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Summary

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The European Commission has published Product Environmental Footprint (PEF) guidelines to promote a harmonised product group-specific environmental footprint assessment. The need for harmonised methods in environmental footprint assessment has arisen from increasing number of green claims used especially in marketing of products. There has been a growing desire to communicate the environmental footprints of food products, but in the absence of well-established, standardised assessment guidelines, green claims have been made on variable grounds.

The PEF method developed by European Commission is based on Life Cycle Assessment (LCA) and the current 16 environmental impact categories included are relying on scientifically sound impact assessment methods that are agreed at international level. While the harmonised methods of Product Environmental Footprint Category Rules (PEFCRs) are suitable for assessment of environmental impacts of products and for comparison of performance of products from the same category, comparability across different categories has not been the objective.

Based on previous results and ongoing work, the main objective for the work reported here, has been to investigate to what extent the LCAs conducted with the PEF methodologies provide comparability even between product categories and will provide insights from a Nordic perspective.

The review was conducted by comparing the PEFCRs and the general PEF guidance in parallel, per life cycle stage, to find deviations especially between different PEFCRs. General PEF guideline consisted of the Commission recommendations and the guidance given in Annexes. Previous studies were utilised here as a basis together with the PEF method and guidance documentation, for summarising the relevant differences and coherence in collecting inventory data, requirements for modelling, utilised emission factors (EF), system boundaries, allocation approach and functional units (FU). The transition phase PEFCRs were reviewed in order to find coherence or discrepancies in strictness regarding data quality requirements. The revised Recommendation by European Commission was included to some extent, in a more general level.

For the evaluation of the potential differences in LCA results of products assessed with the PEF method, the application of PEFCR of dairy products in the Nordic countries (Denmark, Finland, Norway, Sweden) was analysed in more detail, focusing on the largest contribution to global warming potential, i.e., methane from enteric fermentation.

In overall, it was seen that PEF method is promoting comparability and the given guidance increases consistency, transparency, and reliability of the conducted studies. Yet, many aspects discussed in the report remain unsolved and need more careful considerations in forthcoming PEF studies and PEFCR guidance's if comparisons across product categories are made. Raised issues were regarding functional unit, system boundaries, allocation, manure handling and use stage modelling. Prior to utilising PEF method in comparison of product LCAs, harmonisation of these issues should be conducted across PEFCRs.

In the case of estimating the product footprint across countries, the use of different National Inventory Report (NIR) assessment models, here illustrated by enteric methane, was found problematic as the level of emission potentially change due to the model parameters and not because of the production data. The used NIR assessment models should be validated for fair comparison. This problem is already existing in PEF methods, when comparison is conducted within a product group and by following PEFCRs. The use of national assessment models is problematic, even in the case that they are approved by IPCC as they are not validated for comparison.

Keywords: Product Environmental Footprint, PEFCR, Life Cycle Assessment, environmental impact, Nordic, Food products

Contents

1. Introduction

The European Commission has published Product Environmental Footprint (PEF) guidelines to promote a harmonised product group-specific environmental footprint assessment. The need for harmonised methods in environmental footprint assessment has arisen from increasing number of green claims used especially in marketing of products. There has been a growing desire to communicate the environmental footprints of food products, but in the absence of well-established, standardised assessment guidelines, green claims have been made on variable grounds. The PEF methodology is designed as a solution for this methodological non-transparency, to result in reliable and comparable assessment of environmental performance within a product category.

The European Commission started work on establishing a common harmonised basis for the environmental communication of products and organisations and first presented the harmonised methods – Product and Organization Environmental Footprint (PEF and OEF) as part of the Integrated Product Policy initiative "Building the Single Market for Green Products" in April 2013. The first Recommendation on use of Life Cycle approach in harmonised was published in 2013, with PEF Guide as its Annex II (European Commission 2013). The PEF method is based on Life Cycle Assessment (LCA) and the current 16 environmental impact categories included are relying on scientifically sound impact assessment methods that are agreed at international level (though for a few of the impacts the methods are still under development).

In 2014, the so-called PEF pilot phase was launched and produced 11 food related PEFCR's (Product Environmental Footprint Category Rules). While the aim of the PEF methodology is to support a fair assessment of environmental impacts for communication of environmental information to both consumers and businesses, and to aid in decision making and potential benchmarking of products. The PEFCR aims to increase the comparability, reproducibility, consistency, relevance, targeting and effectiveness of PEF studies within that product category. The European Commission has published general guidelines for the development of product group-specific assessment guidance's (European Commission 2013, 2018a, 2021a) and a number of product group-specific guidance's.

The pilot phase continued until 2018 and some of the PEFCR's were completed and moved on to transition phase (2018-2021). The transition phase between 2018 and 2021 resulted in the publication of the revised methodology in 2021 (European Commission 2021).

At present there are PEFCR's for 6 food related categories (beer, dairy, feed, packed water, pasta, wine) developed based on the general PEFCR guideline (European Commission 2018a, 2018b, 2018c, 2018d, 2018e, 2018f, 2018g). One PEFCR is in the process of development (marine fish; European Commission 2021b) and several PEFCR's didn't complete all steps in the PEFCR process and are not finalised CR's (coffee, olive oil, red meat; European Commission 2014, 2018h, 2018i). This leaves the need for many new categories to be described and CR's to be developed if all food categories should be covered. Yet, the more recent, revised PEF guideline is enabling a PEF study to be made for a product lacking own PEFCR (European Commission, 2021).

In 2021, in the Official Journal of the European union, the preamble states, inter alia, the Recommendation: "In schemes relating to the measurement or dissemination of information on life cycle environmental performance, the PEF method and the OEF method and the related PEFCRs and OEFSRs should be used as a reference method to measure or communicate information on the life cycle environmental performance of products and organisations". The updated PEF-methodology is revised based on the pilot phase PEFCR's and the working documents from Commission's Joint Research Centre, JRC (Zampori & Pant 2019a, Zampori & Pant 2019b).

While the environmental information and performance of a certain product evaluated according to a PEFCR method can be compared only within its product category, the demand for comparisons across product categories is increasing. The environmental impact of food products is receiving increasing attention from stakeholders, especially concerning the climate performance. The COM PEF initiative aims at reducing complexity and harmonise the approach but at the current speed of developing new CR's the demand cannot be satisfied.

Much research and knowledge synthesis has already been undertaken by Nordic institutions in this field and important work has been undertaken by the 'NordPEF agri' group in creating Nordic input to the COM working group on agricultural LCA modelling (AWG) and implementing the use of PEF in the Nordic agriculture/Food sector.

Based on previous results and ongoing work, the main objective for the work reported here, is to investigate to what extent LCAs conducted with the PEF method can provide comparability between product categories and to provide insights from a Nordic perspective.

The comparison of different food products with variable nutritional functions is an understood challenge. In the work forming this report, the comparability of various food items per their nutritional function is not considered. The comparability is investigated for the value chain and for the methodological choices and rules of different PEFCRs. The aim is to find comparability and point potential controversies, overlapping, double counting (or homeless emissions), which might make the comparisons difficult or impossible. This work can also provide basis for further investigations of potential methods for inclusion of nutritional elements of products.

Insights from a Nordic perspective are provided for data requirements and as a case study on performance of PEFCR approach in assessing methane from dairy cattle enteric fermentation. Greenhouse gas (GHG) emission from enteric fermentation is an important contributor to the total emissions from livestock – and for ruminants it can contribute to more than half of the total emissions. Significant work is ongoing worldwide to predict emission at experimental level and this information is included in the National Inventory in order to document the present level and the development over time. In this report, the aim is to give an overview about the methods used in the Nordic countries and to give insight in effect compared between the countries and in relation to other standards and ongoing initiatives based on data and results related to dairy cows from the most updated Nordic national emissions reports (National Inventory Report, NIR).

2. Material and methods

In this current study, **the main research question** for the investigation was if the product specific environmental information can be used across food categories to give the consumer a possibility to make more informed decisions in order to reduce the climate and environmental burden from the daily food consumption. Attention was also given to inventory data requirements and applicability from the Nordic perspective; what is the current potential in Nordic companies to implement PEFCR's.

