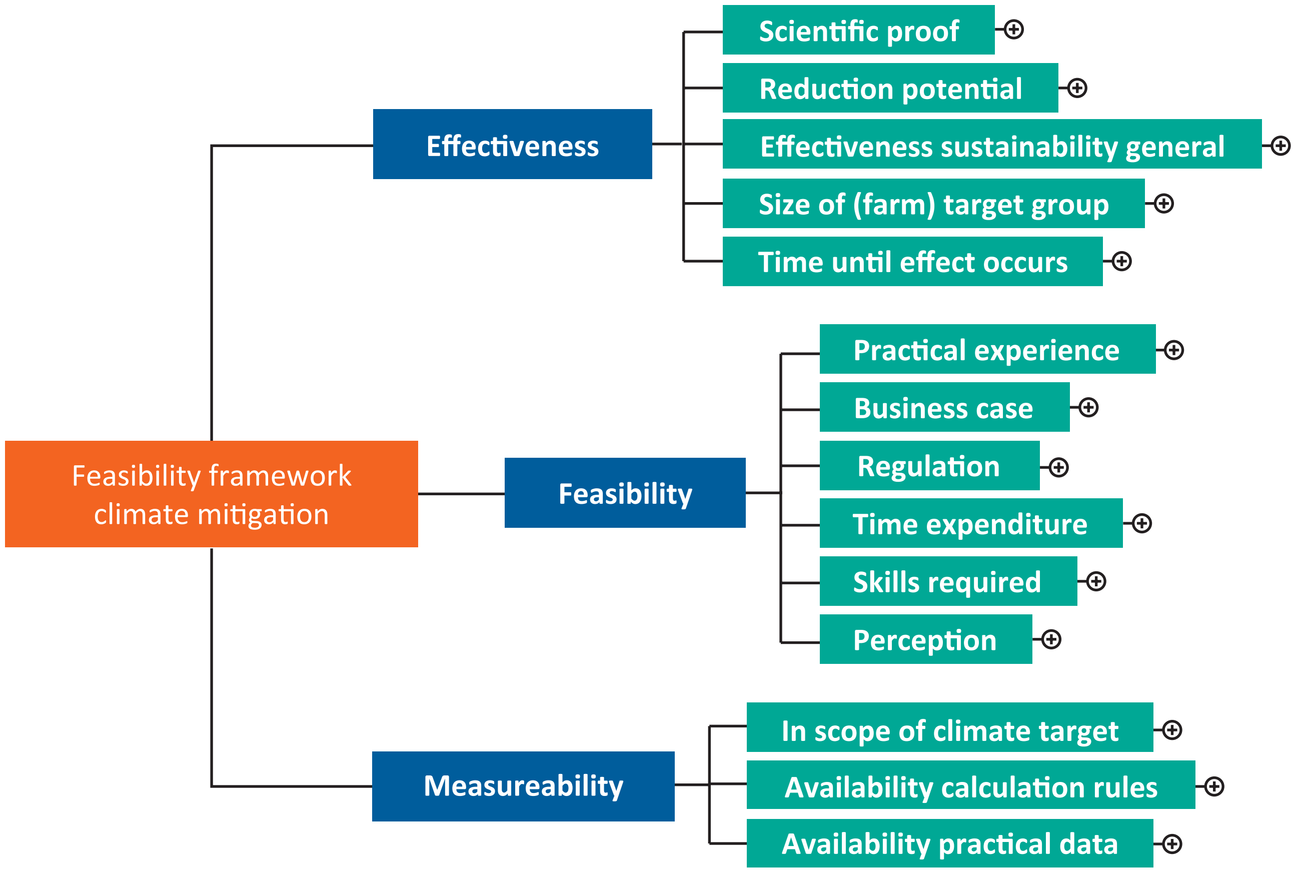
Farm Products	
Total quantity of milk supplied	Total quantity of milk supplied by this type of farm
Milk production	Average annual milk production of a dairy cow (kg/dairy cow/year) or dairy buffalo (kg/dairy buffalo/year)
Fat content and protein	Average fat and protein content of milk from the area (% by mass)
Meat production	At farm-gate this is the kg live-weight sold for meat processing
Other	May include manure sold, draught role of dairy animals, fuel/energy/heat Wealth management
Cow Herd	
Reproduction	The number of births per annum per animal and the number of young animals per birth (fertility and prolificacy, respectively). An estimate is needed of the number of male animals required for re- production (natural or artificial) according to the bull-to-cow ratio
Growth	This refers to the increase in animal live-weight between birth and adult age. The adult age is defined as the age at which growth stops and can coincide with when the female animal gives birth for the first time.
Death	The annual percentage of animals dying is split in three groups: young animals at birth, young animals between birth and adult-hood and adult animals
Replacement	The number of adult animals that are replaced annually by new younger adult animals
Animals above replacement	The previous replacement rates define the number of young animals that are necessary to maintain a herd at a constant size. The other animals can be sold or kept within the same production system
Weights	Larger and heavier animals need more energy for maintenance. Also, the growth from calving weight to adult or slaughter is more, which demands more energy
Ranging, grazing or stall feeding	When animals have to search for their feed and have to walk a lot, the energy requirements are higher than when they are inside and no labour is needed for collecting feed
Manure Management	
Storage	The type of storage and the time of storage define the level of emissions
Manure application	The type of manure application defines the emissions to the environment. Also, when manure is used for non-feed crops or for fuel, this is defined in the manure compartment In case of anaerobic digestion, quality of digester and storage of digestate determines MCFs.

