Underestimates of US emissions and global implications for industrializing animal agriculture

A guidance memo for the Tiny Beam Fund

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Abstract

Environmental impacts of intensive, industrial meat and dairy production are a major concern. However, the majority of global warming emissions from animal agriculture are estimated to come from extensive, pastoral systems of production.

Animal emissions are estimated using complex models, but these models can contain multiple errors that often go unreported. Modeled emissions estimates can be corroborated using measurements of greenhouse gases in the air above and downwind of areas where animals are raised, using planes, tall towers, and satellites. These atmospheric measurements suggest that total global animal emissions are accurately estimated by models. However, in the US, where production is predominantly industrialized, animal emissions are frequently underestimated by models.

Intensive methods of meat and dairy production are expanding globally. This expansion is frequently justified by environmental science and economic development experts as a way to reduce the carbon footprint of meat and dairy. This guidance memo demonstrates that the emissions savings potential of intensifying production may be oversold.

Reducing consumer demand for meat and dairy products, while helping producers diversify their income and shift toward food crops where possible, is recommended as a more reliable strategy for mitigating global warming. Reducing consumption and production avoids environmental tradeoffs associated with intensification, including confinement, water pollution, and antibiotic resistance. Additionally, improving the efficiency of pastoral systems can reduce environmental impacts, provided that improvements are accompanied by strict ecosystem conservation and do not lead to animal confinement.

1. How Industrial Animal Agriculture is Justified on Environmental Grounds

1.1 Rising demand for animal foods

In the coming decades, global meat consumption is expected to increase by nearly two thirds (Alexandratos and Bruinsma, 2012). This increase is not primarily driven by population growth, which is expected to rise approximately 26% by the year 2050, but rather, rising affluence. Growing wealth in low- and middle-income countries will allow more people to afford meat and dairy.

Animal agriculture has been reported to represent 14.5% of greenhouse gas (GHG) emissions globally (Figure 1), as calculated by the Food and Agriculture Organization of the United Nations (FAO) (Gerber et al., 2013). Of the major animal food categories, beef is responsible for the highest number of emissions, followed in descending order by milk, pork, poultry, and eggs (Harwatt, 2019).

Emissions coming from animals consist of **direct emissions** (enteric fermentation, commonly known as "cow burps", and manure management) and **indirect emissions** (feed production, and farm energy use). Animal agriculture is responsible for emitting all three of the most common GHGs: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Directly, however, animals are net emitters only of the non-CO_2 gases (Figure 1).

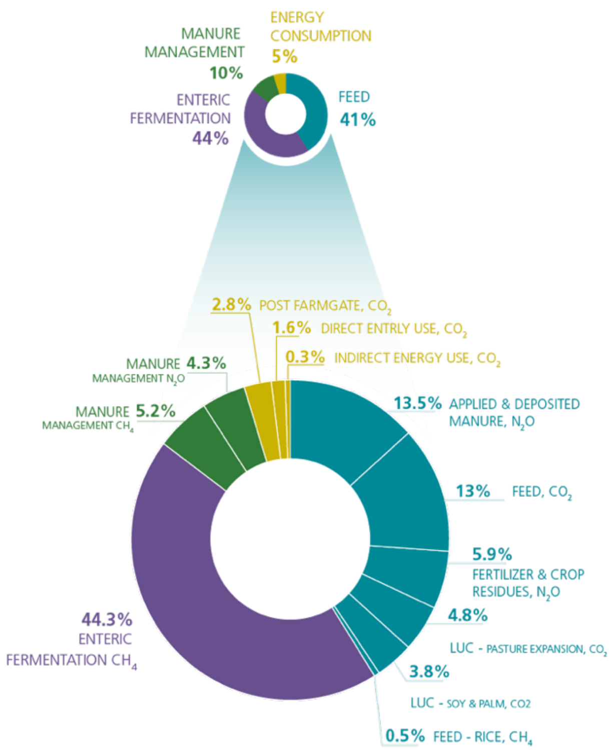

Figure 1. Emissions from animal agriculture, by lifecycle stage and greenhouse gas, as estimated by the Global Livestock Environmental Assessment Model (GLEAM) from UN FAO. Direct emissions in purple and green; indirect emissions in blue and yellow.

