Climate Innovations in Meat and Dairy

Deliverable 2.5

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1. Introduction

Decarbonizing the EU28 is required to reach the objective of keeping the increase in average global surface temperature under 2°C compared to the pre-industrial period, especially if striving for the 1.5°C as ratified in the Paris Agreement in 2016 (UNFCCC, 2015). The European Commission (2011) has agreed to reduce domestic GHG emissions within the EU by 80-95% in 2050 compared to 1990. This requires reaching net-zero emissions for CO_2 by 2050 with the remaining emissions being mainly methane (CH_4) and nitrous oxide (N_2O) from agriculture which must be net-zero later in the century (European Commission, 2018a).

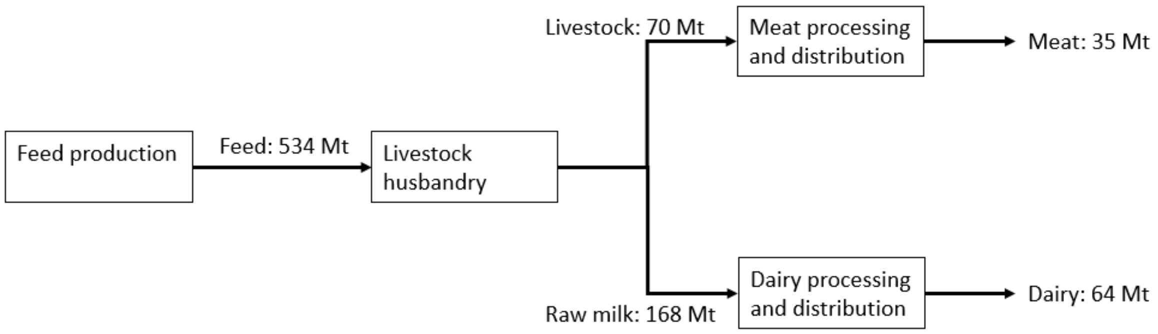
This report has the objective to analyse the decarbonisation options of the meat and dairy production system which emits 15% of the total greenhouse gas (GHG) emissions in the European Union (EU) (European Environment Agency, 2012; FAO, 2017a). The share of agricultural CH_4 and N_2O is much higher, around 77% of the total. These emissions must reduce from 454 Mt CO_2-eq to 277 or even 230 Mt CO_2-eq in 2050 (aan den Toorn et al., 2019; European Commission, 2018b). To analyse the decarbonization options, the report addresses the following two questions:

- What are the mitigation measures for decarbonising the meat and dairy production system?
- What are the opportunities and barriers for the identified measures?

2. The meat and dairy production system

The global production in 2016 of meat and dairy was 330 Mt carcass weight and 810 Mt raw milk, respectively. As one of the major producers, the EU accounted for around 15 % of all meat and 20 % of all dairy. Figure 1 illustrates the production stages and main product flows in 2016 (aan den Toorn et al., 2019). First, feed production provided 534 Mt of feed by using agricultural inputs. Next, this feed was consumed by livestock husbandry which provided 70 Mt live animals and 168 Mt raw milk. Finally, the live animals were processed into 35 Mt of meat and raw milk into 64 Mt of dairy. This section gives an overview of feed and livestock production, meat and dairy processing, and the related energy use and greenhouse gas emissions.

Figure 1: Flowchart of the meat and dairy sectors (excluding agricultural inputs, energy, water, and by-products)



2.1 Feed and livestock production

For the EU, the majority of the 534 Mt of consumed feed was cultivated within the EU. This feed consists of fodder crops such as silage maize, grains such as barley, grazed biomass, and compound feed (Table 1). Unlike the other feeds, compound feed is processed industrially. It provides a protein rich diet for livestock which is made by combining grain (50%), oil meal (39 %), and by-products (11 %) from agriculture and the bioeconomy. The oil meal is particularly important as a protein source. It is produces by pressing oilseeds such as soy and rapeseeds which has vegetable oil as a co-product. Besides production within the EU, 40% of the consumed oil meals and 36 % of the pressed oilseeds were net imported in 2016.

The livestock sector takes the feed as its main input and produces live animals and raw milk (Table 1). In 2016, 7368 million chicken and turkey, 259 million swine, 50 million sheep and goat, and 26 million cattle were sent to abattoirs for slaughter (Eurostat, 2018). This was equivalent to a total of 70 Mt live weight mostly provided by swine, chicken, and cattle. In addition, dairy cattle, sheep, goat produced 168 Mt raw milk, 97% coming from dairy cattle. Moreover, since most nutrients such as nitrogen (N) remains in manure, it was returned to the fields as fertilizer which contributed to the circularity of the system.