Feed	
Digestibility	Reflects the difference between the amount of gross energy or nutrients in feed intake and faecal output.
Nitrogen content	Nitrogen content of the feed.
Neutral detergent fibre (NDF) content	Carbohydrate fraction that includes hemicellulose, cellulose and lignin
Utilisation	Account for feed eaten relative to total feed. Non-utilised feed (feed 'wastage') may go into manure management system and contribute to emissions.
Feed Production (Land for Feed)	
Dry matter yield per hectare	
Percentage of the total crop yield	In the case of crop residues or wastes, a percentage of the total crop yield (e.g. grains + straw) must be defined
Use of manure and fertiliser	
Energy use by machinery	For crop management (e.g. tillage, harvesting and conservation) and farm maintenance (e.g. hedges, lanes, drain-cleaning)
Transport of feed	Transport of feed components to the animal production site
Further processing of feedstuffs	Further processing of feedstuffs to concentrates in the feed mill
Actual land use	In the case of grassland, grassland management has to be defined in order to estimate whether the condition is improving, constant or decreasing. The latter is the case with overgrazing and land degradation. In the case of arable land, the tillage system can play a role in degradation and soil carbon depletion
Previous land use	Large amounts of carbon are lost when forest is converted to grass- land or arable land and when grassland is converted to arable land. In the case of land use change, a time frame of 20 years is used, according to the guidelines of the IPCC [48]
Other External Inputs	
Energy needed for milking	
Energy needed for heating	
Energy needed for cooling	
Water supply	
Others	Includes herbicides, pesticides, as well as refrigerant loss
Processing	
Raw milk	Total allocated to manufacturing plant Transportation of raw milk to manufacturing plant
Ingredients	Ingredients other than raw milk Country of origin Transportation of ingredients to manufacturing plant

Intermediate products	Inter-site/company transfers (e.g. cream, butter milk, lactose) Transportation of intermediate products
Energy	Electrical and thermal energy use Source of energy (black coal, natural gas, oil, LPG and biogas) Cogeneration systems
Chemicals	Main chemicals used in CIP systems (e.g.,caustic, nitric acid, triplex, sodium hypochlorite) Transportation of chemicals to manufacturing plant
Packaging	The quantity of packaging materials and their respective material compositions: paper, cardboard, LDPE, LLDPE Nitrogen and carbon dioxide used during packaging of finished products Country of origin for packaging material
Refrigerants	Quantity and type of refrigerants used in manufacture and storage of finished product
Water	Quantity of water and water treatment process
Wastewater	Quantity of wastewater produced and wastewater treatment process
Solids waste	Quantity of solids waste product and amount recycled
Finished product	Quantity of product (milk, yoghurt, cheese, milk powder etc.) produced at the manufacturing plant