Focus of the study was on climate impact, but also taking other impact categories into consideration. The evaluation was conducted for the transition and pilot phase PEFCRs for food and edible/drinkable agricultural products for their coherence in the use of system boundaries, functional units inventory data, allocation, modelling requirements, emission factors.

While the comparison of the PEFCRs is to provide insight to theoretical uniformity of the guidances, detailed analysis of applying Dairy PEFCR in Nordic countries was conducted to provide Nordic perspective and demonstrate potential differences generated by the methodologies in use. Focus for the Nordic analysis was on methane from enteric fermentation from dairy cows, an important part when assessing raw milk according to PEFCR of dairy products.

In addition, DQR tables (Data Quality Requirements (DQR, European commission 2018a, 2021) and assessment of data quality are reviewed and analysed for their uniformity.

The basis for the study lies in previous studies conducted by NordPEF agri group (Hermansen et al. 2017, Hietala et al. 2021, Møller et al. 2021) and LCAFoodPrint project (Hietala et al., 2023). Here, the previous research findings are utilised to construct an analysis of the application of PEF methodology in comparison of product LCAs in the Nordic countries.

2.1. Review of PEFCR guideline and pilot phase PEFCR guidance

The PEF guidelines and the PEFCR guidance's for food published by the European Commission, as well as other assessment standards and guidance, such as ISO 14040 series and 14067 and the LEAP guidelines, were reviewed by Hietala et al. (2023). Aim of this review was to find harmonised, well adapted methods to form a basis for a methodological recommendation for Finnish food LCA. The review included also some draft versions of the PEFCRs and other relevant reports regarding PEF, e.g., JCR working document by Zampori & Pant (2019), the Commission's recommendation on the use of the Environmental Footprint methods (European Commission 2021) and the PAS 2050 standard (BSI 2011). The finalised assessment guidance included were PEFCRs for beer, dairy products, feed, packed water, pasta and wine. Reviewed unofficial guidance drafts included marine fish, olive oil, coffee and red meat. The review was conducted by comparing the PEFCRs and the general PEF guidance in parallel, per life cycle stage, to find deviations from the general PEF guideline and between different PEFCRs and drafts. General PEF guideline consisted of the Commission recommendations and the guidance given in Annexes (European Commission 2013, European Commission 2018a). The review by Hietala et al. (2023) is utilised here as a basis for summarising the relevant differences and coherence in collecting inventory data, requirements for modelling, utilised emission factors (EF), system boundaries, allocation approach and functional units (FU). The transition phase PEFCRs were reviewed also in order to find coherence or discrepancies in strictness regarding data quality requirements. The revised Recommendation by European Commission was included to some extent, as analysis of the impacts of revised methodology is better conducted after its implementation to PEFCRs (European Commission 2021).

2.2. Application of Dairy PEFCR on dairy products in Nordic countries – a detailed analysis for assessing methane emissions from enteric fermentation

The PEF guideline and PEFCRs require the use of IPCC 2013 methodology in assessing climate change impacts. The IPCC methodology has three Tier levels, which provide different methodological complexity. Tier 1 is the most simplified, using country-level defaults, and Tiers 2 and 3 are more complex, using more detailed equations and data. Tiers 2 and 3 are considered to provide more accurate regional assessment with country specific equations and emission factors. While the Tier level description of methods is provided in IPCC guidance, the details for National Inventory monitoring are given in each country's own National Inventory Report (NIR). Thus, when PEFCR recommends using IPCC Tier 2/3, the country's NIR is determining the valid method and emission factors. As the NIR methods have been developed for national monitoring of greenhouse gas emissions, i.e., to monitor country's performance in comparison to its previous years, methods have not been adjusted to be used for comparing assessments conducted in parallel in different countries and are using different NIR methods.

While the overall aim of this study has been to evaluate if different products LCA results can be compared across the PEFCRs, this comparison of NIR methods provides knowledge on the potential differences rising from methodological differences.

In this study, we wanted to test whether a difference can arise due to use of different NIR methods of Nordic countries in assessing methane from rumination by following Dairy PEFCR. Currently, a globally harmonised method is being introduced for predicting dairy cows' methane from rumination, which has been included in this comparison (Niu et al. 2018).

For the evaluation of the potential differences in LCA results of products assessed with the PEF method, we analysed in more detail the application of PEFCR of dairy products in the Nordic countries (Denmark, Finland, Norway, Sweden). As it is well acknowledged, the most important life cycle stages forming the environmental impacts of cattle products are enteric fermentation for the rumination, manure management and feed crop production, all related to primary production. Emphasis is given here to these life cycle stages, focusing mainly on the largest contribution to global warming potential, i.e., methane from enteric fermentation. While enteric fermentation can cause over half of the carbon footprint of raw milk, together with manure management and feed crop production, their contribution can be appr. up to 90%. Remaining life cycle stages from Dairy PEFCR point of view are processing of raw milk, packaging, transportation, storage and use stage, together with the remaining activities in the primary production stage: energy use, bedding materials, water use, chemicals etc.

The implementation of PEF regarding calculations of feed production environmental footprints (the PEFCR for "feed for food producing animals", European Commission 2018d) feed crop production assessed in the Nordic countries has been investigated in a workshop with stakeholders in the feed industry, in 2021 reported by Møller et al. (2021). Insights from the workshop and the report are summarised in conclusions.

Regarding manure management emission modelling according to PEF (methane and N2O from manure storage), findings from Hietala et al. (2021) were included, this as well is summarised in the conclusions.

3. Results and discussion

3.1. Review of PEFCR guideline and pilot phase PEFCR guidance

3.1.1. Coherence in system boundaries and functional unit (FU)

According to the PEFCR guideline as a ground rule the PEFCRs include the whole life cycle, meaning a **system boundary** set from cradle to grave. In the review of the pilot and transition phase PEFCRs, it was noticed that this rule is mainly followed. Differences concerning *inclusion of the use phase was however found*. Also, as the guidance of the PEFCRs differ in the level of detail which has raised, questions whether this might lead to discrepancies. The system boundary and life cycle stages included in the transition phase PEFCRs are presented in **Table 1**. Yet, even if the system boundaries are set from cradle to grave, differences might rise from the *interpretation what is to be included.* As a general cut-off rule is presented and in the most recent PEFCR guidance (European Commission 2021, Annex I) the level of cut-off is lifted to 3% from previous 1%, which is to be based on contributions of the PEFCR screening study. This has been previously used namely to leave capital goods and infrastructure out from the PEF study based on the cut-off rule, as previous guideline stated that capital goods are to be included if they cannot be excluded based on cut-off rule (European Commission 2018a). This has also been the case as only the PEFCR of feed products is including capital goods for the primary production. The revised guidance is phrased differently, and it should be stated in the PEFCR if cut-off rule is applied or not for capital goods, and if they are included clear instructions are to be given besides explanation why they are relevant (European Commission 2021).

Table 1. System boundaries of different official PEFCRs. Grey coloured cells: secondary data is accepted, green coloured cells; primary data is required. Lighter coloured green/grey; optional or case dependent.

Transition phase PEFCRs

Drinkable products	**Input production, not company specific**	**Input production, company specific**	**Transport of inputs**	**Production**	**Distribution**	**Use stage**	**End of life**
Dairy [1]	Non-dairy ingredients supply (e.g., for fermented dairy products, cheeses etc.), raw milk production (when not a contract production, or not managed by company)	Raw milk production (only companies with direct access to farmers, e.g. as co-operatives)	Inbound transport of raw milk to processing	Dairy processing, packaging	When no primary data, use defaults from PEFCR	Use stage, PEFCR defaults	End of life, end of life formula with defaults
Beer[2]	Cultivation of grain for malting	Other raw materials, production of packing materials	Inbound transportation of inputs	Malting, other ingredient processing, brewery operations	Outbound transportation	Use stage	End of life
Wine[3]	Oenological practises, packaging production, energy and water production, transport of other than grape	Grape production	Inbound transportation of grape (CS), other inbound transportation not-CS	Wine manufacturing	Distribution	Consumption	End of life
Packed water[4]	Water extraction (if primary data is not available), container filling and grouping (if no primary data)	Water extraction (if primary data is available), container filling and grouping (if primary data is available)	Transport of inputs is incl. to inputs (gas, PET, etc.)	Packaging materials production (except glass bottles), Gas production for carbonated process, Container washing operations	Distribution to retail (in some cases)	Use	Packaging end of life
Other							
Pasta[5]	Ingredient production (eggs, spinach, etc.), cereals cultivation and fertilisers production, raw material transformation, transportation	Packaging materials, transportation, manufacturing	*Included in inputs*	Pasta manufacturing	Distribution	Cooking	End of life
Feed[6]	Production of feed ingredients (non-company specific allowed)	Production of feed ingredients (company specific allowed)	Transport of feed ingredients	Feed production	Feed delivery to farm		