Table 1: Livestock husbandry feed input and product outputs in 2016 (aan den Toorn et al., 2019).

Products	Feed input (Mt)	Livestock output (Mt)
Fodder crops	269	
Feed grains	35	
Grazed biomass	85	
Compound feed	145	
Feed grains	72	
Oil meal	29	
By-products	16	
Livestock for slaughter		70
Raw milk		168

2.2 Meat and dairy processing

Meat processing in the EU produced 35 Mt of meat and 14 Mt of by-products through the slaughtering of 70 Mt of livestock in 2016 (Table 2). First, livestock is split through slaughtering into carcasses, hides, and inedible by-products called rendering materials. Next the carcasses are divided into cuts through primary processing with some of the unsuitable parts sent for rendering. These cuts can then be distributed for consumption, but over 40 % is turned into sausages, smoked meat, and other processed meat; these production steps are collectively called secondary processing. Finally, the rendering materials are converted into proteins and fats suitable as inputs for the food, pet food, feed, oleochemical, and energy industries.

Table 2: Meat processing inputs and outputs in 2016 (aan den Toorn et al., 2019).

Process	Product	Input (Mt)	Output (Mt)
Slaughtering & primary meat processing	Livestock	70	
	Primary meat		35
	Rendering materials		34
Secondary meat processing	Primary meat	15	
	Secondary meat		15
Rendering	Rendering materials	34	
	Rendering products		12

Dairy processing in the EU produced 64 Mt of dairy and 12 Mt of by-products (Table 3). Converting the 168 Mt of raw milk to dairy products generally starts with the following three processes: pasteurisation which destroys microorganisms and increases shelf-life, standardisation which adjusts the fat content to the desired level by either adding skimmed milk or removing cream, and homogenisation which breaks down fat into smaller sizes to prevent the formation of a cream layer. After these processes, milk can be turned into different products which can be distributed for consumption. Also, cheese production leads to whey which constitutes 95% of dairy by-products. Other by-products are lactose, lactalbumin, and casein which are small in quantity but important inputs for the food and pharmaceutic sectors (Gutiérrez et al., 2012).

Table 3: Dairy processing inputs and outputs in 2016 (aan den Toorn et al., 2019).

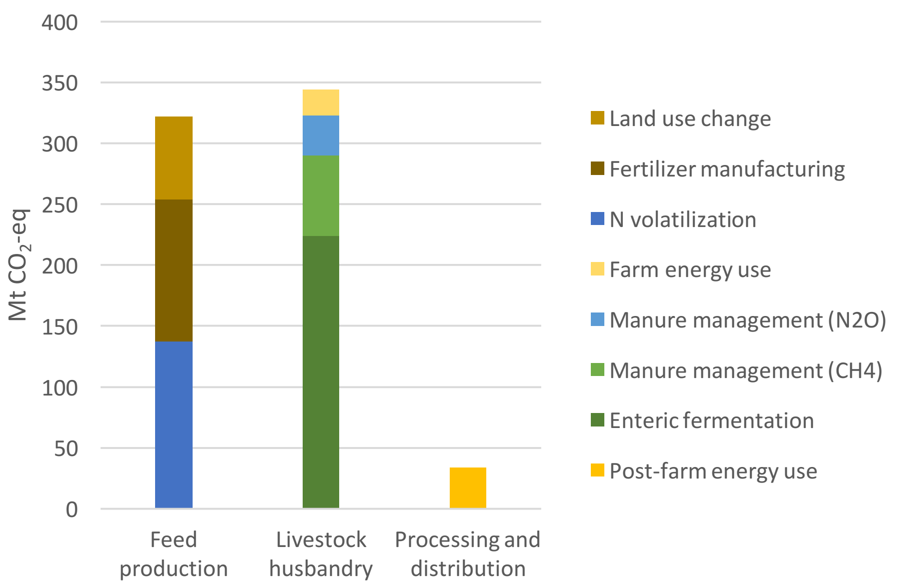
Product	**Input (Mt)**	**Output (Mt)**
Raw milk	168	
Drinking milk		35
Cheese		11
Acidified milk		8
Other dairy		10
Whey		11

The EU exports a significant fraction of the produced meat and dairy. Of the available meat in 2016, 12 % was exported with the largest share being swine (64%), chicken (25%), and beef cattle (9%). For dairy, the export was 6 % on product basis and 11 % on raw milk basis. Dairy export was dominated by drinking milk (30 %), dairy powder (27 %), cheese (22 %), and concentrated milk (8 %). Except for drinking milk, these products are suitable for long distance transport as dairy powder, cheese, and concentrated milk have long shelf-life due to their reduced water content. In contrast, import was less 2 % of the available meat and less than 1 % for dairy.

