°REPORT 2016:06

Climate Footprints of Norwegian Dairy and Meat - a Synthesis

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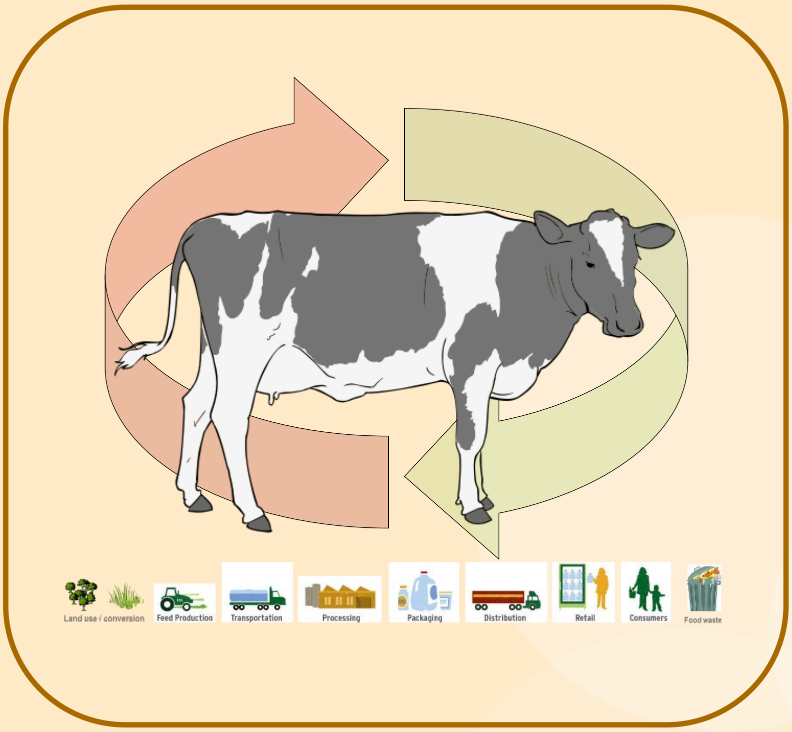
Climate Footprints of Norwegian Dairy and Meat – a Synthesis

A literature study of emissions of Norwegian dairy and meat products compared to other relevant products and regions, commissioned by TINE AS

Bob van Oort, Robbie Andrew

July 2016



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Title: Climate Footprints of Norwegian Dairy and Meat – a Synthesis

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CICERO Rapport 2016:06

Financed by: TINE and the Norwegian Research Council (SIS KliMAT)

Project (CICERO project number):: 30821 and 30790

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Keywords: Climate Footprints; Emissions; Meat; Milk; Dairy; Norway

Abstract: This report reviews the current literature on meat, milk and dairy, with a special focus on Norway. To understand differences in reported emissions, the report explains the variation in methodological approaches such as division over co-products, functional unit selection, and system boundaries. Cattle meat, milk and dairy emissions are analyzed and compared with selected other foods that could act as a replacement, according to the various system boundaries used in the studies. Emissions from meat and dairy in Norway are compared with the Nordics and west-Europe, and other regions where relevant. Comparisons are also made between different production systems, including conventional and organic, intensive and extensive, and beef production from different types of cows. Finally, the report analyses the relative impacts of the different life cycle stages of meat and milk production and consumption. In a short section, it highlights some of the potentials for change of milk and meat impacts on the climate that emerged from the literature.

Key findings summarize emissions for meat from dairy cows (around 19,5 kg CO_2 equivalents per kg product), young bulls (around 19 kg CO_2eq/kg), suckler cows (around 30 kg CO_2eq/kg) and milk (around 1,2 CO_2eq/kg). Norway's emissions from combined meat-milk production are higher than in other Nordic and Western European countries, mainly because other countries have higher yields and lower methane emissions. Cattle meat and milk emit more than potential alternatives. Use of functional units and comparison between products depends on the stakeholders and context for comparison. In Norwegian meat and milk production, on-farm processes play by far the largest role, with around 78% of the emissions. Pre-farm stages contribute 22%. Most, around 38%, come from methane from ruminant digestion. Importantly, few if any studies present allocations over the full life cycle, which means that proportions for pre-, on—and post-farm emissions may change significantly when including all life cycle stages. Finally, the report finds no clear differences between conventional and organic meat and milk production in terms of climate impact, while intensive and extensive systems both have large mitigation potential.

Language: English

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Contents

1 Introduction

1.1 Report Aim

TINE commissioned this report to create a factual, objective basis for a better, unbiased and critical understanding of the emissions (CO_2 and equivalents of other greenhouse gases) of Norwegian meat and dairy production.

The report provides a context for TINE's "nutrition strategy towards 2018" which, in a separate report, will evaluate the role of meat and dairy in a sustainable and climate friendly diet (sustainable nutrition). The role of agriculture in terms of sustainability is increasingly relevant, in terms of both climate change, population change, and public opinion. There are many references to the climate impacts of agriculture, especially cattle, on climate.

A complete lifecycle analysis of Norwegian produced meat and dairy, covering the existing variety of different production methods, (types of) energy use, and all inputs and outputs with an effect on the climate, would give the best answers, but this was too ambitious for this report. Thus, the report does not create new knowledge, but summarizes current and relevant knowledge on emissions in the Norwegian dairy and meat production. There is an understanding that different regions, production methods, and different inputs and outputs and system boundaries related to emission numbers result in a range of different answers to the amount of emissions related to meat and dairy production. Very few studies include a complete life cycle of these products, and equally few studies compare production methods or products using the same approach for Norway. Thus, we focus on findings for Norway, and compare and complement these with similar studies in the Nordic countries (Sweden, Denmark, Finland), and comparable countries in Europe (e.g. Netherlands, UK, Germany). Furthermore, we use data from the rest of Europe or other at the global level to put Norwegian emissions in perspective. We also analyze emissions in the different steps in the production-consumption chain to assess which factors contribute to higher or lower emissions in the meat and dairy industry. Finally, with an eye on the need to curb climate change and thus emissions, and the potential role and consequences for the meat and dairy industry in this, we analyze emissions of some alternative products that potentially play a role as meat or dairy substitutes.

Sustainable and climate friendly food production and consumption are also issues of increasing focus and relevance in the scientific community. The request of TINE for this report coincides with an increased focus at CICERO on the needs and options to decrease emissions on the production and consumption side of the food value chain.

1.2 Background

Through natural processes, livestock generate emissions of gases that have a warming effect on the world's climate. While those emissions might still be regarded as 'natural', the enormous scale of the industry across the globe means that those emissions contribute significantly to the warming already seen in global temperatures. Emissions from the livestock industry as a whole have been estimated to contribute almost 15% of total anthropogenic emissions of greenhouse gases (GHGs; Gerber et al., 2013). Natural processes are not the only sources of greenhouse gas emissions from agriculture, with significant use of fossil fuel, both as an energy source and as an ingredient in fertiliser manufacture, as well as carbon emissions from land-use change, both deforestation and draining of wetlands.

A large proportion of emissions from the livestock industry come from ruminant animals (cattle, sheep, and others) and their management, with beef and cow milk production contributing about 60% combined to the industry's total global emissions (Gerber et al., 2013). In 2013, there were about 3.7 billion ruminant livestock globally (FAOSTAT, 2016).

In Norway, the agricultural sector is responsible for about 8% of total emissions, some 4.4 $MtCO_2e$ per year. These have gone down slightly in recent years, from 4.9 Mt in 1990 to 4.4 Mt in 2015 (preliminary estimate; Figure 1) largely as a result of reduced numbers of cattle and an increase in the use of concentrated feed in place of fodder (Arbeidsgruppe til Landbruk og Klima, 2016).

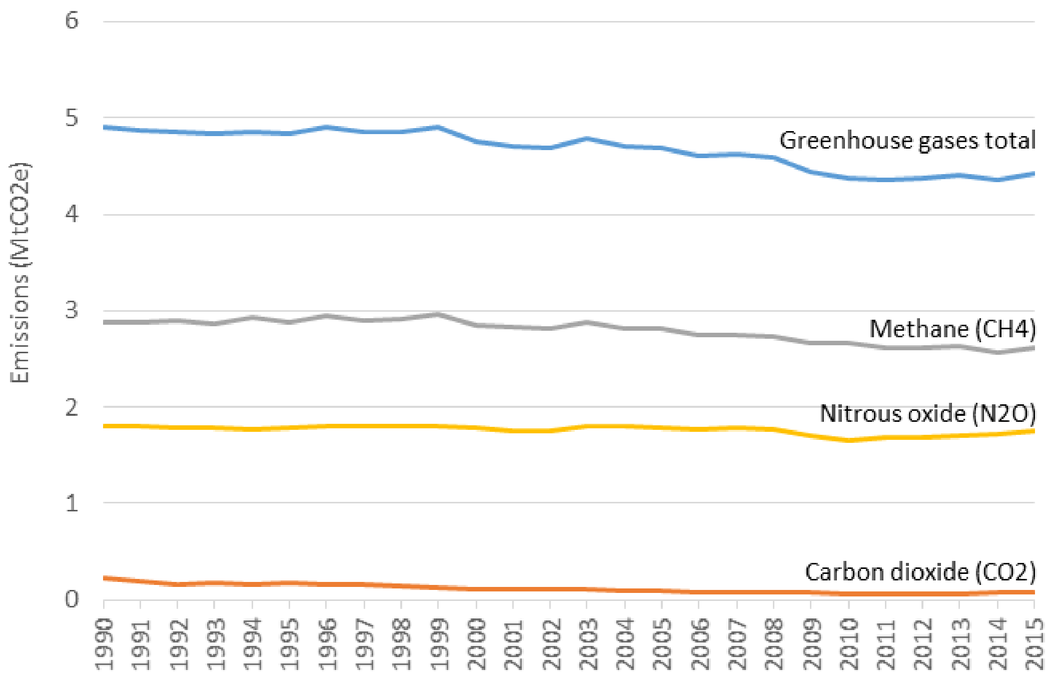

Figure 1: Trends of greenhouse gas emissions from the agricultural sector in Norway, 1990-2015. These exclude emissions from production on drained wetlands, on-farm energy use, and all off-farm emissions (Source: SSB).

However, these figures represent the agricultural 'sector' as defined in international accounting terms, and thereby exclude important emissions such as those from energy use on farms (e.g., tractor fuel) and, most significantly, agricultural production on drained wetlands. When wetlands are drained, the rich carbon content of their soils gradually combines with oxygen from the air to form carbon dioxide, which escapes to the atmosphere. Despite these drained wetlands amounting to only about 6% of Norway's agricultural area, their slow oxidation adds about 1.8 Mt CO_2 of annual emissions. When these additional emissions are included, the total from agriculture increases to about 6.3 Mt, or 12% of Norway's total greenhouse gas emissions (Arbeidsgruppe til Landbruk og Klima, 2016). The livestock sector in Norway contributes about 90% of this total (Grønlund & Harstad, 2014), while globally the proportion is lower because of emissions from other forms of agriculture, such as rice cultivation. Table 1 presents various contributions to agriculture's emissions in Norway.

Table 1: Sources of emissions from land-use in Norway (Source: Grønlund & Harstad, 2014)

Source	1000 tonnes CO_2e	% total land use
Enteric fermentation	1892	30%
Manure	924	15%
Artificial fertiliser	604	9%
Fossil fuel combustion	449	7%
Runoff	310	5%
Cultivation of wetlands	1785	28%
Cultivation of mineral soils	149	2%
Other	228	4%
TOTAL	**6340**	**100%**

Furthermore, emissions reported officially by SSB and to the UNFCCC include only *direct* emissions, i.e. those that occurred in the sector in Norway. They therefore exclude emissions that occur upstream in the supply chain and those associated with imported goods and services. These are sometimes called indirect emissions, resulting as they do indirectly from the activities of the agricultural sector. Similarly direct emissions also exclude those occurring in necessary downstream activities such as those in the food-processing sector, and in food distribution and retail.

1.2.1 Agricultural Emissions

Emissions of greenhouse gases associated with agricultural production include both on-farm and off-farm emissions. On-farm emissions are those that occur in the agricultural context, such as carbon dioxide (CO_2) emissions from use of tractors and other machinery, methane (CH_4) emissions from ruminant digestion ('enteric fermentation') and manure, and nitrous oxide (N_2O) emissions from fertiliser use and urine. Off-farm emissions are mostly CO_2 and occur in other parts of the supply chain, such as in electricity generation, fertiliser production, transportation, refrigeration, and food processing. While CO_2 is the most important greenhouse gas globally, CH_4 and N_2O are significantly more important in the agricultural context.

All developed nations report national emissions inventories annually to the United Nations Framework Convention on Climate Change (UNFCCC). The format and structure of these inventories is carefully designed by the Intergovernmental Panel on Climate Change (IPCC) with consistent methodologies between all countries. Emissions fall into five 'sectors': Energy; Industrial Processes and Product Use; Agriculture; Land Use, Land Use Change and Forestry (LULUCF); and Waste. However, many readers do not understand is that this Agriculture sector includes only those types of emissions that do not occur in other sectors, such as the methane from enteric fermentation, but exclude all other emissions, such as energy use on the farm and in fertiliser production, which are included in the Energy sector. When discussing total emissions in Norway's agriculture sector, it is therefore inappropriate to report only the total of the IPCC Agriculture category given in the national emissions inventory. The IPCC accounting framework is set up in this way to prevent any double counting of emissions.

While the national emissions inventory covers all greenhouse gas emissions in Norway, it intentionally does not include emissions overseas. In contrast, a carbon footprint necessarily includes emissions overseas, if they are generated in the product's supply chain. In the present context, emissions associated with soy bean production in Brazil and their transportation to Norway should be included in the calculation of a carbon footprint for Norwegian meat and dairy products.

Some experts argue that grazing leads to increased carbon content of soils, i.e. carbon that is sequestered from the atmosphere via grass, leading some to suggest that increased grazing will help in the mitigation effort against climate change. Certainly some soils under grazing do gain carbon, but this is highly dependent on the type of soil and how long it has been grazed for. Organic soils, as discussed above, lose large amounts of carbon following draining, while mineral soils can gain carbon. In Norway, mineral soils are estimated to be storing additional carbon every year, and these additions are included in SSB's estimates, which are submitted as the National Inventory Report to the UNFCCC. However, not all footprint analyses include these soil carbon fluxes, which is an important aspect to be aware of during interpretation.

To add together the emissions of different greenhouse gases it is necessary to use what is called a metric, and the most frequently used of these is Global Warming Potential (GWP), which allows for conversion of the values of each gas emission to the equivalent warming effect of CO_2. The current standard values, as used in national reporting to the UNFCCC, are 25 for CH_4 and 298 for N_2O. That is, emission of 1 kg of CH_4 has the same warming potential as 25 kg of CO_2, and 1 kg of N_2O has the warming potential of 298 kg of CO_2. Therefore emissions of CH_4 and N_2O are multiplied by these factors first before all three gasses are added together and presented in terms of the equivalent amount of CO_2 that would result in the same warming, denoted $kgCO_2e$.

A complicating factor is that these equivalency factors are based on integrating the warming effect over a 100-year period, and, arguably, with the 2 °C threshold potentially only 20-30 years away (Friedlingstein et al., 2014), shorter integration periods could be more appropriate in a policy context to reflect near-term warming. Shorter periods yield a significantly higher global warming potential for methane, making it as much as three times more important (i.e. the factor of 25 increases to as much as 85). Probably because of resistance to national emission accounts suddenly changing quite substantially, this issue remains largely unaddressed, and the arbitrarily chosen 100-year timeframe is almost always used, as a matter of convention.

Because of significant variations in production methods, climate, and other factors (e.g. Opio et al. 2013), emissions from livestock per unit of final product vary significantly around the world (Figure 2). In Western Europe, emissions are very low by world standards, but there are also variations within this region, and it is important to have estimates specific to Norway.

