SCIENCE ADVISORY PANEL BRIEFING: ADDRESSING METHANE IN AGRICULTURE AND LIVESTOCK

BACKGROUND

The increase of methane in the atmosphere has caused the largest radiative forcing by any greenhouse gas after carbon dioxide. Methane concentrations have grown as a result of human activities related to agriculture, including rice cultivation and the keeping of ruminant livestock, coal mining, oil and gas production and distribution, biomass burning and municipal waste landfills. Globally, the agricultural sector is responsible for a little more than half (~55%) of all anthropogenic non-CO_2 greenhouse gas emissions (5.4-5.8 $GtCO_2eq$/year).

Factor	Response to CO2	Response to CH4
Heat	↓	↓
Drought	↓	↓
Fertilization	↑	–
Ozone	–	↓

Figure 1: Comparing methane and CO_2 crop damage impacts; credit: Drew Shindell

Methane has a direct influence on climate, but also has a number of indirect effects including its role as an important precursor to the formation of tropospheric ozone. Thus, some methane mitigation measures provide local air-quality benefits with important benefits for public health and ecosystems (including crop yields). With respect to impacts on crop yields, methane's influence on surface ozone in combination with its warming effect result in significant crop yield losses that often vary between 5 to 15% in regions with elevated ozone (Figure 1).

The 2011 UNEP/WMO *Assessment of Black Carbon and Tropospheric Ozone* identified two measures to address methane emissions in the agricultural sector: 1) farm-scale anaerobic digestion of large farms with liquid manure management, and 2) intermittent aeration of continuously flooded rice paddies.[1] The 2011 *Near-Term Action* report added an additional agricultural methane measure: Feed changes for dairy and non-dairy cattle.[2] In this briefing we look at additional opportunities and measures for addressing methane emissions from enteric fermentation as well as barriers and uncertainties that should be addressed to achieve near-term emissions reductions at scale.

Table 1 – Methane Measures

Measure	Emission reduction potential in 2030 (Mt methane)	Non-climate benefits of measure
Farm-scale anaerobic digestion on large farms with liquid manure management	2.2	Energy efficiency, crop protection
Feed changes for dairy and non-dairy cattle	3.9	Improved meat quality
Intermittent aeration of continuously flooded rice paddies	9.1	Crop protection

[1] UNEP and WMO (2011) Integrated Assessment of Black Carbon and Tropospheric Ozone; *and* Shindell, D. *et al.* (2012) Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security, Science 335 (6065), 183-189.

[2] UNEP (2011) Near-term Climate Protection and Clean Air Benefits: Actions for Controlling Short-Lived Climate Forcers – A UNEP Synthesis Report.

ENTERIC FERMENTATION

Enteric methane emissions, arising predominantly from the fermentation of ingested feed in ruminant animals (e.g. cattle, sheep, goats, buffalo, etc.), account for approximately 35% of all CO_2 equivalent (using GWP100) agricultural emission and approximately 25% of total global anthropogenic methane emissions[3]. Over the period 2000-2010, emissions were dominated by cattle (75% of the total), followed by buffalo, sheep and goats.

Enteric methane emissions have been growing at a rate of 0.95% per year since the 1960's and this is a direct reflection of increased ruminant populations; since 1970, there has been a 1.4 fold increase in the numbers of cattle, buffalo, sheep and goats. Asia and the Americas are the largest contributors to global enteric methane emissions, followed by Africa and Europe[4]. Emission growth rates are largest in Africa (2.4%/year), followed by Asia and the Americas (1-1.2%/year), while they are decreasing in Europe (-1.7%/year).

As a result of population growth, rising per-capita energy intake and changing human dietary preferences, the demand for agricultural products in the future is anticipated to increase significantly, especially in the developing countries of Asia and Africa. Predictions are that by 2050 total food consumption will increase by 70% and global meat and milk consumption will increase by 73% and 58% respectively[5]. Livestock-related emissions are estimated to increase under 'business as usual' scenarios by 25-40% by 2050 with increases in all major regions except Europe and Africa. The influence future changes in diet may have is reflected in the projected emissions for China, a 60% increase by 2050 despite a static human population.

MEASURES FOR MITIGATING ENTERIC METHANE EMISSIONS

Existing measures for mitigating enteric methane emissions fall into three categories:
1) Supply-side measures focusing on reducing emissions per unit of animal product (e.g. milk, or beef);
2) Demand-side measures focussing on changing consumption patterns; and,
3) Emission reduction technologies.