2.3 Energy use and greenhouse gas emissions

Energy consumption by the EU meat and dairy production amounted to between 680 and 780 PJ in 2016 (aan den Toorn et al., 2019). Electricity and fuel accounted for 40 % and 60 %, respectively. More than 50 % of the energy was being used in feed cultivation (20 %), meat processing (18 %), and dairy processing (18 %) due to each having relatively high fuel consumption. In contrast, electricity use was fairly well distributed between the processes.

Figure 2: Total GHG emissions for feed production, livestock husbandry, and processing and distribution in 2010 (FAO, 2017b)



The product flows within the meat and dairy sector are linked to various GHG emission sources emitting around 700 Mt CO_2-eq (FAO, 2017b). These emissions are divided between the production stages (Fig. 2) and composed of enteric fermentation (225 Mt), N volatilisation (140 Mt), feed and agricultural input energy use (115 Mt), manure management (95 Mt), land use change of soy and palm (70 Mt) post-farm energy usage (35 Mt), livestock husbandry energy use (20 Mt). The non-CO_2 emission sources together contribute most to climate change. These emissions are inherent in the production processes as enteric fermentation results from the digestion in ruminants, N volatilisation results from the application of fertilizer, and manure management emissions result from the storage of manure. Additionally, N fertilizer production also has inherent CO_2 emissions unrelated to energy production. This production chain starts with the Haber-Bosch process combining atmospheric N_2 with H_2 to produce ammonia. However, the H_2 is often sourced from natural gas and coal through steam reforming which separates H_2 from CO_2, emitting the latter. As these inherent emissions are linked to feed cultivation and livestock husbandry, decarbonisation measures should either target or avoid these processes.

3. Decarbonisation options

This section describes mitigation measures for the meat and dairy production system. The decarbonisation options are divided into the following three categories: waste reduction, emission and energy efficiency, and reducing consumption.

3.1 Waste reduction

The first category aims to reduce GHG emissions by reducing and reusing food waste. This should in turn lead to less production of meat, dairy, and feed; about 14.5 % of meat and 7.5% of milk are wasted at the retail and consumption stage (FAO, 2011). By eliminating this waste, a lower quantity of produced meat and dairy can fulfil the same demand. This is assumed to reduce production and the related GHG emissions along the supply chain. Alternatively, the waste can be utilized for feed production, thus replacing feed cultivation. This reduces GHG emissions from N volatilisation and steam reforming by avoiding N fertilizer use. A variety of promising initiatives were documented in the REINVENT innovation database (Table 4). These initiatives have the potential to increase the circularity of the meat and dairy sector while simultaneously decreasing GHG emissions.

Table 4: Decarbonisation measures reducing waste

Reduction pathway	**Innovation**	**Description**	**Source**
Food waste reduction	BestFør.no	Application for the food and health sector that gives an alert when food nears the expiration date.	https://bestb4.azurewebsites.net/english#time
	No Food Wasted - Afgeprijsd	Application for grocery stores to log items about to expire for customers to buy at a discount.	http://www.nofoodwasted.com/en/
	Winnow	A system for logging food waste by type (e.g. oranges) and origin (e.g. peelings or leftovers) and calculating wasted costs.	http://www.winnowsolutions.com/company
	Community Fridge Network	A community fridge for sharing surplus food with local residents	https://www.hubbub.org.uk/the-community-fridge
Food waste recycling	Sistema BioBolsa	Sistema Biobolsa manufactures and distributes small-scale, affordable biodigester systems that transform livestock waste into organic fertilizer for crops and biogas for cooking, heat and electricity.	http://sistema.bio/
	Protix - Insect proteins	Protein ingredients based on insects with applications in feed and pet food. Potentially human food in the future.	https://protix.eu/ingredients/