[1] European Commission 2018c, [2]European Commission 2018b, [3]European Commission 2018g, [4]European Commission 2018e, [5]European Commission 2018f, [6]European Commission 2018d

Functional units (FU) used in PEFCRs vary according to the function of the product utilised. In general food LCA characterisation is not being based on a function, which would be nutrition. In lack of a nutritional FU, mass or volume are usually applied as the declared unit. As reported by Hietala et al. (2023) the nutritional function of the food products is not integrated into utilised functional units, and thus comparability is achieved solely within a product group. When the nutritional quality of the different products is the same, volume or mass based functional units are adequate for comparisons. In PEFCRs, either volume or mass based functional units are in use (**Table 2**).

Drinkable liquids form a good share of the food PEFCRs, including beer, liquid milk, packed water and wine. For all these the functional unit is based on metric litre, even if the quantity varies from 100 ml to 100 L. Unofficial guidances for coffee uses for the drinkable coffee a cup or a portion as a functional unit. Other liquid form products include olive oil, which unofficial PEFCR draft uses 1 litre of packed olive oil. All of these are convertible to equal volume for comparisons, yet the *issue of different nutritional function remains unsolved*.

Remaining transition phase food PEFCRs are for feed and pasta, which both are using mass based functional units. For pasta the measure is for dry pasta, and feed is measured as feed delivered to farm gate as fed. As the function of these products are very different, and feed is treated as intermediate product, comparison between products is not possible. Also benchmarking intermediate products is forbidden.

The other unofficial guidance's marine fish and red meat use mass based functional units, yet the meat product can include bones or offals, depending on the product, while fish includes only edible parts, i.e., fillet without bones and skin. Thus, the type of the product analysed with the different PEFCRs can be very different and similarly, *the different nutritional quality of the products cannot be overcome*.

In the revised PEFRC guideline (European Commission 2021) the description of the definition of functional unit has been also amended. It is now included, that if packaging has impact to products shelf-life, it must be taken into account. Also, when shelf-life (date marking) is printed on the packaging, the food losses at storage, retail and consumer stages must be quantified. As these updates are taken into new PEF studies, inclusion of food losses and impact of packaging will bring more accuracy to the analyses. If products were compared across PEF categories, this would probably give more variation to different products. Although, quantification of food losses along the production chain can become a source of inaccuracy.

Table 2. Functional units utilised in PEFCRs and related guidance.

Pilot and transition phase PEFCRs						Drafts and other guidance		
Feed	Dairy	Pasta	Beer	Wine	Packed water	Red meat	Marine fish	Coffee
1 tonne of animal feed product as fed and delivered to the livestock farm (or fish farm) entry gate	**Liquid milk**: Liquid milk, consumed at home as final product without heating, cooking or further transformation, **1000 ml** **Dried whey products**: Dried whey product, at plant gate, for further processing into final products, **1000 kg** **Cheeses**: Cheese, consumed at home as final product without cooking or further transformation, **10 g dry matter equivalent** **Butterfat products**: Butterfat product, consumed at home as final product without cooking or further transformation. **50 g** **Fermented milk products**: Fermented milk or yoghurt, consumed at home as final product without cooking or further transformation. **125 g**	**1 kg of dry pasta** being cooked at home with boiling setting	**1 hectolitre of beer**	Consumption of **0.75 litres of packaged wine**	**100 ml of water from sealed containers** ready to be drunk at the mouth contributing to hydration.	**1 tonne of red meat product** from a specific animal species, as sold to the retailer, secondary processor and or food service.	**1 kg edible marine fish**. Edible is here defined as gutted and filleet	**Green coffee beans (kg)**, green coffee delivered to port of origin **Packed coffee at retail** (dependent on the product) **Cup of coffee at home** (typical serving size)

3.1.2. Coherence in using inventory data, modelling requirements, allocation and emission factors (EF) across PEFCRs

3.1.2.1. Modelling requirements and inventory data regarding primary production

Modelling requirements and inventory data of PEF studies were also reviewed by Hietala et al. (2023). Here, the main findings are summarised for the different stages, and revised from Nordic perspective. Life cycle stages include crop and livestock primary production, processing and production stage, electricity, transportation, storage, capital goods, use stage and end-of-life.

For the food products, the primary production phase can be considered as the main contributor. Of the PEFCRs included in transition phase, this relates to dairy, feed, pasta, beer and wine, and of the draft versions to olive oil, coffee and red meat. Focus is mainly in current PEFCRs, and drafts are reviewed when relevant. Overall, the modelling requirements are relying on the IPCC methodology of climate impact assessment and the set terminology on the level of complexity; Tier 1, Tier 2 or Tier 3. Three tiers are described for categorising both emissions factors and activity data. Tier 1 is the basic method, using IPCC-recommended country-level defaults. Tier's 2 and 3 are each more demanding in terms of complexity and data requirements.

Of the reviewed guidances, the primary data requirement for primary production is set as mandatory for wine only, while other PEFCRs and drafts allow the use of secondary and default datasets. Also, wine PEFCR allows the use of secondary data if the grape production is not directly controlled by the producer. Similarly, for dairy products, it is allowed to use secondary data when the raw milk production is not for example a contract production. Secondary and default datasets are allowed to be used either when the primary production phase is not controlled by the company (e.g. further processed dairy products) or with no access to primary data.

For livestock production, primary production of feeds is well understood as a large contributor to most impact categories. Thus, in dairy PEFCR, it is recommended that whenever primary data is available, it should be used to model the utilised feeds, following the PEFCR of feed products. Similarly, the draft of the red meat PEFCR requires the farm grown feed to be modelled with primary data, following the PEFCR of feed products. For other cases, with no primary data and for feed crops grown outside animal farm, the PEFCR of feed for food producing animals is to be used as a basis and source for secondary datasets or LCI data for modelling.

Other activities and data needs related to primary production according to dairy PEFCR include cattle characteristics (dairy cattle, heifers, calves), manure management system, energy use, feed characteristics, bedding materials, pesticides, silage plastics and water use. Similarly, the draft version of the red meat PEFCR lists the farm activities to be included as herd characteristics (beef cattle, pigs or sheep), feed intake and composition, mass and nutrient balances of animals, housing and manure system and energy and material flows (incl. bedding materials and water). While pesticides or silage plastics are not mentioned in meat PEFCR, these are in scope of the PEFCR for feed and thus included. Nutrient balance and excretion to manure is to be calculated based on feed composition in both of the PEFCRs, utilising the equations by IPCC.

The main difference between dairy PEFCR and draft of the red meat PEFCR is that according to red meat PEFCR the use of Tier 1 level for N2O from manure management yields to a penalty of +1 in DQR, while in dairy PEFCR the Tier 1 method is considered as minimum requirement (without penalty in DQR).

Other unofficial animal product guidance’s include draft PEFCR of marine fish. This guidance covers both wild marine fish and farmed fish, thus primary production phase of the farmed fish can be considered to be corresponding to on-farm production of live animals. Marine fish guidance includes in the life cycle stage of raw material acquisition the production of the production of feed raw materials and in the production stage the hatching, juvenile production and growing of the fish. Similarly, as other livestock guidances, the feed is instructed to be modelled according to PEFCR of feed for food producing animals.

For the farmed fish production, company specific, primary data is mandatory for feed efficiency, energy use (farm and transport), feed characteristics, excess nutrients from uneaten feed, manure, chemical use, mass balance of fish, value of co-products, freshwater use, waste amount and handling and wastewater management. For wild fish, the production stage isn’t included, and raw material acquisition stage includes the activities regarding fishing, i.e., energy use efficiency regarding catch, refrigerants in vessels, bait use, mass balance (target fish, by-catch, discards), value of the co-products and yields per species.