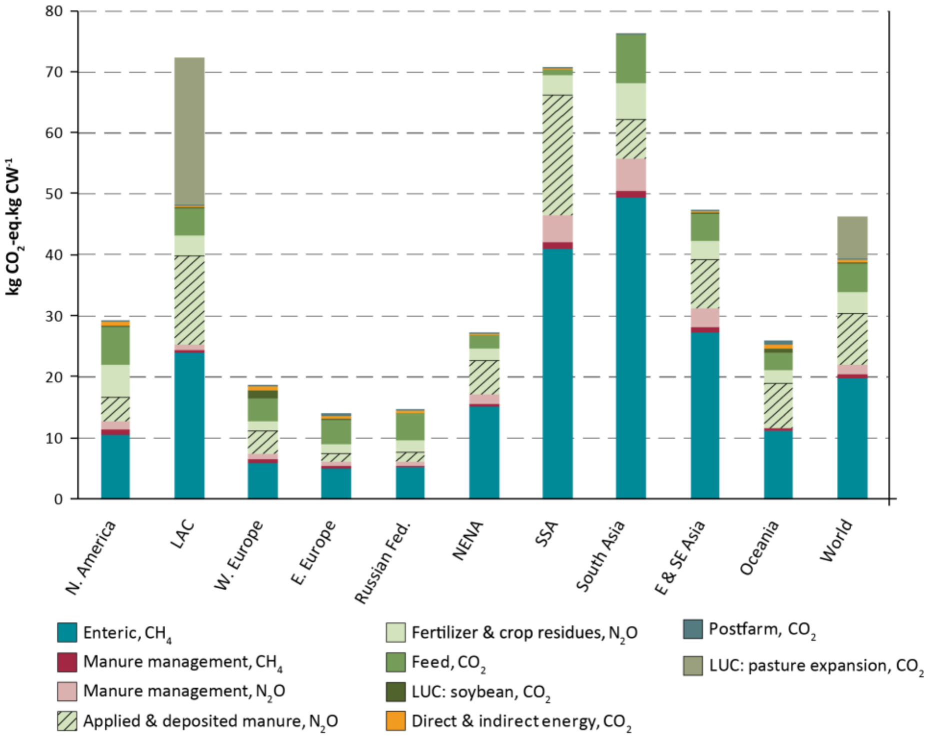

Figure 2: Greenhouse gas emissions per unit of carcass weight by category and world region (Source: Gerber et al., 2013)

1.2.2 The Norwegian Context

It is useful to compare the environmental consequences of Norwegian agricultural production to other countries for several reasons. The most important is perhaps to determine where Norwegian production lies relative to 'best practice', and to gain understanding of what scope there is to change Norwegian practices to reduce environmental impacts. This understanding might lead to implemented changes, or might be used to explain to Norwegian consumers and regulators why Norwegian production results in different environmental outcomes. A secondary reason would be a market assessment, looking to understand the positions of potential international competitors as a way of dealing with risks of changes in the trading environment. Either way, comparison with other countries can lead to important lessons.

Norway's agricultural production context is significantly different to that of many other countries. With a short and cold growing season, prevalence of thin soils, steep and isolated farm plots, and small proportion of arable land, Norway is relatively poorly suited to agricultural production. Of the approximately 1 million hectares of agricultural land, 45% is suitable only for grass production (Blandford et al. 2015). Furthermore, significant use is made of non-agricultural land (utmarka) for grazing. This context, along with the high domestic cost structure, means that sustaining agricultural production requires significant financial support but also that Norway has specific production methods, input requirements, opportunities for economies of scale, etc. Understanding this particular Norwegian context is necessary when comparing the environmental consequences of Norwegian agricultural production to those of other countries.

Therefore, one should be careful when choosing countries to compare with Norway. Comparing with New Zealand production, for example, would not be appropriate, despite claims made in Norwegian media in 2014 that conditions in the two countries were identical, with the only difference being the complete lack of subsidies in New Zealand (Magnus, 2014). New Zealand lies much closer to the equator than Norway, receives considerably more annual sunshine, is without snow over much of the country in winter, and has very large contiguous areas suitable for agriculture with good soils. The contrast in farming conditions could hardly be starker. While we could learn some lessons from New Zealand's methods of agricultural production, to a large degree that country's production is a poor point of comparison for Norwegian production.

In contrast, countries such as Sweden, Denmark, and Switzerland have much more similar conditions and agricultural production models to Norway and therefore serve as useful points of comparison. We will focus on these countries in this report.

Within the Norwegian context, the issue of imported concentrated feed, such as soya beans from Brazil, has loomed large in the Norwegian media. While soy meal made up only about 10% of concentrated feed in 2015, overall imports amounted to 45% (Landbruksdirektoratet, 2016). About 60% of a Norwegian cow's diet is roughage (grazed or baled), so the amount of soy in the overall diet is perhaps 3% by weight. However, soy contributed about 35% of the protein to cows' diets in 2015 (Volden, 2016).

As noted, emissions from agriculture in Norway have declined slightly since 1990, and this is primarily a result of developments in the milk industry. Increased use of concentrated feed and breeding have both led to increased milk yield per cow, resulting in turn in a decline in cow numbers and a consequent decline in emissions. A further consequence of this is the development of the suckling cow industry to make up for reduced meat production from the milk industry, and this development means that beef meat in Norway is produced from these two industries.

1.3 Life Cycle Assessment

While there are several different types of 'carbon footprint' found in the literature, the most suitable and widely used method available for estimating the carbon footprint of products is Life Cycle Assessment (LCA, sometimes Life Cycle Analysis). The core purpose of LCA is to estimate environmental impacts associated with all stages of the production chain, use, and disposal of a product; carbon emissions are one such impact. In the agricultural context, this means not only estimation of impacts from on-farm activities, but also from all activities in the supply chain. The use (i.e. consumption) and disposal phases are not always included in assessments.

Industry has run simple in-house LCAs since the 1960s, but it was not until 1990 that the term was coined (PE International 2013). Because results of LCAs could vary very widely based on assumptions made and methodologies used, international standards were established, beginning in 1993 and eventually becoming ISO 14040 and 14044, in 2006. The existence of these standards, and the requirement that they be followed if an LCA is to be published in academic journals, has helped to ensure greater consistency and transparency in the LCA field. Nevertheless, the range of permissible assumptions and methodologies mean that LCA results require careful interpretation, as we will discuss in the next section.

The LCA standards lay out a four-step procedure, although only the first three are strictly required.

- The first, Goal and Scope Definition, makes a clear statement of the purpose of the assessment, defines the 'functional unit' (described below in section 1.4.1), and sets out the system boundary: what will be included in and excluded from the assessment (see section 1.4.4).
- The second stage, Life Cycle Inventory, involves the collation of all relevant data within the specified scope: all resources consumed and all flows of waste. All quantities are scaled to the specified functional unit: for example how much of each emission in the supply chain results from production of one kilogram of cheese. Software and existing databases are very often used to help in this process.
- Then follows Impact Assessment, in which inventory components are translated to (potential) environmental impacts (e.g., via the global warming potential, discussed above) and potentially all different impacts are combined into an overall score.
- Finally an Interpretation of the results leads to discussion and conclusion, particularly relating to the consequences, the sensitivity of the analysis to particular assumptions, and any limitations of the study.

1.4 Consistency Among Estimates

In 2014, researchers at UiB and Bioforsk wrote an opinion piece in the newspaper Dagbladet suggesting that Norway's emissions from agriculture could be significantly reduced while maintaining domestic food supply, largely by reducing consumption of red meat (Gaasland et al. 2014). While their analysis was based on a detailed and complex model, for the purposes of the article they presented just a few numbers to support their case, including the proportion of Norway's emissions coming from land use and the emissions per kilogram of meat from suckler cows (ammekyr) and sheep. Three weeks later came a response from researchers at NMBU challenging the figures used and conclusions given by UiB and Bioforsk, pointing to 'official figures' that contradicted what had been presented (Aass & Vangen 2014). Furthermore, the NMBU researchers argued that various factors were overlooked and, in particular, that Norwegian cows are used for both milk and meat, so the emissions should be divided between these two products.

At the global level, there remains widespread confusion in the media and society as to whether the emissions from livestock agriculture amount to 15% of the global total (Gerber et al. 2013) or 50% (Goodland & Anhang 2009).

When researchers cannot agree on the appropriate figures to use, it becomes impossible for the public, business, or policy-makers to make informed decisions based on these figures, resulting in both confusion and a danger that the most 'suitable' numbers are used, those that best fit the goals. There are a number of reasons why data on emissions differ between different sources, and in this section we will describe the most important of these.

According to González et al. (2011), the carbon footprint of cucumbers produced in Sweden can vary between 0.08 and 2.6 kgCO_2e/kg product, depending on whether they're grown outdoors in summer (low) or in fuel-oil heated glasshouses in the off season (high). Sometimes, as in the case of Swedish cucumbers, the production method is most likely the reason for the differences in carbon footprint estimates, and this is indeed the information that we seek from LCAs. However, there are several other reasons why estimates can vary; we will discuss these below.

1.4.1 Appropriate comparison: Functional units

It is conventional wisdom that one should not "compare apples with oranges", but if the question is how to best provide fruit for consumption while achieving various relevant policy goals, then exactly such a comparison is required. The question then becomes whether and how such comparisons should be performed. While it might be obvious that we should not compare meat with shoes when considering options for nutrition, it might not be so obvious that it is inappropriate to compare bacon with lettuce, as evidenced by widespread media attention in late 2015 on that very subject (e.g. Withnall, 2015). Bacon and lettuce serve entirely different purposes in the diet, and the role of lettuce is certainly not to provide calories, so any comparison on a calorific basis is misleading at best.

One of the primary goals of LCA is to allow comparability between products that serve the same purpose so as to identify the environmental consequences of the choice. Examples include comparison of paint with wallpaper, re-usable nappies with disposable nappies, nuclear power with bioenergy, and brooms with leaf-blowers.

In the case of paint, a researcher might specify the inputs required for, and environmental consequences resulting from, production of one litre of paint. However, such a 'functional unit' would make comparison impossible with different paints that require different surface preparation, or different numbers of applications, let alone comparison with wallpaper. Rather, the researcher might choose to specify inputs and outputs for one square metre of internal wall covered for 10 years, with an implication that all required maintenance of that wall covering is included.

This process of defining the functional unit is critical in LCA, and different choices can lead to significant differences in the analytical results. It is therefore necessary to identify which properties of the products to compare: Does a drink need to be white? Does it need to be suitable for use with breakfast cereal? Does it need to contain high levels of calcium? Does it need to mix well with coffee? In contrast, when comparing two effectively identical products with different production methods (e.g. conventional and organic milk, or Norwegian and Swiss milk) then this identification of properties is less important.

Because of the sensitivity of LCA results to the choice of functional unit, the case for making this choice must be transparently made, and the LCA community has established clear procedures for doing this (e.g. Weidema et al. 2004). Ideally, the same researchers should perform comparative LCAs of two products at the same time, so that the functional unit, scope, and all assumptions are the same. However, with the considerable effort required to undertake an LCA and the enormous number of products, making comparisons based on existing, disparate literature is often required. One should be careful to identify how comparable two separate LCAs are when presenting their results.

For example, when comparing meat to alternative products, it seems reasonable to use a protein basis. However, protein is not the sole reason that consumers purchase meat; one should also consider the nutritional completeness of proteins, fat content, taste, ease of preparation, versatility, among many other potential characteristics. While for some comparing meat with powdered protein might seem a bridge too far, it is not necessarily clear when comparisons are in fact reasonable.

Comparing fresh dairy milk with alternatives such as soymilk, oat milk, and rice milk simply per litre of product ignores differences in the nutritional content, cooking properties, or cultural reasons for consuming these products, along with (macro-) economic consequences such as the effects on national trade balances. The fat- and protein-corrected milk (FPCM) measure partly addresses the issue of differing nutritional contents, essentially elevating fat and protein content as the most important factors. However, because products are generally inherently different to some degree, it generally is not possible to choose a functional unit that makes them perfectly comparable, and simplifications are necessary. One could compare milk to two separate products that each provide one of milk’s services: healthy beverage and baking ingredient.

1.4.2 Data Specificity

In collating data for a life cycle assessment, averages are not only unavoidable but also entirely necessary. Data from a specific Norwegian farm on a specific day are very unlikely to be representative of the average Norwegian farm on an average day. Moreover, conditions change through the course of the year, for example with different feed requirements and availability, and from year to year with climatic, management and market variations. The international origins of imported feed can change from year to year, the proportions of different cattle breeds used in the industry change, the ratio of suckling cows to milk cows, the yield, the number and size of farms, and so on. Because of such variation, carbon footprints of products must be calculated and presented as averages. Some LCAs use data averaged over three years or more to reduce their sensitivity to short-term variations.

Because of the effort required to collect data, and consequent cost, sometimes data from previous studies are used. Data or information from one domain (e.g. Danish dairy farms) might be transferred are transferred for use in another domain (e.g. Norwegian dairy farms). While such transferring saves expense and time, one should carefully documented and identify the similarities and differences between the two domains to prevent biasing the assessment.

The variation in conditions of the supply chain also necessitates an assessment of both uncertainty and sensitivity. Uncertainty means 'how sure are we of the result?' while sensitivity means 'how much would the result change if a particular data point were to change?' Sensitivity is very important for two reasons. Firstly, it gives some indication of how the result might vary in future. Secondly, it points to 'hot spots' in the supply chain, changes to which would lead to significant changes to the footprint. For example, it might turn out that the amount of supplementary feed fed to livestock has a large effect on the carbon footprint, or perhaps the age at slaughter of milking cows. Knowing to which parts of the supply chain the result is sensitive is therefore very valuable.

1.4.3 Co-products

When there are two or more products of a production process, the environmental impacts of the process must be divided between those products, e.g. milk and meat from the dairy industry. Yet how much of the carbon emissions occurring in the supply chain to the farm gate come from the meat production and how much from milk?

There are three standard methods to resolve this:

- Physical Allocation makes assumptions about how the inputs used in the farm physically end up in the milk and meat. An example might be to use the nitrogen content of milk and meat to divide the nitrogen fertiliser impacts.
- Economic Allocation allocates all environmental consequences based on the economic value of the products: if the process produces 2 kroner of milk and 1 krone of meat, then two-thirds of the impacts are allocated to the milk and one-third to the meat. The argument for economic allocation is that economic demand drives production.
- System Expansion (also Substitution and Avoided Burden) isolates one of the co-products by subtracting the environmental consequences of the most likely alternative means of producing the other co-products (Weidema, 2000).

We note in passing that there are two further approaches to dealing with co-products. One is to simply ignore one of the co-products and allocate all impacts only to the other. The second is to leave the two co-products combined and report the environmental impacts associated with two products at the same time (e.g. the joint production of milk and meat from the dairy industry, Blandford et al., 2015). Neither of these is particularly useful.

Physical Allocation and Economic Allocation are termed attributional methods, describing the present state but giving a poor indication of the consequences of a change. According to Plevin et al. (2014), attributional approaches give misleading advice to decision-makers. The reason for this is that these studies look at averages, not at margins, i.e. that any change in the scale of production merely results in a linear scaling of impacts. In addition, both methods are normative: arbitrarily supporting a particular worldview. The System Expansion method, on the other hand, is consequential: it indicates what would happen when changing from one production method to another. While this gives more appropriate guidance to decision-makers, it comes at the expense of relying on specific scenarios: the results are valid only for the change specified in the scenario precisely because marginal factors change with quantity produced, although sensitivity analyses can go some way to mitigating this problem. Unfortunately, while the information provided is more accurate, the System Expansion method is considerably more complex. Almost all studies in the literature use attributional methods. While such studies can be highly informative, they are not ideal for describing how environmental impacts would change in switching from one production (method) to another.

1.4.4 System boundaries

While the ideal goal of an LCA study is to assess the entire lifecycle of a product, from 'cradle to grave', this is not always feasible. Figure 3 depicts the common stages of the life cycle of a product. Sensitivity to post-retail stages can be very large and outside of the control of the producer. For example, whether a consumer drives to the supermarket in a 20-year-old car or takes public transportation can have a huge effect on the total footprint of their food consumption. Disposal stages can also be beyond the control of the producer, with significantly different consequences dependent on the decisions of consumers to compost food waste, send it to incineration, or to biogas production, and similarly on the options provided by municipalities for waste collection and disposal. Indeed, how much food the consumer wastes can increase their dietary footprint by more than 50%. The impact of food wastage also depends on the type of food and its GHG impact up to consumption (or waste). For cereal for example, the driver seems to be mostly the wastage volume, whereas for meat, the driver is the carbon intensity of the commodity. The FAO (2013) reports that at the global level, products of animal origin account altogether for about 33 percent of total carbon footprint, whereas their contribution to food wastage volumes is only 15 percent.

However, important lessons can be learned from evaluating the entire life cycle of the product, and producers do have some influence over the post-retail stages. In a seminal study, Procter & Gamble analysed the entire life cycle of laundry detergent, finding that more than 80% of energy use occurred in the consumer stage, mostly in heating water (Saouter & van Hoof, 2002). This led to the development of cold-water detergents, with potentially significant consequences for global energy consumption. Manufacturers also have some control over impacts of the disposal stage of their products by designing with repair and recycling in mind. Consumer-stage food waste can be greatly reduced by wrapping products in plastic film, with the cucumber being a clear example, lasting up to three times as long when wrapped in plastic, greatly reducing waste, and directly translating into reduced production and environmental impacts (Aldrige & Miller, 2012). Therefore, it can be beneficial to include post-retail stages in life-cycle assessments.

When different parts of the supply chain are included in an LCA, different terms are used to describe the assessment (see also figure 3):

- 'Cradle to grave' is used when the full life-cycle is included in the system boundary,
- 'cradle to gate' describes the supply chain only up to production at the factory or farm,
- 'cradle to plate' or 'field to fork' ('jord til bord') describes the process specifically for food products to the point of actual consumption (and therefore should include purchasing, transportation home, storage in the home, and preparation).