3.2 Emission and energy efficiency

The second category implements technical measures that reduce GHG emissions while maintaining the same level of production (Table 5). For enteric fermentation, several studies (Cottle et al., 2011; Hristov et al., 2013; Patra, 2012) have reviewed mitigation options which can be grouped into the following three categories: reduction of methanogens, changing feed, and breeding targets. Different compounds have been tested for their capacity to reduce methanogens with a wide range in effectiveness from below 10% to around 30% reduction, but some compounds may be toxic to cattle and for others more research is necessary. Changing feed by improving the quality of forage, increasing concentrates, and improved grazing management have been reported to each reducing enteric fermentation from below 10% to 30% or higher. Despite the higher methane emissions from forage-fed ruminants, using grazing land can help retain or increase soil carbon reserves (Guyader et al., 2016). Good grazing management can also contribute to other ecological issues such as conserving biodiversity. Finally, the possibility of breeding low CH_4 emissions ruminants has been studied as CH_4 emissions differ for individual ruminants. Researchers have focused on finding inheritable characteristics that that are correlated to low enteric fermentation, but the potential has not been sufficiently quantified. Although potential for decarbonisation exists, the measures with most potential may also adversely affect the ruminant digestive system thus caution is required with wide scale adoption.

To reduce N volatilisation, two types of measures were developed. The first are nitrification inhibitors which are used to interrupt the processes leading to N volatilisation. One example is dicyandiamide which is included in the REINVENT innovation database. The second are polymer-coated fertilizers regulating the release of N so less is lost to emissions. Meta-analyses show that nitrification inhibitors and polymer-coated fertilizers reduce N_2O emissions by around 40% and 35%, respectively (Akiyama et al., 2010; Gilsanz et al., 2016). However, the actual reduction ranges widely depending on factors such the characteristics of the soil. Thus, the implementation of the measure will have to be determined per location to ensure its effectiveness.

For emissions from manure management, the following mitigation options have been reviewed: anaerobic digestion to capture CH4 for energy, composting to ensure the degradation mainly emits biogenic CO2, manure acidification to decrease N2O emissions, and improved storage to avoid interaction of manure with the atmosphere (Gerber et al. 2013). The mitigation potential for CH_4 is estimated from 10% to over 30%, although combining anaerobic digestion with solids separation could reduce emission up to 40% (Holly et al., 2017). However, the total effect on climate change is not clear as some measures can lead to an increase in N_2O emissions.

Finally, the possibility of replacing steam reforming in N fertilizer production has been research by several studies (Bicer et al., 2016; Giddey et al., 2013). One possibility is to replace the Haber-Bosch process with an electrochemical production pathway which could reduce energy consumption by over 20% (Giddey et al., 2013). Furthermore, the production of H_2 through steam reforming could be replaced by electrolysis, although the climate change impact will depend on the electricity source. If both measures are adopted alongside a renewable energy source, the fossil-based CO_2 emissions would be eliminated.

Table 5: Decarbonisation measures reducing GHG emission sources.

GHG emission source	**General innovation**	**Company/ initiative/ product**	**Description**	**Source**
Enteric fermentation	Inhibitors	Project Clean Cow	A methane inhibitor decreased rumen methane production in a long-term trial with high-producing dairy cows	https://www.dsm.com/corporate/science/challenges/climate-energy/project-clean-cow.html Hristov et al. 2013 Cottle et al. 2011 Patra 2012
	Defaunation		Elimination of gut bacteria to reduce methane production	Cottle et al. 2011 Patra 2012 Hristov et al. 2013
	Vaccination		Vaccination targeting methanogenic bacteria producing methane in ruminants.	Cottle et al. 2011 Patra 2012 Hristov et al. 2013
	Plant bioactive compounds	Mootral	Feed supplement reducing methane emissions from ruminants.	https://www.mootral.com Hristov et al. 2013 Patra 2012 Cottle et al. 2011
	Changing feed		Improve digestibility of feed to reduce methanogenic bacteria activity	Patra 2012
	Breeding		Breeding based on characteristics correlated with low enteric fermentation	Patra 2012
Nitrogen volatilisation	Nitrification inhibitors	Dicyandiamide	Compound to reduce total nitrogen losses including from volatilisation.	https://thechemco.com/chemical/dicyandiamide/ Akiyama et al. 2010 Gilsanz et al. 2016
	Polymer-coated fertilisers		Coated fertiliser to ensure slow release to reduce N emissions	Akiyama et al. 2010
Manure management	Anaerobic digestion	Sistema BioBolsa	Large or small-scale process turning manure and other waste into biogas for energy and digestate as organic fertilizer.	http://sistema.bio/ Gerber et al. 2013