Estimates of GHG emissions from animal agriculture are produced using emissions models, developed by standards from the Intergovernmental Panel on Climate Change (IPCC), the standardizing body for calculating all greenhouse gas emissions and their impacts. These models will be discussed more in-depth in the following section.

Globally, the majority of global emissions are estimated to come from lower efficiency, pastoral systems (Steinfeld et al., 2006). These systems include long-range grazing, backyard, and mixed crop-livestock systems (Gerber et al., 2013), forms of animal agriculture more officially referred to as **extensive production systems** because of their larger land footprint.

High-efficiency systems, which often rely on industrial-style confinement of animals, like those in North America and the EU, are referred to as **intensive production systems**. Intensive systems are collectively estimated to be responsible for fewer global emissions and fewer emissions per unit of meat or dairy produced.

Intensively-managed animals are more efficient at turning energy from feed crops into meat, dairy, or eggs (Swain et al., 2018). As a consequence, intensively managed animals need less feed—leading to fewer indirect emissions from feed production—and produce fewer wastes like manure, urine, and belches—creating fewer direct emissions.

Because intensively managed animals are raised in confinement and fed enriched feeds, they also fatten up more quickly, hence have shorter lives over which they produce GHGs, than animals that roam freely, foraging and grazing for their foods (Gerber et al., 2013; Hayek and Garrett, 2018).

Overall, the reasoning goes that the more efficient animals are at converting feed into meat and dairy, the less feed they need, and a smaller fraction of that feed gets converted into harmful GHG emissions.

1.2 The role of intensification in sustainable development

Because extensive and pastoral systems seemingly emit more GHGs per unit of meat or dairy produced, many advocate that these systems should be intensified. Extensive animal management is prevalent in low and middle-income countries where demand for these products is also rising. *Intensifying production is frequently advocated for by researchers, governments, and nongovernmental organizations as a critical part of economic development.*

Producing more meat and dairy with fewer resources, like land and feed, and fewer emissions, is commonly referred to as **sustainable intensification**. Sustainability, however, can refer to dozens of environmental and societal impacts, like air and water quality, disease, erosion, biodiversity, income equality, profitability, food security, gender equality, and far more (Herroro and Thornton, 2013). *Because there are so many facets of sustainability, common critique of the term is that it can mean whatever the person or entity using it wants it to mean* (Lovvorn, 2018).

Improving the efficiency of animal production through intensification can positively promote some facets of sustainability, but may hinder others. As a positive example, helping extensive cattle ranchers in Brazil amend their soil with lime and sow better-quality grasses can improve their lands' productivity and profitability, while preventing the need to deforest more land elsewhere to increase profits (Ceddia et al., 2014; Garrett et al., 2017a). As a negative example, confining chickens into indoor sheds, while making feeding more efficient, can promote disease outbreaks and require more persistent use of antibiotics, leading to antimicrobial resistance. Both of these are examples of intensifying animal production, but have a very different positive and negative co-impacts.

Intensification does not always mean confinement, as seen in the first of the two examples provided above. However, investing in efficiency for extensive systems can, in practice, make industrialization more attractive and affordable. For example, methane emissions from animal manure can be captured and used for energy generation, referred to as manure biogas. While small-scale solutions exist for backyard systems, any new infrastructure is costly. Recouping an investment in new equipment can make producing larger quantities attractive. Producing larger quantities, in turn may entail concentrating animals and consolidating their manure production in one large place (Paolini et al., 2018). *Following the advice to implement sustainable intensification within animal systems may often, in practice, involve moving across animal systems, and veering into industrial production.*

2. Estimating animal emissions using models

2.1 How emissions models work

How do we know how many emissions come from animal agriculture overall, and how do GHG emissions differ between animal species, geographic regions, production systems, and animal food products?