In this report, we refer to several studies that used the 'whole farm' system boundary. These are LCAs essentially the same 'cradle to farm gate' (Crosson et al., 2010), as they generally include GHG emissions from all processes up until the point the primary product is sold from the farm. Emissions from production of external farm inputs (e.g. concentrate feeds and fertilisers) are also typically included in the analysis. However, to avoid misinterpretations, we have as much as possible kept the same wording of the original papers and use 'whole farm' alongside 'cradle to farm gate' and other system boundaries.

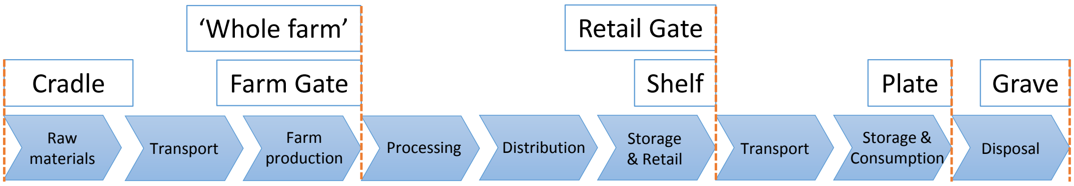

Figure 3: Graphical representation indicating different system boundaries and which parts of the supply chain they include.

System boundaries extend not only along the supply chain, but also describe the depth of analysis at each stage. An LCA is produced by creating an inventory of each input in the supply chain and assessing their cumulative impacts. However, supply chains are always complex, with inputs such as use of services often assumed to introduce negligible environmental impact compared to physical processes. In the early 2000s, it became clear that the assumption that many contributions to the life-cycle impacts were small wrong, with up to 50% of life-cycle impacts being 'truncated' in this way (Lenzen, 2001). As a result, LCAs now typically combine supply-chain-specific inventory analysis and databases that include the life-cycle impacts of generic (i.e. averaged) services and other inputs that were previously considered negligible.

Other life-cycle impacts that may or may not be included in an LCA system boundary are: land-use change emissions, soil carbon fluxes, consequential effects for food production elsewhere (particularly important for bioenergy LCAs), pesticide manufacture and use, and more.

2 Approach and Results

2.1 Literature search, syntax

To cover the available literature, we followed a number of different approaches. Firstly, we performed a systematic search using the following (table 2) search terms in the ORIA (www.oria.no) and Google Scholar (www.scholar.google.com) databases.

Table 2: Search syntax used in the database searches

Emissions AND	Products AND	Production method AND	Location
Emission* OR footprint OR LCA	Agriculture OR food OR dairy OR milk OR beef	Production OR ecologic*	Norway OR Nordic OR Scandinavi* OR Sweden OR Switzerland
Utslipp OR *avtrykk OR livssyklus*	Jordbruk OR mat OR meieri OR melk OR kjøtt	drifts* OR økologisk*	Norge OR Nordisk OR Skandinavi* OR Sverige OR Sveits

As an example of this approach, Google Scholar initial results (80.400 hits) were further limited by using a cut-off date from 2000 to 2016 (20.500 hits). Narrowing the syntax to just including Norway and making LCA a necessary inclusion (Emission* OR footprint AND LCA AND food OR dairy OR milk OR beef AND Norway) within the 2000-2016 range, the number of hits were further reduced to 5.390. Narrowing the search even further to articles published between 2000-2016 containing all of the words "Emission * AND LCA AND food AND Norway", the exact phrase "lifecycle analysis", and at least one of the words "dairy milk beef production ecologic" anywhere in the article yielded 138 results. We scanned these results for relevance and included them in the attached bibliography.

While systematic, the search for e.g. (Emission* OR footprint OR LCA) AND (Agriculture OR food OR dairy OR milk OR beef) AND (Production OR ecologic*) AND (Norway OR Nordic OR Scandinavi* OR Sweden OR Switzerland) in oria.no gave 15 hits, while the Norwegian search gave no hits. This indicates that the available literature is limited, or that the key words used are not delivering the desired results. To account for this potential gap, we included other approaches to cover the available literature and sources to (Norwegian meat- and dairy) emissions data included trawling through the reference lists of available and newly identified literature, and communications and literature and other data exchange with TINE and experts at e.g. the Norwegian University of Lifesciences (NMBU). A final list of relevant material is included in the bibliography.

2.2 General overview

The sections in this general overview will present some comparisons of emissions of products, distinguishing between system boundaries, countries and functional units. The details of Norwegian emissions for each food category (meat, dairy) or production systems will be highlighted and analyzed more in depth in the consecutive sections (2.3 and onward).

The total number of references including emission numbers for products in Norway is relatively low, with 21 references, some of which are indirect references (referred to in another report or article). As source of our references, we only use research articles or reports that are considered to present objective data. Thus, any reports from sources that could have an interest in representing the data subjectively are omitted. Likewise, our search and sources does not include newspaper articles and websites and similar, with the exception of illustrating a point or discussion in the media.

Otherwise, the search resulted in a bibliography of **168** articles or reports which were considered relevant to the topic**, 118** of which were used to extract emission numbers for different products and countries, and **21** of these included emission numbers to Norway (for various products). Table 3 shows how many emission numbers related to Norwegian food items (covering different products, often using both average, upper and lower ranges for the same products) from each study. The number of emission data for different Norwegian products added up to 135. By far the most studies relate to meat (52), while 24 studies concerned dairy products. Fish and other food/drinks were covered by respectively 28 and 27 studies, and eggs by 4 studies.

Some important and recent reference works on Norwegian or Nordic emissions in the agricultural sector were also consulted. These include e.g. Arbeidsgruppe til Landbruk og Klima (2016), Andersen Nesse (2015), or Landbruks- og matdepartementet (2016). These and many other works are extensively used in the discussion, but as these are reviews of research and emission data already presented in other reports – as is this report – these reference works are not listed in table 3. A typical example of this is the often-quoted emission data from Bonesmo et al. (2013) who used the HOLOS model adapted for Norwegian dairy and beef production system.

Table 3: Studies including emissions for Norway, with counts for each study indicating the number of emission values used from that reference and which system boundary the study used.

Reference	cradle to retail gate	cradle to farm gate	whole farm model	(blank)
Blonk et al. (2009)		1		
Bonesmo et al. (2013)			12	
Ellingsen et al. (2009)		1		
FHL (2009)				2
Findus (2008)				3
Grønlund (2015)			5	
Grønlund and Harstad (2014)			4	
Grønlund and Mittenzwei (2016)			5	
Hille et al. (2012)	64			
Leip et al. (2010)		1		
Mittenzwei (2015)			6	
Nymoen and Hille (2010)		3		
Pelletier et al. (2009)		1		
Refsgaard et al. (2011)		7		
Roer et al. (2013)		6		
Silvenius and Grönroos (2003)		1		
Storlien and Harstad (2015)			2	
Svanes et al. (2011)		1		
Ziegler and Valentinsson (2008)		1		
Ziegler et al. (2013)	2			
Åby et al. (2015)			7	

Most studies and results presented could not be compared directly. There are differences in methodology, as allocation between meat and milk and sometimes the system boundaries or the factors they include are different. The scale of measurement may differ, with some studies based on one or a few farms, others on farm modelling and yet others on national averages. These latter have a tendency to show higher results, partly since more flows are covered than in the other two types but mainly due to changed weighting factors for methane and nitrous oxide introduced in 2007, which make results from older studies slightly lower than results from newer studies (Sonesson et al. 2010).

Notarnicola et al. (2013) mention that the most commonly considered system boundary is the cradle to farm-gate because of the lack of sufficiently detailed information in the cradle to retail or consumer supply chains. Those studies including post-farm processes usually simplify the input/output flows related to the agricultural phase. In addition, if a comparative LCA is undertaken, and it is known that a particular part of the system is identical between the two or more processes being compared, sometimes that part is omitted entirely. For example, in comparing organic and conventional chicken production, an assumption might readily be made that all post-retail phases of the system are identical and therefore do not need to be enumerated. Thus, final product emission numbers may differ and be incomplete for many reasons.

2.2.1 Comparison of food items

As discussed in section 1.4, "emission values" depend on many factors, including the system boundaries used, if land use and land-use change or waste are included, how the emissions are distributed over the different co-products of an animal, which type of production system was used, and the unit in which the emissions are expressed. Variation in these and more factors makes inter-comparison of emission data at this level near impossible. Of all data collected, "cradle-to-retail-gate" and "cradle-to-farm-gate" were the most used system boundaries (see table 4), but even between these, methods and inclusion or exclusion of certain factors (such as waste or land use/change) could differ – and hence the comparability between emissions numbers.

Nevertheless, the results give us a general idea of how emissions of different food items compare based on general knowledge of emissions in land-use, of differences between ruminants and mono-gastric animal, differences in transportation distance, and in waste. The following sections will analyse these differences in more detail, and highlight some data and studies with multiple comparisons with the same methodology.

Table 4: Count of the type of system boundary used or indicated in the collected studies from Norway to global level. The overview is not comprehensive, as system boundaries are not always indicated or registered for each study in the database

	Norway	Nordic	Europe	Global	Total
cradle to grave			36	1	37
whole LCA (excluding waste)		16	4		20
cradle to retail gate	66	15	147	275	503
cradle to farm gate	23	19	107	49	198
whole farm model	41				41

Near all studies find that there is a large difference in carbon footprint between beef on the one hand, and pork and chicken meat on the other, regardless of where in the world production takes place (Norden, 2014). Table 5 shows an approximation of how different food items relate to each other, comparing emissions (per weight) of the collected data on different foods across a selection of system boundaries. Indeed, the table shows great differences in emissions between the main product groups, i.e. meat, dairy, eggs, fish, other foods and vegetarian. Also within each category (e.g. meat) there can be large differences, especially for beef, various cow meat[1] and mutton (sheep - and goat), which have much higher emissions per kg product than pork or chicken. Lamb and sheep meat emit slightly more than beef, largely because beef's emissions per kilogram are reduced with some emissions allocated to milk. The clear division to make here is that ruminant livestock produce substantially higher emissions than other livestock.

Refsgaard et al. (2011) argues that the environmental impact from animal and vegetable products often differs by a factor of 10. Our results also show large variations in impact between animal and vegetable products. The differences hinge on whether we compare vegetable products with dairy (milk has about 2,5-3,5 times higher emissions than wheat) or meat (meat from dairy cows has about 21-29 times higher emissions than wheat), and which system boundary is used. The factor is again different when comparing nutrient value instead of weight (table 8), but it should be born in mind that such a comparison may be meaningless.

One notable study (or rather: news coverage of a study) underlining the point of meaningless comparisons denied that vegetables have lower emission than meat: The "lettuce versus bacon" news story (e.g., Nosowitz, 2015) seems to make a baffling and contradictory claim: It is possible that adjusting our diets from meat-heavy to produce-heavy could actually result in an increase in greenhouse gas emissions. However, the article was based on a study that calculated that in an unlikely, extreme modelling situation, one diet could be devised where lettuce could be worse

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[1] See the list of definitions at the end of this report.

than pork meat. However, there are many critics to both the study and the presentation of it in the media. A main take-home message is that it is an invalid and extremely unlikely comparison, since we are never going to scale lettuce consumption up to the point where we obtain all our (replacement for meat) calories from it.

Table 5: Emissions (average of kg CO_2eq/kg product) for selected food products collected in this report, including studies from many countries. The table differentiates between different system boundaries used in the studies, and averages emissions per food category. Meat is generally calculated per carcass weight, and milk as fat and protein extracted weight

Category/product	cradle to grave	whole LCA (ex. waste)	cradle to retail gate	cradle to farm gate	whole farm model	unknown
Meat	5,63	13,71	15,79	20,51	14,55	11,79
Beef		28,35	39,03	29,60	14,24	24,69
Dairy cows			18,40	15,33	21,40	18,00
Suckler cow				29,67	28,15	28,55
Veal/Young bulls			19,48		16,83	
Sheep, Lam, Goat			22,12	41,57	27,64	
Pork	3,83	8,39	5,51	5,36	2,58	4,99
Chicken	6,23	4,41	4,13	3,46	1,32	3,07
Dairy	4,50	3,71	5,38	1,29	0,97	1,93
Milk, cattle	1,41	1,14	3,21	1,23	0,97	1,09
Milk, small ruminants			6,39	3,00		
Yoghurt		1,24				
Cream	5,22					
Ice cream		2,60				
Butter	9,50		20,32			
Margarine			1,50			
Cheese		6,80	8,93			9,48
Eggs	4,44	2,10	3,39	3,40	0,93	3,00
Fish		2,97	1,76	6,29		3,00
Cod		4,47	2,70	5,67		4,00
Herring		1,47	0,89	1,10		1,40
Mackerel			0,95	3,18		
Pangasius				3,00		
Salmon			3,25	4,22		3,20
Shrimp				22,90		

Category/product	cradle to grave	whole LCA (ex. waste)	cradle to retail gate	cradle to farm gate	whole farm model	unknown
Other food/drink			0,82	2,08		0,71
Wheat			0,87	0,53		0,67
Potatoes			0,43			0,20
Pulses				1,20		
Rice			4,00	4,00		
Cabbage and roots			0,31			
Tomatoes						2,04
Apples			0,30			
Strawberries			0,26			
Vegetarian	1,00	0,40		2,48		1,58
Vegetarian burger				2,60		7,30
Tofu				2,00		
Soy milk	1,00	0,40				0,74
Oat milk						0,42

Davis et al. (2010), who compared meals with varying protein sources (similar content of protein, fat and energy), showed that a meal with a pea burger is associated with significantly less GHG's compared to a pork chop meal. However, this study highlighted the need for efficient processing of products with vegetable protein such as veggie burgers, since these products are often sold frozen due to small stock units, which can result in high-energy costs for freezing and frozen storage. Of the other alternatives, especially some types of fish or seafood (e.g. shrimps) have much higher emissions, due to the catching methods.

A second highlight in the table 5 is the great differences between emission numbers using different system boundaries. Generally, the more "steps" from cradle to grave are included in the analysis, the higher the emission for a product. This does not become immediately obvious from the category averages (which may or may not include all products for each boundary analyses), but comparing for a product across the different system boundaries one can see for e.g. beef, cattle milk, or pork, that "cradle to retail" gives higher emissions than "cradle to farm gate" or for the "whole farm model".

Table 6: Overview of emissions (average of kg CO_2eq/kg product) for selected food products comparing within the system boundary “cradle to farm gate” between different countries and products.

Category/product	Norway	Nordic	West-Europe	Global
Meat	15,95	9,66	20,41	25,22
Beef	22,00	24,00	26,34	32,83
Dairy cows	16,06	18,95	11,27	
Suckler cow	34,00		27,50	
Sheep, Lam, Goat			57,00	21,50
Pork	4,50	4,48	6,12	3,49
Chicken	2,73	2,54	4,77	2,06
Dairy	1,53	1,05	1,17	1,10
Milk, cattle	1,53	1,05	1,17	1,10
Eggs			3,93	1,70
Fish	3,30	6,70	4,65	16,27
Cod	3,60	6,70		
Herring			1,10	
Pangasius				3,00
Salmon	3,23		8,20	
Shrimp				22,90
Other food/drink	2,61		2,00	0,80
Wheat	0,53			
Pulses			2,00	0,80
Rice	4,00			
Vegetarian			2,48	
Vegetarian burger			2,60	
Tofu			2,00	

Comparing between countries in table 6, using only one much used system boundary (cradle to farm gate), suggests that Norway has lower emissions for a number of products such as beef and meat from dairy cows, or fish, when compared to the Nordics, west-Europe or global numbers. Some other products, such as meat from suckler cows or milk seem to end up higher in Norway compared to the other regions, but to analyse the specific reason for this these differences must be analysed and sometimes using reports and details from only single articles to account for differences in system boundaries etc. Beef from South America for example has a significantly higher climate impact than European beef due to high CO_2 emissions from LUC as well as high CH_4 emissions due to low animal productivity. Other potential meat alternatives such as fish, pulses or vegetarian also have much lower emissions than beef or cow meat per kg product, but the difference with pork or chicken is much smaller. Only a few studies exist with enough data to do inter-comparisons of emissions across production systems or regions. These studies and comparisons feature in section 2.5 in this report where we focus on different production methods, especially conventional versus organic systems and intensive versus extensive systems[2].

A comparison between products just for Norway (table 7), differentiating studies with different system boundaries, shows similar findings. Cow meat generally has higher emissions (per kg product) than other types of meat, with suckler cows having highest emissions, followed by beef and then by veal and dairy cows. Pork meat and chicken meat register much lower emissions (5 to 10 times lower) in comparison with various cow meat. Fish has about 5 to 10 times lower emissions, except for lobster due to the intensive fishing method. Vegetables and fruit also have much lower emissions when comparing per kg product, with up to a factor of 100 difference when comparing strawberries with veal. Cheese and butter are relative intensive dairy products and have higher emissions than just milk.