	Composting		Aerobic decomposition of manure	Gerber et al. 2013
	Manure acidification		Addition of acidic compounds to reduce N volatilisation by retaining N as Ammonium instead of Ammonia	Gerber et al. 2013
	Improving storage practices		Improve storage by separating solids, aerating liquid manure, decreasing storage time, creating a crust or straw cover, sealing the storage, and regulating temperature.	Gerber et al. 2013
N manufacturing	Electrochemical H_2 and NH_3 production		Combining H_2 and N_2 into NH_3 in a reactor using electrolytes	Giddey et al. 2013
	Electrolysis H_2 production		Using electricity to separate H_2 and O_2 from water	Bicer et al. 2016

3.3 Reducing consumption

The third category reduces GHG emissions by reducing the consumption of meat and dairy (Table 6). Several innovations target this reduction directly by promoting meatless days or reduced meat portions. Although open to consumer choices, specific alternative proteins may be promoted. The production of these alternative proteins is the focus of another group of innovations with plant-based protein products the furthest developed. Although less developed, cultured meat and yeast-derived milk have potential as direct replacements as they can be biochemically indistinguishable from conventional meat and dairy. By avoiding conventional meat and dairy consumption and production, these innovations aim to reduce GHG emissions by eliminating livestock husbandry.

To estimate the impact of substituting meat and dairy, several carbon footprints and LCA studies have been conducted. A comprehensive systematic review (Clune et al., 2017) shows that ruminant meat emits around 28 kg CO_2-eq per kilogram bone-free meat. The values for pork and poultry are significantly lower at around 5 kg CO_2-eq per kg. Meat substitutes generally have equal or lower emissions than pork and poultry (Broekema and van Paassen, 2017; Mattick et al., 2015; Smetana et al., 2015; Tuomisto and Teixeira De Mattos, 2011). Similarly, despite milk having a low carbon footprint of 1.4 kg CO2-eq per kg, plant-based and yeast-derived alternatives have even lower footprints between 0.4 – 0.9 kg CO2-eq per kg (Clune et al., 2017; Steers, 2015). These studies show that replacing meat and dairy with alternatives will likely lead to a reduction in GHG emissions.

Table 6: Decarbonisation measures replacing meat and dairy with alternatives.

Reduction pathway	**General innovation**	**Company/ initiative/ product**	**Description**	**Source**
Alternative protein production	Clean meat	Memphis meats	Production of clean meat in labs without animal slaughter.	http://www.memphismeats.com/about-us/
	Plant-based protein	Canola protein	Proteins from rapeseed oil by-products for food applications.	https://www.worldfoodinnovations.com/whizz/DSM:%20Rapeseed%20Canola%20protein:%20Turning%20a%20by-product%20into%20a%20valuable%20Food%20Protein
		Potato protein Solanic	Vegetable proteins from potato starch capable of replacing animal proteins	https://www.avebe.nl/producten/solanic/
	Plant-based milk	Oatly	Milk like drinks from oats	http://www.oatly.com/about-the-company/
	Yeast-derived milk		Milk produced through genetically modified yeast.	(Steers, 2015)
Reducing meat & dairy consumption	Campaign for reducing meat consumption	Meat Free Mondays	Campaign to encourage people to not eat meat one day a week.	https://www.meatfreemondays.com/about/
	NGO and company collaboration	Green & lean	A collaboration between WWF and Sodexo (catering company) to provide meals with no more than 1/3 of the meal from meat	http://uk.sodexo.com/home/corporate-responsibility/green-lean.html
	Alternative Dietary Recommendations		Dietary guidelines recommending two meat-less days a week and a maximum of 300g of red meat per week. Includes alternative meatless diet	http://www.fao.org/nutrition/education/food-based-dietary-guidelines/regions/countries/netherlands/en/
	Plant-based industry collaboration	Green Protein Alliance	A partnership for promoting plant-based protein consumption	http://greenproteinalliance.nl/

4. Opportunities and barriers

In this section, the REIVENT theory of change is used to uncover potential opportunities and barriers for the three categories of mitigation measures. REINVENT conceptualized sectors as socio-technical systems which operate through complex value networks that encompass finance, production, consumption and waste (D 1.3). The dynamics of low-carbon transitions are understood through theories of socio-technical systems. Low-carbon transitions are driven by the co-evolution of components within systems. They can follow different pathways, which interplay between inertia and innovation, and are largely determined by the following conditions:

1. Identifying new agents of change.
2. Developing the conceptualisation of power.
3. Understanding the role of materialities.
4. Uncovering the geographies of deep decarbonisation.

