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WHAT'S ON THE TABLE? MITIGATING AGRICULTURAL EMISSIONS WHILE ACHIEVING FOOD SECURITY

January 2018

KEY MESSAGES

- Mitigating emissions from agriculture is key to achieve deep cuts in emissions in line with the Paris Agreement's long-term goal of "net-zero" emissions.
- Options for emission reductions on the supply side include efficiency improvements, take-up of best practices and innovative approaches in farming.
- Mitigation opportunities on the demand side are equally important—e.g. in transport, storage and consumption of food—and this is where consumer behaviour plays a major role.
- Changes in consumer behaviour, resulting in substantial benefits for public health, hold large potential for deep reductions in agricultural non-CO_2 emissions while ensuring the growing demand for food worldwide can be met.

INTRODUCTION

Agriculture accounts for roughly 10% of global GHG emissions, and as much as 50% of global non-CO_2 emissions, at 5–6 $GtCO_2e$/year (US EPA 2014; Smith et al. 2014; FAOSTAT 2016a), but contributes less than 2% to emissions related to energy use (IEA 2016). Limiting agricultural emissions must therefore focus on non-CO_2 emissions: specifically, nitrous oxide (N_2O) and methane (CH_4). Reducing these emissions is critical for long-term temperature targets (Gernaat et al. 2015).

World population is set to increase by more than 15% in the next 15 years (UN 2015). Food consumption is rising quickly across the developing world, while hundreds of millions of people remain undernourished (FAO 2016). How can agricultural emissions be reduced while achieving the Sustainable Development Goal (SDG) to end hunger, achieve food security and improved nutrition, as well as promote sustainable agriculture?

Achieving the Paris Agreement temperature goal of limiting warming to well below 2°C, and to pursue efforts to limit the increase to 1.5°C, is important for this objective, as the challenge of providing enough food will be further exacerbated by climate change itself. Rising temperatures and changing rainfall patterns could cause pest outbreaks, disrupt pollination, make farm labour more difficult and reduce the yields of certain crops, resulting in a rise in food prices (Myers et al. 2017; Challinor et al. 2014). Yield declines due to climate change are already being observed in certain regions, and warming above 1.5˚C–2˚C would raise the risks of severe production losses substantially (World Bank 2013). Even between warming of 1.5°C and 2°C, the difference in yield declines could be significant in certain regions: local yield reductions in wheat and maize in the tropics could be up to two times lower under 1.5°C than under 2°C (Schleussner et al. 2016).

While the rise in atmospheric CO_2 may improve productivity in high latitude regions, it may also lower the protein and nutrient content of major crops such as rice and wheat (Myers et al. 2014). If warming is kept well below 2°C, adaptation in agriculture may be able to compensate for some of these impacts, and the faster global emissions are mitigated and such impacts are avoided, the lower the burden of such adaptation.

To limit global warming to 1.5°C by the end of the century, scientific models estimate that CO_2 emissions from energy and industry will need to reach net zero around 2050 (Rogelj et al. 2015).

Agricultural non-CO_2 emissions cannot be reduced to zero, but still need to be reduced as much as possible to contribute to the goal of net zero GHG emissions.

A preliminary reduction target for non-CO_2 emissions mitigation in agriculture compatible with a 2°C pathway has been identified by Wollenberg et al. (2016) as around 1 $GtCO_2e$/year (11%–18%) reduction by 2030 (and rising thereafter), compared with a business-as-usual (BAU) scenario. Such a target would effectively cap agriculture emissions at just above today's levels. A target compatible with 1.5°C would be even more stringent: for example, Frank et al. (2017) suggest that mitigation of 2.7 $GtCO_2e$/year would be required by 2050 to meet this target, compared with a BAU scenario.

This briefing looks at options for mitigating non-CO_2 emissions from agriculture from two angles: first, we broadly consider the most important categories of emissions and options for mitigation "on the field," and second, we look at trends in consumer behaviour, and how these may affect agricultural production and related emissions in the future.

Importantly, agriculture-driven land-use change also results in CO_2 emissions, but these are not usually classified under agriculture. Projections show that in 2050, if business-as-usual continues, emissions of about 7 $GtCO_2$/year could come from deforestation due to animal agriculture (Bajželj et al. 2014); see the Annex for more.

CATEGORISING AGRICULTURE EMISSIONS

Sources of non-CO_2 emissions in agriculture are very diverse. The two main gases here are nitrous oxide (N_2O) and methane (CH_4). The different categories according to IPCC definitions (IPCC 2006; FAOSTAT 2016a) include emissions from:

- **Enteric fermentation:** the production of CH_4 in the digestive system of ruminant animals;
- **Manure**: the production of CH_4 from anaerobic decomposition, and of N_2O during (de)nitrification processes in the soil, related to animal dung;
- **Rice cultivation**: the release of CH_4 from decomposition of organic matter in flooded rice paddies;
- **Synthetic fertiliser**: the release of N_2O from (de)nitrification processes and volatilisation / leaching processes in the soil from ammonium or urea-containing fertiliser;
- **Crop residues:** the release of N_2O from (de)nitrification in crops left on soils;
- **Cultivation of organic soils**: the release of N_2O from decomposition of organic matter in soil drained/used for cultivation.

This multiplicity of emissions sources, plus the fact that the agriculture sector differs hugely between countries—with large-scale industrial agriculture dominating in some and small-scale subsistence farming in others—means that there is no "one size fits all" approach of limiting emissions from agriculture.