GHG emissions from farmed animals are quantified by animal emissions models. These models tally up populations of each type of animal, then multiply the tally by how much each animal emits daily.

Estimates of daily per-animal direct emissions are called **emission factors**. For each type of animal, separate emission factors exist for (1) enteric fermentation (belches) and the (2) handling and storage of their manure. Adding up all the animals in a country and multiplying by their animal- and country-specific emissions factors gives the total amount of emissions produced.

Models can also calculate indirect emissions from feed production and manure application to fields. However, this guidance memo will mostly discuss *direct* emissions of animal agriculture, with some exceptions.

Emissions factors are calculated using complex models, which are essentially a series of equations, provided in the IPCC in the guidelines of the Fourth Global Assessment Report (Dong et al., 2006). The models take detailed input information on how animals are raised in each region, such as their feed, exercise, manure disposal, and local climate, along with their productivity, such as weight gain, lactation amount, and breeding rate. This input information is inserted into equations that produce methane and nitrous oxide emissions factors as outputs (Dong et al., 2006).

The details of the model inputs can often get very fine grained, and consist of estimating minutiae. The models require information regarding how much an average animal moves during a day, whether or not a dried crust is allowed to form on top of the slurry tanks that handle liquid manure, the temperatures of a given animal operation and the seasonal cycle of weather conditions, and many other very specific details. *Estimating the necessary input information for emissions models accurately is challenging, even for countries with detailed agricultural censuses.*

Because all of these details must be collected at the ground-level through counting, interviewing, and census-taking, then multiplied and added up to produce a total, animal emissions models are often referred to as **bottom-up** estimates.

2.2 Uncertainties in emissions models

Understanding the exact level of detail represented in these animal models is not critical to understanding their limitations. It suffices to simply know that they are very finely detailed. *Detailed input information contributes to the precision of models (the degree to which they can detect changes between one system or another), but not necessarily their accuracy (how close their estimates are to the truth).*

As more details are added and multiplied within the models, the error in the model gets larger as well. As Miller et al. (2014) explain, these models

> "require a series of assumptions, for which errors compound as several factors are multiplied and added. Feed matter intake and emission factors both have substantial uncertainties, as do the IPCC manure methane emission factors…these uncertainties…are inherent in all bottom-up inventories".

The sheer number of inputs into these models, which are collected and estimated imperfectly, means that the output, the total estimated emissions, are considerably more uncertain than any single input.

In addition to uncertain inputs, models have dozens of other numbers that describe how inputs and outputs relate to one another, called **parameters**. These parameters are derived from small-scale studies up to 40 years old. Therefore, *animal emissions models may be outdated or not representative of the wide variety of production systems in the real world* (Wolf et al., 2017).

In summary, bottom-up animal emissions models have high precision but their overall level of accuracy is unknown. *Although emissions from the models are uncertain does not mean that they are wrong. It means that how wrong or right they are is unknown.* To assess the accuracy of emissions estimates, *independent methods* are needed that quantify animal emissions using entirely different means.

3. Quantifying emissions from the sky

3.1 Testing the models using atmospheric measurements

The GHG emissions estimates produced by bottom-up models can be tested for accuracy by *measuring the air above animal operations*. Atmospheric measurements of GHGs are taken by instruments on tall towers, airplanes, and satellites.

Atmospheric measurements, by themselves, can monitor gas concentrations, i.e. amounts of gases already in the air, but cannot by themselves tell where these gases come from. To link the GHG concentrations in the air back to their sources on the ground, researchers use models and observations of wind direction, speed, and turbulence. Wind information helps determine whether some airborne methane, for instance, came from a feedlot to the east or an oil field to the west. After measuring over prolonged periods of time, these methods can gauge how many emissions came from various sources over months or years. Because atmospheric estimates start by measuring GHGs in the sky, then trace those GHG back to their source regions on the ground, these are referred to as **top-down** estimates.