4.1 Waste reduction

Agency

Consumer behaviour must be addressed to reduce food waste, as households are responsible for a large fraction of food waste. There are several reasons for this wastage, such as to consumer preferences, wrong purchase planning, incorrect interpretation of expiry dates, inadequate storage, cooking of oversized meals and lack of knowledge about how to reuse leftovers (Priefer et al., 2016). These factors are also driven by societal and economic trends including growing prosperity, decreasing food prices, urbanisation, rising number of single households and increasing employment of women. Proposed solutions include improving packaging labelling and taxes on food waste. However, innovations such as BestFør.no and No Food Wasted – Afgeprijsd, and envision a more active role of consumers in reducing both household and retail food waste.

Recently, firms providing digital solution to measure food waste are targeting the supermarket and hospitality sector. In supermarkets, food waste may result from packaging damages, exceeding of expiry dates, inadequate stock management, marketing strategies and logistical constraints (Priefer et al., 2016). This waste is being addressed through apps that provide a channel to communicate to potential customers when there is discounted food close to their expiration date. However, total food waste from supermarkets may be relatively small compared to households (Parfitt et al., 2010). In contrast, the hospitality sector can waste up to 80 % of their food input although rates between 20 – 40 % appear more common (Papargyropoulou et al., 2016; Pirani and Arafat, 2016). For these firms, data measuring innovations can provide practical insights to reduce waste and save significant operating costs. The use of cloud computing combined with making data registration convenient may provide further waste saving opportunities in other sectors.

Power

The circular economy as a concept has benefitted food waste reduction by unifying policy makers, industry, and other stakeholders within a more holistic framework. Concretely, the Circular Economy Action Plan included a revised waste legislative framework which strengthened food waste prevention and management (European Commission, 2019). Additionally, the Fertilising Products regulation explicitly aims to harmonise rules for fertilisers made from bio-waste. Some EU regulations can both benefit and impede the potential to recycle food waste. For example, insects are conceptualised as livestock. As a result, farming insects is accepted within the existing regulations as a form of livestock husbandry which removes regulatory hurdles for scaling-up the sector. However, these regulations also limit the potential for food waste recycling, since only food waste approved as safe for all livestock is allowed as feed (Dou et al., 2018). This disregards the ability of insects to convert waste into safe nutrition thanks to a high resistance to toxics, diseases and contamination (Bosch et al., 2017; Lalander et al., 2019). However, as a circular bioeconomy is considered key to a more sustainable society, these rules are like to adjust to the benefit of food waste recycling (European Commission, 2018c).

Materiality

The continuous degradation of biomass is a fundamental aspect to recycling food waste. The aim of mitigation options is to convert the nutrients in biomass to a form that is usable for agriculture and the bioeconomy. Digestate from biogas production and compost can recycle carbon, nitrogen, and other nutrients to the agricultural sector. However, the quality of compost and digestate is key (European Commission, 2018c). If there is insufficient consideration for the nutrient composition, physico-chemical properties, and disease suppression then the use of compost and digestate will be limited.

Geography

The region where food waste and loss occur is crucial to the suitability of waste reduction options. The sustainability of mitigation measures is linked to local contexts such as specific economic and environmental situations (European Commission, 2018c). For example, there may be a mismatch between waste generation and potential use within a region. Strict regulations for waste transport can hamper the movement of nutrients concentrated in urban areas to rural regions.

4.2 Emission and energy efficiency

Agency

The effective development and commercialisation of emission and energy efficiency measures has been led by consortiums of industry and research institutes. For example, Project Clean Cow was a 10-year project centred around Royal DSM in collaboration with researchers across the globe. This resulted in the chemical 3NOP which will be trialled by another consortium including feed industry leaders (DSM, 2019). By involving large well-established firms, promising developments could be financed consistently for years and potentially be scaled-up rapidly.

Power

The necessity for long-term research and financing of many measures may lead to further concentrate profit and market power into relatively few large firms. In contrast, farmers will have to implement the measures despite low profit margins and investment capacities. This is a potential obstacle since the uptake of products such as 3NOP will depend how it impacts the profitability of livestock husbandry instead of large agri-food firms (NOS, 2019).

Materiality

Emission and energy efficiency measures can result in large greenhouse gas reductions, but they cannot reach net-zero emissions alone. The CH_4 and N_2O emissions are inherent agricultural processes and cannot be completely eliminated. Although most are still at the experimental stage, there are already innovations being commercialised as shown by the innovations included in the REINVENT database. After implementation, the remaining emissions could be compensated for by enhancing carbon stocks through soil regeneration or reforestation (European Commission, 2018c).