CHANGING FARMING PRACTICES

Globally, enteric fermentation and manure management dominate the emission profiles of the agricultural sector - as shown in Figure 1.

On a national level, emission profiles may show various patterns (see Annex). In the **EU, US and China**, a large share is due to synthetic fertiliser usage. In **South and East Asia**, emissions from rice cultivation contribute large shares. In **Indonesia**, non-CO_2 emissions from decomposition of drained peatland for cultivation are substantial, but globally they only represent a minor share. (However, CO_2 emissions from drained peatland, usually classified under land-use change, are substantive—see Annex.) Below, we discuss mitigation options for emissions in the agriculture sector in the four largest categories.

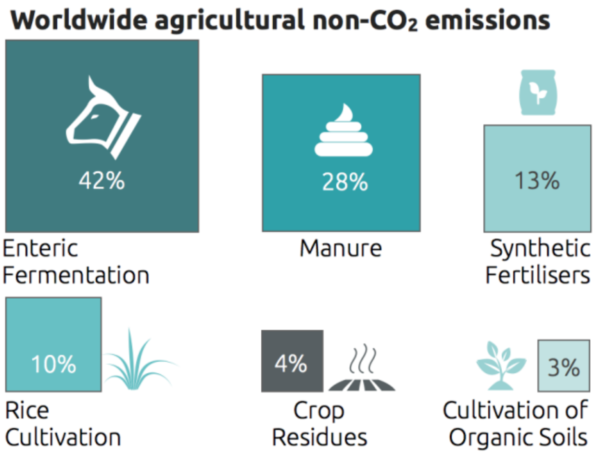

Figure 1: Contributions to worldwide agricultural non-CO_2 emissions in 2014. Data from (FAOSTAT 2016a).

Cattle are by far the largest contributor to emissions from **enteric fermentation,** at an estimated 73%, of which roughly three-quarters are from non-dairy cattle (FAOSTAT 2016a). This category of emissions can be influenced—to some extent—by improved diet practices for livestock, through diet additives that act as methane inhibiting agents, and by obtaining more efficient or less methane-intensive animals through breeding (FAO 2014b; Smith et al. 2014).

According to (Smith et al. 2008), the full technical mitigation potential lies in the order of 200 $MtCO_2$/year by 2030, around 10% of worldwide emissions from enteric fermentation. Beyond such "technical" options, improved health monitoring for cattle could help to reduce meat waste and thus decrease emissions (Smith et al. 2016).

Cattle are also the largest contributor to emissions from **manure**, at 55% (FAOSTAT 2016a). Manure can lead to emissions in all stages of the manure management process—from livestock rearing, to storage and treatment, to spreading over land.

For livestock rearing, the main way to limit N_2O emissions is to optimise the nitrogen content of the animal feed.

For storage and treatment, emissions of CH_4 can be limited through preventing anaerobic decomposition conditions with airtight covers, or frequent turning / agitation of the manure / slurry to reduce anaerobic zones (Chadwick et al. 2011).

But for most animals worldwide, excretion occurs in the field and the listed "manure handling opportunities" are not even relevant, as few activities like storage or treatment take place at all (Smith et al. 2008). According to (Smith et al. 2008; Herrero et al. 2016), the full technical potential for emissions reduction from manure is of the order of 100 $MtCO_2e$/year by

2030—less than 10% of global manure-related emissions (FAOSTAT 2016a).

For both enteric and manure-related emissions, deeper cuts can most realistically be obtained through lower animal stocks, by either sustainable intensification (increasing yield per unit stock, so that the same demand can be satisfied with lower stocks) or demand reduction.

Emissions from synthetic fertilisers have seen the strongest increase worldwide among the major categories discussed here. Globally, agricultural emissions increased by roughly 16% between 1990 and 2014, but emissions from fertiliser use grew twice as fast (see Annex).

The most recent increase in global synthetic fertiliser use seems to have been accompanied by a loss in efficiency, with more than 50% of nitrogen added for fertilisation now being lost to the environment, compared to close to 30% in the 1960s. This implies that further increases in fertiliser use would lead to a "disproportionately low" increase in agricultural productivity (Lassaletta et al. 2014). Improving the efficiency of nitrogen use by reducing over-application could therefore hold substantial potential for emissions reduction—probably in the order of 100 $MtCO_2e$/year [1] —without affecting food production, while also lessening environmental concerns such as nutrient pollution in water.

It has also been suggested that the relationship between the intensity of fertiliser use and emissions may be nonlinear, meaning that limiting fertiliser usage has highest mitigation potential in areas where it is already being over-applied (Shcherbak et al. 2014). Other measures to reduce fertilisation emissions include applying biogas digestate (Baldé et al. 2016; Al Seadi & Lukehurst 2012) and applying sequential cropping instead of having fallow periods, using the residual biomass as organic fertiliser (Wittwer et al. 2016).

Rice cultivation makes up 10% of agricultural non-CO_2 emissions worldwide, more than 30% in some countries, and plays a vital role in food security. Reductions in emissions can be achieved through draining rice paddies during the wet season, and applying organic fertiliser (e.g. residues from the previous season) during the dry season instead of the wet season (Smith et al. 2008; Qiu 2009).