1) Supply-Side Mitigation Measures – Increasing Efficiency

Although absolute emissions from livestock have increased markedly since 1961, increases in the efficiency in which animal products are produced has resulted in consistent decreases in emissions intensity i.e. the quantity of GHG emitted per unit of animal product. Quantifying these declines is challenging due to methodological issues but crude estimates demonstrate that they are substantial. For example, dividing total ruminant emissions by total animal product (milk plus meat) indicates that emissions per unit of product in Asia fell from 12.9kg CO_2e to 4kg CO_2e between 1961 and 2012.

The routes for increasing efficiency are well known and, to a large extent, based on existing technologies that improve production efficiency at both the individual animal and herd level. The improved availability of better quality feed, improvements in animal health and the use of improved, locally adapted, livestock breeds will improve individual animal and herd performance. All of these will increase productivity at a faster rate than emissions. Emissions per unit of product are much higher in developing countries than developed countries and

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[3] Ciais, P., C. Sabine, G. Bala, L. Bopp, V. Brovkin, J. Canadell, A. Chhabra, R. DeFries, J. Galloway, M. Heimann, C. Jones, C. Le Quéré, R.B. Myneni, S. Piao, P. Thornton, 2013: Carbon and Other Biogeochemical Cycles. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 465–570.

[4] Smith P., M. Bustamante, H. Ahammad, H. Clark, H. Dong, E.A. Elsiddig, H. Haberl, R. Harper, J. House, M. Jafari, O. Masera, C. Mbow, N.H. Ravindranath, C.W. Rice, C. Robledo Abad, A. Romanovskaya, F. Sperling, and F. Tubiello, 2014: Agriculture, Forestry and Other Land Use (AFOLU). In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[5] FAO. 2011. World Livestock 2011 – Livestock in food security. Rome, Italy.

developing countries have the largest potential to mitigate emissions via the efficiency route. They also are likely to have the largest barriers to overcome.

Decreasing emissions via productivity increases is strongly synergistic with increased income. The CCAC Phase 1 enteric methane project conducted in 13 countries identified practices that individually and collectively improved income and reduced GHG emissions. Understanding and overcoming the barriers to the uptake of these known technologies will be a key challenge. Increasing efficiency is also synergistic with development goals and enhancing food security.

Where livestock production is relatively static, increasing efficiency can both reduce emissions per unit of product and absolute emissions. Where the sector is expanding, it will, at a minimum, reduce emissions below 'business as usual'. Increasing efficiency is therefore a key component of agricultural GHG mitigation.

Reducing waste across livestock product supply chains may also have considerable GHG mitigation potential although there is a recognized lack of comprehensive data to accurately quantify this potential in general, and for CH_4 in particular.[6] Many losses occur in the post harvesting phase of supply chains (storing, handling, packaging and consumption) although some do occur during the livestock production phase e.g. mortality due to disease. Losses in the livestock production part of the supply chain are an integral component of efficiency gains discussed under mitigating emissions via efficiency improvements.
Anecdotal evidence suggests that rapid progress is being made in the development of alternative synthetic milk and meat products derived from plants, many of which seem rely on fermentation processes using genetically modified organisms (GMO's). Proponents claim that potentially these plant-based products have reduced GHG emissions, reduced land use and generally reduced environmental impact. Currently it is difficult to assess what the mitigation potential of these milk and meat alternatives is but if they become used widely it could be substantial. However, these products face challenges ranging from resistance to the use of GMO's in some jurisdictions through to social acceptability, price and the economic consequences for rural livelihoods.

2) Demand-Side Mitigation Measures

Supply side measures may not be enough to bring about absolute reductions in enteric methane emissions and there is growing interest in whether changing the demand for specific foods (for example via changes in consumption patterns) could make a strong contribution to mitigation efforts. This could also lead to improved human health via, for example, reductions in red meat consumption in areas where current intake exceeds healthy guidelines.

Livestock products, while varying considerably in their emissions per unit of energy and protein, generally have much higher emissions compared with plant based products. However, there is a lack of systematic analysis on whether the mitigation potential is feasible in economic, social and political terms. Evidence from developed countries suggests that the achievable mitigation potential of demand side interventions is likely to be significantly lower than current estimates of the technical potential[7].