The details for why certain emissions are higher than other will be discussed further down in this report. The relative emissions for these food items stem from a number of selected studies, but are comparable to many studies. Norden (2014) has similar findings for fish, finds that vegetables in general are associated with fairly low GHG emissions and have generally lower life-cycle GHG emissions than animal products. Grain products, e.g. wheat flour, typically have emissions of around 0.5 kg CO_2-eq per kg, while potatoes and other root vegetables such as carrots are particularly efficient in cultivation, since the yield is high per ha, resulting in low GHG emissions per kg product. GHG emissions from greenhouse products, such as tomatoes, are very sensitive to the source of heating of the greenhouse. Substituting fossil fuels with biofuels will thus have a significant impact on the product's emissions. Generally, vegetables grown in open air have lower emissions than products grown in greenhouses using fossil fuels, but – the report states - transport of such products can be of importance for vegetables imported to the Nordic countries. As example they bring the well-known Spanish tomatoes vs imported tomatoes example: transport emissions represent almost half of the Spanish tomatoes' total emissions, resulting in a slightly higher impact than (Swedish) tomatoes cultivated in greenhouse with bio-fuels but significantly lower CF than tomatoes grown in greenhouse using fossil fuels.

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[2] See brief list of definitions at the end of this report.

Table 7: Emissions (average of kg CO_2eq/kg product) for food products collected in this report, for Norway (based on 21 available studies). The table differentiates between different system boundaries used in the underlying studies, and averages emissions per food category

Category/product	cradle to retail gate	cradle to farm gate	whole farm model	unknown
Beef		22,00	14,24	
Dairy cows		16,06	21,40	
Suckler cow		34,00	28,15	
Veal/Young bulls	22,00		16,83	
Sheep, Lam, Goat	18,70		27,64	
Pork	4,95	4,50	2,58	
Chicken	3,30	2,73	1,32	
Milk, cattle	1,32	1,53	0,97	
Butter	15,07			
Margarine	1,50			
Cheese	9,90			
Cod	2,70	3,60		4,27
Herring	0,89			1,20
Lobster		86,20		
Mackerel	0,95			
Salmon	3,25	3,23		
Saithe	2,60			
Bread	0,94			
Wheat	0,87	0,53		
Oats	0,75			
Potatoes	0,43			
Rice	4,00	4,00		
Cabbage and roots	0,32			
Apples	0,30			
Strawberries	0,22			

2.2.2 Comparison of functional units

In a final general comparison of emissions between different products and product groups, it is useful to look at the functional unit or different ways of expression of emissions. As explained in section 1.4.1, one should not "compare apples and oranges", but depending on the needs, this may indeed be exactly what is required. Thus, a comparison of emissions between products based on weight (should I eat 500 gram of meat today, or should I replace that with 500 gram of fish?) depends on whether food items are in fact potential substitutes for each other or if they serve very different purposes in a diet. The emissions then also depend on the requirements; is it valid to compare emissions of the amount of food – or should you look instead how fish could replace the energy, proteins or other nutrients that are provided by meat? Finally – it would be relevant to ask if the replacement would fit with the other items on the plate for the dinner planned that day, or the quality or financial aspects when purchasing or comparing fish versus meat.

Table 8 shows the emissions of some comparable food items (edibles, including meat, fish and vegetarian options in the upper section of the table, and dairy or drinkables in the lower section of the table. It is clear that meat has more proteins per kg than most other products (except cheese). It is also clear that while meat has a high-energy content, fish and several vegetarian substitutes (but not tofu or pulses) are higher in energy. In general, the CO_2-emission per kg food is much higher for the animal products than for the plant products, although the differences decrease especially between meat and milk when the energy content of food is considered. The emission from cattle meat is from about 11 to 23 CO_2-eq per kcal, from milk is around 2.5 CO_2-eq per kcal, while production of wheat only contributes with from around 0.2 kg CO_2-eq per kcal. The emissions however are highest for meat regardless of functional unit.

Table 8: Overview of emissions related to a number of selected food products, comparing emissions per kg product, per kg protein, and on an energy basis (kcal) for comparable system boundaries used in the studies in the database: cradle-to-farm-gate for edibles, and whole LCA without waste for dairy products. The red gradation indicates in which edible group and items the highest emissions are, while the green gradation indicates likewise for dairy products.

Product	**kg CO_2eq /kg**	**gr.protein /100 gr**	**kg CO_2(eq.)/kg protein**	**Kcal /kg**	**gr. CO_2eq /kcal**
Edibles: cradle to farm gate					
Meat:					
Beef	29,60	21	170,19	1440	15,28
Dairy cows	15,33	21	66,30	1440	11,15
Suckler cow	29,67	21	160,23	1440	23,61
Sheep, Lam, Goat	41,57	20	238,00	2210	18,81
Pork	5,36	19	28,19	2230	2,02
Chicken	3,46	19	16,78	1970	1,39
Fish:					
Salmon	4,22	20	21,20	2240	1,44
Mackerel	3,18	19	16,00	1870	1,70
Cod	5,67	18	28,33	810	4,44
Herring	1,10	17	5,00	2930	0,38
Eggs:	3,40	12	26,60	1420	2,39
Vegetarian:					
Wheat	0,53	12	4,34	3355	0,16
Rice	4,00	8	52,63	3515	1,14
Tofu	2,00	8	17,00	770	2,60
Vegetarian burger	2,60	7	16,00	1920	0,57
Pulses	1,20	2	5,33	1140	1,75
Dairy: whole LCA excluding waste					
Milk, cattle	1,14	3	33,93	463	2,46
Soy milk	0,40	4	10,00	410	0,98
Cheese	6,80	27	25,18	3510	1,94
Yoghurt	1,24	4	28,84	685	1,81

Looking at meat only, cow meat again has higher emissions regardless of functional unit, except for mutton. Within the category cow-meat, dairy cows are most "climate friendly" especially in terms of protein, although these numbers are in relation to what the "Norwegian Food Composition Table 2016" reports as protein and energy content – and this source does not distinguish between beef and dairy or suckler cows. For the dairy products, cheese is an outlier about both protein and energy content. When comparing emissions for milk and soymilk we see that milk has higher emissions both per weight, per protein content and per energy content.

Functional units can have a great say in the different ways of allocation of emissions, as Gonzalez-Garcia et al. (2013a, in Notarnicola et al 2015) note when discussing the effect of different allocation methods among milk, cream and butter on the total life cycle results: in addition to a mass allocation approach, the authors performed a sensitivity analysis in which economic and protein-based allocations were applied to the system. The results showed that economic allocation improved the environmental performance of milk production by 34 %, whereas protein-based allocation worsened the results by up to 5 %. Gonzales Garcia et al. (2013b) analysed the effect of different allocation approaches and found that mass allocation improved the impact of cheese more than the economical one, because the economic value of whey per unit of mass is lower than that of cheese.

2.3 Dairy

In this section, we will analyse in depth what the available literature finds regarding dairy emissions of production in Norway, compared to other regions, and considering different production systems (conventional, organic, etc.). As earlier described in the report, emissions are very dependent on the system boundaries. This means we can only compare countries and production systems when also the system boundaries are taken into consideration. Even then, there will be differences in what the analysis includes and excludes, but the available literature and differences between studies still makes the results valid.

Table 9 shows, not surprisingly, that milk has the lowest emissions as compared to "milk derivatives" butter, cheese, cream and yoghurt. Especially cheese production is emission intensive compared to milk. Also not surprisingly, there is a trend towards the more inclusive the system boundary, the higher the emissions, though this finding is not consistent, and there are large variations between the different system boundary emissions. Also the ranges are large at times: For Norway, the average emission for milk across system boundaries and production methods is 1.15 kg CO_2eq/kg. The range (0,50-1,92) is larger than the emission factor itself, indicating that there is great variability in the emissions, due to many factors: system boundary, production method, and between farms (with different soils, number of animals, yield per animal, energy use, etc.).

Because dairy cows need to be milked regularly, distances to the milking parlour are usually short. This means intensive grazing takes place nearby the farm, or grazers are kept indoors permanently. Therefore, Nijdam et al. (2012) argue, livestock management systems of dairy farms generally do not vary greatly, with values between 1 and 1.5 kg CO_2-eq/kg milk (12 studies). Weiske et al. (2006) give an average of 1.4 kg CO_2-eq/kg for milk for the EU-15. In a study by the FAO (2010), an average of 1.3 kg CO_2-eq/kg is calculated for Western Europe. The differences can be traced back to soil condition and consequent N_2O emissions (De Vries and De Boer, 2010), feed composition and race (related to yield) (Vergé et al., 2007), intensity of farming (mainly related to yield and diet) and manure management (Haas et al., 2001; Phetteplace et al., 2001; Weiske et al., 2006).

Table 9: Overview of emissions related to milk and dairy, comparing Norway with other regions, and distinguishing between different production methods and system boundaries. Emissions are given as average and range in kg CO_2eq/kg product.

Product / System boundary / Production method	Norway	Nordic	West-Europe	Europe	Global
Milk, cattle	1,15 0,50-1,92	1,06 0,87-1,24	1,33 0,95-1,70	1,40 1,30-1,50	3,75 1,00-10,80
cradle to grave Conventional			1,66 1,23-2,4		
whole LCA (excluding waste) Conventional		1,14 1,09-1,24			
cradle to retail gate	1,32 0,84-1,92	0,94 0,87-1,00	1,59 1,19-1,70		3,86 1,00-10,80
Conventional	1,32 0,84-1,92	0,94 0,87-1,00	1,55 1,19-1,70		3,72 1,00-10,00
Organic, grass based			1,67 1,60-1,70		4,01 1,50-10,80
cradle to farm gate	1,53 1,47-1,59	1,05 1,00-1,10	1,17 0,95-1,50	1,40 1,30-1,50	1,10 1,09-1,10
Conventional	1,53 1,47-1,59	1,05 1,00-1,10	1,18 0,95-1,50	1,40 1,30-1,50	1,10 1,09-1,10
Mixed			1,10		
Organic			1,19		
Organic, grass based		1,05			
whole farm model	0,97 0,50-1,36				
Conventional	0,92 0,50-1,30				
Organic, grass based	1,07 0,82-1,36				
Yoghurt		1,24			
whole LCA (excluding waste) Conventional		1,24			
Cream			5,22 2,96-6,12		
cradle to grave Conventional			5,22 2,96-6,12		

Product / System boundary / Production method	Norway	Nordic	West-Europe	Europe	Global
Butter	15,07 8,80-22,40		21,55 9,50-27,60		
cradle to grave Conventional			9,50		
cradle to retail gate Conventional	15,07 8,80-22,40		25,57 23,50-27,60		
Margarine	1,50 1,05-1,95				
cradle to retail gate Conventional	1,50 1,05-1,95				
Cheese	9,90 6,30-14,40	6,80 3,44-9,23	7,97 6,80-9,00		
whole LCA (excluding waste) Conventional		6,80 3,44-9,23			
cradle to retail gate Conventional	9,90 6,30-14,40		7,97 6,80-9,00		

Overall, the picture that emerges is that Norway has higher milk production emissions compared to other countries in the Nordic region (Sweden, Finland, Denmark), but lower emissions than (Western) Europe and globally. This is true when one looks at cradle-to-retail boundaries. However, when comparing cradle-to-farm-gate analyses, Norway has highest milk emissions across the compared regions. The variety or range between emission data from Norwegian studies is the largest compared across the regions, indicating that the greatest variety is *within Norway*, and not between Norway and other regions. However – in the cradle-to-farm-gate studies, the lowest Norwegian emissions for milk (1.47) are higher or near the highest emissions for other regions (1.10-1.50) suggesting that Norwegian milk has higher emissions than elsewhere at least when comparing conventional production. Butter production on the other hand seems to be less emission intensive in Norway than in west Europe, while cheese production is more emission intensive both compared to west Europe and other Nordic countries.

Table 10 compares dairy products within single studies and confirms the results of table 9: milk-derived products in general have larger emissions than milk itself, and especially cheese has relatively high emissions.

Table 10: This table shows emissions of a variety of dairy products compared in two studies/reports, one in Denmark and one in the UK. Within each of the studies, the same production system (conventional), system boundaries (whole LCA excluding waste in the one, cradle to grave in the other) and methodology are used, making emissions numbers comparable within each study for different products. Reference: Werner et al. 2014 (Denmark) and Tesco 2012 (UK).

Product	kg CO_2eq/kg
Denmark, whole LCA (ex. waste)	
Milk, mini milk 0,50% fat	1,09
Milk, skim milk 0,30% fat	1,09
Milk, butter milk 0,50% fat	1,24
Milk, yoghurt 0,50% fat	1,24
Cheese, 20+ 17% fat	8,47
Cheese, 30+ 31% fat	9,23
Cheese, smoked	6,05
Cheese, cottage 20+ 4% fat	3,44
Ice cream	2,80
UK, cradle to gave	
Semi-Skimmed Milk	1,41
Skimmed Milk	1,23
Whole Milk	1,58
Tesco Fresh Single Cream	2,96
Tesco Fresh Double Cream	6,12
Tesco Fresh Extra Thick Double Cream	6,12
Tesco Whipped Cream	5,00
Tesco Fresh Whipping Cream	5,10
Creamfields Cream	6,00
Tesco English Salted/Unsalted Butter	9,50

Comparing the Danish study (table 10) with Norway (table 9) for "whole LCA" is not possible, but judging from the other system boundaries for we see that Denmark likely has lower emissions than Norway. The English study (table 10) is similarly not comparable to Norway, but - again judging from the other system boundaries - it appears that Norwegian and English product emissions are fairly similar.

A final comparison of emissions of dairy products in the Nordic countries (including Norway) lists the different studies and system boundaries used in these.

Table 11: Overview of emissions of dairy products in the Nordic countries (including Norway) from the different studies, listing product, country, system boundaries and reference.

Product	kg CO_2eq/kg	Location	Main system boundary	Reference
Milk, cattle	0,99	Denmark	cradle to farm gate	Kristensen et al. (2011)
Milk, cattle	1,09	Denmark	whole LCA (excluding waste)	Werner et al. (2014)
Milk, cattle	1,09	Denmark	whole LCA (excluding waste)	Werner et al. (2014)
Milk, cattle	1,24	Denmark	whole LCA (excluding waste)	Werner et al. (2014)
Milk, cattle	1,02	Norway	whole farm model	Bonesmo et al. (2013)
Milk, cattle	0,82	Norway	whole farm model	Bonesmo et al. (2013)
Milk, cattle	1,36	Norway	whole farm model	Bonesmo et al. (2013)
Milk, cattle	1,20	Norway	cradle to retail gate	Hille et al. (2012)
Milk, cattle	0,84	Norway	cradle to retail gate	Hille et al. (2012)
Milk, cattle	1,92	Norway	cradle to retail gate	Hille et al. (2012)
Milk, cattle	1,17	Norway	whole farm model	Mittenzwei (2015)
Milk, cattle	1,47	Norway	cradle to farm gate	Roer et al. (2013)
Milk, cattle	1,59	Norway	cradle to farm gate	Roer et al. (2013)
Milk, cattle	1,54	Norway	cradle to farm gate	Roer et al. (2013)
Milk, cattle	0,64	Norway	whole farm model	Storlien and Harstad (2015)
Milk, cattle	0,50	Norway	whole farm model	Storlien and Harstad (2015)
Milk, cattle	1,00	Norway	whole farm model	Åby et al. (2015)
Milk, cattle	0,90	Norway	whole farm model	Åby et al. (2015)
Milk, cattle	1,30	Norway	whole farm model	Åby et al. (2015)
Milk, cattle	0,87	Sweden	cradle to retail gate	Cederberg and Flysjö (2004b)
Milk, cattle	1,00	Sweden	cradle to farm gate	Cederberg and Flysjö (2004b)
Milk, cattle	1,10	Sweden	cradle to farm gate	Cederberg and Flysjö (2004a)
Milk, cattle	1,05	Sweden	cradle to farm gate	Cederberg and Stadig (2003)
Milk, cattle	1,00	Sweden	cradle to retail gate	de Vries and de Boer (2010)
Milk, cattle	0,99	Sweden	cradle to retail gate	Smedman et al. (2010)
Butter	14,00	Norway	cradle to retail gate	Hille et al. (2012)

Product	kg CO_2eq/kg	Location	Main system boundary	Reference
Butter	8,80	Norway	cradle to retail gate	Hille et al. (2012)
Butter	22,40	Norway	cradle to retail gate	Hille et al. (2012)
Margarine	1,50	Norway	cradle to retail gate	Hille et al. (2012)
Margarine	1,05	Norway	cradle to retail gate	Hille et al. (2012)
Margarine	1,95	Norway	cradle to retail gate	Hille et al. (2012)
Cheese	11,30	Denmark		Hille et al. (2012)
Cheese	8,47	Denmark	whole LCA (excluding waste)	Werner et al. (2014)
Cheese	9,23	Denmark	whole LCA (excluding waste)	Werner et al. (2014)
Cheese	6,05	Denmark	whole LCA (excluding waste)	Werner et al. (2014)
Cheese	3,44	Denmark	whole LCA (excluding waste)	Werner et al. (2014)
Cheese	9,00	Norway	cradle to retail gate	Hille et al. (2012)
Cheese	6,30	Norway	cradle to retail gate	Hille et al. (2012)
Cheese	14,40	Norway	cradle to retail gate	Hille et al. (2012)
Cheese	8,80	Sweden		Hille et al. (2012)

The relatively low emissions of milk production in (Norway and) the Nordics (see tables 9 and 11) compared to Europe and at the global level, is discussed in several studies (e.g. Norden, 2014). These low emissions are especially due to the high animal productivity and high feed efficiency in Europe. Several studies (table 11) find that emissions from milk in Norway, Sweden and Denmark have a carbon footprint at the farm-gate slightly above 1 kg CO_2-eq per kg milk (in fact, 1.11 kg CO_2eq/kg on average of presented studies), not including emissions from LUC. The Norden study concludes that “adding these emissions (the FAO estimates close to 0.1 kg CO_2 per kg milk from LUC for European milk) as well as post-farm emissions suggests that milk production from Nordic countries lies in the lower range of European milk production and thus worldwide”. Indeed, in their FAO report, Gerber et al. (2013) find that industrialized regions in the world exhibit the lowest emissions for milk, ranging between 1,6-1,7 kg CO_2-eq/kg (FPCM, as expressed for milk emissions in most studies), which is higher than the Nordics or Norway. Emissions in developing countries on the other hand emissions for milk range between 2-9 kg CO_2-eq/kg FPCM, the latter being milk emissions for sub-Saharan Africa.