Substantial emissions reductions have been achieved in the past through such measures (Qiu 2009), and the technical potential of rice management practices is estimated to be in the order of 200 $MtCO_2e$/year by 2030 (Smith et al. 2008; Smith et al. 2014). This would represent around 40% of total emissions from rice paddies (FAOSTAT 2016a).

In addition to emissions savings, paddy drainage also has significant benefits in the form of water conservation and increased yields, the initial reason for take-up in China (Li et al. 2002).

When we consider the total technical potential of mitigation in the agricultural sector, we must be mindful that an estimated 12% of global farm area is tilled by smallholder farmers, representing 84% of farms, with much higher percentages in certain regions (smallholders own 35%–40% of farm area in both South Asia and Sub-Saharan Africa) (Lowder et al. 2016). The barriers to a *worldwide* roll-out of "alternative" farming practices are therefore likely to be substantial, given that they would need to be adopted by *all* farms, and indeed several practices may not be appropriate for smallholders.

While options for improved practices that can reduce non-CO_2 emissions do exist, and their take-up could help strengthen resilience (Nordic Council of Ministers 2017), research suggests that their aggregate effect—under ambitious assumptions of worldwide take-up—will achieve less than the necessary reductions required for compatibility with the Paris Agreement's 1.5°C temperature limit (Wollenberg et al. 2016; Havlík et al. 2014). The absence of viable opportunities for deep reductions in animal-related emissions (almost 70% of agricultural non-CO_2 emissions) is of particular concern.

Recent research on achieving ambitious mitigation in the agricultural sector in line with the Paris Agreement has highlighted the risks that poorly designed policies could pose for food security. Frank et al. (2017) warn that a GHG tax on agricultural products could lead to food insecurity in some vulnerable regions if not accompanied by social safety nets and if regional differences are not considered. In order to achieve ambitious emissions reductions while ensuring that food remains affordable, smart, socially progressive policies will be needed alongside additional mitigation options in the land use sector, such as soil organic carbon sequestration (see Annex), and options on the demand side, such as diet shifts and food waste reduction (Frank et al. 2017). These demand side options are discussed below.

[1] Current emissions from fertiliser were 660 $MtCO_2e$/year in 2014 (FAOSTAT 2016a), so lowering nitrogen loss back to 1960 levels could save in the order of 100 $MtCO_2e$/year based on current emission levels.

CHANGING DIETS

With global population projected to increase by 15% between 2015 and 2030, the anticipated rise in per capita calorie consumption in developing countries means that total food demand is expected to grow by even more (Havlík et al. 2014). Providing the additional food supply required to achieve food security, while ensuring emissions mitigation targets are met, is likely to require changes in consumption.

Figure 2 shows current average calorific consumption levels for eight countries, and the share of meat therein. Some countries are below world average, mainly in South Asia and Sub-Saharan Africa, where rates of undernutrition are also most prevalent (IFPRI 2016), whereas others are consuming significantly above the world average. The average person in industrialised nations already eats twice as much meat as is considered healthy (Wellesley et al. 2015).

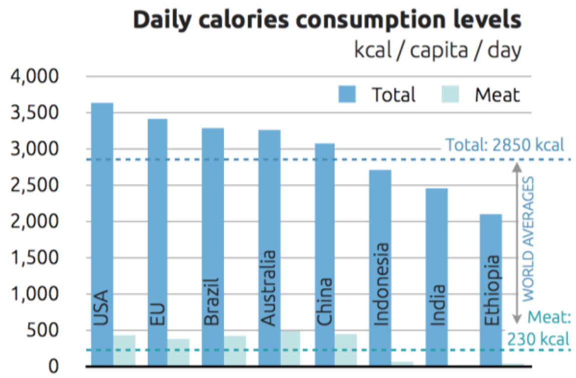

Figure 2: Total food consumption in 2011 in eight different countries as compared to the world average. Data from (FAOSTAT 2016b). *The 230 kcal/day corresponds to approx. 80–160 g meat daily for a range of standard meat products; see e.g.* (USDA 2017).

The UK's National Health Service indicates an average range of calorie intake classified as a "healthy, balanced diet" as 2000-2500 kcal/cap/day (UK NHS 2016), with no more than around 70 g/day of red and processed red meat (note that the definition of "red meat" usually does not include fish and poultry).[2]

The health benefits of a switch to a low-emissions, more plant-based diet should not be underestimated—in both industrialised and developing countries. Springmann et al. (2016) show that a healthy diet with no more than 43 g of red meat—and at least five portions of fruit and vegetables per day—could avoid five million deaths a year from heart disease, stroke, cancer and Type II diabetes globally by 2050, with developing countries avoiding the greatest number of deaths. An additional health benefit could come from reducing reliance on industrial animal farming. Many factory farms use antibiotics to increase productivity, contributing to drug resistance in humans and posing a significant public health risk (Landers et al. 2012). Reducing antibiotic use, or consuming less industrially-produced meat, could therefore help alleviate the spread of antibiotic resistance.

The emissions savings associated with a global switch to a healthy, low-emissions diet are estimated at 30% of food-related emissions, relative to continuing current dietary trends (Springmann et al. 2016).

Further research is needed into the types of low-carbon diet that are best for meeting nutritional requirements in different regions. In many cases, a large change may not be necessary: research in France has shown that a significant number of people are already self-selecting diets that are nutritious and relatively low in carbon, and a 30% reduction in emissions from the average French diet could be achieved without compromising on nutrition or affordability (Perignon et al. 2017).