As the different animal-based products differ largely by their primary production phase, differences between the relevant activities can be considered as acceptable. For the cattle-based products the actual production systems can be considered similar and thus it is expected that the PEFCR for dairy and draft of the red meat PEFCR are uniform in their main features. This seemed to be also the case when the system boundaries, inventory and included activities related to the primary production were reviewed. Thus, *the activities included for inventory data collection was found to be uniform for the primary production stage*.

For the inventory data collection and modelling requirements, some differences apply. PEFCR for dairy products and the draft of the red meat PEFCR instruct differently the need of primary data. For assessment of dairy products, primary data demand is dependent on the production chain and whether the primary production is controlled by the company. Thus, it is possible to use secondary data for the raw milk supply in cases where the primary production is not contract production and company doesn't have direct access to farms. In the draft of the red meat PEFCR the requirement for primary data is set on a percentage basis, yet, it needs to be kept in mind that red meat PEFCR is not a finalised PEFCR. Strictness of modelling the manure management emissions was found to be slightly different between guidance's as the N_2O emission assessment according to Tier 1 was penalised with +1 DQR in the red meat guidance while for dairy production it was minimum requirement without penalty.

Other transition phase PEFCR guidance which include **agricultural primary production** are the PEFCRs for **beer, wine, pasta and feed for food producing animals**. Unofficial guidance included **coffee and olive oil**. For the drinkable products, beer and wine, *the primary production of the ingredients is included with different requirements*: for beer, the grain cultivation can be modelled using secondary data, while on farm wine production needs to be based on primary, company specific data. Yet, the wine PEFCR leaves an opportunity for the use of default data when grape production is not run by the company or company specific data is not available. Wine PEFCR requires the use of the certain given default dataset when primary data is not available.

Beer PEFCR includes to the primary production phase the processes of fertiliser production and application, manure application, fuel production and use, water consumption, pesticide production and use and infrastructure. Wine PEFCR describes the grape production processes in less detail, yet all different processes related with vine plantation, plant and soil management, grape harvesting and vine destruction are included. Inventory data for grape production is needed to be collected from 3-year period, or for specific reasons a minimum of 1 year period is accepted. Modelling of the grain cultivation in Beer PEFCR and grape cultivation in Wine PEFCR, is instructed as is presented in general PEFCR guidances and rely on IPCC Tier 1 methodology (PEFCR guideline 6.3. and European Commission 2021, Annex I).

In Pasta PEFCR, the primary production of the cereals and eggs is included with prioritised option for company specific data and when that is not available, secondary datasets can be utilised instead for cultivation, milling and egg production. Agricultural modelling is instructed similarly to beer and wine, following the general guidance (PEFCR guideline 6.3., Annex I). Inventory data is to be collected for annual crops for a 3-year period (1 year in minimum is accepted for specific reasons) or 3 consecutive cycles for crops with shorter cultivation period.

As the Feed PEFCR provides instructions to livestock related crop production, it was reviewed in parallel to other PEFCRs instructing crop cultivation assessment. The PEFCR of feed for food producing animals leaves it open for the PEF study operator to decide whether to model the cultivation of feed ingredients with primary data or to use secondary datasets. When primary data is used, it is required to quantify the used seeds, fertilisers, manure, fuel use, irrigation water, crop protection, used chemicals and auxiliary materials. For the production and transportation of the used inputs PEFCR provides secondary data which is to be used.

Other unofficial guidance included the draft of the olive oil PEFCR and guidance for coffee assessment. Draft of the olive oil PEFCR instructs the modelling of the olive fruit production following an older version of PEFCR guidance, thus the method might vary due to that, and comparison was not made in this review. The unofficial guidance for coffee instead is instructing the *modelling to be conducted following the general PEFCR guideline 6.3. and thus, similarly to transition phase PEFCRs*.

3.1.2.2. Processing and manufacturing stage

Processing and manufacturing stage can be considered in PEF terminology a typical foreground process. This stage is typically considered to consist of processes which are run by the company, and thus, primary, company specific data is required. This stage was shortly discussed in the review by Hietala et al. (2023), stating mainly the relevant processes to be included. Thus, for this investigation a more detailed comparison was made.

For the drinkable products, the manufacturing stage was considered in parallel. Manufacturing stage of **packed water** includes processes of water extraction, filling and grouping of the containers, gas production and cleaning of the refillable containers. Thus, the activity data to be collected regarding packed water manufacturing includes the energy and water consumption of the processing plant, i.e., energy and water consumption of the different processes.

Manufacturing of **wine** according to Wine PEFCR includes the steps of wine making, and it includes processes of vinification, ageing, packing of wine, cleaning and waste management. Wine PEFCR guidance gives a specific list of all processes which are to be included.

Manufacturing stage of **beer** according to Beer PEFCR includes processes of brewing, washing returnable containers, filling and packing. Here also the refrigerants are included and similarly to Wine PEFCR, a list of processes to include are given on separate spreadsheet.

The Dairy PEFCR provides guidance for several **dairy-based products**, both drinkable and edible. Yet, similarly to manufacturing stage of other products, the stage includes material use (raw milk, other dairy inputs, chemicals for cleaning) and energy and water consumptions. Also, in the case of dairy processing, the refrigerants are to be included. Of the produced outputs, it is needed to collect data on co-products, wastewater and direct emissions. Dairy PEFCR doesn't include processing of the cull cows and calves after farm gate in the scope of the Dairy PEFCR and allocation is set between raw milk and sold live animals at farm gate.

The other livestock related guidance's are draft versions of **red meat** and marine fish. For the red meat, the manufacturing stage is defined as slaughterhouse processes and includes steps from animal slaughtering to cutting and deboning, aging and refrigeration and packing. Primary data is thus to be collected for produced red meat and edible organs and other co/by-products, use of energy carriers, on-site energy production, animals, packaging and auxiliary materials together with allocation factors. While Dairy PEFCR considers also the allocation regarding cull cows and calves, the differences in allocation are discussed later in this chapter.

For **marine fish**, the manufacturing stage is considered to include the further preparation of the fish raw materials (from fishing or aquaculture). Processes which are to be included are harvest (slaughter, for aquaculture only), gutting, filleting, refrigeration and/or freezing. Data which is to be collected includes energy use, fish mass balance, relative value of the fish co-products and refrigerants used.

Other transition phase PEFCRs which were reviewed regarding manufacture stage were pasta and feed for food producing animals. For assessment of **pasta**, manufacturing activity data that need to be collected is electricity and fuel consumption, water consumption, auxiliary materials and transportation of materials and waste. Waste amounts are mandatory to include, and defaults are given for this purpose when no primary data are available.

Regarding the manufacturing of the **feed products**, required process data includes energy inputs (electricity, gas, heat, other fuels) and water.

In overall, the manufacturing stage modelling requirements and activity data varied depending on the nature of the product. As the system boundary of the stage included the relevant inputs and processes regarding the produced product, *no crucial differences, which would cause incomparability were found.*

3.1.2.3. Transport, inbound and outbound, and storage at retail

Transport, inbound and outbound, and storage at retail were also investigated by Hietala et al. (2023). Regarding **inbound transportation** of the inputs or ingredients, it was noticed that not in all cases it is specified when the transportation is to be included. Yet it was stated, that typically, the transportation of raw materials and packaging materials to a processing plant, the transportation of a product to a distribution center, retail, etc., and transportation to a waste facility are included. In the PEFCRs and drafts the transportation stage (inbound and outbound) was instructed to be modelled according to the general PEFCR guideline which also provides defaults for modelling (European Commission 2018a, 2021) and *thus only little variation between PEFCRs is likely*. Yet, in the revised Recommendation (European Commission 2021) some clarifications have been given: new default for transportation to composting and inclusion of End-of-Life distribution to EoL stage instead of distribution stage. Also, intermediate products should now exclude distribution stage besides use stage and EoL. *These clarifications are potentially improving the consistency of the new PEF studies.*

Storaging is included olive oil, packed water, wine, beer (for grain at farm as capital goods, cooling of the beer at use stage), marine fish, dairy products, red meat, while storage of the product is not included for pasta or feed as the shelf life of the products is considered to be short. While the storage is to be included for most of the products, it often is not described in detail how. General PEFCR guideline is giving instructions for modelling storage and thus it was *considered as harmonised method for modelling* (European Commission 2018a, 2021).