10.10. FEASIBILITY MATRIX FOR MITIGATION OPTIONS

When implementing or assessing the reduction potential of mitigation options on the farm and when including them in CF assessments, it is important to consider the topics listed in the following feasibility framework for climate mitigation and to distinguish and regard in the CF between technical potential of a mitigation option and the practical feasibility and scale of implementation.



10.11. MITIGATION OPTIONS FOR CF REDUCTION

Table 5. Mitigation options for GHG emissions throughout the dairy life cycle

Mitigation options	A brief description
1.0 ENTERIC CH4 INHIBITORS	
1.1 *Feed supplements*	
CH_4 inhibitors	The IDF recognise there are products commercially available, and following report will enable you to review these. https://globalresearchalliance.org/wp-content/uploads/2021/12/An-evaluation-of-evidence-for-efficacy-and-applicability-of-methane-inhibiting-feed-additives-for-livestock-FINAL.pdf
Electron receptors	Nitrate may be promising CH_4 mitigating agents, particularly in low-protein diets that may be benefited from non-protein **n**itrogen supplementation.
	Examples: Fumarate, malate, nitrate, sulphate, nitroethane etc.
	Limitations: Rumen microbes adapt to nitrate compounds, risk of NH_3 production and toxicity from intermediate product (nitrite). Fumarate and malate are required to be applied in large doses and because of their higher cost, they might be of limited use.
Ionophores	Ionophores help decrease in acetate: propionate ratio in the rumen. Through their effect on feed efficiency and reduction in CH_4 per unit of feed, ionophores would likely have a moderate CH_4 mitigating effect in ruminants fed high grain or mixed grain-forage diets. This effect is less consistent in ruminants fed pasture-based diets.
	Example: Monensin
	Limitation: Chances of antibiotic resistance. Not allowed as a growth promotor.
Plant bioactive compounds	Polyphenolic compounds such as tannins (condensed and hydrolysable) are anti-methanogenic and therefore may offer an opportunity to reduce enteric CH_4 emissions by up to 20%. Hydrolysable tannins directly inhibit methanogens whereas condensed tannins inhibit fibre digestion and thereby CH_4 production. Long term studies on saponins and essential oils are required before they could be recommended for use.
	Examples: Plant secondary metabolites such as tannins, saponins, essential oils and their active ingredients.
	Limitations: Tannins may compromise feed intake and animal production (tannins reduce absorption of amino acids and therefore act as anti-nutritional when dietary crude protein concentrations are limiting milk production).