In aggregate, a global shift to healthier diets could dramatically reduce agricultural emissions. The scenarios investigated in Stehfest et al. (2009) indicate that worldwide adoption of the "Harvard diet"—which implies reductions in meat consumption in the developed world and increases in countries with protein-deficient diets (Smith et al. 2013)—could bring about reductions in non-CO_2 emissions (compared to a reference scenario without diet shifts) in the order of 1.5 $GtCO_2e$/year by 2030.

The finding that diet shifts can potentially have higher mitigation impacts than technological changes on the supply side is echoed by a number of other studies (Bajželj et al. 2014; Hedenus et al. 2014). Dietary changes could even bend the agricultural emissions curve downwards, something which technical mitigation alone is not expected to do (Popp et al. 2010). Further, Erb et al. (2016) show that future pathways of human diets, and in particular their meat content, are stronger determinants of whether world food demand by 2050 can be met without causing deforestation than e.g. assumptions on future cropland availability, yield, and livestock feeding practices.

Clearly, transitioning to healthy diets can have substantial and necessary benefits for climate change mitigation, but implementing such a transition requires careful consideration of local

[2] This is the average recommended intake per person, and should not be compared with national averages. A national average of 2000-2500 kcal/cap/day would still mean that some members of the population are likely undernourished and others over-consume. Also, data on consumption is likely to be slightly higher than actual per-capita intake of nutrition, due to part of the food being thrown away.

contexts and nutritional needs. What constitutes a healthy and sustainable diet in a given region depends on several factors—the levels of over-consumption and malnutrition, local geographical and cultural contexts, poverty levels, and the role of agriculture in local livelihoods. Grazing animals can provide a crucial source of income, and in some contexts also deliver important environmental benefits: manure can improve soil quality, and livestock can consume crop residues that humans cannot eat, potentially resulting in avoidance of other types of emissions (Garnett 2009). Completely cutting out animal agriculture is clearly unlikely to be either feasible or desirable.

Although cattle are the largest contributor to emissions from enteric fermentation and manure, simply shifting "away from beef" does not guarantee large reductions, as e.g. goat and sheep meat have carbon intensities comparable to beef (see Annex). Also, meat is not the only high-emission food: enteric and manure-related emissions make up roughly 50% of the total carbon footprint of milk in the US (FAO 2014b), and non-dairy cattle make up 17% of total cattle stock and 25% of non-CO_2 emissions from cattle worldwide (FAOSTAT 2016a), so any "diet-shift" scenario will need to include limiting dairy consumption. This will be a challenge in the context of rising milk demand. Demand growth is highest in Asia (where over half of anticipated global increase in demand by 2020 is expected to occur), with growth rates in other developing regions, such as Sub-Saharan Africa, not far behind (FAO 2014a; Cornall 2016).

Another important co-benefit of shifting to more plant-based diets is that this would ease stress on land use, which in turn can lead to reduced land use CO_2 emissions (see Annex).

Around 70% of global agricultural land is currently being used as grazing land for ruminants (Stehfest et al. 2009), with more land used for grazing animals than for any other single use.

Less than a third of animal husbandry occurs on pasture unsuitable for cropping, or is fed by crop residues or processing co-products. The remaining 70% of livestock thus represents an inefficient use of land and resources for food, as the conversion from cereal to animal matter is accompanied by substantial energetic losses—e.g. for cattle, the conversion factor is 5–10 kg cereals per kg animal weight (Garnett 2009).

A global shift to, for example, the "Harvard diet" could therefore reduce land use demand by more than one billion hectares, roughly the size of the US (Stehfest et al. 2009), and this could reduce food-related deforestation (and its associated CO_2 emissions)—or even allow the natural regeneration of some areas of land, leading to carbon sequestration.

Policy makers have historically been reluctant to intervene in dietary choices, but the growing prevalence of diet-related public health issues is starting to change this. Research has shown that citizens in industrialised countries expect their governments to address unsustainable meat consumption (Wellesley et al. 2015).

Some governments and government agencies have introduced policies to encourage the public towards more sustainable diets: China set new guidelines in 2016, suggesting that meat consumption should be halved from current levels (to 40–75 g/day) (Wellesley et al. 2015). The Netherlands suggests that high-carbon meats should make up no more than 300 g/week (Voedingscentrum 2017). However, further research is needed to better understand how public policy can be used most effectively to encourage changes in consumer and retailer behaviour (Wellesley et al. 2015).

Market-based approaches are likely to be necessary to achieve significant changes on the short timescales required. For instance, a fertiliser tax to combat over-application has been tested (with varying success) in different EU countries (WWF 2010; Bayramoglu & Chakir 2016). Another option is an emissions tax on food commodities, with exemptions for healthy foods. Springmann et al. (2017) suggest that such a tax could reduce global food-related emissions by almost 1 $GtCO_2e$ in 2020, mostly from reductions in beef and dairy use, as well as avoid up to 500,000 deaths. Crucially for the public acceptability of such a scheme, the revenues should be used to protect vulnerable groups from food price increases and income losses.

REDUCING FOOD WASTE

Over a third of the food we produce—about 1.3 billion tonnes each year—is lost (FAO 2013a). Emissions associated with food waste are already significant, and rising (Hiç et al. 2016). According to the FAO, if food waste were a country it would be the third largest GHG emitter, with an estimated 2011 level of 3.5 $GtCO_2e$/year (this includes CO_2 emissions from on-farm energy use, but excludes CO_2 emissions from LULUCF, which would add 0.8 $GtCO_2$/year) (FAO 2011).