3) Emissions Reduction Technologies

There are a number of currently available technologies that have demonstrated enteric methane reduction potential (reduction per unit of feed eaten) to some degree, as well as technologies currently in development

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[6] Kiff L, Wilkes A, Tennigkeit T. 2016. The technical mitigation potential of demand-side measures in the agri-food sector: a preliminary assessment of available measures. CCAFS Report No. 15. Copenhagen,Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).
[7] Kiff, L, Wilkes, A, Tennigkeit, T, 2016 The technical mitigation of demand-side measures in the agri-food sector: a preliminary assessment of available measures. CCAFS Report No. 15. Copenhagen.

that could become available in the next few years to a decade with a potentially large capacity to reduce emissions

Existing mitigation technologies include:

- Concentrate feeding
- Increasing the concentration of oils in ruminant diets
- Tannin containing forages
- Nitrate supplementation
- Plant derived bioactives e.g. garlic, essential oils
- Direct fed microbials e.g. yeasts

Despite the current availability of these measures, the uncertainty and variability of the mitigation impact, concerns about animal safety, costs, and a lack of good agronomic species in some regions represent significant barriers which limit the extent to which the mitigation potential can be realised in practice.

Technologies currently in development, include: modifying the rumen process, suppressing methane production through vaccines, and selective breeding. Modifying rumen processes to bring about substantial reductions in CH_4 emissions is making rapid progress. Hristov *et al.* (2015) reported the successful testing of a compound (3NOP) which reduced emissions from lactating dairy cows by ~30% and had a positive benefit for liveweight gain.[8] The economics and practicality of using such compounds, in particular the mode of delivery (currently the product is incorporated into feed and is fed continuously), will need to be confirmed but the development of a compound that brings about a substantial reduction in emissions, is animal friendly and appears to have a productivity benefit is a major breakthrough. These type of compounds could be available commercially as early as 2020.

Researchers in New Zealand and Australia have also been working on stimulating the ruminants' own immune system to suppress methane by identification of antigens that can be incorporated into vaccines. Antibody production in saliva and blood has been successfully achieved in sheep but reductions in methane have only been demonstrated in the laboratory. The generally low cost of vaccines, the mode of delivery, the promise of infrequent treatment, and the potential applicability to all classes of livestock make this mitigation route highly attractive. However, it is technically challenging and progress has been slow since the initial idea emerged twenty years ago. Commercial availability is likely to be 7+ years away.

Individual ruminant animals differ in the amount of methane they produce when fed the same quantity of feed and this trait is heritable (reductions of 1% per annum are possible). In addition, some animals eat less but achieve the same level of productivity and so will produce less CH_4 because of the strong link between intake and CH_4. Since continuous improvement in performance via animal breeding is well accepted and highly cost effective, the animal breeding route is highly attractive. Emissions reductions however, may not come at a zero cost since selecting for the low emission trait may reduce the rate of progress in other economically important traits. The applicability of this mitigation is limited to those areas having a well-developed animal breeding and selection infrastructure.

THE MULTIPLE-BENEFITS OF ENTERIC METHANE MEASURES

Numerous studies have indicated that there is still considerable scope for reductions in emissions per unit of product across all production systems and that there is wide variation between and within systems of

[8] Hristov, A. N. *et al.* (2015) An inhibitor persistently decreased enteric methane emission from dairy cows with no negative effect on milk production, Proceedings of the National Academy of Sciences of the United States of America 112(34), 10663-10668.

production. The FAO[9] estimates the widespread adoption of known good practices that increase productivity at the individual animal and herd/flock level could reduce 18 Mt of enteric CH_4 emissions per year (i.e. more that the total from the three measures listed in Table 1). Estimates using the TM5-FASST tool show that such measures can provide co-benefits for avoided premature mortality and avoided crop losses in every region of the world. See Table 2.

Table 2: Co-Benefits from 'best practices' livestock management methane measures.

Methane		18 Mt methane emissions					
Impact	**Unit**	**OECD90**	**REF**	**MAF**	**LAM**	**ASIA**	**GLOBAL**
Change in ozone concentration (characterised as the highest 6 month mean max hourly ozone)	ppbv	-0.4	-0.3	-0.4	-0.3	-0.3	
Change in premature mortality	#/year	-359	-105	-89	-86	-965	-1,605
Change in crop yield loss (for 4 staple crops)	metric Tonnes	-790,000	-360,000	-110,000	-21,000	-600,000	-1,900,000

Widespread adoption of an effective vaccine/inhibitor package, together with the breeding of low methane-emitting animals, could deliver large emission reductions in some animal production systems (30-50%). However, apart perhaps from the breeding of low-emitting sheep, the effectiveness, complementarity, and long-term sustainability of the technologies still have to be demonstrated in real farm situations. The global potential will be much less due to the technologies not necessarily being suitable for all ruminant production systems. The success of new technologies such as vaccines, inhibitors and low-emissions animals will critically depend on how their widespread adoption can be encouraged; this could mean putting a price on agricultural emissions, something which no country has done to date.