3.1.2.4. Use stage and End-of-Life modelling

Use stage was included in all reviewed food PEFCRs and unofficial guidance. Some differences could be found on what is included in the use stage. For most of the drinkable products typically cooling of chilling in households was included, when relevant. Coffee guidance was the most detailed in the use stage description and included also coffee maker production, energy use in cooking besides the cup used for drinking and dishwashing. Many of the guidances included dishwashing and the cup which is used for consumption. For pasta, cooking in water was included, but also the needed ingredients in cooking (water, salt). Packed water PEFCR included also carbon emissions of carbonated water to use stage. Often the waste handling was included yet mainly for or as wastewater. Few guidances included also food waste. In overall, use stage boundaries were set differently for many of the products. *Typically energy used for preparing the product for consumption was included, but some guidances included also the dishes and washing or food wastes, which was seen as potentially causing incomparability between results.*

For the **End-of-Life (EoL)** modelling, *end-of-life formula or circular footprint formula was utilised in all of the guidance's*. Some differences were in the processes to which the formula is applied to. Only the red meat guidance instructs to use it for all materials. Most typical was the use for packaging only (pasta, packed water, feed) or to leftovers of the product and packaging (olive oil, wine, beer, marine fish, dairy). Dairy PEFCR mentions also the inclusion of the transportation of the wastes to be included. In the unofficial guidance of coffee includes besides of product waste (coffee grounds) and packaging also the end-of-life of coffee machines and dishes.

3.1.2.5. Emission modelling

Emission modelling is throughout the transition phase PEFCRs following the general guideline given by the EC (European Commission 2018a, PEFCR guideline 6.3., European Commission 2021, Annex I). Thus, e.g., IPCC 2013 methodology is in use for global warming potential (GWP) in the current PEFCRs, and it is also given as recommended method in the latest guideline (European Commission 2021, Annex I). The draft versions or unofficial guidance had deviations in methods. Thus, if these are utilised, they should be harmonised according to recent PEFCR guideline (European Commission 2021, Annex I).

3.1.2.6. Allocation

Allocation was reviewed in separate for all of the PEFCRs' by Hietala et al. (2023). It was stated that there are differences in allocation between different PEFCRs' and unofficial guidance's. When the allocation was investigated separately for each life cycle stage, it was noted that for primary production, economic allocation was used for plant-based products (Hietala et al. 2023). For the livestock, biophysical allocation was instructed for dairy according to IDF method, and this was instructed in general guidance as well (European Commission 2018a, 2021). In separate, here the fur product PEFCR was reviewed in parallel, as it gives guidance to sheep allocation and manure handling (European Commission 2018j). In fur product PEFCR the allocation of sheep is to be made based on economic value, for meat and hides. For red meat, allocation at slaughterhouse level is instructed with mass basis, which also considers sheep.

In the manufacturing or processing stage was also allocated most often with economic allocation. For pasta and beer no allocation was made to side streams. *Largest differences were in livestock products, where processing of dairy products was allocated based on dry matter, red meat according to mass and general PEFCR guidance recommends the use of economic allocation factors (which was also the case in fur product guidance).*

For the processing facility and transportation, all guidance's recommend the use of physical (mass or volume) allocation.

Only the unofficial guidance of coffee included instructions to allocation of the use stage, which was based on duration of use.

In livestock related guidance (dairy, red meat, and fur products) controversial instructions for manure handling were given. For dairy products, emissions can be allocated to manure if it is considered as valuable product. For red meat, crediting is utilised, and emissions of the substituted fertiliser can be reduced. And for fur products, manure is handled as waste, which would require the use of circular footprint formula.

3.1.2.7. Data quality requirements

To assess the quality of the data, for both primary and secondary, the PEF guideline provides assessment frameworks, Data Quality Requirements (DQR, European commission 2018a, 2021). Here, the DQR tables were reviewed according to existing PEFCRs and 2018 PEF guideline. DQR scoring must be assessed separately for the various stages of the production chain, in accordance with the boundary conditions set by the PEFCR. Each PEFCR guidance provides at least one DQR table for primary data and one for secondary data to assess the accuracy of the data collected (Precision, P), Time Representativeness (TiR), Technological Representativeness (TeR) and Geographical Representativeness (GR). Each criterion is given minimum requirements for a certain point level (values 1-5). Based on these, the DQR of the dataset and the overall DQR score can be calculated.

In the general PEFCR guideline (European Commission 2018a, 2021), instructions are given for calculation of the DQR score for both primary and secondary data. In the recent recommendation the maximum score for the DQR of company specific, primary data was lowered to 1.5 from previous 1.6.

In the review by Hietala et al. (2023) it was stated that all PEFCRs follow the same principles in data quality requirements, which are set following the general PEFCR guideline (European Commission 2018a). The data collection is divided to primary data and secondary data based on the system boundary definitions in each PEFCR. Quality of the primary and secondary data is evaluated with two different DQR tables, one for primary data and one for secondary data. Also, PEFCRs are required to mention if sampling is allowed in data collection. Some variation was found in the given details and quality requirements of sampling. Sampling is allowed in PEFCRs for pasta, dairy, wine and feed, and unofficial drafts for marine fish and olive oil.

3.2. Effect of application of national models for enteric methane in the Nordic countries

Emission of GHG from enteric fermentation is an important contributor to the total emission from livestock – and for ruminants it can contribute to more than half of the total emission. Significant work is ongoing worldwide to document emission at experimental level and this information is included in the national inventory in order to document the present level and the development over time.

The PEFCR for dairy products refers to IPCC (2006) Tier 2 as minimum requirement. In addition to the PEFCR for dairy product IDF (2015) has in their standard quide, recommended the use of either Tier 2 or Tier 3 defined by IPCC.

The purpose with this short note is the give an overview about the methods used in the Nordic countries and to give insight in effect compared between the countries and in relation to other standards and ongoing initiatives, based on data and results related to dairy cows from the national emissions report.

3.2.1. Results from different standards

Based on that to elaborate on the use of high-level Tier approach as part of PEF – comparing product across countries.

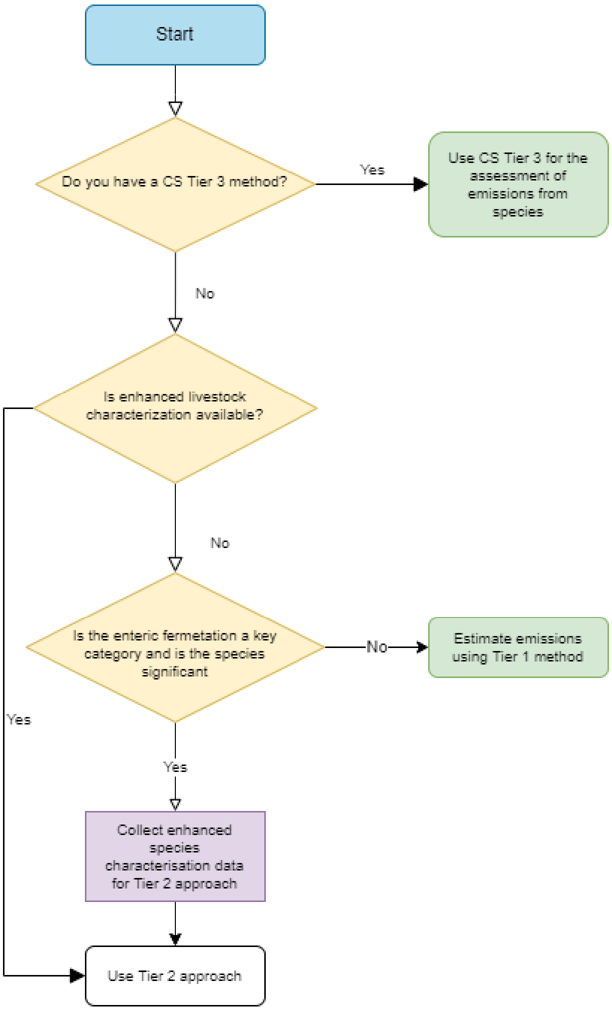

Fig. 1. Decision tree for CH_4 emissions from enteric fermentation modified from IPCC (2019).