The amount of food waste is related to a country's development stage (Hiç et al. 2016), and industrialised nations have much higher per-capita food wastage carbon footprints than developing nations. This is partly because in industrialised nations more waste occurs later in the supply chain—at the retail and consumer levels—while in developing countries most waste occurs on-farm and during distribution. The average diet is also important: more emission-intensive diets incur more emission-intensive waste. For example, while meat makes up only 5% of total food waste, it contributes a fifth of food waste emissions (FAO 2011).

Food waste and its carbon footprint is likely to increase substantially. Hiç et al. (2016) look at projected levels of food surplus—the extra food available in a country beyond what is required to feed the population—and estimate this could be more than three times higher in 2050 than in 2010. With a growing middle class producing more household waste, and an anticipated 50% rise in meat consumption by 2050 (based on projected meat production in 2050, compared with a 2011–13 baseline (FAOSTAT 2016a; FAO 2013b)), an increasing proportion of food waste would come from high carbon intensity meat and consumer waste without additional policies.

Reduction of food waste could have substantial mitigation benefits, with potential non-CO_2 emissions reductions of up to 2 $GtCO_2e$ by 2030 (Wollenberg et al. 2016), and between 1.3–4.5 $GtCO_2e$ by 2050, compared with business-as-usual (Bajželj et al. 2014). The uncertainty in these estimates stems from uncertainty on future diets, population size and agricultural productivity (Wollenberg et al. 2016). This reduction potential is likely to exceed the mitigation potential of all currently available supply-side non-CO_2 mitigation options. It is also compatible with the UN's 12th SDG, which calls for food and agricultural waste to be halved.

Up to a third of household food waste may be linked to date marking (European Commission 2016). While best-before dates play an important role in reassuring consumers of the quality of products throughout their shelf-life, a European Commission study showed that less than half of Europeans understand the meaning of "use by" and "best before" labels. The Commission is now considering how to alter labelling requirements to reduce waste while ensuring consumer safety. Several US states have already eliminated unnecessary date labels, e.g. New York City no longer requires labelling for milk (ReFED 2017), which is safe to consume long after its taste becomes unpalatable.

In developing countries, more efficient storage and distribution systems are needed to reduce on-farm and post-harvest losses. Fruit, vegetables and meat can spoil quickly in hot climates, and farmers with inadequate storage may be forced to sell their produce even when demand is low. Investment is needed to improve roads, facilitate entry to markets, and develop storage technologies (e.g. evaporative coolers, plastic storage bags) (WRI 2013).

A substantial amount of food grown in sub-Saharan Africa for export to Europe is wasted before it reaches the shop floor because European supermarkets reject it based on shape, size or colour.

To minimise waste and protect farmers, some countries (e.g. the UK) have made it illegal for supermarkets to cancel orders without compensating suppliers (Stuart 2009). Where avoidance of food waste is not possible, the next best option is to reuse it. Some policies currently hinder the donation of excess food to food banks and NGOs. To counter this, several US states have put in place rules such as liability protection for retailers donating leftover food (ReFED 2017). Another way to reuse food waste is feeding it to livestock. If animal scraps are appropriately heat-treated they can be safely fed to pigs, but many countries have policies that prohibit this use of animal products in feed because of concerns that disease epidemics among animals could arise if animal scraps are not properly treated. This is starting to change: some US states (Connecticut, North Carolina) allow animal food waste to be fed to swine, if heat treated (ReFED 2017). In China, maggots are used to manage food waste, feeding on it before themselves being processed into animal feed (Ehret 2017).

CONCLUSION

To keep global warming within the limits specified by the Paris Agreement, agriculture will be a key factor, given the need for achieving food security for a growing population. This briefing summarises emission abatement options on the **supply side**, e.g. through changed farming practices, and on the **demand side**, e.g. through shifts in consumer habits. The total mitigation potential on both sides is significant.

There are physical limitations to what can be achieved on the supply side, and opportunities are scattered. Demand side mitigation can achieve large reductions without compromising global nutritional health; see Figure 3.

The national emissions reduction commitments made under the Paris Agreement give relatively little emphasis to agriculture, especially on the demand side—currently there is no mention of reducing food waste or changing diets, even though most NDCs consider mitigation in agriculture in some way (Pauw et al. 2016).

The close interdependence between supply and demand—with mitigation potential on one side being dependent on mitigation action on the other—means that both must be addressed. These topics will need to enter the policy debate more prominently in the future.

Businesses need to step up mitigation action in their supply chains to tackle both sides, and multilateral coordination efforts such as the EU's Effort Sharing scheme should be pursued to drive down agricultural emissions on a regional scale.

In addition to **research and innovation** in food production and widespread **adoption** of best practice techniques, policies to e.g. **subsidise** low-GHG products or discourage high-GHG ones and to **promote healthy diets** without overconsumption are likely to be needed. Without demand-side changes, emission reductions in line with the Paris Agreement may be out of reach.