In the following sections of this report, we will first analyse emissions in Norwegian meat production versus other regions, considering different system boundaries. Then we will compare emissions of dairy and meat production for different production methods, and discuss which life cycle stages of meat and dairy have the greatest climate impact.

2.4 Beef

This section deals more in-depth with the emissions from meat production, comparing Norway with other countries and regions in the world. Table 12 shows that there are great differences in emissions between different sorts of meat production, at the global all the way down to the Norwegian scale. To understand the differences, it is necessary to compare within system boundaries and production methods. Looking then at the whole farm (marked in yellow), with conventional farming, we see that beef has the lowest emissions (14.24), together with veal (15.40), closely followed again by dairy cows (19.09) and finally suckler cows (28.15)[3]. In Norway, beef comes from dairy cows, suckler cows and veal. From the analysed studies it was not clear which of these "beef" referred to, so we have kept this category. Looking however at the cradle-to-farm-gate boundary with conventional production (orange marking), we see that dairy cows have the lowest emissions (17.33), followed by beef (22.00) and again suckler cows having most emissions (34.00). Comparing these relative distributions for the other regions, e.g. west Europe, Europe or globally (green marking), we see a similar picture to the latter, with dairy cows having lowest emissions followed by beef and finally suckler cows with the highest emissions.

This latter pattern, with dairy cow emissions lowest and beef and suckler cow emissions higher is indeed consistent with what several studies write about the comparison of emissions between these different meat production systems, which at the same time explains a major difference between European (and Norwegian) beef production as compared to other parts in the world. E.g. the FAO in Opio et al (2013) describes that emissions for beef in much of the industrialized world (Western Europe, North America and Oceania) is lower than the global average mainly because these regions have a high efficiency in production and high feed digestibility.

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[3] See brief list of definitions at the end of this report.

Table 12: Overview of emissions related to cattle meat, comparing Norway with other regions, and distinguishing between different production methods and system boundaries. Emissions are given as average and range in kg CO_2eq/kg product.

Product / System boundary / Production method	Norway	Nordic	West-Europe	Europe	Global
Beef	16,83 13,70-22,00	25,33 20,00-28,00	25,28 9,00-129,00	30,25 26,00-39,00	39,95 9,90-103,00
whole LCA (excluding waste) Conventional		27,99		28,70	
cradle to retail gate			21,22 17,30-24,10		44,59 17,40-103,00
Conventional			20,43 17,30-24,10		45,22 18,90-103,00
Organic, grass based			22,00 20,40-23,90		43,92 17,40- 93,40
cradle to farm gate	22,00	24,00 20,00-28,00	26,34 9,00-129,00	30,77 26,00-39,00	32,83 9,90-80,00
Conventional	22,00	24,00 20,00-28,00	22,38 9,00-42,00	30,77 26,00-39,00	35,05 9,90-80,00
Free-range			21,80		
Mixed			71,60 14,20-129,00		14,00
Organic			19,05 18,20-19,90		21,30 12,00-34,90
whole farm model Conventional	14,24 13,70-14,79				
Dairy cows	19,49 11,00-37,46	18,95 15,60-22,30	11,27 9,00-15,80	15,95 12,00-19,90	18,40
cradle to retail gate Conventional					18,40
cradle to farm gate	16,06 11,00-18,40	18,95 15,60-22,30	11,27 9,00-15,80	15,95 12,00-19,90	
Conventional	17,33 15,00-18,40		11,27 9,00-15,80	15,95 12,00-19,90	
Organic, grass based	11,00	18,95 15,60-22,30			
whole farm model	21,40 12,00-37,46				
Conventional	19,09 15,40-25,00				
Organic, grass based	24,28 12,00-37,46				

Product / System boundary / Production method	Norway	Nordic	West-Europe	Europe	Global
Suckler cow	30,10 25,00-34,00		27,50 25,00-30,00		
cradle to farm gate Conventional	34,00		27,50 25,00-30,00		
whole farm model Conventional	28,15 25,00-31,30				
Veal/Young bulls	19,04 11,75-32,00		16,97 7,40-28,00		
cradle to retail gate Conventional	22,00 14,00-32,00		16,97 7,40-28,00		
whole farm model	16,83 11,75-22,90				
Conventional	15,40				
Organic, grass based	17,30 11,75-22,90				

On average, European beef has the lowest carbon footprint in the world, because much (80%) of its beef comes from the dairy sector (slaughtered dairy cows, bull dairy calves), and the region has a generally high animal productivity (Opio et al., 2013; Gerber et al., 2013). Indeed, in Norway, Ulleberg (forthcoming) reports that around 75% of beef production comes from dairy farms. Such a combination of both beef and milk production reduces the emissions as these are distributed over more products (both milk and beef), though the ultimate allocation depends on the productivity, or how much milk and meat dairy cows produce. Nijdam et al. (2012) argue that the environmental impact of the beef from culled dairy cows is lower than that from beef cattle mainly due to the relative efficient co-production of meat and milk in intensive systems. The meat production from the dairy sector is also a consequence of the need to sustain milk production through production of calves in order to keep cows lactating.

Cows reared for both milk and meat live longer (and thus produce more methane and other emissions) than cows reared solely for meat. Studies such as the “UK GHG inventory report 1990-2012” report that beef cows produced about half the amount of methane compared to dairy cows, which suggests that dairy cows would have about double total emissions than beef cows. This is clearly not reflected in table 12, because it is the productivity of an animal (and thus the distribution over milk and/or meat) that ultimately determines the emissions that a beef or dairy cow ends up with.

Although the data in table 12 may look comparable within the system boundaries used, it is important to notice that not all studies use the same emission factors even when using the same or similar system boundary. A typical factor that is often omitted is land use and land-use change related emissions, which can add a significant portion to the final emissions for beef (or milk). For example, for beef production in Latin America pastures may be expanded into forested areas. Consequently, land-use change is a major driver of emissions in the region, representing approximately one-third of the footprint (Opio et al., 2013), equivalent to 24 kg CO_2-eq/kg CW – an estimate with a high level of uncertainty.

Finally, between studies and even within studies calculated emissions may vary greatly. Table 13 highlights this point showing the sources of the emissions data used in this report, and the variation within single studies even for specific sources of meat.

Table 13: Overview of emissions of cattle meat products in the Nordic countries (including Norway) from the different studies, listing product, country, system boundaries and reference.

Product, short	kg CO_2eq/kg	Location	System boundary	Reference
Beef	27,99	Denmark	whole LCA (excl. waste)	Werner et al. (2014)
Beef	13,7	Norway	whole farm model	Grønlund and Mittenzwei (2016)
Beef	22	Norway	cradle to farm gate	Leip et al (2010)
Beef	14,79	Norway	whole farm model	Mittenzwei (2015)
Beef	28	Sweden	cradle to farm gate	Cederberg et al. (2009b)
Beef	20	Sweden	cradle to farm gate	Cederberg et al. (2009b)
Beef	32	Sweden		LMD (2016)
Beef	20	Sweden		LMD (2016)
Beef	23	Sweden		LMD (2016)
Beef	39	Sweden		LMD (2016)
Beef	29	Sweden		LMD (2016)
Beef	22	Sweden		LMD (2016)
Beef	29	Sweden		LMD (2016)
Beef	40	Sweden		LMD (2016)
Dairy cows	21,67	Norway	whole farm model	Bonesmo et al. (2013)
Dairy cows	12	Norway	whole farm model	Bonesmo et al. (2013)
Dairy cows	37,46	Norway	whole farm model	Bonesmo et al. (2013)
Dairy cows	15,4	Norway	whole farm model	Grønlund (2015)
Dairy cows	26	Norway	whole farm model	Grønlund and Harstad (2014)
Dairy cows	21,06	Norway	whole farm model	Grønlund and Mittenzwei (2016)
Dairy cows	15	Norway	cradle to farm gate	Refsgaard et al. (2011)
Dairy cows	11	Norway	cradle to farm gate	Refsgaard et al. (2011)
Dairy cows	17,7	Norway	cradle to farm gate	Roer et al. (2013)
Dairy cows	18,4	Norway	cradle to farm gate	Roer et al. (2013)
Dairy cows	18,2	Norway	cradle to farm gate	Roer et al. (2013)
Dairy cows	18	Norway	whole farm model	Åby et al. (2015).
Dairy cows	16	Norway	whole farm model	Åby et al. (2015).

Product, short	kg CO_2eq/kg	Location	System boundary	Reference
Dairy cows	25	Norway	whole farm model	Åby et al. (2015).
Dairy cows	18	Sweden		Cederberg and Darelius (2000)
Dairy cows	22,3	Sweden	cradle to farm gate	Cederberg and Stadig (2003)
Dairy cows	15,6	Sweden	cradle to farm gate	Cederberg and Stadig (2003)
Suckler cow	31,3	Norway	whole farm model	Grønlund (2015)
Suckler cow	34	Norway	cradle to farm gate	Refsgaard et al. (2011)
Suckler cow	25	Norway	whole farm model	Åby et al. (2015).
Veal/Young bulls	17,25	Norway	whole farm model	Bonesmo et al. (2013)
Veal/Young bulls	11,75	Norway	whole farm model	Bonesmo et al. (2013)
Veal/Young bulls	22,9	Norway	whole farm model	Bonesmo et al. (2013)
Veal/Young bulls	15,4	Norway	whole farm model	Grønlund and Mittenzwei (2016)
Veal/Young bulls	20	Norway	cradle to retail gate	Hille et al. (2012)
Veal/Young bulls	14	Norway	cradle to retail gate	Hille et al. (2012)
Veal/Young bulls	32	Norway	cradle to retail gate	Hille et al. (2012)

2.5 Production methods

2.5.1 Comparison of organic and conventional production

There is an ongoing debate about the merits of ecologic or organic farming methods versus conventional methods. The debate originally revolved around the assumed differences in impacts on the environment, e.g. "organic agriculture which is often seen by the public as producing food free of chemicals and being more environmentally friendly as compared to poorly managed conventional farms" (e.g. Trewavas, 2004). While the environmental friendliness and management practices are part of a wider discussion, the focus in this section is specifically on the climatic impact of production systems.

Table 14: Literature emission data for Norwegian dairy and cattle meat under different production methods and system boundaries compared to other regions. Emissions are given as average and range in kg CO_2eq/kg product. Red markings illustrate lower emissions for conventional methods, and green markings illustrate lower emissions for organic production. Yellow indicates complete overlap of ranges.

Region		cradle to farm gate		cradle to retail gate	
Product		**Conventional**	**Organic**	**Conventional**	**Organic**
Norway	Beef	16,83 13,70-22,00			
	Dairy cows	18,31 15,00-25,00	21,63 11,00-37,46		
	Suckler cow	30,10 25,00-34,00			
	Veal/Young bulls	15,40 Not available	17,30 11,75-22,90	22,00 14,00-32,00	
	Milk, cattle	1,12 0,50-1,59	1,07 0,67-1,36	1,32 0,84-1,92	
Nordic	Beef	24,00 20,00-28,00			
	Dairy cows		18,95 15,60-22,30		
	Milk, cattle	1,02 0,75-1,32	0,99 0,67-1,29	0,94 0,87-1,00	
West-Europe	Beef	22,38 9,00-42,00	19,05 18,20-19,90	20,43 17,30-24,10	22,00 20,40-23,90
	Dairy cows	11,27 9,00-15,80			
	Suckler cow	27,50 25,00-30,00			
	Veal/Young bulls			16,97 7,40-28,00	
	Milk, cattle	1,18 0,95-1,50	1,19 Not available	1,55 1,19-1,70	1,67 1,60-1,70

Various studies have compared the environmental impacts of conventional, integrated and organic farming (e.g. Refsgaard et al 2011). Trewavas (2004) mentions that there are economic and environmental considerations for organic production, which uses less energy, and preserves biodiversity and soils better. Indeed, the study finds that "organic farming practices generally have positive impacts on the environment per unit of area, but not necessarily per product unit. The variation between farms and systems however is very wide, and the only significant differences between organic and conventional systems found in the study were soil organic matter content, nitrogen leaching, nitrous oxide emissions per unit of field area, and land use (all higher in organic production), and energy use (lower in organic production).

Norway is well behind Sweden and Denmark in consumption of ecological products, but increased ecological production and consumption is a political target: 15 percent of the production and consumption of food (both national produce and import) should be ecologic by 2020 (Solemdal and Friss Pederssen, 2014). The reason for this is especially environmental, and not necessarily climatic. There are somewhat different signals in the popularity of both production and sales of ecological food, including meat and dairy. Solemdal and Friss Pederssen (2014) find that most ecological produce is sold in Oslo and Akershus, where its popularity is increasing – an increase with 16% in supermarkets in 2013, and with 14% through other (informal) channels. SLF (2013) reports that especially the number of ecologically fed cattle has been increasing over the years. As a result, the report finds that ecological production of cow milk has increased slightly from 3,4 to 3,5 percent of the total milk production, in spite of a decrease in producers of ecological milk. Paradoxically, the ecological production of cattle meat has been decreasing. The reasons for these may reside in price differences and subsidies. Surprisingly, the production of ecological milk increases more than the actual sales (Stette Høyberg, 2016), and this difference is increasing. One potential explanation for this is that organically produced milk is increasingly mixed with conventionally produced milk prior to sales. Some supermarkets (e.g. Rema 1000 - in Solemdal and Friss Pederssen, 2014) on the other hand report that delivery/purchase of ecological food to supermarkets is a problem, except for milk – and one reason for the fluctuations in demand can be the price differences between conventional and ecological products: especially for meat the difference can be high.

However, what are the emissions and climatic differences between organic and ecologic production methods? Because of their lower impact on the environment, ecologic products are intuitively expected to have a lower impact on climate, with lower emissions than conventional production systems. However, in contrast to other environmental impacts, the GHG emission differences are much less clear (Trewavas, 2004; Refsgaard et al., 2011). Table 14 sums up findings from previous tables on emissions for meat and milk under different production systems and system boundaries. The data are inconclusive, and point to no or only small differences between production methods. While emissions for meat production from Norwegian dairy cows and veal seem to be lower in a conventional production system than in an organic production system, this difference is smaller and non-significant for veal. For milk, the organic system seems to have lower climatic impact, but the range for conventional production completely overlaps with the narrower range for organic production, and the small difference in the average emissions is therefore not significant. For the Nordics, only a comparison for milk is possible. The results are similar to Norway with a lower climatic impact for organic production, but here the lowest organic emissions are slightly lower than for conventional production. On the west-European scale however, most results are inconclusive. If only considering the averages, conventional milk production gives lower emissions than organic, while the results for meat production (beef) depend on the method (or study) used. However, ranges are overlapping for all west-European products and studies, making the results very inconclusive. Overall, it seems that in Norway conventional production is better for meat, while organic production may be slightly better for milk production.