Dietary lipids	Dietary lipids undergo biohydrogenation in the rumen thus reduce availability of hydrogen or reducing equivalents for methanogenesis. In addition, lipids also exert their anti-methanogenic effect due to overall suppression of bacteria and protozoa in the rumen. Dietary lipids are effective in reducing CH_4 emission, but their feasibility depends on their cost-effectiveness, potential effects on feed intake, productivity and milk fat content.
	Examples: Calcium salts of fatty acids, prilled fat, vegetable oils, oilseeds, tallow etc.
	Limitations: At higher level of inclusion unprotected lipids affect fibre digestion and thus results in milk fat depression.
Exogenous enzymes	Exogenous enzymes may improve feed efficiency and thus indirectly reduce CH_4 emission.
	Examples: Endoglucanase, xylanase etc.
	Limitations: Due to inconsistencies in the data, exogenous enzymes cannot be recommended as an effective mitigation practice.
Direct-fed microbials (DFM)	Indirect effects of DFM includes stabilization of rumen pH, increase in total VFA production, decrease lactate, increase oxygen scavenging, supply of growth factors for microbial growth, increase organic matter and fibre digestibility, duodenal microbial protein and methionine flows. Indirect effects of yeast might moderately decrease CH_4 emission intensity.
	Examples: Yeast products (live yeast, yeast culture) of *Aspergillus oryzae* and *Saccharomyces cerevisiae*
	Limitations: No limitations as such, however there is insufficient evidence of direct effect of yeast on CH_4 mitigation.
Defaunation	Defaunation is a process in which protozoa are removed from the rumen by means of defaunating agents. During this process population of protozoa-associated methanogens is also reduced in the rumen.
	Examples: Lauric acid, coconut oil, linseed oil etc.
	Limitations: Protozoa play important role in fibre and organic matter digestion. Therefore, defaunation may have negative impact on digestibility, animal production and milk fat level. In addition, removal of protozoa-associated methanogens may trigger an increase in the population of bacteria-associated methanogens. Due to variability and uncertainty in defaunation response, it cannot be recommended as a practical CH_4 mitigation strategy.
Vaccination against methanogens	Vaccines against rumen archaea are based on the concept of a continuous supply of antibodies to the rumen through the saliva. To be effective, the vaccine has to cover the entire methanogen community and not just individual species. This approach is still under development and is not ready for practical application.

1.2 *Feeds and feeding management*	
Effect of feed intake	As feed intake increases, the Ym factor decreases by about 1.6% units per each level of intake above maintenance. Increasing feed intake increases fractional passage rate and decreases digestibility (dependant on diet-quality) and thus CH_4. However, reduced digestibility as a result of increased dry matter intake may increase excretion of fermentable organic matter with manure and thus CH_4 and N_2O emissions depending on the type of manure management system.
Concentrate inclusion	Increasing the proportion of concentrate in the ration can lower enteric CH_4 emission per unit of feed intake and animal product. However, this may not be a viable long-term GHG mitigation strategy because it ignores the importance of ruminants in converting fibrous feeds into edible products, the shift in grain diversion to biofuels, and the increasing priority of grains to feed the growing human population. Increasing the concentrate proportion in the diet to high levels will negatively affect fibre digestibility, which, in addition to potential loss of production, will results in increased concentration of fermentable organic matter in manure and may increase CH_4 emissions from stored manure.
Forage quality and management	With increasing plant maturity NDF, ADF and lignin contents are of forage increases which negatively affects digestibility. Enteric CH_4 emissions are correlated with greater nutrient quality (forage type) and digestibility (stage of maturity). Within grasses, C3 (cool season) grasses are more digestible than C4 (warm season) grasses, with the later having higher concentrations of lignin p-coumarate esters. Harvesting forage at an early stage of maturity increases its soluble carbohydrate content and reduces lignification of plant cell walls thereby increasing its digestibility and decreasing enteric CH_4 emission per unit of digestible dry matter.
Feed processing	The processing of grain to increase its digestibility is likely to reduce enteric CH_4 emission**s** per unit of animal product. However, this mitigation practice may not economically feasible in low-input production systems.
Precision feeding	Precision feeding, i.e. closely matching animals' nutrient requirement and dietary nutrient supply, is important for maximising feed utilization, stabilizing rumen fermentation, maximising microbial protein production, improving rumen and animal health, and minimising nutrient excretion in manure. These effects of precision feeding are expected to decrease enteric and manure GHG emissions.