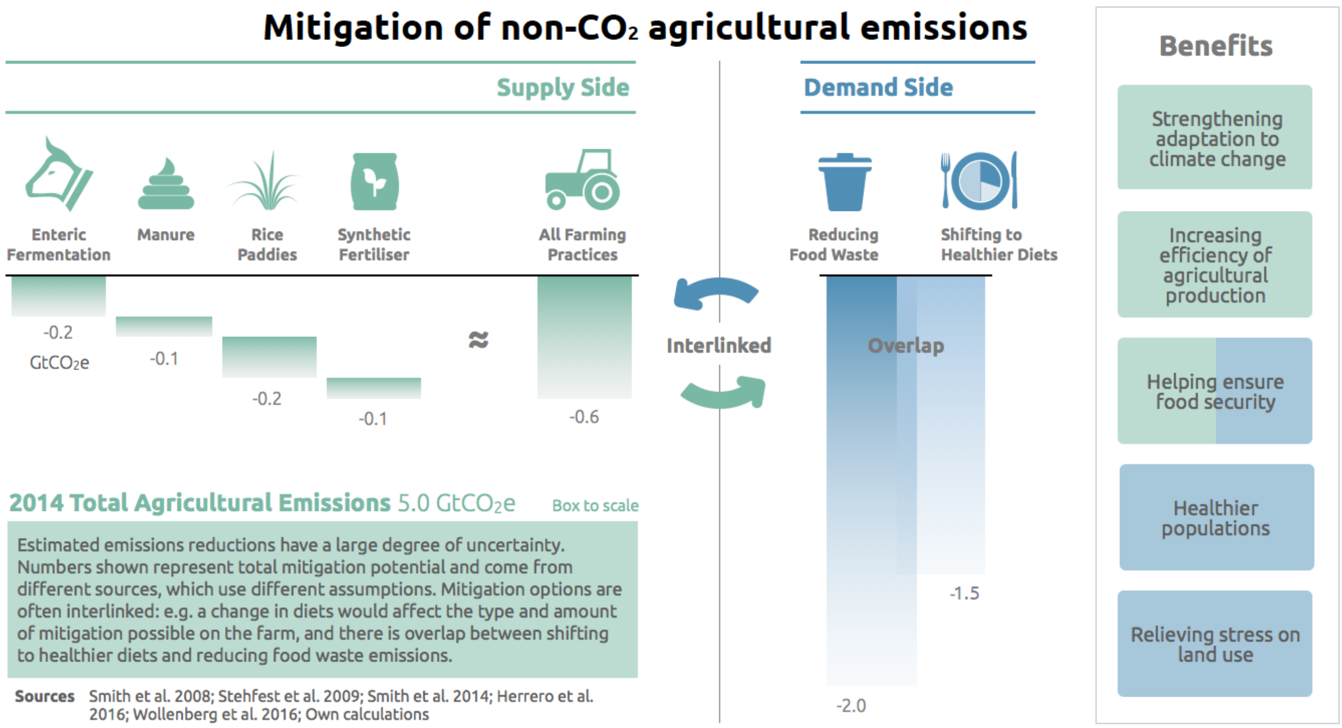

Figure 3: Infographic showing the multiplicity of emission mitigation potential on the supply side and demand side of agriculture. The bars show the estimated mitigation potential (in $GtCO_2e$/year) by 2030 per category; see text for details.

AGRICULTURAL NON-CO_2 EMISSIONS BY COUNTRY

In Figure 4, we show the relative contribution of different categories to total agricultural non-CO_2 emissions for various countries, and a bar chart giving the absolute values of these emissions, as per FAOSTAT data. Together, these countries accounted for 58% of global agricultural non-CO_2 emissions in 2014.