Comparing these findings with other studies, we find contrasting or diverging results. For milk, Kristensen et al. (2011) however found in their study in Denmark that emissions were larger in the organic system (1.27) compared to conventional (1.20). This is due to higher methane and nitrous oxide emissions and lower milk production per animal found Thomassen et al. (2008), who reported the same difference. Tuomisto et al. (2012) report that only Cederberg and Mattsson (2000) and one of the cases in Olesen et al. (2006) found lower GHG emissions from organic milk production. Refsgaard et al. (2011) on the other hand report on about 20 Swedish case studies where emissions were higher for conventional milk and lower for organic milk (about 0.98 kg CO_2-eq per kg for conventional and 0.95 for organic). Other studies in the Nordics or west Europe conclude that there was no difference between organic and conventional production systems in terms of GHG emission per kg milk (Cederberg and Flysjö, 2004b; Thomassen et al., 2008; Trewavas, 2004; Tuomisto et al., 2012). For beef, both Refsgaard et al. (2011) and Tuomisto et al. (2012) find that organic beef had lower emissions due especially to lower emissions from industrial inputs (referring to Casey and Holden, 2006) – contrary to the findings of Table 15 for Norway.

Hille et al. (2012) report on a number of comparisons in GHG emissions between organic and conventional productions systems. While for plant foods (but not vegetable), a majority of comparative LCAs seem to suggest that organic products have lower carbon footprints than conventional products, for milk and meat they too find that the results are split. In the case of milk, most studies only show small differences between organic and conventional products, while for meat the results diverge with some studies indicating that GHG emissions from organic production were significantly higher and others the opposite. Refsgaard et al. (2011) mention the importance of considering the total emissions versus the "per kg product": milk and beef meat generally have lower emissions in an organic production system than from the conventional system considering overall average numbers for different types of model farms. "The average emissions for conventionally products are from 30% to 70% higher than for the organically products with the lowest difference for beef. There is however variation in the CO_2-emission for each of the analysed products depending on type of production system. The CO_2-emission from beef meat produced in combination with milk is only half the CO_2-emission when produced from suckler cows where the emission is around 34 kg CO_2-eq per kg beef meat."

Some of the lack of differences can be explained by methane emissions from enteric fermentation being higher per unit product in organic than in conventional systems, while emissions from production of feed tend to be lower. Mondelaar et al. (2009) (in Hille et al. 2012) pointed out that the avoidance of artificial fertilisers and pesticides in organic production, along with less use of feed concentrates (kraftôr), had a downward influence on GHG emissions in organic production (because of the decrease land-use effects). However, higher methane emissions from ruminants due to a smaller fraction of concentrates in their feed (digestion effect) and more fuel consumption for mechanical weed control were among factors with an opposite effect, although Refsgaard et al. (1998) and others (see Hille et al. 2012) found no differences in diesel consumption between the two systems. Hille et al. point out that yields and fuel consumption also have an important influence on the ultimate emissions – higher with low yields.

2.5.2 Other production methods

Production methods of course extend beyond the comparison of organic versus conventional. There are many farm-level production system differences that have a large influence on the ultimate emissions for meat or milk. Bergslid et al. (2016) mention in this context various case studies that have partly contradicting conclusions depending on the actual management intensity, farming context, climate and soil conditions, crops, etc. There are many different management systems and combinations of these in cattle farming – example include the duel use of dairy cows for milk and meat, meat production from suckling cows or from intensively fattening of oxen indoors or extensively kept and fed castrated oxen in pastures. Notarnicola et al. (2013) note that the amount of GHG emissions per kg beef (or milk) depends on these different cattle farming systems can have very different climate impacts.

Leip et al. (2010) compare emissions from beef on a European scale, and find that differences in systems but also climate and other factors can be as large ranging from 6,49 kg CO_2eq per kg meat in the Italian region "Abruzzo" to 51,16 kg in the Finish region "Laensi-Suomi" (mainly due to high emissions from organic soils). Importantly, with regard to which production system gives lowest emissions, they find that there may be various solutions: the best performing countries are not necessarily characterized by similar production systems, and be as diverse as Austria and the Netherlands. While the Netherlands save emissions especially with low methane and N_2O rates indicating an efficient and industrialized production structure, Austria outbalances the higher methane emissions by lower emissions from land use and land use change (LULUC) indicating high self-sufficiency in feed production and a high share of grass in the diet. However, both countries are characterized by high meat yields, while emissions in Norway are relatively high in part due to low meat (and milk) yields and thus a less efficient production structure. For meat, intensive maize systems show the lowest, and extensive systems (such as in Norway) the highest emissions.

The type and quality of feed has a large influence on methane emissions: it has already been mentioned that concentrates lower the methane emissions, while Leip et al. (2010) find a relation between high methane emissions with animals spending much time on pastures. The FAO (www.fao.org/gleam) also indicates that feed quality is closely correlated with enteric emissions: Poorly digestible rations, i.e. highly fibrous ingredients, yield higher enteric methane emissions, while Grøndahl (2010) finds that cows fed ryegrass had the lowest methane emission (25 g/kg dry matter intake) and red clover had the highest emission (51 g/kg dry matter intake).

N_2O emissions increase with the share of solid systems or manure fallen on pastures. Different manure management systems can lead to different emission levels, and in general terms, methane emissions are higher when manure is stored and treated in liquid systems (lagoons or ponds), while dry manure management systems such as drylot or solid systems tend to increase nitrous oxide emissions. Finally, high CO_2 emissions (electricity, transportation) indicate a strong dependency on feed imports and, in general, feed crops.

For milk, Leip et al. report a variability of emissions in Europe ranging from 0.41 kg CO_2-eq per kg of milk in the Italian region "Abruzzo" to 3.03 kg in the Greek region "Kriti". To some degree such differences can be attributed to lower milk yields, such as in Norway. However, if feed concentrates (which give higher milk yields) are imported from overseas, they again are often accompanied by higher emissions from land use change, as in the case of the Netherlands, which is a typical example of an intensive system creating very low methane emissions and NO2 emissions, but "overcompensates" these by land use and land use change emissions. Overall, the authors find that intensive maize and extensive grassland systems produce the lowest total emissions while free ranging subsistence and climate-constrained systems emit more.

Nijdam et al. (2012) reviewed 15 LCA studies on beef production in a variety of cattle farming, finding that the production of 1 kg of extensively farmed beef results in three to four times as many greenhouse gas emissions as the equivalent amount of intensively farmed beef. According to these authors, the differences in feed transformation efficiency are higher in intensive systems; Intensive production systems result in higher total production levels and higher feed efficiency (based on higher quality feeds) in intensive production systems results in lower GHG emissions per kg of product compared to extensive systems (Nijdam et al. 2012). Peters et al. (2010) compared grass-fed with the feedlot systems in Australia, similarly finding lower total GHG emissions for the latter; the additional effort in producing and transporting feeds was effectively offset by the increased efficiency of meat production in feedlots.

An advantage of intensive farming it seems is that technological advances to reduce GHG emissions are often more easily implemented because the animals are housed indoors in confined areas and there are more opportunities for handling both manure and gas emissions. Additionally, the high costs of implementing new technologies in an intensive high-input/high-output system can be justified, whereas a similar increase in costs will turn a low-input/low-output system into an unprofitable enterprise (Notarnicola et al., 2013). In extensive grazing systems on the other hand, the sequestration of GHG may balance the generally higher GHG emissions. Again, conclusions are not clear-cut: the Norden report (2014) finds that especially beef production by specialised beef breeds is generating large GHG emissions relative to the amount of human edible food produced. This is particularly due to suckler cows, which consume large amounts of feed but are producing only one calf per year and no milk for human consumption. In contrast, dual-purpose breeds (or combi-cows), which produce both milk and beef, are producing more human food for the same GHG emissions.

Kristensen et al. (2011) found that the *production system effects* on meat and milk are highly dependent on the allocation method (between milk and meat) used. In their model, they find that an average of 15% of total farm GHG emissions was allocated to meat. However, depending on the method, the amounts allocated to meat range from 13% for economic value, 18% for protein mass, 23% for system expansion and up to 26% for biological allocation. The allocation method highly influences the GHG emission per kg meat (in Kristensen: 3,41 to 7,33 kg CO_2-eq. per kg meat), while the effect on the GHG emission per kg milk was lower (0,90 to 1,10 kg CO_2-eq. per kg energy corrected milk). After allocation there was no significant effect of production system on GHG emission per kg milk.

2.6 Which life cycle stages of meat and dairy have the greatest impact?

Earlier in this report, in section 1.2.1, we described the status of Norwegian agricultural emissions. These amount to about 8% of total emissions, we stated, around 4.4 Mt CO_2e per year. This however was based on a fairly loose accounting, and if we include farming in wetland in these numbers, the total for Norwegian agriculture goes up to about 6.3 Mt, or 12% of Norway's total greenhouse gas emissions (Arbeidsgruppe til Landbruk og Klima, 2016). As stated, the livestock sector in Norway contributes about 90% of this total (Grønlund & Harstad, 2014). At the global level, agriculture contributes about 50% of the global CH_4 emissions (mostly livestock) and about 60% of the global N_2O emissions (Crosson et al., 2010).

But how do milk and dairy account, how are their emissions distributed over the different production related factors, the on- and off-farm processes?

According to Leip et al. (2010), the main emission sources vary between animals, production systems, countries and climates. Some of the impacts, related to methane, food quality, manure handling, are already described in section 2.5.2. Analyzing European emissions of the agricultural sector, Leip et al. find that for beef around 39.6% of its total CO_2eq is emitted as methane, 26% as N_2O and 34.4% as CO_2. Methane stems primarily from ruminant digestion, N_2O stems from fertiliser use and urine, while 16.5% of the CO_2 emissions come from the use of energy and 17.9% from land use and land use change (although these latter are highly uncertain numbers, with a wide range). For milk, the distribution of gases is similar, with 36.7% emitted as methane, 21.3% as N_2O and 42% as CO_2, from which 17.7% stem from energy use and 24.3% from land use and land use change. These percentages do include pre-farm processes such as land-use change, but do not include the after-farm processes, and are thus somewhat misrepresenting for the overall sources.

Reporting on a UK study by Garnett (2008), Hille et al. (2012) include some of these pre-and post-farm processes and find that 45 % of the carbon footprint of food consumption in the UK was allocated to primary production, 5 % to upstream processes, 21 % to processing, 15 % to distribution and 14 % to trade, including restaurants etc. But even these percentages are not inclusive of all processes, as the contributions of storage and preparation of food in homes and of the waste stage have been left out of the total, although Garnett also estimated these - taken together amounting to about that of trade. Also the upstream processes were not complete, as only fertiliser production was counted. Other studies such as Weber and Matthews (2008) find that only 4 % of the carbon footprint of food in the US was due to distribution, and 5 % to trade. When counting *all* transport, they found this part contributed 16 % to the life cycle carbon footprint.

Food waste is rarely included in the accounting, but this has been gaining attention over the past few years, especially at the consumer level. Werner et al. (2014), in a Danish study, estimate that around one third of all food produced is not consumed, and the largest share in industrialized countries of this food waste occurs at consumer level. This would add significantly to the overall emission of food. However, the amount of waste (at consumer level) differs substantially for different food groups, with bread and cereals (emissions increasing with around 34% due to waste) and fruits and vegetables (increasing with 23-25% due to waste) topping the list. Emissions of beef (and pork and chicken) increase with about 12% due to waste (going from about 28 to 31.5 CO_2eq/kg product). For milk and cheese emissions increase with 7 and 8% respectively (from 1.09 to 1.17 for milk, and from e.g. 9.23 to 9.93 for cheese with 31% fat). Fish, for comparison, has a 12% increase due to waste, similar to that of meat, while soy drink emission increase is comparable to milk. Thus, reducing food losses is another improvement option. Assuming a product loss of 20%, it is found that if meat and dairy product loss is reduced to 17.5%, the climate effect of milk decreases by 1.75%. Sevenster and de Jong (2008) highlight that while the most important stage in the milk life cycle up to the farm is enteric fermentation, followed by feed production, for the total milk life cycle, electricity use due to household storage is also significant. The IMPRO study (Sevenster and de Jong, 2008) has calculated that changing the energy efficiency of refrigerators in households could reduce the climate effect of milk by 1%.

The FAO (www.fao.org/gleam) similarly mentions that energy consumption occurs along the entire supply chain. Production of fertilisers and the use of machinery for crop management, harvesting, processing and transport of feed crops generate GHG emissions. Energy is also spent on animal production site for ventilation, illumination, milking, cooling, etc. Finally, livestock products are processed, packed and transported to retail points, which involves further energy use.

The FAO presents disaggregated information on emissions from the four main processes: enteric fermentation (about 40% of total emissions), manure management (about 10%), feed production (about 47%) and energy consumption (both on-farm and post-farm: 5%). Figure 4 shows the distribution of emissions along the livestock supply chain at the global level. These emissions reflect to a great extend the distribution of the emissions of dairy and meat.

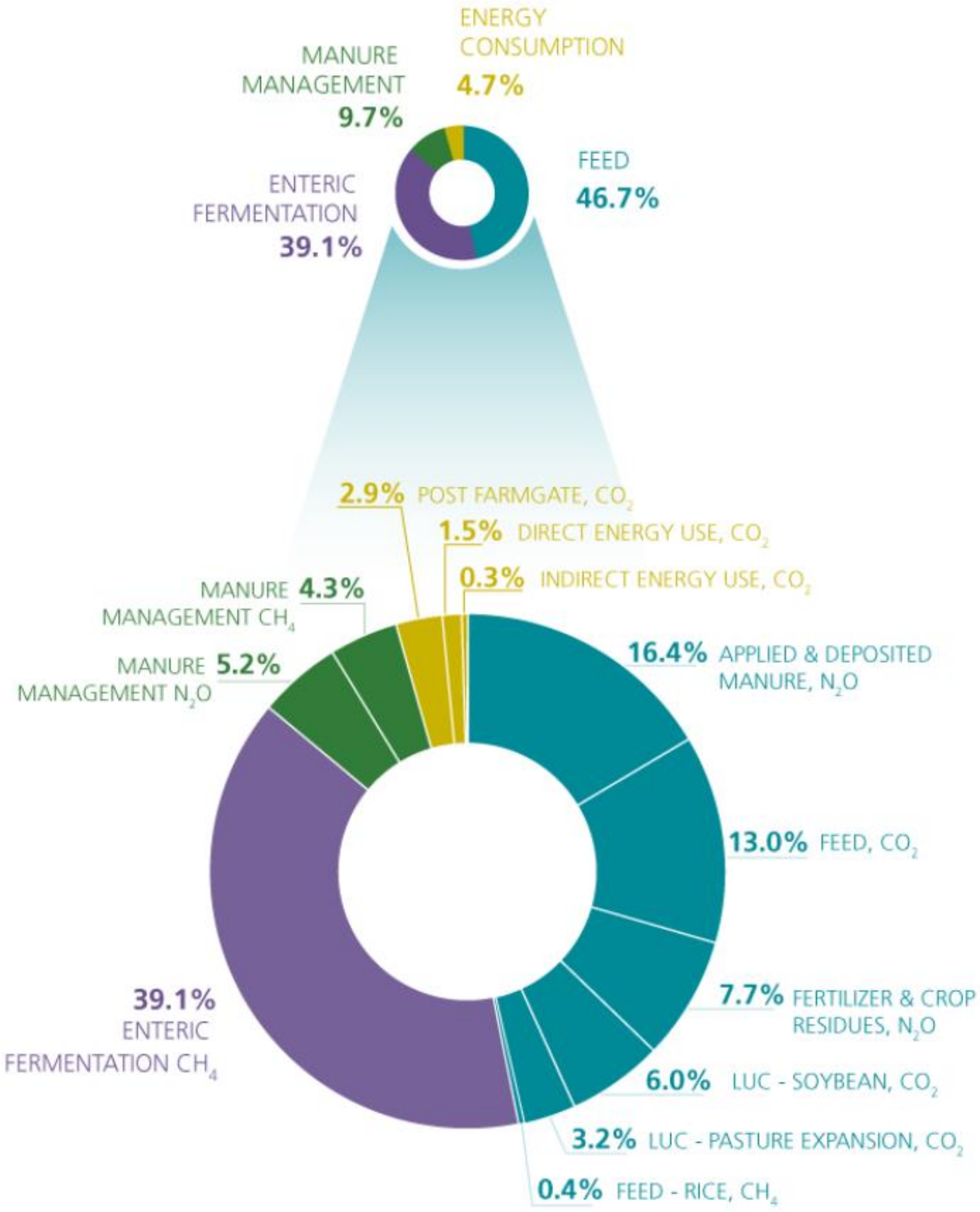

Figure 4: Global emissions by source. Relative contribution of main sources of emissions from global livestock supply chains. Source: www.fao.org/gleam.

For meat and dairy in Norway in particular, Bonesmo et al. (2013) listed the emissions for 30 different farms in Norway, with minimum and maximum emissions for different factors, ranging from fermentation, soil carbon change, energy use, manure handling, etc. (see figure 5). They find that there is great variation between farms.