2.0 MANURE AND MANURE MANAGEMENT	
Dietary manipulation (protein content)	Feeding low-protein diets to cows results in reduced N_2O emissions during manure storage. However, decreasing dietary rumen-degradable protein concentration may reduce total tract fibre digestibility, increase fermentable carbohydrate concentration, which in turn may increase CH_4 production from manure. However, these effects may be counteracted by reduced enteric CH_4 production because fibre degradability in the rumen will decrease. Excess dietary protein should be avoided because this will likely increase NH_3 and N_2O emissions from manure. Feeding protein close to animal requirements, including varying protein concentration with the productive stage of animal, is recommended as an effective manure NH_3 and N_2O emission mitigation practice. Low protein diets for ruminants should be balanced for RDP in order not to impair microbial protein synthesis and fibre degradability in the rumen. Diets should be balanced for amino acids to avoid feed intake depression and decreased productivity.
Biofiltration	This technology is based on treatment of ventilated air from animal buildings using biological scrubbers to convert NH_3 into N_2O, or biological beds to absorb NH_3. Preventing NH_3 losses may also indirectly reduce N_2O emissions by reducing ammonium deposition and consequent conversion to N_2O. When using biofiltration, potential N_2O production in biofilter scrubbers should be taken into consideration (biofilters used to scrub NH_3 from exhaust streams in animal houses generate N_2O as a result of nitrification and denitrification process in the biofiltration media).
Manure storage and separation	Most mitigation options for GHG emissions from stored manure, such as reducing the time of manure storage, aeration, slatted floors and stacking, are generally aimed at decreasing the time allowed for microbial fermentation processes to occur or at creating aerobic conditions before land application. These mitigation practices are effective, but their economic feasibility is uncertain. Separation of manure into liquid and solids and aerobically composting the solids has been shown to reduce CH_4 but may have a variable effect on N_2O emissions and will increase NH_3 and total manure N losses.
Manure storage covers	Semi-permeable covers are valuable for reducing NH_3, CH_4 and odour emissions but likely increase N_2O emissions; therefore, their effectiveness is not clear and results may vary widely. Impermeable membranes, such as oil layers and sealed plastic covers, are effective in reducing gaseous emissions but are not very practical. Combusting CH_4 accumulated under impermeable covers to produce electricity or heat is recommended.
Manure acidification	Moderate decrease in manure pH through acidification significantly reduces NH_3 volatilization and CH_4 losses from stored manure.
Composting	Composting animal manure causes significant N and CO_2 losses, but the benefits of reducing odour and CH_4 emissions, compared with anaerobically-stored manure, make it a recommended GHG mitigating option. However, nitrogen losses, predominantly as NH_3 but also N_2O, are considerable.

Anaerobic digestion	Use of anaerobic manure digesters is a recommended GHG mitigation strategy that has a significant potential to capture and destroy most CH_4 from manure, generates renewable energy and provides sanitation opportunities in developing countries. Management of digestion systems is important, so that they do not become net emitters of CH_4. There might also be a potential for mitigating N_2O emissions following land application of the digested manure, although results are not clear at present.
Manure application	Lowering the concentration of N in manure, preventing anaerobic conditions or reducing concentration of degradable manure C are successful strategies for reducing GHG emissions from manure applied to soil. Separation of manure solids and anaerobic degradation pre-treatments can mitigate CH_4 emission from subsurface-applied manure, which may otherwise be higher than from surface-applied manure. Timing of the manure application (e.g. avoiding application before a rain) and maintaining soil pH above 6.5 may decrease N_2O emissions.
Urease and nitrification inhibitors	Nitrification inhibitors offer promise for reducing N_2O emissions from intensive livestock production systems, but result in limited benefits to the producer apart from reducing N losses. Urease inhibitors are effective in preserving urea and reducing NH_3 volatilization. However, urease inhibitors may result in increased N_2O emissions due to potential increase in ammonium and subsequently nitrate concentration in soil.
3.0 ANIMAL HUSBANDRY	
Enhancing animal productivity	In many parts of the world, the single most effective GHG mitigating strategy is to increase animal productivity, which may allow a reduction in animal numbers providing the same edible product output at a reduced environmental footprint. Improving animal productivity may be achieved through multiple mechanisms including animal genetics, feeding, reproduction, health and overall management of the animal operation. Improving forage quality, including grains in the diet, achieving the genetic potential of the animal for production through proper nutrition and use of local breeds or crossbreeds are recommended approaches for improving animal productivity and reducing GHG emissions per unit of product.
Animal genetics	The potential of using residual feed intake (RFI) as a selection tool for low CH_4-emitters is an interesting mitigation option, but currently there is inconclusive evidence for whether low-RFI animals have lower CH_4 emissions per unit of feed intake or product. Therefore, the immediate gain in GHG reductions through RFI is considered uncertain. However, selection for feed efficiency will yield animals with lower GHG emission intensity. Breed differences and maximum utilization of the genetic potential of the animal for feed conversion efficiency can be powerful GHG mitigation tools in both ruminants and non-ruminants.
Animal health and mortality	Improved animal health and reduced mortality and morbidity are expected to result in increased herd productivity, diluting non-CO_2 GHG emissions per unit product.