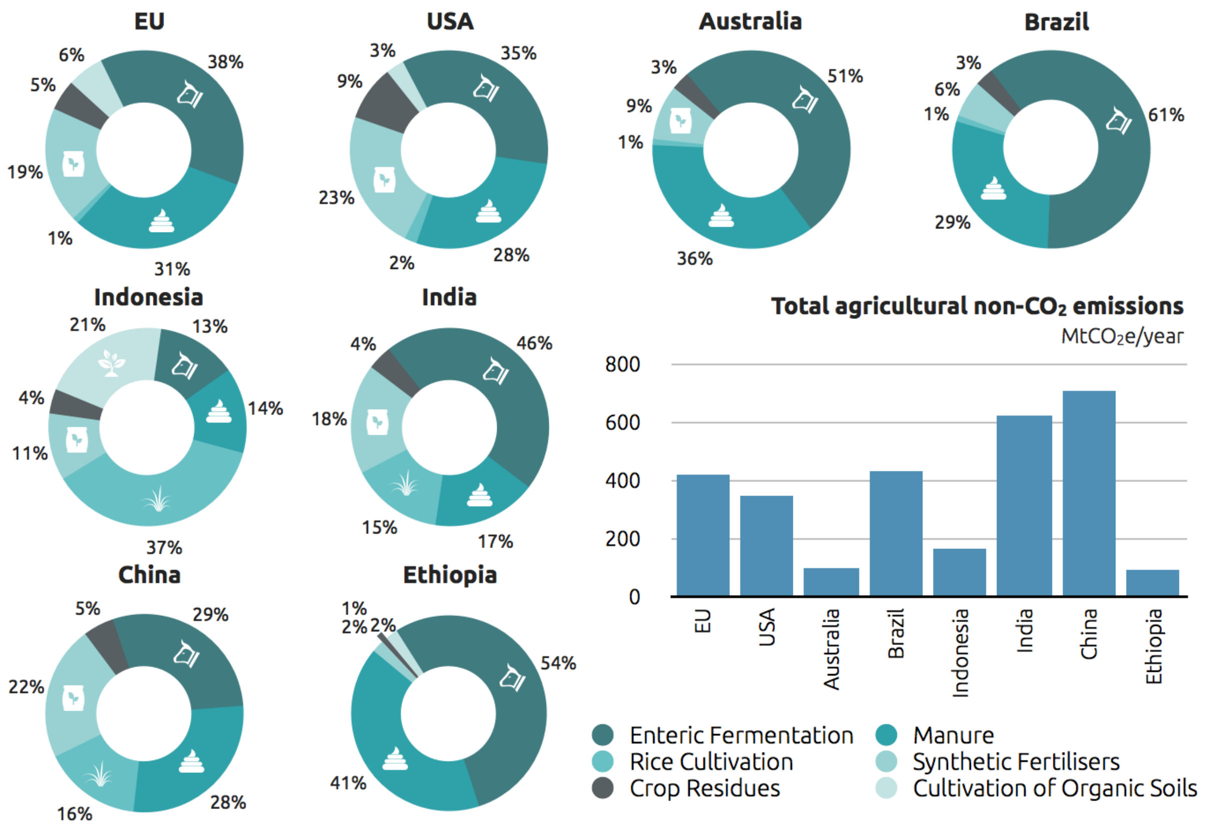

Figure 4: Pie chart for the different categories in agricultural non-CO_2 emissions for eight countries, and a bar chart showing total agricultural non-CO_2 emissions. Data from (FAOSTAT 2016a).

EMISSION FACTORS OF MEAT AND DAIRY PRODUCTS

Around 73% of emissions from enteric fermentation, and 55% of emissions from manure (including manure management, manure applied to soils, and manure left on pastures) is attributable to cattle (excluding buffalos), according to FAOSTAT data (FAOSTAT 2016a). Cattle stock—measured in number of animals—is, however, only slightly larger than the number of sheep, goats and swine. This is shown in Figure 5.

These numbers imply that the emission factor of enteric and manure-related emissions, measured in tCO_2e *per animal* per year, is around seven times higher for cattle than for sheep, goats and swine (who together account for 93% of global animal stock excl. poultry). (Note that non-dairy cattle make up about 83% of total cattle stock.)

However, calculating specific emissions on a *per-animal* basis is not a fair comparison in discussions that concern diet shifting, as a cow will yield much more meat than a sheep or a goat. Correcting for typical animal weight, the ratio of meat obtained per unit of live weight, and the typical protein content per unit of meat weight, shows that the emissions per unit of potential meat yield is not as vastly different across these animal types as a first glance at overall emissions may suggest (Wellesley et al. 2015; FAO n.d.).

For instance, small ruminants (e.g. sheep, goats) have emissions intensities in the same range as cattle, and small ruminants' milk has a higher intensity on average than does cows' milk. All are substantially higher than pork and especially chicken meat, which is in the same order of magnitude as soybean, often used in meat alternatives.

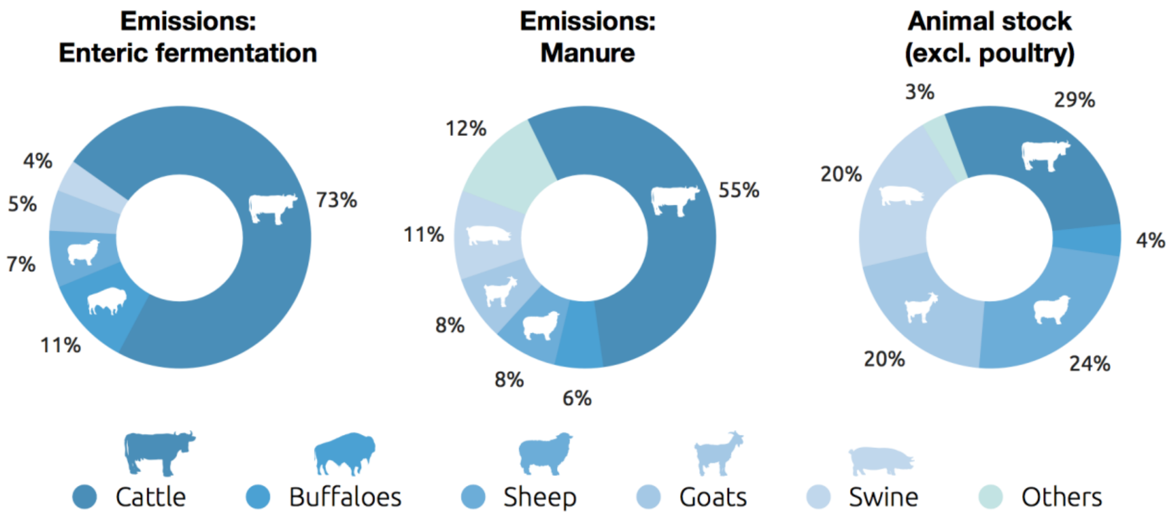

Figure 5: Data from (FAOSTAT 2016a) *indicate that cattle are responsible for 73% of global enteric fermentation emissions (ca. 1.5 $GtCO_2e$/year) and 55% of manure-related emissions (ca. 0.76 $GtCO_2e$/year). Measured in number of animals, they represent only 29% of total animal stock excl. poultry.*

In this context, it is important to note that "beef does not equal beef", as there may be substantial differences, for instance, between carbon intensities of different methods of feeding cattle, e.g. grass-fed vs. grain-fed beef, the latter of which produces fewer enteric emissions per unit live weight (Desjardins et al. 2012), but may require more fertiliser and more irrigation water (Eshel et al. 2014).