For milk, the maximum emission is 1,7 times higher than the minimum, and while most emissions are related to fermentation, the greatest variation is found in the N_2O emissions from soil (between 2-39% in young bulls; 8,5-38% in cows and heifers; and 11-40% of the total emissions for milk) – underlining the importance of correct use of fertiliser, i.e. that purchase fertiliser should complement livestock fertiliser (Storlien and Harstad, 2015). The difference in soil carbon change was the next largest variable factor (down to -22% and up to 9,6% in cows and heifers, while indirect energy use in the production of fertiliser also played a role in the farm differences. Importantly – the enteric fermentation of the animals was not a major variable between the farms.

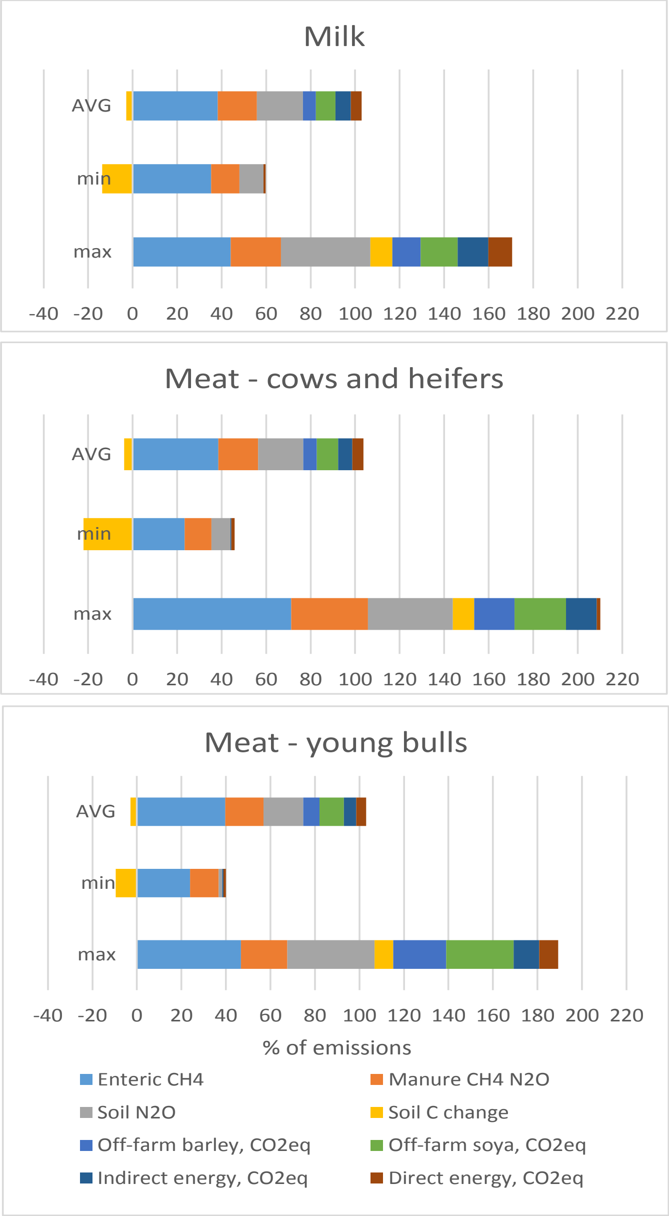

Figure 5: Mean, minimum, and maximum values (in percentage) of GHG emission intensities, expressed as kg CO_2eq/kg fat and protein corrected milk (FPCM) and kg CO_2eq/kg carcass weight, for culled cows/heifers and for young bulls based on data from 30 Norwegian dairy farms in 2008. Values less than 0 indicate removal from the atmosphere (i.e., soil C gain = carbon uptake). Adapted from table 4 in Bonesmo et al. 2013.

Gerber et al. (2010) provide a breakdown of emission sources and specify that 93% of total GHG emissions from milk production globally occur up to the 'farm gate'. Besides emissions on the farm, there are many other crucial emissions further down the production and consumption chain. Sevenster and de Jong (2008) find that post-farm emissions add another 10-20% to cradle-to-farm gate emissions, still excluding household energy use such as cooling, but including product loss. Assuming an amount of product loss varying between 5 and 20%, Sevenster and de Jong calculate that product losses are responsible for 57% of the post farm emissions. Almost 41% of the post farm emissions is due to milk processing (including cheese and milk powder production). Svenskmjolk finds that post farm emissions are equivalent to approximately 10% of the emissions up to the farm gate.

The most important post farm stages are market/consumer (36%, mostly fossil fuel use due to the consumer driving to the shop) and packaging (29%). These estimates for post farm emissions are under-estimates since storage of milk in the household are left out of the analyses, while the IMPRO study has shown that household storage has a substantial impact (Sevenster and de Jong, 2008). Notarnicola et al. (2015) identified some hotspots for dairy products other than milk. The production of powdered and concentrated milk needed for yogurt production for example is the main hotspot for the dairy factory phase, mainly due to the high-energy consumption required for their production processes. Also the production of packaging materials and energy requirements contributes significantly to yogurt emissions. Finally, the distribution phase, consumption at the household and final disposal showed a low contribution. Although the production of milk is the main environmental concern of cheese production, several authors (references in Notarnicola et al.) focused on the environmental impact of cheese manufacturing plants, and found that fossil fuel both for energy production and for transport plays a major role here.

Refsgaard et al. (2011) also compare some of the allocation differences under different production systems: the largest main contributor to CO_2-emission from milk is the direct emission from husbandry production, i.e. the CH_4 and N_2O from digestion and manure contributing with 54% of the total emission at farm gate from conventional production and 71% from organic production. Kristensen et al. (2011) likewise find in their Danish study comparing emissions under different production systems that organic production has higher (98%) on-farm emissions than the conventional system (88%).

For Norwegian meat production, Bonesmo et al. (2013) find that the main culprits responsible for GHG emissions per kg of carcass weight were, in order of relevance: soil's nitrous oxide emissions, indirect energy use, soil C loss and enteric methane. Figure 5 shows that there is a difference between culled (dairy) cows and heifers (DC+H) on the one hand, and young bulls (YB) on the other hand. Enteric fermentation has the largest emissions in both groups – around 38,5-39,5% of the emissions. The variation in YB however is smaller (24-46%) than in DC+H (23-71). The second biggest source is soil N_2O (18% YB – 20% DC+H) closely followed by manure, with about 17-18%, and again more variation DC+H than in YB. Off-farm soy and barley feed production make up around 16-18%, and direct and indirect energy use 4 to 6% each, for both YB and DC+H. Finally, the test farms had a net soil carbon uptake (around 3%) which could be as much as 22% in DC+H and 9% in YB.

Assumptions about electricity: Determining the emissions associated with one unit of electricity input requires an assumption about the generation mix used to produce that one consumed unit. While Norway's generation mix is almost entirely hydropower, through the course of the year the country both imports and exports electricity to neighbouring countries, such that the physical electricity at the socket is no longer almost entirely derived from hydropower. Moreover, because of financial arrangements, certificates of origin are sold by Norwegian power companies to other countries, such that from an accounting perspective the electricity mix in Norway contains significant coal generation input. The combination of both physical and financial trade of electricity across borders adds significant complexity to estimation of emissions associated with electricity inputs in an LCA. The consequences of these assumptions are demonstrated in Table 15.

Table 15: Breakdown of GHG emissions (in percent) caused by food consumption in Norway in 2006. Source: Hille et al. (2012).

Process stage	Assuming Norwegian mix of electricity*	Assuming European mix of electricity*
Production of capital goods and inputs to agriculture and fisheries	17	15
Primary production	57	51
Food processing	9	14
Transport, downstream of primary production	15	13
Trade in food	2	8
Total	100	100

*Refers to electricity used for processes occurring in Norway

Based on the Norwegian generation mix, almost all of which is hydropower, electricity contributes very low emissions to the total, and this is most obvious in food processing and the trade stage of the supply chain, as seen in Table 15. These two stages are high users of electricity inputs, and because of Norway's very low emissions per unit of electricity, they contribute very low emissions. In contrast, when the European electricity-generation mix is assumed, these two stages have much higher emissions, and become much more significant overall. The trade stage is no longer negligible (was 2%, now 8%) and emissions in the food processing stage increase from 9% of the total to 14%. Consequentially, the proportional contributions of all other stages go down because they have low electricity inputs. This shows the sensitivity to the assumptions used in the analysis.

Farm size: An interesting point to make here is that preliminary findings from ongoing (unpublished) research shows that diesel use may be higher on larger farms than on smaller ones in Norway. This has implications for the emission allocations to direct energy use on the farm, and will also play through in the relative allocations of emissions to other on-farm and off-farm processes. There are more differences between small and large livestock holdings than that: smaller farms are reported to have cattle out for longer times of the year than larger farms, which has implications for the amount of feed for these animals that comes from pasture grazing – and thus affects emissions (see e.g. Landbruks- og matdepartementet 2008).

Table 16 summarizes the emissions and allocations to different life-cycle stages for milk and meat based on some individual papers cited in this section 2.6. The table distinguishes estimates for the three main stages pre-farm, on-farm and post-farm. Across the studies on cattle (cattle, milk and meat), the on-farm processes play by far the largest role; in Norway, with around 78% of the emissions. As the table shows, and many studies have reported previously, for the on-farm emissions enteric fermentation is the greatest factor, with about 38-40%. Pre-farm stages contribute about 22%, while fertiliser, manure and pre-farm inputs and indirect energy use play about an equal large role with between 17 to 22%. Finally, on-farm energy use and soil carbon storage are only small, with 5% and -4% respectively.

Table 16: Estimates of allocation of total emissions (in percentage of the emissions per kg product) of meat and milk broken down to different life-cycle stages.

	TESCO 2012	Thoma et al. 2013	Bonesmo et al. 2013			Hille et al. 2012	FAO Gleam
	UK	USA	Norway				Global
	Milk	Milk	Milk	Meat, DC+H	Meat, YB	Food	Cattle
LUC							6
Inputs, Indirect energy			22	22	22	5	14
Pre-farm gate ↑			22	22	22	5	20
Enteric CH_4			*38*	*38*	*40*		39
Manure CH_4+ N_2O			*18*	*18*	*17*		26
Fertiliser N_2O			*21*	*21*	*18*		8
Direct energy			*5*	*5*	*4*		2
Soil C			*-3*	*-4*	*-3*		
LUC							3
Farm production ↑	73	70	78	78	76	45	77
Transport		4					
Processing	9	7				21	
Packaging		3					
Distribution	3	5				15	
Retail	10	6				14	
Consumption	3	5					
Recycle and Waste	2						
Post-farm gate** ↑	27	30				50	3

As the table shows, not all studies cover all stages. The allocation and resulting figures for each stage clearly depends on which factors are included. Therefore, the data for Bonesmo et al. (2013), which covered until farm-gate, are an overrepresentation of the actual allocations: The proportion for pre-farm and on-farm emissions would go down if they had added post-farm emissions. Another major point is that land use change, which in Norway is about 30% of the agricultural emissions. Nearly all of Norway's agricultural land is used for livestock in one way or another, but this often-omitted part in the lifecycle of meat and dairy in Norway plays a major role. Also, there appears to be considerable inconsistency between the various estimates of soil carbon fluxes, so where these data have been included their proportional role may vary greatly, also then affecting the proportional allocation of emissions to the other life cycle processes.

Comparing the allocation of Norwegian emissions related to cattle to the more general emissions from food (Hille et al. 2012) also highlights some interesting points. Firstly, on farm emissions are much lower for food in general compared with livestock on-farm emissions. This makes sense, since there are no methane and nitrous oxide emissions related to non-livestock, which bring the overall food related emissions for on farm production down. A second point of interest is the low pre-farm emissions: these again are lower because the much lower proportion of emissions related to feed imports (for livestock) and related land-use change. Finally, the proportion of post farm operations are much higher as a result of the lower pre- and on-farm processes.

Interestingly, at the global level FAO estimate that post-farm activities contribute only 3% to total emissions, much lower than the contributions from other sources in this table. The most likely explanation for this is that the developed-country sources are not representative of the global situation: in developed countries there is considerable energy use in food processing and wholesale/retail trade, while in most other parts of the world these stages are much more basic and therefore require very little energy input.

Finally, the table and this discussion about partial life cycle studies highlights the point that to really understand allocations properly, there is a need for more detailed whole life-cycle LCAs, for different products and at farm level.

2.7 Potential for change?

Cattle production has been identified as one of the causes of climate change because of cows emitting methane, which is a GHG with a warming potential at least 25 times that of CO_2. Consequently, a number of strategies that could reduce methane emissions have been the focus of research. This report did not extensively search for potential to improve (decrease) emissions from milk and meat production in Norway. However, we came across several studies that indicated some options, and comparisons between Norwegian/Nordic and other production systems, and we use this section to bring some important issues to the attention.

In general, life-cycle GHG emissions of vegetable foods are more sensitive to alternative energy use and efficiencies and transport modes in the supply chain than animal food's climate impact, since emissions of methane and nitrous oxide are so significant in milk and meat supply chains (Norden, 2014). Thus, for milk and meat, emission cuts potentials must be sought elsewhere.

Production: Overall, Norwegian meat and dairy production seems to have a relatively high environmental impact, compared to other European countries (Roer et al., 2013). In both milk and meat production, field emissions from forage production and direct emissions from the animals contribute significantly to the environmental burdens as assessed by LCA. In Norwegian milk production, the rather low yields per cow, high use of nitrogen fertilization, long storage period for manure and high diesel consumption all contribute to high environmental impacts. The same goes for Norwegian beef production when compared with foreign production. However, due to different allocation methods, the lack of available transparent reports on mixed dairy and beef production, and different system boundaries between studies, it is difficult to rank the impacts and conclusively say that Norwegian production has higher impacts. Yet - moderate yields per cow, high use of N fertiliser but still rather low forage yields may be outlined as 'hot spots' in Norwegian combined milk- and meat production in an LCA perspective.

As discussed in section 2.5.2 on production systems; choice of feedstuff or diet composition, feed additives and genetic strategies for breeding animals can significantly contribute to lower emissions (e.g. Norden 2014). Previously, pasture was the main feed source for all cattle, at least during the grazing season. However, dairy cattle are increasingly being kept indoors all year round in highly intensive systems, e.g. in Denmark, Holland and Germany, whereas in other regions grazing still prevails and is expected to continue (e.g. Ireland, New Zealand). Several studies have shown that high-producing dairy cows have lower emission rates, mainly because maintenance costs are diluted over a higher production (references in Norden, 2014). Thus, dairy farmers could raise efficient cows and improve yields and simultaneously reduce methane emissions. However, it may not be so simple, and complicating issues, also in the Norwegian context, are raised and discussed by several authors, including Bonesmo et al. (2013) and Åby et al. (2015). Thus, strategies for mitigation should address both intensive and extensive systems, but possibilities are dependent on the individual system. Intensive systems allow for a number of controlled options and technologies that reduce methane emissions from animals, farms and/or manure, while in extensive systems, genetic selection for improved efficiency and reduced methane emissions is a more feasible option – options that could be applied to intensive systems as well.

As the milk yield per cow and year is considerably lower in Norway than under similar production systems in Sweden and Finland and the finishing of young dairy bulls on Norwegian farms is far from optimal, mitigation options for both in milk production and beef production from the dairy herds are feasible (Bonesmo et al., 2013). Åby et al. (2015) confirm this scenario by calculating that an increase in milk yield per cow would reduce GHG emissions to 0.9 kg C02eq per kg milk by 2030. Fewer dairy cows would produce the same total amount of milk. This would reduce methane emissions (fewer animals), emissions from manure, fertilization and energy use. However, in a country with milk quotas, as in Norway, an increase in milk yield would result in fewer dairy cows and less calves for beef production. If this loss in beef production would be replaced by a suckler cow type beef production system, which have higher emission than dairy cows, the net result may not actually lower total GHG emissions from Norwegian agriculture as the initial gain in milk yield and reduced number of dairy cows is lost (Bonesmo et al., 2013; Åby et al., 2015).

Another option would be to increase the yield of milk and meat by feeding cattle with more concentrates (kraftfôr) and protein rich feed resulting in more milk. Storlien and Harstad (2015) however argue that this strategy is not a viable solution for decreasing the overall emissions in milk and meat production: it is argued that while less cows are needed to produce the same amount of milk, the need for protein rich feed (soy) increases per cow. If the impacts of land-use change related to soy production (i.e. deforestation) are considered, then the "reduced emissions" as a result of increased yield are much decreased.