Animal fertility	Poor fertility increases GHG emissions from animal production systems; this is primarily because poor fertility causes livestock producers to maintain more animals per unit of production and keep more replacement animals to maintain herd/flock size. Optimum weaning and puberty attainment, reducing age at first calving, nutritional flushing, enhanced periparturient care and health, and use of assisted reproductive technologies can contribute to reducing GHG emissions. Use of reproductive technologies where they are available and cost-effective, such as genetic/genomic selection for fertility, artificial insemination, gender-selected semen, embryo transfer and oestrous/ovulation synchronization increases reproductive efficiency and reduces the number of animals and GHG emission intensity.
4.0 PROCESSING AND TRANSPORT	
Energy saving	Reducing energy used per kg product produced and investing in energy-saving measures may pay dividends
Green energy	We recommend generation and use of green electricity, biobased fuels, electrification
Good processing practice	Avoid food waste and downgrading, CIP, switch to coolants without GHG emissions and adopt energy-efficient drying techniques
Sustainable sourcing	Purchase (non) dairy ingredients with a low CF
Packaging	Use packaging materials with a low CF, pay close attention to attention for portion size in order to reduce food waste and the amount of packaging material used. Amend packaging design to avoid food waste, weight reduction, use recycled or biobased materials if they result in a lower CF.
Transport	Reduce transport distance where possible and optimise efficient supply chains Use energy-efficient modes of transport (modern vehicles). In general, use transport by ship, then train, then truck, then aviation (ranked by impact, low to high) to reduce GHG emissions. Avoid product spoilage and damage through optimium cooling and appropriate secondary and tertiary packaging. Use biobased fuels, hydrogen powered trucks, electric trucks and other sustainable non fossil energy sources for road transport
Dry matter content	Consider transport distance and time - liquid whey ingredients are better if transport is short, but whey should be powdered if transport is considerable Avoid repetitive drying and dilution of ingredients for blended dairy products
Recipe	Balance the CF and nutritional value of (blended) dairy products. Also take account of the water, saturated fat, salt and sugar contents, which should be optimized to minimize CF and maximize nutritional value.

5.0 RETAIL CONSUMPTION AND END OF LIFE	
Retailer	Inform the consumer about CF of food products and nutritional value, including further differentiation based on good quality data Avoid spoilage and damage, efficient logistics and storage in line with recommendations for processing and transport.
Consumer	Reduce fossil fuel use when shopping for food Use energy-efficient appliances Avoid spoilage, damage to products, food waste and overconsumption.
End of life	Recycle packaging, but pay attention to energy use for recycling. Avoid food waste - use it as animal food if permitted under local or national regulations, or compost it, but take account of composting emissions. Avoid landfill - CH_4 capture and energy generation are preferred Avoid burning of waste, if applied try to combine it with energy capture

10.12. GUIDANCE ON CALCULATING THE FU, TO CONFORM WITH THE NRF 9.3 DIETARY INDEX

The NRF 9.3. score [89] includes:

- A bonus for “qualifying” nutrients: protein, fibre, vitamin A, C and E, iron, potassium, calcium, magnesium
- A penalty for “disqualifying” nutrients: saturated fatty acids, added sugar, sodium.