The IPCC guideline leads to use of either Tier 3 – country specific approach – or Tier 2, in case the area is a key category and the species in question account significant (more than 25-30%) to the emission of enteric methane **(**Fig. 1, IPCC, 2019). If this is not the case Tier 1 can be used, where standards are given based on 9 geographic regions. For the Nordic countries, being part of the West European region, this gives an emission of 126 kg CH_4 per dairy cow annually (IPCC, 2019), which is based on 7410 kg milk in average annual milk yield. This can be compared to a Tier 1 standard value of 138 kg CH_4 based on annual yield of 10250 kg milk for North America or 93 kg CH_4 in Eastern Europe based on 4000 kg milk annual (not fat and protein corrected).

If Tier 2 is used the intake, either in MJ gross energy (GE) or in kg dry matter intake (DMI), has to be calculated. This can be based on either standard demand from data defining animal productivity or direct intake data. Often these are not representative and in cases where some of the intakes are from grazing not complete for the year. IPPC (2019) gives standards for these calculation and methane conversion factors (Ym) either based on GE (% of MJ) or DMI (g CH_4

per kg DMI) for four groups of dairy cow group by milk yield and an underlying feed digestibility and neutral detergent fiber (NDF) content (**Table 3**).

IPCC (2019) notes that if the national data for production levels are inconsistent with the feed quality bounds that are defined by the categories in **Table 3**, *it is good practice* to develop their own country-specific Ym factors, and they should also use their information on animal diets to validate their choice of Ym against methane yield equations recommended in Niu *et al.* (2018).

Table 3. Standard methane conversion factors (Tier 2) for dairy cows (IPCC, 2019)

			Methane conversion factor	
Production level, kg milk annual per cow	Feed Digestibility, % of DM	NDF, % of DM	CH4, g per kg DMI	Ym, % of GE
< 5000 kg	<62	>38	21,4	6,5
5000-8500 kg	63-70	>37	21,0	6,3
8500 kg	>70	>35	20,0	6,0
8500 kg	>70	<35	19,0	5,7

Tier 3 approach can be used – after "wide degree of international peer review" (IPCC, 2019a).

3.2.1.1. Animal working group

As part of updating the PEF methodology for agricultural products, the European commission set down and agricultural working group. The task of the AWG was to look into a range of areas and suggest solutions to technical issues. The subgroup on enteric methane is one of them. At the last meeting the group recommended to use a Tier 2 approach based on national data for dry matter intake and content of NDF, as input to the formula after Niu et al. (2018):

$$CH_{4\text{ g per animal per day}} = 33.2 + 13.6 \times \text{DMI (kg per day)} + 2.43 \times \text{NDF (\% in DMI)}$$

They also note that where relevant Tier 3 /advanced Tier 2 approaches that can be used in the form of country specific methods for estimating enteric methane emission, which are often based on an extensive understanding of the local animal and dietary factors affecting enteric methane emission. It is here understood that the method used is approved by UNFCCC (United Nations Framework Convention on Climate Change) for national reporting of methane emission and that the production chain in question is based on a livestock production system comparable to the overall country specific conditions.

If results allow, the formula above may be updated at a later stage including also dietary concentration of fat and starch, where appropriate.

3.2.1.2. The Nordic emission reports

Sweden and Norway use a Tier 3 approach based on models from Nordic experiments, while Finland and Denmark use a Tier 2 approach with national data and in Denmark this is combined with a national estimated Ym factor, while Finland use the IPCC standard.

In the following section the methods used in each country are briefly described. More specific information including trend over time can be found in the national reports.

Sweden uses annual information about milk production, proportion of silage in the ration and the digestibility of the silage. These data, combined with standard requirement and feed values are used in models (Bertilsson, 2016) to estimate energy intake (MJ, ME), dry matter intake and the fatty acid (FA) content, which is used to calculate the daily methane by an equation developed by Nielsen et al. (2013).

CH_4 (MJ) = 1,39*DMI (kg)-0,091*FA (g per kg DMI)

Norway has used a model to estimation of methane from typical feed ration (DMI, Fat and NDF content) using NORFOR in the range from 5000 to 12000 kg of milk. These data sets were used to make models in order to calculate a national GE and Ym factors from annual milk yield and proportion of concentrate in the rations (Niu et al., 2021).
The equations are:

GE =137.9 + 0.0249 × Milk305 + 0.2806 × Concentrate_proportion
GE = gross energy intake, MJ/day
Milk305 = 305 d lactation yield of ECM
Concentrate_proportion = proportion of concentrate in the total diet on net energy basis, %

and

Ym = 7.38 - 0.00003 x Milk305- 0.01758 x Concentrate_proportion
Ym = methane conversion rate, %
Milk305 = 305 d lactation yield of ECM
Concentrate_proportion = proportion of concentrate in the total diet on net energy basis, %

Finland using IPCC Equation to calculate GE based on animal weight, average daily weight gain, milk production, pregnancy, digestible energy of forage and length of pasture season, based on data from agricultural statistics and registries and country-specific feed digestibility value DE combined with the standard Ym of 6,5% based on Finnish experts (J. Nousiainen).

Denmark has developed a model predicting the methane conversion factor Ym from a range of experiments based on DMI and content of fat, ash, NDF and starch in the ration (Hellwing et al., 2016).

Ym (% af BE) = 7,55 – 0,0343×DMI (kg/d) – 0,0199×crude fat (g/kg DMI) – 0,0014×ach(g/kg DMI) + 0,0028×NDF (g/kg DMI) – 0,0045×starch (g/kg DMI)

Based on annual updated figures for feed intake and ration content (collected by SEGES) the model is used to recalculate the Ym factor (Lund et al., 2020) and feed data is used to calculated GE intake (DCE, 2020).

3.2.1.3. Results

Across countries the annual data needed for calculation of enteric methane are
S: Milk yield, roughage % of DMI and DE
N: Milk yield, concentrate % of DMI
F: Milk yield (and other performance data), DE forage
DK: Feed dry matter intake, (GE)

Looking in the reports with data over time, it is milk yield and dry matter intake that have changed, while the other input data with more specific information about feeding have shown minor change over time, like for DK GE per kg DMI from 18,6 in 1990 to 18,9 in 2020 and for N proportion of concentrate from 39,1 in 1990 to 45,4 in 2020. In the same period has milk yield increased from 6320 to 8463 kg per cow annual in Norway. The combined effect of change in milk yield and concentrate proportion is an increase of 14% in methane and if the model is used assuming that only milk yield increase, the change in methane is 16%.

Besides the needed data, the Danish report states that the Ym can be updated based on information about DMI and nutrient content in the diet (ash, fat, NDF and starch). This has been done in 2018 and 2020 resulting in a change from 5,94 to 5,78 in the Ym factor.

Table 4 gives the national level of methane per dairy cow in each country compared with the level using either country specific production data or the IPCC standard, first the simple Tier 1 and then using either the methane conversion factor based on GE or DMI from **Table 3**. For Sweden GE is calculated from ME in the national report, GE using a factor 0,62 (Østergaard, 1983). As shown in **Table 4** the Ym factor in DK and N is close to the standard in IPCC, knowing that the NDF in Denmark is below 35% leading to 5,7 as conversion factor. The Ym in Finland is set to 6,5% due the use of IPCC (2006) standard, if using the updated version (IPCC, 2019) the value would be 6,0.
The country specific level of methane is in all countries higher than the Tier 1 level, due to higher yield than average of Western EU. Even higher using the figures from North America (138 kg CH_4) at a yield level comparable to the one in the Nordic countries.
The Tier 2, GE method, is at the same level as the country specific in Norway, while higher in Denmark or lower up to 11 kg or 7% in Finland. In the two countries having information about DMI, indicates that the methane emission is at the same level as using the GE method.