Modelling studies suggest that switching to 'healthier' more plant based diets can reduce agricultural greenhouse gas emissions. For example, these can achieve a 29-70% reduction in non-CO_2 greenhouse gas emissions by 2050 alongside a 6-10% reduction in premature mortality[10]. These have been estimated to potentially lead to improvements in human health worth hundreds of billions of dollars in direct healthcare spending and indirect lost productivity[10], as well as to reduced environmental damages also valued at hundreds of billions of dollars in social costs[11].

Most studies have been conducted with relevance to diets and populations from developed countries and the relevance to developing countries is questionable. Increasing the proportion of animal products in the diets of some populations may increase health outcomes and changed demand for animal products could have severe social and economic consequences in some highly vulnerable regions.

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[9] Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. & Tempio, G. 2013. Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome.

[10] Springmann, M, Godfray, H. C. J.Rayner, M., Scarborough, P. 2016. Analysis and valuation of the health and climate change co benefits of dietary change. PNAS, 113, 4146–4151.

[11] Shindell, D., J.S. Fuglestvedt, W.J. Collins, The Social Cost of Methane: Theory and Applications, *Faraday Disc.,* doi: 10.1039/C7FD00009J, 2017.

CHALLENGES FOR ADDRESSING ENTERIC METHANE EMISSIONS

The potential to mitigate agricultural emissions in general has to be considered alongside the growing demand for food from a projected population of ~9 billion, increased dietary energy intake and the trend for increased consumption of animal derived protein. Business as usual scenarios project an increase in emissions and reducing emissions below an historical baseline e.g. 1990 will be extremely challenging. It may also be challenging to provide adequate food supplies to the ~9 billion projected population *without* reducing land-use demands from livestock.

Livestock production systems vary enormously with and between countries and regions of the world. Mitigation approaches need to be tailored to this diversity. Not all systems have an equal opportunity to mitigate emissions.

The mitigation of agricultural greenhouse gases also has to be placed in context. Production systems vary widely – as does the social, environmental, technical and economic context. Mitigation needs to be appropriate to the local circumstances and take account of the social and poverty dimension of livestock since hundreds of millions of the world's poorest smallholder farmers rely, to some extent, on livestock for their daily survival. For these farmers mitigating GHG emissions must be seen, and if possible captured, as a co-benefit of more important actions such as improved food security and economic wellbeing.

Accurately measuring and monitoring enteric methane emissions also presents a challenge, as emissions from individual animals vary continuously and there are billions of individual point sources. Methods for measuring emissions from individual animals are well developed but expensive and relatively few countries have access to these facilities. Measurement at paddock/landscape scale is possible but attribution of emissions to a specific source is challenging, particularly at the landscape scale. Monitoring the effectiveness of mitigation measures by necessity uses proxy values obtained from controlled experiments alongside local animal performance and population data.

Livestock emission estimates are bottom-up estimates and obtaining these estimates is challenging due to the lack of good data. This extends from data on animal populations through to those things that directly influence enteric methane such as diet type and quality. Data limitations mean that most countries have adopted very simple approaches when estimating emissions. This poses large challenges when it comes to estimating the impact of mitigation measures.

Those inventories reliant on default emission factors (e.g. fixed emissions per animal per year) obtained from literature cannot easily incorporate mitigation actions, especially those reliant upon changes in efficiency. The only mitigation possible is a reduction in animal numbers. More complex inventories involve population structure models, specifically incorporate animal and feed characteristics and have emissions data per feed type derived from local data. These types of inventories can incorporate and report on the effectiveness of a broad range of management interventions.

Even with complex national accounting approaches some types of mitigation may be very difficult to get recognised. Feeding concentrates reduces enteric methane emissions but only if fed at >40% of the diet and the impact increases as the proportion in the diet increases. It may be possible to monitor in intensive systems where diets are highly controlled, but this is challenging in many systems. This contrasts with measures such as vaccines where sales can be monitored at the individual farmer level.

Encouraging and helping countries move away from very simple accounting systems is a high priority. Without this many countries that are taking action may not get recognition for those actions. Mitigations via efficiency improvement are automatically captured by more complex accounting systems.