Data collection for the NRF 9.3 score [89] requires:

- The amount of nutrients mentioned above per 100 kcal (alternatively per serving or per 100 gram) of the product under study
- Local (or if not available, global) ‘recommended daily allowance’ of listed nutrients (except free sugar)
- For added sugar the WHO [90] definition of “free sugar” is used, i.e. sugar naturally occurring in fruit, vegetables and dairy is not to be taken into account. Sugar formed during processing, e.g. by breaking down carbohydrates is taken into account. For free sugar the WHO [90] recommends a maximum of 10% of total energy per day. This means for female a maximum of ~50 gr and for male of ~60 gr
- For the other nutrients recommended daily allowance (RDA) for average males and females preferably local values are used. An exception can be made when the study aims at specific target groups, for example in the case of infant formula or nutrition for elderly people.

Table 6. Example calculation of the NRF 9.3 score for a dairy product

BONUS	(Unit)	Nutrients/100 kcal		RDI		NRI 9.3 score
Protein	g	8	* 100/	50	=	15
Fibre	g	0	* 100/	35	=	0
Vitamin A	mcg	33	* 100/	800	=	4
Vitamin E	mg	0	* 100/	13	=	0
Vitamin C	mg	2	* 100/	75	=	3
Iron	mg	0	* 100/	11	=	0
Potassium	mg	356	* 100/	3500	=	10
Calcium	mg	273	* 100/	950	=	29
Magnesium	mg	27	* 100/	350	=	8
Average						8
PENALTY						
Saturated fatty acids	g	2	* 100/	-20	=	-10
Added sugar	g	0	* 100/	-60	=	0
Sodium	mg	93	* 100/	-6000	=	-2
Average						-4
NRI 9.3 total score						4

INTERNATIONAL DAIRY FEDERATION

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- Files to be sent electronically by e-mail or via our FTP site. Login details will be sent upon request.
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- References in the document to be numbered and placed between square brackets.
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    - If the publication is a book, names of the publishers, city or town, and the names and initials of the editors;
    - If the publication is a thesis, name of the university and city or town;
    - Page number or number of pages, and date.

Example: 1 Singh, H. & Creamer, L.K. Aggregation & dissociation of milk protein complexes in heated reconstituted skim milks. J. Food Sci. 56:238-246 (1991).

Example: 2 Walstra, P. The role of proteins in the stabilization of emulsions. In: G.O. Phillips, D.J. Wedlock & P.A. William (Editors), Gums & Stabilizers in the Food Industry - 4. IRL Press, Oxford (1988).

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Conventions on spelling and editing

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ANNEX 1
IDF CONVENTIONS ON SPELLING AND EDITING

In the case of native English speakers the author's national conventions (British, American etc.) are respected for spelling, grammar etc. but errors will be corrected and explanation given where confusion might arise, for example, in the case of units with differing values (gallon) or words with significantly different meanings (billion).

"	Usually double quotes and not single quotes
? !	Half-space before and after question marks, and exclamation marks
±	Half-space before and after
microorganisms	Without a hyphen
Infra-red	With a hyphen
et al.	Not underlined nor italic
e.g., i.e.,...	Spelled out in English - for example,
that is	
litre	Not liter unless the author is American
ml, mg,...	Space between number and ml, mg,...
skimmilk	One word if adjective, two words if substantive
sulfuric, sulfite, sulfate	Not sulphuric, sulphite, sulphate (as agreed by IUPAC) AOAC INTERNATIONAL Not AOACI
programme	Not program unless a) author is American or b) computer program milk and milk product rather than "milk and dairy product" - Normally some latitude can be allowed in non scientific texts
-ize, -ization	Not -ise, -isation with a few exceptions
Decimal comma	in Standards (only) in both languages (as agreed by ISO) No space between figure and % - i.e. 6%, etc. Milkfat One word
USA, UK, GB	No stops
Figure	To be written out in full
1000-9000	No comma
10 000, etc.	No comma, but space
hours	Ø h
second	Ø s
litre	Ø l
the Netherlands	

Where two or more authors are involved with a text, both names are given on one line, followed by their affiliations, as footnotes for example A.A. Uthar[1] & B. Prof[2]

[1] University of ....

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