Table 4. Country specific data and EF compared to EF estimated from IPPC Ym and country specific data, kg CH4 per dairy cow annually

	Year	Milk	Intake		Ym factor, %		Methane, kg per cow annual			
		Kg annual	Kg DM annual	GE per Day	Country	IPPC, Tier 2	Country	Tier 1 (W. EU)	Tier 2 (GE)	Tier 2 (DMI)
Sweden	2018	9385	6315	331	6,45	6,0	140	126	130	126
Norway	2020	8463		363	6,34	6,3	151	126	150	
Finland	2020	9309		378	6,50	6,0	161	126	149	
Denmark	2020	10950	8029	416	5,78	5,7 [1)]	158	126	164	161

1) NDF in average ration 33,7% (Lund et al., 2020)

In order to compare the methods used in each country more closely, a standard feed ration was defined based on Lund et al. (2020) and GE per kg DMI. In order to illustrate how the methods can capture change in production, the effect of three different scenarios were analysed (**Table 5**).

- High fat defined as 54 g fat per kg DMI compared to 45 g as standard. Fat is one of the promising mitigation options. CH_4 should be reduced.
- Low NDF defined as 270 g NDF per kg DMI compared to 335 g as standard. The NDF level is correlated to proportion of concentrate (barley 14% NDF, grass silage 45% NDF in DMI). Higher proportion of concentrate is a known mitigation strategy. CH_4 should be reduced.
- High efficiency defined as more milk per kg DMI (1,36 kg milk per kg DMI in standard compared to 1,43). This is not a direct mitigation options but management effect. CH_4 is expected to be reduced.

Table 5. Input to scenario – illustration of effect based on standard ration and three different changes

Ration	Milk, kg	DMI, kg	GE, MJ / DM	Roughage, % of DMI	ash g / DMI	fat g / DMI	NDF g / DMI	Starch g / DMI
standard	30	22	18,45	60	75	45	335	175
high fat	30	22	18,45	60	75	54	335	175
low NDF	30	22	18,45	60	75	45	270	175
high eff	30	21	18,45	60	75	45	335	175

Methane in kg per cow annually for the 4 rations **Fig. 2**. Enteric methane feeding dairy cows four different feed rations (Table 3) estimated by 8 different methods. is calculated using methane conversion factors either the Tier 2 IPCC standard, the proposed model by the AWG or the national models, including the underlying version in Denmark (DK-model) and the one in Norway (N-model) based on detailed ration content as this is part of annual update to take into account change in ration composition (**Fig 2**).

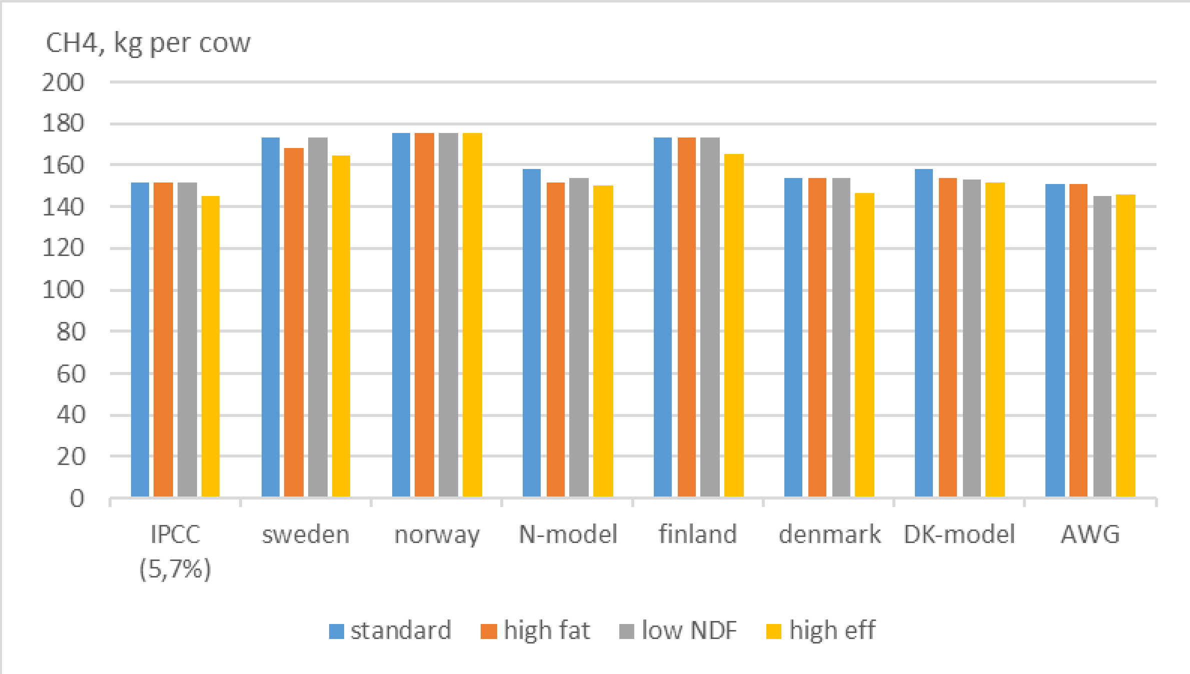

Fig. 2. Enteric methane feeding dairy cows four different feed rations (Table 3) estimated by 8 different methods.

The methane emission based on standard ration data is 152 kg CH_4 per dairy cow using IPCC standard, which is lower than all other models except the AWG proposed model. Change in fat content is included in the models from Sweden with an estimated reduction of 6 and 8 kg CH_4. Lower NDF is included in the model proposed by AWG with a reduction of 6 kg CH_4. If the change in NDF is due to change in roughage – concentrate proportion, the change would also be reflected by the Swedish and Norwegian models. Higher efficiency is reflected in all models, except Norway, with a reduction from 5 kg in the AWG model to 9 kg CH_4 in the model used in Sweden.Using the underlying models in Norway (N-model) and Denmark (DK-model) affects the methane emission both for the standard ration and the three scenarios.

In a PEF for raw milk about 40-50% of the total GHG emission is related to enteric methane, so these differences will also have a major impact on the milk product footprint.

4. Discussion and conclusions

In this current study, the most material aspects of comparable, environmental product Life Cycle Assessment were revised by reviewing of the PEFCR guidance (transition phase and unofficial) and review by Hietala et al. (2023) in parallel with previous Nordic reports of feed products, manure management and data requirements (Møller et al. 2021, Hietala et al. 2021, Hermansen et al. 2017).

As it was found by Hietala et al. (2023), it seems that there are small differences between PEFCRs in the setting of the **system boundaries** and mainly the system boundaries are uniform or including the relevant processes regarding to typical production system. According to Hietala et al. (2023) factors which might be excluded from the system are, e.g., machinery and equipment, veterinary medicines, detergents, and refrigerants. The main finding regarding the modelling of the primary production stage was that PEFCRs define very generally how various agricultural inputs should be included in the assessment, *which might become a source for variation in the assessments.* The revised PEFCR guideline (European Commission 2021) seems to slightly increase consistency of methods due to the revised description how the cut-off rule is to be used and requirement to include instructions how capital goods are to be included, when cut-off rule is not applied.

Functional unit has been acknowledged as one major issue for incomparability of the PEF study LCA results. Even if the issue was ruled out from this analysis as an insurmountable problem, some considerations were included. One major issue is that the nutritional function of different food products is not truly translated to the used functional units, which namely are based on physical quantity, mass or volume. If the function of a drinkable product would be to provide glass of drink, then a volume based functional unit would be adequate. But if the function is to provide nutrition, or even hydration, quality of the product regarding that function should be better included to achieve comparability of the LCA results of different products. Handling food products similarly to feed products, as intermediate products, could be seen as solution. Although benchmarking of intermediate products has been previously denied in PEF method and now in the revised PEF guidance it is optional and may be excluded (European Commission 2018a, 2021). Thus, comparison of intermediate products is not supported.

In the revised PEFCR guideline (European Commission 2021) it is now included, that if packaging has impact to products shelf-life, it must be taken into account. Also, when expiration date marking is given on the packaging, the food losses must be quantified. Inclusion of food losses and impact of packaging to shelf-life were seen as potentially bringing more accuracy to the PEF studies, but also, quantification of food losses can become a source of uncertainty and variation.