Geography

Due to the dependence of agriculture on the local geography, the available measures and their effectiveness may vary considerably. For example, the effectiveness of nitrification inhibitors and polymer-coated fertilisers appears to depend on the type of soil (Akiyama et al., 2010). Also, the emissions from manure management are temperature dependent (VanderZaag et al., 2010); thus, the time of year and overall climate influence the emission rate and the reduction potential of mitigation measures. This variability in impact may lead to adverse effects if measures are untested in a given region.

4.3 Reducing consumption

Agency

Consumers have been the main driver of market formation for alternative protein products, in particular for plant-based protein products. Health, animal welfare, sustainability and broader ethical concerns have led to an increased willingness to reduce animal product consumption (Hartmann and Siegrist, 2017; Siegrist et al., 2015; Tziva et al., 2019). Although the substitute industry originally catered to vegetarians and vegans, the rise of the consumer group "flexitarians" is perceived as the main opportunity for the plant-based protein sector. Due to growth in demand for plant-based protein products, many new entrants are entering the sector and a few have experienced significant growth, such as Vivera and Schouten Europe who have grown to be among the leading firms of the European sector. As this trend in demand continues, the opportunity for reducing meat and dairy consumptions increases.

Meat processing companies and a few front-running incumbent firms in the agri-food sector have started experimenting with alternative protein products or acquiring firms in the sector. The profitability of the meat processing sector has been declining since 2003, mainly due to a steady decline in profit margins and a gradual rise in input costs (ECSIP Consortium, 2016). In the case of plant-based protein products, some struggling meat processing firms either managed to shift the largest share of their production or discontinued meat processing all-together while experiencing growth and higher profit margins. In terms of product types, growth is expected in most product categories ranging from meat analogues to novel protein products. This contrast with the mature meat and dairy sectors has been highlighted by reports from international and national organizations which encourage further innovation and entrepreneurial experimentation (FAIRR, 2011; ING, 2017). The entrance of large agri-food firms shows that these firms are not necessarily locked into the current meat and dairy production system (Tziva et al., 2019). Thus, these firms are less likely to oppose a reduction in meat and dairy consumption; instead, they may boost investments into the development of alternative protein products. This is in contrast with livestock farmers who have actively opposed this development through actions such as contesting the naming of meat substitutes.

The alignment of governments and semi-governments with current meat and dairy consumption practices can either enable or create barriers to reduced consumption. The influence of the agricultural lobby on the national and EU level can be seen through the efforts to ban meat and dairy terms for substitutes (FoodNavigator, 2018). However, alignments can and have shifted. Of particular importance is the alignment of dominant cognitive institutions (Tziva et al., 2019). For example, the Dutch Nutrition Center filed a complaint to a meat substitute producer for directly comparing their product with meat in the early 2000's. This attitude changed by 2015 when the official guidelines were revised to advise reducing meat consumption.

Power

Broad supply chain cooperation can enable firms and innovations to scale-up and influence policy. Scaling-up the development of alternative protein products is a challenging process. Industrial scale food processing entails several potential bottlenecks in ensuring stable production which requires large up-front investments in equipment and machinery. Compliance with food safety regulations, such as the Hazard Analysis Critical Control Point (HACCP) system, lie primarily with the processing sectors leading to fixed added costs. These high entry costs erect market entry barriers. Moreover, production costs remain high due to relatively low volumes in the initial stages of a sector. Additionally, retailer generally impose considerably higher profit margins for new products and quickly withdraw products that don't produce the desirable turnover in shops. Therefore, it challenging to establishing a product in the market. However, cooperation between producers and end-product firms can overcome some of these challenges. For example, when the innovative firms Ojah launched in 2010, the Vegetarian Butcher was launched simultaneously as the principle customer (Tziva et al., 2019). This end-product firm could focus on innovative marketing strategies, while Ojah could continue focusing on developing the product. Furthermore, broader multi-stakeholder networks have the ability to influence government policies. As an example, the Green Protein Alliance in the Netherlands was able to include and influence the Dutch Nutrition Center and align it with the goal of changing the Dutch plant to animal consumption balance from 37:63 to 50:50 (Tziva et al., 2019).