Andersen Nesse (2015) specifies that there are great variations in emissions between farms. It is exactly these great variations that allow for adaptations in production systems – or mitigations - at the farm level. As the variation among the farms was higher for the GHG per kg product for beef production than for milk production, Bonesmo et al (2013) indicate a large mitigation potential for meat production under this system. We hereby also refer to figure 5 in the next section 2.6, which indicates the farm differences in emissions, and room for improvement. Although theoretically, increasing animal productivity should reduce GHG emission per kg milk and beef, studies that use real farm data indicate that this is not always the case. Using farm data, Vellinga et al. (2011) found no reduction in GHG per kg milk when production exceeded 6500 kg milk per cow and year. Similarly, Bonesmo et al. (2013) showed no significant relationship between milk yield and GHG emission intensity or between daily live weight gain and GHG emission intensity.

Consumption: Although the consumer side of meat and dairy does not stand for the greatest amount of emissions and is not covered explicitly in this report, there is certainly room for cuts. Some of the options we have come across include a paper by Pira et al. (2016), who find that in the Nordics there is a general reduction in the number of dairy herds but an increase in yield per milk cow in the Nordic countries. The number of farms with cattle has also decreased greatly in the Nordic countries, leading to increased demand for imported meat in some cases. There is a general trend showing a decline in the production of beef in favour of poultry and pork. This suggests that the yield increase options posed by Bonesmo et al. (2013), Åby et al. (2015) and Storlien and Harstad (2015) may be viable after all, if the increased demand for meat would be filled by pork and poultry instead of suckler cows.

Indeed, one aspect that potentially is one of the most powerful in combating food's impact on climate change is the choice of products, i.e. our diets. In their report "Kunnskapsgrunnlag for lavutslippsutvikling" (2014), the Norwegian Environment Agency suggests a transition from red to white meats as an important mitigation effort. The production of cattle meat is suggested to be drastically reduced down to 40% of today's levels by 2025. This, they claim, will reduce the emissions of nitrous oxide and methane from changed animal husbandry, and lowered carbon emissions from land use and land use change. Since the differences in life cycle GHG emissions are so very large between products fulfilling similar nutritional functions, the scope for improvement is large. However, in order to efficiently work with "climate smart diets" more knowledge is needed about life cycle impact of single products and connections between diets and how the food chain is affected by changed diets (Sonesson et al. 2010).

In Sweden, price cuts on beef and increase in income per capita have fuelled beef consumption since the 1990s. Today, annual per capita beef consumption in Sweden is about 26 kg (in CW), which is about 40% higher than the EU average. Other European countries with relatively high beef consumption (20 kg CW per capita and year) include Denmark. In contrast with beef, per capita consumption of chicken and pork in Sweden are 16% and 28%, respectively, lower than the EU-27 averages (Lesschen et al. 2011). For dairy products, long-term per capita consumption trends show declining milk consumption, whereas cheese consumption has doubled since the 1960s (Cederberg et al., 2013).

For Norway, the SSB (2015) report several changes in the Norwegian consumption pattern related to meat and dairy: "Not only do we spend less money on food, but we also buy different kinds of food. Since 1958, the consumption of butter and margarine have halved during this period. While the per capita consumption of meat has remained largely stable for the past 25 years, we are eating more fruit and vegetables. The consumption of milk has fallen from almost 170 litres per person to around 70 litres. Whereas most people used to drink whole milk, semi-skimmed and skimmed milk are most popular nowadays. On the other hand, milk yield per cow has increased substantially from approximately 2 000 litres in 1949 to 7 100 litres. Stocks of sheep and goats are also declining, while the number of pigs and chickens is increasing. This is reflected in the development in meat production and there has been a marked increase in white meat, particularly poultry." These changes, while not promising for the dairy and (cattle) meat sector, are positive for the climate. It should be noted however, that several of the numbers are listed as "per capita" – and Norway's population has seen a substantial increase since 1960 (3 568 000) and 1990 (4 233 000) to today (5 168 000) (SSB 2015).

Assuming future changes in Norway may be similar to those in Sweden, the observations of Cederberg et al. (2013) may be interesting: This study foresees that by 2050 the emissions intensity per unit of produce in Sweden may have decreased, primarily by using greener energy, improving manure management and removal of N_2O formation from synthetic fertilisers. Biogenic emissions, those from enteric fermentation and N turnover in agricultural soils, are hard to reduce. Under the optimistic assumption that "emissions of CO_2 from fossil fuels and CH_4 from manure management are reduced to zero in animal production in 2050, the life cycle emissions would only be lowered by 40% to 50% for pork and poultry and 20% to 25% for dairy and beef. The consumption of animal-based food at a level like Sweden in 2005 could jeopardise the current climate targets. Of course, emissions from animal-based food products are not the only emissions that have to fit within this 2050 limit. All emissions from food, as well as from energy, transportation, and industry, have to fit within that budget.

Finally, Sevenster and de Jong (2008) show how changes in milk can cut emission. Post farm emissions play an important role in milk emissions: Electricity use for storage is one, but product loss (after the best before date) is another. In this context, one option for improvement is a shift from fresh milk to alternatives such as UHT-treated milk which and can be kept for many months before opening.

3 Key points and final remarks

These “key points” provide short answers to TINE’s main questions about current and future meat and dairy production in Norway. We urge cautious use of numbers from these key points, because there is great uncertainty about emission data. The available datasets are incomplete and there are large differences between studies.

What are the emissions for cattle meat and dairy?

There is no simple answer to this question. Not a single study presented a complete emission analysis for either milk or meat, including all factors connected to their inputs, production, processing, consumption, and waste. The more elements of the production chain are included in the analysis, the higher the emissions.

Studies allocate emissions differently between milk and meat. Older studies (before 2007) give slightly lower numbers than newer studies because of different conversions for methane to CO_2 equivalents. Moreover, the results differ between farms, depending on production methods, soil type, and many more factors. Because of the lack of post-farm gate allocation data, we use cradle-to-farm-gate figures only.

In Norway, most meat comes from combined milk and meat production, while a smaller but growing proportion comes from suckler cows and young bulls. The combined total emissions for the different meat types per kg product (i.e. carcass weight, including meat and bones) are as follows:

- Dairy cows: approximately 19,5 kg CO_2 equivalents per kg product (range: 11-37,5).
- Young bulls: approximately 19 kg CO_2 equivalents per kg product (range: 11,75-32)
- Suckler cows: approximately 30 kg CO_2 equivalents per kg product (range: 25-34)

For milk, the numbers hinge on the allocation of emissions between meat and milk. The studies referred to in this report find the following:

- Milk: approximately 1,15 kg CO_2 equivalents per kg product (range: 0,5-1.6)

For more details refer to sections 2.3 and 2.4, and the studies mentioned in these sections.

How do Norwegian meat and dairy emissions compare to other countries?

In general, high-yielding production systems give lower emissions. The more products come from the same animal, the lower the emissions per product. In Western Europe and Norway, most cows produce both meat and milk. In addition, yields are higher in Western Europe. As a result, Western Europe has the lowest meat and dairy emissions globally.

Norway's emissions from combined meat-milk production are higher than in other Nordic and Western European countries. This is mainly because other countries have higher yields and lower methane emissions. Yields are a function of both breeding and the digestibility of foodstuffs. The range in meat emissions is larger in Norway than elsewhere, and this means that the potential to cut emissions is high in Norway if all production were to move towards best practice.

Also for milk, emissions are slightly higher in Norway than in other Nordic countries but lower than in Western Europe overall. Looking at other dairy products, Norwegian butter production emits less than in other countries, but cheese production more. Again, the range in milk emissions is large in Norway. Yet the potential for emission cuts is smaller because meat stands for a bigger share of the emissions of combined production.

For more details we refer to sections 2.3 and 2.4, and the studies mentioned in these sections.

How do emissions from cattle meat and milk compare to alternatives?

In nearly all studies, the carbon footprint of beef is much higher than that of pork, chicken, fish and vegetarian alternatives. But lamb and sheep meat emit slightly more than beef, largely because beef's emissions per kilogram are reduced with some emissions allocated to milk. The clear division is that ruminant livestock produce substantially higher emissions than other livestock.

The average difference in emissions, depending on the system boundaries and study, is as follows:

- Lamb and sheep meat emits 0.7 times more than beef;
- Beef emits 4.5 times more than pork (range 3.5–8.5);
- Beef emits 8.5 times more than chicken (range 4.5–16);
- Beef emits 6.4 times more than fish (range 3–20 depending on the species and catching method);
- Beef emits 7 times more than vegetarian burgers or tofu (range 6-8)

It is not easy to compare milk to plant-based alternatives, because the alternatives do not have the same nutrients and are not equally suitable for all purposes (e.g. in coffee, sauces). When only assessing the emissions, the alternatives are slightly more climate-friendly:

- Soy and oat milk emit 1.5-3 times less than milk

For more details we refer to sections 2.2.1 and 1.4.3 and the studies mentioned in these sections.

Do units matter when presenting meat and dairy emissions?

Life cycle analysis allows comparing different products' impacts on the environment. But can a kilogram of meat simply be replaced by a kilogram of fish or tofu? Or should we also compare the energy content and price? What is the best way to present emissions - per kg product, per kg protein or per kcal? Do alternatives offer the same nutritional value as meat and milk?

Which unit is most relevant depends on the context and the target group:

- For farmers, different units can be relevant. If the purpose is to highlight which phase in the production process has the largest impact and potential for improvement, emissions can be shown by mass, energy content or economic value. To compare different production methods - organic, integrated and conventional farming, mass– or energy-based emissions are most interesting, as farmers will mostly be concerned about productivity and costs.
- Consumers typically do not purchase foods based on mass content, but are more interested in emissions per servings, per protein or energy content.
- To help decision makers or local communities assessing single products, emissions are best expressed in term of surface, mass, energy, nutrient content or economic value.

When we know a product's emissions per kg, it is relatively easy to convert this to emissions per kg protein or per kcal.

Regardless of the unit used, cattle meat has higher emissions than alternatives like pork, chicken, fish or vegetarian products. Likewise, milk has larger emissions than soymilk, regardless of choice of unit.

For more details we refer to section 1.4.1 and the studies mentioned in this section.

Which stages in the meat and dairy life cycle cause most emissions?

Emissions from meat and dairy come during all stages of the production and consumption chain and in many forms. The biggest source are methane emissions from ruminant digestion, followed by methane and nitrous oxide from manure, carbon dioxide and nitrous oxide related to feed production, fertiliser use and land use change. In addition, carbon dioxide emissions come from electricity use, transport and food processing stages.

How much does each step in a product's lifetime contribute? Most studies do not include a complete life cycle analysis: typically, they leave out the post-farm emissions, such as from processing, distribution, retail, consumption and waste, or indirect emissions such as land use or land use change or carbon sequestration. Leaving out certain steps will lower the total emissions and will allocate higher shares to on-farm and pre-farm stages.

Based on the results in the literature, which are mostly partial life cycle studies often excluding post-farm and land use changes, we find the following results for meat and milk production in Norway:

- On-farm processes account for almost three quarters (ca. 76-78%) of the emissions.
- The pre-farm stages contributes 22%.

The biggest individual source of emissions is methane from digestion processes, with around 38-40%. The second most important may well be land-use change, which contributes around

30% to Norwegian agriculture, most of which is used for livestock, in some way, so these land-use change emissions (e.g. dyrket myr) certainly contribute to the footprint of milk and meat. Still, studies often ignore this factor. Fertiliser, manure and pre-farm inputs and indirect energy use have a similar share of the emissions, between 17 and 22%. Finally, the contributions from on-farm energy use and soil carbon storage are limited, 5% and -4% respectively.

For more details we refer to section 2.6 and the studies mentioned in this section.

Are there differences in emissions between conventional and organic – or other - production systems?

Organic farming is generally more environment-friendly than conventional methods, putting less strain on biodiversity, water and land. Many people assume it is more climate-friendly as well. Yet our analysis shows no or only small differences between the two systems. The results from studies are inconclusive.

We have compared greenhouse gas emissions between conventional and organic milk and meat production in Norway and other Nordic and Western European countries. We have also studied the climate impact of intensive versus extensive production and from meat production with beef cattle versus combined production of meat and milk with dairy cows.

For milk, the results are inconclusive: in Norway, organic and conventional production have the same emissions. For the Nordic region, organic production has slightly lower emissions, but the difference is insignificant.

For meat, conventional production from dairy cows has lower emissions than organic production in Norway. However, the range in organic production is much larger, suggesting that there are opportunities for cuts in the most emitting farms. In Western-European context, results were inconclusive.

When we look more closely at different meat production methods, dairy cows come out as the winner. Being able to share emissions over two different products - milk and meat, the climate impact of dairy cows is clearly lower than for suckler cows. On average, dairy cow meat produces 30% less emissions than suckler cow meat. Veal meat scores similarly or better than dairy cows in some studies.

Compared with other countries, Norwegian meat production is relatively emission-intensive. The Norwegian management system is extensive: most dairy cows spend at least 3-4 months on pastures and about 60% of their diet is roughage (grazed or baled). Milk and meat yields are low, in contrast to for example the Netherlands or Austria. While both of these have high meat yields, their production systems are quite different from each other and they save emissions in different ways. The Netherlands has managed to cut methane and N_2O emissions thanks to an efficient and industrialized production structure, while Austria has low emissions from land use and land use change, thanks to high self-sufficiency in feed production and a high share of grass in the diet. In conclusion, there are different recipes for limiting emissions from milk and meat production in Europe, but Norway is not among the best.

For more details we refer to sections 2.5 and 2.7 and the studies mentioned in this section.

4 Brief list of definitions

Cattle:

Beef cattle are cattle raised for meat production, as distinguished from dairy cattle, used for milk production. (norsk: okse, storfe).

Dairy cow refers to cattle bred for the ability to produce large quantities of milk, from which dairy products are made. (norsk: melkeku, kombiku)

Heifer is a cow that has not borne a calf, or has borne only one calf. (norsk: kvige)

Suckling cow is a cow used to breed and suckle calves for beef. (norsk: ammeku)

Farming methods:

Conventionally grown refers to a method often using fertilisers and pesticides which allow for higher yield, out of season growth, greater resistance, greater longevity and a generally greater mass. It is opposite to organic growing methods, which attempt to produce without synthetic chemicals (fertilisers, pesticides, antibiotics, hormones) or genetically modified organisms.

[4]**Organic/Ecological food** is produced by methods that comply with the standards of organic farming. Standards vary worldwide; however, organic farming in general, features practices that strive to foster cycling of resources, promote ecological balance, and conserve biodiversity. Organizations regulating organic products may choose to restrict the use of certain pesticides and fertilisers in farming. In general, organic foods are also usually not processed using irradiation, industrial solvents or synthetic food additives. Currently, many countries require producers to obtain special certification in order to market food as organic, within their borders. In the context of these regulations, organic food is food produced in a way that complies with organic standards set by national governments and international organizations.

In Norway, organic/ecological food is characterized by minimal use of additives, good welfare for livestock and no use of chemical pesticides. The E-brand (Norwegian: Ø-merket) and EU-logo on organic food guarantees the mode of production, but not for a specific nutrient content in products. Organic livestock ensures all animals the ability to move outdoors, also outside the grazing seasons. Indoors, organic animals have more space than in conventional operations.

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[4] http://www.matportalen.no/merking/tema/okologisk_mat/

Organic animals receive organic feed. Farms and companies that want to produce, process, and sell organic foods must be inspected and approved by Debio. Debio also approves foreign goods sold in Norway. FSA (Mattilsynet) has the overall responsibility for the rules relating to the production, processing, storage, import and sales of organic agricultural products and foodstuffs in Norway.

Free range refers to a method of husbandry where the animals, for at least part of the day, can roam freely outdoors, rather than being confined to an enclosure all day. On many farms, the outdoors ranging area is fenced, thereby technically making this an enclosure, however, free range systems usually offer the opportunity for extensive locomotion and sunlight prevented by indoor housing systems. Free range may apply to meat, eggs or dairy farming. The term is used in two senses that do not overlap completely: as a farmer-centric description of husbandry methods, and as a consumer-centric description of them.

Intensive management system refers to a system with great use of purchased inputs such as feed and fertiliser and high animal growth rates and yields. Intensive animal husbandry involves either large numbers of animals raised on limited land, usually confined animal feeding operations, or managed intensive rotational grazing. Both increase the yields of food and fibre per acre as compared to traditional animal husbandry.

Extensive management system refers to a system with little use of purchased inputs such as feed and fertiliser, and typically uses small inputs of labour and capital relative to the land area being farmed. Extensive farming is often (but not always) characterized by low animal growth rates and yields.

5 Acknowledgements

The authors want to thank Elisabeth Lannoo and Asbjørn Aaheim for reading through this text and providing their comments and help in formatting while on holidays or otherwise unavailable.

We also want to thank TINE for their funding and this opportunity to dig into some very interesting material, and to support CICERO's strategy to broaden its niche into "food, climate, and sustainability".

Finally, we want to thank the Norwegian Research Council and CICERO for giving the green light to the strategic research initiative SIS KliMAT, which co-financed the writing and research for this report.

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