Regarding **manufacturing stage**, all PEFCRs and drafts include the manufacturing as company specific with mandatory requirement for primary data collection. System boundaries of the manufacturing are set according to product and the required activity data in most cases are to be collected for energy used in processes (electricity, gas, heating, other fuels) and water consumption. When relevant, allocation factors are to be collected as primary data. Similarly, for the products requiring cool storage, refrigerants are included. *Thus, for the manufacturing stage no crucial differences were found and mandatory primary data requirement was seen essential.*

Transportation of the raw materials, products, co-products and wastes were typically included in the guidance. Yet, as reported by Hietala et al. (2023) there was variation in accuracy and detail to which the guidance was given. For both transportation and storage, the modelling was guided to be conducted according to general guidance for PEFCR (European Commission 2018a, 2021). In the revised PEF guideline, clarifications have been made for transport to composting and inclusion of EoL of transportation to EoL stage. *For transportation, clear description on inclusion and method for the different inbound and outbound transportation would aid comparability.*

The use stage included typically the chilling phase or the cooking phase of the product, depending on the nature of the product. For some products, dishwashing is also included for the use phase. The unofficial guidance for coffee was the most detailed in describing the use stage modelling and included also the production of the coffee machine and coffee cups. For the red meat the use stage was stated to be out of scope of the guidance, yet secondary data was pointed to be used for modelling. For few of the cases the guidance instructed to include product wastes, e.g., beer, wine and dairy. Thus, preparation energy use was included in minimum, but then depending on the characteristics of the products, more processes were included besides that. *As the use stage is often causing smaller contribution to the products environmental burden, in most cases the differences between use stage boundaries are causing probably only small variation in results. Yet, for some products, use stage is significant contribution (e.g., beer) and thus for better comparability, similar types of products should have the same processes included for the assessment.*

For **the End-of-Life modelling**, all of the guidances instruct the use of circular footprint formula (or the earlier drafts end-of-life formula). *Variation was seen on which wastes are included, which can cause differences in results.*

Allocation was reviewed separately for each stage and in parallel, over the different guidances. As it was reported by Hietala et al. (2023), the main allocation choice for primary production is economic allocation and facilities, transportation and storage use physical allocation (mass, volume). Largest differences were found in livestock related guidance, especially the different handling of co-products for red meat and fur products can lead to unaccounted emissions. The different handling of manure in each of the livestock related guidance's impairs also comparability between products. For comparison of food LCAs, it is especially important to have similar allocation methods for similar products. *Thus, the controversies in allocation of different animal based products need a detailed investigation so that a fair and uniform result is achieved for all. For example, the manure handling in different animal product guidances should be conducted the same way.*

Data quality and primary data utilisation has been recognised as one potential source for variation. The data collection in PEFCR guidance is divided to primary data and secondary data based on the system boundary definitions in each PEFCR. Quality of the primary and secondary data is evaluated with two different DQR tables, one for primary data and one for secondary data. The company specific data has lower limit for maximum DQR score, and depending on the system definitions, the requirement for this higher quality data is set for certain processes. As all of the PEFCR guidances require company specific data for the manufacturing stage, the primary data DQR is to be followed by all. Now, depending on the characteristics of the product and producer, primary data might be required for primary production of the ingredients as well. This would mean for example for dairy products, which are made with milk-based ingredients, e.g., milk powder from wholesale, that secondary data would be accepted with higher DQR score limit, while for modelling a product of a producer who has contract production of dairy, requires always primary data collection from farms.

PEFCRs are required to mention if sampling is allowed in data collection. Some variation was found in the given details and quality requirements of sampling. Yet, as it has been guided in the general guidance for the PEFCRS, how the sampling can be conducted and that the details need to be given in the PEFCR, the instructions seem to follow this guidance. Still, the sub-grouping can be based on variable information given in PEFCRs. Sampling is allowed in PEFCRs for pasta, dairy, wine and feed, and unofficial drafts for marine fish and olive oil.

As regarding the accessibility to required data, Hermansen et al. (2017) have already raised the need for Nordic life cycle inventory data for livestock production, such as feed use and herd composition. Yet, the importance of the primary production stage is pointed as the most important for the livestock product LCAs. While the 5-year-old report states the requirement for easily accessible farm data, the current situation isn't any better. Thus, adequate, accurate national LCI data together with Nordic defaults for minor inputs are still on the wishlist as presented by Hermansen et al. (2017).

As the PEFCR review provided insights to what extent the guidance is uniform, and wether the comparability can be achieved in theory, the application of Dairy PEFCR in Nordic countries was conducted to investigate potential differences caused by the accepted national, country specific methods.

For the implementation of Feed PEFCR in Nordic countries, the previous Nordic report was reviewed. According to Møller et al. (2021) there was a general agreement among the stakeholders on the importance of harmonising methodologies. There are major differences in how far and how the different feed producers and other stakeholders in the Nordic countries had come in using PEF or equivalent systems. However, the pressure to feed suppliers to communicate environmental information is increasing. Although the PEFCR recommends a number of impact categories, there has so far been focus only on carbon footprints and secondly on soil sequestration and land use/land occupation. Data quality was deemed crucial. Also type of data, primary or secondary was discussed. The advantage of using secondary datasets is that there will be equal conditions for all suppliers in the same market. When a method allows both secondary data and primary data, it requires a review system, which approves data, or the source behind data in general, before they are used. *There was a general agreement that case (farm, region) specific data is needed in order to stimulate growers and feed industry to introduce mitigation in the production lines.*

For the assessment of manure management, the previous Nordic report by Hietala et al. (2021) was reviewed. In this report it was stated that for assessing nitrogen retention and excretion according to PEFCR (regarding pork production) and following the national inventory report methods, each of the Nordic countries utilised own national method. This was found acceptable, as the Nordic breeds differ from the one utilised in IPCC 2019 guidance. More differences were found in methane assessment methods of manure storage and comparison of manure methane from similar breeding sows resulted with large differences between Nordic countries with similar conditions and breeds. The higher Tier level gives more resolution to the assessment and could potentially be recommended to be used in assessment of products from the same country. *Since the differences of the method can lead to false variation in results, more harmonised methods should be suggested to be used in comparable assessment of products. Especially for the manure emission assessment, as suggested by Hietala et al. (2021) harmonised definition for Nordic conditions of the methane conversion would be needed.*

As a conclusion for this study, it can be stated that PEF method is providing a much-needed harmonisation to food LCA. In overall, PEF method and the given guidance promote consistency, transparency and reliability of the conducted studies. And it promotes comparability.

Yet, many aspects which were discussed in this report remain unsolved and need more careful considerations in forthcoming PEF studies and PEFCR guidance's if comparison across product categories is desired. Some of the found differences arise from the comparison of finalised PEFCRs and drafts or unofficial guidance, and these differences can be solved with the updates of the PEFCRs following the new revised PEFCR guidance. While the remaining differences would need revision of the guidance's. The issue of functional unit is acknowledged as major hurdle for comparison, and potentially too large to be solved as PEF method. But also solving allocation differences, harmonising use stage boundaries, handling of manure across the PEFCR guidance's should be done prior to utilising PEF method for comparison of products across the product categories. As the PEF method has all the potential for achieving this, a driver, and interest of the PEFCR developers to find harmonisation between PEFCRs would be needed. As currently, PEFCRs are developed to provide comparability within product group, harmonisation across PEFCRs is not controlled. Thus, e.g., different handling of manure emission can be selected as best practice for different PEFCRs. The revised Recommendation from the European Commission provides many clarifications and additions to PEF method, and it remains to be seen how these are interpreted and adopted to PEFCRs. And if it also promotes harmonisation across product categories. Yet, the clarifications can be seen to increase consistency and transparency of the method.

In this current study, method for assessing methane from enteric fermentation was investigated. Using different IPCC approved methods and models, in this case to estimate enteric methane from dairy cows in the Nordic countries, can change both the level of emission of kg CH_4 annual per cow, and how countries rank in respect to these emissions. Potential change, to mitigate enteric methane, is captured partly across models and if captured with some variation in the amount of methane that is reduced.
Using different models in each country for estimating the trend or development in the emission must include the mitigations options defined by the country.
In the case of estimating the product footprint across countries, the use of different models is problematic if the level of emission change due to the model parameters and not the production data. This problem is already existing in use of PEF methods, within a product group and by following PEFCRs. It is therefore problematic that the AWG and PEF allow the use of national models, even in the case that they are approved by IPCC as they are not validated for comparison.

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