Materiality

The development of alternative protein products has focused on creating analogues with similar taste and texture as meat and dairy. Meat analogues based on soy, wheat and mycoprotein have been established in the market and are experiencing fast-market growth. Meat-analogues based on pea and lupine are emerging and increasingly available. Through various breakthrough technologies, the options are widening and experimentation is taking place with novel protein sources such as duckweed, algae, cultured meat, and insects; however, such products currently have very limited or no commercial applications. This follows the past development of plant-based protein products, where breakthroughs in cooking extrusion processes, inventive product designs and marketing strategies have led to the availability of products which consumers perceive as having an increased quality (Tziva et al., 2019). However, the idea of the need to fully mimic the taste and structure of meat has started being contested, due to concerns over the feasibility of this direction, the sustainability profile of necessary ingredients and the acceptance of highly processed food products by consumers.

There is still a limit in the available ingredient sources for alternative protein products. For example, the limited range of available plant-based protein ingredients makes it challenging for entrepreneurs to satisfy consumer expectations. Plant-based protein product firms largely depend on soy as their main ingredient, despite the limited cultivation within the EU and the growing importance to consumers of the local origin of products (aan den Toorn et al., 2019; Tziva et al., 2019). However, the majority of plant-based protein crops other than soy have a lack in functionality and/or a green colour and an off-taste. As a result, there is an increasing attention to increase the yield per hectare of European protein crops, such as pulses and nuts, which require less processing and/or can be consumed directly while having a more positive environmental profile. Improving the yield of suitable protein sources will enable a growth that is not dependent on imported soy and its related land use change emissions.

Geography

In Europe, there has been a rapid growth in the markets for alternative protein products. This was particularly concentrated in Germany, Denmark, the Netherlands, Sweden, and the UK (Tziva et al., 2019). This high concentration of growth in these Western European countries provides the opportunity to more easily distribute meat and dairy substitutes to consumers.

Additionally, Europe has several innovation clusters with strong linkages between industry, knowledge institutions and relevant government agencies. For example, Food Valley, a food innovation cluster in Ede, has a concentration of international food companies, research institutes and Wageningen University and Research (WUR), a world-renowned food technology university (Tziva et al., 2019). Harnessing these clusters can results in more rapid knowledge diffusion for the development of alternative protein products.

Conclusion

Fully decarbonising the meat and dairy sectors is challenging although greenhouse gas emissions can be reduced significantly. Of the 700 Mt CO_2-eq, most are CH_4 and N_2O which are inherently produced in enteric fermentation, manure management, and nitrogen volatilisation. Various mitigation measures have been applied or are being researched which can be grouped into three categories: reducing food waste, improving emission and energy efficiency, and reducing meat and dairy consumption.

Reducing food waste has the potential to reduce total demand without reducing consumption. Annually about 14.5% of meat and 7.5% of dairy are wasted at retail and final consumption. More opportunities are created through the overarching concept of circular economy which resulted in harmonisation of EU regulations. However, unsuitable regulations for food waste recycling and insufficient consideration for the practical use of compost and digestate may hamper efforts to reduce food waste and create a circular bioeconomy.

To further reduce emissions, decarbonisation measures can be implemented that target GHG emissions sources. The following are the most important sources: of enteric fermentation (225 Mt), N volatilisation (140 Mt), feed and agricultural input energy use (115 Mt), and manure management (95 Mt). Some of these measures benefit from long-term financing by well-established firms which may increase the potential to scale-up rapidly when commercialised. However, the limited profitability of livestock farms may limit the uptake. Furthermore, the impact on greenhouse gas emissions may depend on local factors, particularly for N volatilisation and manure management. Finally, it is not possible to fully decarbonize the GHG emissions sources besides those related to energy as the CH_4 and N_2O emissions are inherent to the processes. Thus, carbon stocks must be increased to compensate.

In order to avoid non-energy emissions, meat and dairy consumption could also be reduced by being replaced with alternative protein products. LCA studies show that they generally have lower carbon footprints compared to meat and dairy. As technical capabilities improve, a wider variety of higher-quality alternatives becomes available. This drives continuous demand for alternative protein products in the EU which creates the opportunity for reducing meat and dairy consumption. Cooperation along the supply chain can help successfully launch more products and influence policy. Also, agri-food and meat processing firms appear willing to invest in alternative protein products in contrast to farmers livestock farmers. Furthermore, innovation clusters in the EU can contribute to more rapid knowledge diffusion for the development of alternative protein products if the links between industry and research are strong. However, there is some contestation over the sustainability of ingredients and the acceptability of highly processed foods. This could limit the growth of meat and dairy analogues.

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