We note that the above data from FAOSTAT are based on 2006 IPCC guidelines for emissions inventories. The input information for these guidelines reflects earlier decades and may no longer be up to date with current practices of livestock rearing. A recent study (Wolf et al. 2017) provides revised bottom-up estimates of carbon fluxes from agricultural systems, showing that emission factors from enteric fermentation and manure management may be considerably higher (though with substantial regional differences) than the 2006 IPCC guidelines suggest.

Alternative non-plant based low-emissions foods are also being explored. The FAO has promoted the inclusion of insects in diets with low environmental impact (van Huis et al. 2013), and R&D into the development of *in vitro* meat is ongoing, though still far from industrial scales (Sharma et al. 2015).

FERTILISER EMISSIONS

The growth in emissions from fertiliser, referenced in the second section of this briefing, as compared to that of overall non-CO_2 agricultural emissions, is displayed in Figure 6. It can be seen that the increase of fertiliser emissions was more than twice that of overall emissions worldwide, and much more in various countries, up to more than seven times in Brazil.

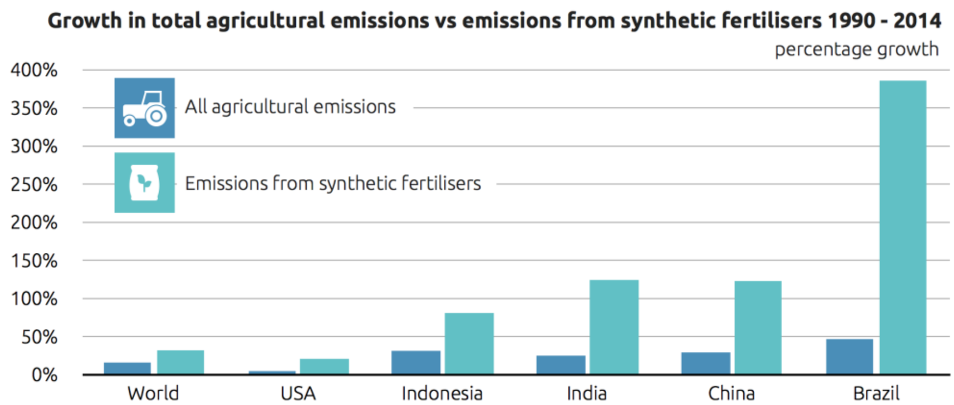

Figure 6: Growth in synthetic fertiliser emissions exceeded that of overall agricultural emissions in many countries. Data from (FAOSTAT 2016a).

Among Annex I countries, the highest relative increase in synthetic fertiliser emissions was in New Zealand, where total agricultural emissions did not increase between 1990 and 2014, but fertiliser emissions increased by more than 600% (FAOSTAT 2016a).

LAND-USE CHANGE AND CO_2 EMISSIONS

This briefing has looked specifically at non-CO_2 emissions—namely CH_4 and N_2O—as net CO_2 emissions from agricultural systems are assumed to be negligible (Smith et al. 2014). However, agriculture-driven land-use change (usually classified under land-use change emissions, not agriculture) contributes a substantial amount of CO_2 emissions. Therefore, when evaluating different non-CO_2 mitigation options, it is also important to consider the effect that these will have on land-use change.

Animal agriculture is the single biggest use of agricultural land, making it a major driver of deforestation, and Bajželj et al. (2014) project that in 2050, if business-as-usual continues, about 7 Gt of CO_2 emissions could come from deforestation due to animal agriculture. These land-use change emissions can be reduced through a reduction in demand. A shift to more plant-based diets would substantially reduce the amount of land required for food production, although expansion into pristine tropical rainforest would be likely to continue unless preventative policies are put in place (Bajželj et al. 2014). However, transitions in the supply side towards more productive systems can also have a significant impact on land-use change emissions: Havlík et al. (2014) suggest that over 85% of the emissions reductions that could be achieved through policies for sustainable intensification would be in CO_2 emissions from land-use change, rather than non-CO_2 emissions.

Agriculture-based mitigation of CO_2 emissions could also be possible through the adoption of soil management and agroforestry techniques that sequester carbon in soil and vegetation. However, the high uncertainties in estimates of the potential for such sequestration—especially under the effects of climate change—mean that these are not included in many mitigation estimates, e.g. Wollenberg et al. (2016), although Frank et al. (2017) suggest that taking into account soil organic carbon sequestration in farmland is an important option for reducing adverse impacts on food affordability that ambitious agricultural emissions mitigation might have.

The amount of land used for agriculture and the associated CO_2 and non-CO_2 emissions depend on a range of interacting assumptions, and are therefore difficult to project into the future. Underlying socio-economic conditions, such as future food demand, agricultural productivity, trade, choice of production systems, dietary patterns, and the use of land-based mitigation measures have a strong influence on future agricultural emissions and land-use dynamics (Popp et al. 2016), which means that we cannot treat any of these factors in isolation.

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This work was funded by the ClimateWorks Foundation

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