Top-down atmospheric estimates rely on wind observations and models with their own errors. Importantly, these errors are different from the errors in bottom-up models. These errors can also be readily estimated and reported, and are non-compounding. *Top-down atmospheric estimates are therefore a reliably independent way of testing the accuracy of bottom-up emissions models.*

Top-down estimates can only detect direct emissions over a given region, but cannot estimate indirect emissions such as feed production sourced over multiple locations. Direct emissions represent the majority, 54%, of all animal emissions (Figure 1).

3.2 Summary of past top-down atmospheric estimates

Methane makes up 92% of direct animal emissions. A summary of top-down atmospheric estimates of methane emissions from animals, and how they compare with bottom-up modeled estimates, are presented in Table 1. Only one global study has been performed. This study indicates that global animal methane emissions are only slightly higher than the bottom-up models predict—about 5% higher—and within the margin of error. This suggests that the UN FAO estimate for animal methane (Figure 1) is in the right ballpark.

The difference is much greater in the United States. Top-down estimates indicate that total US animal methane emissions are 39-90% higher than bottom-up models predict. This implies that animal emissions in the United States, in official reports by government, such as the US EPA, and in numerous peer-reviewed scientific publications, are routinely underestimated. It also implies that a greater proportion of the total emissions that the UN FAO reports may be coming from intensive systems.

Region	Year	Bottom-up model	Modeled estimate (bottom-up)	Atmospheric measurements (top-down)	Scale factor	Reference
Globe USA	2009-2011	EDGAR v4.2	111.0 8.9	116.0 14.8	105% 166%	Turner et al., 2015
USA	2004	US EPA EDGAR v4.2	8.8 8.5	12.2	139% 144%	Wecht et al., 2014
USA	2007-2008	US EPA EDGAR v4.2	9.3 8.9	17.0	181% 190%	Miller et al., 2013
US Midwest	2016-2017	US EPA EDGAR v4.2	2.6 2.7	4.8	185% 178%	Chen et al., 2018
California	2013-2014	CALGEM	0.90	1.33	149%	Jeong et al., 2016

Table 1. Direct methane emissions from farmed animals in Tg CH_4 per year. Scale factor refers to how much higher the top-down emissions estimate is relative to the bottom-up model. Emissions model abbreviations are EDGAR—Emissions Database for Global Atmospheric Research. EPA—Environmental Protection Agency. CALGEM—California greenhouse gas emissions measurement project.

3.3 Why US emissions are underestimated by models

It is unclear why the bottom-up model estimates for animal agriculture in the United States are too low. The problems do not seem specific to one animal or system. California airborne measurements were able to distinguish between dairy cattle and other non-dairy animals' emissions, finding that they were 45% and 69% higher, respectively, than the bottom-up model predicted (Jeong et al., 2016). Multiple animals' emissions are apparently being underestimated by the bottom-up emissions models.

Models appear to underpredict emissions from manure. The models of manure emissions are based on laboratory experiments within controlled test chambers. When methane is measured outside of the lab, in the air directly above manure tanks, pits, and piles, emissions tend to be greater than models predict, sometimes by more than 300% (Owen and Silver, 2015). However, because manure represents only 11% of animal methane emissions (Figure 1), this difference is still not large enough to explain the total gap in methane emissions (Wolf et al., 2017).

Widespread infections in animals in intensive production (Fox et al., 2018 and references therein) could also cause increased methane emissions from enteric fermentation.

Top-down atmospheric estimates are an accurate way to gauge total GHG emissions, but because they are conducted over large areas and windows of time, they are unable to hone in on precisely why, where, and when models underpredict emissions.

Despite this lack of precision, atmospheric measurements suggest that there are multiple problems with bottom-up emissions models, across multiple types of farmed animals and processes, which cause the models to underestimate total animal emissions in the US.

3.4 Environmental tradeoffs of intensive animal production

3.4.1 Differences between greenhouse gases in intensive and extensive animal production

Bottom-up emission models consistently and significantly underestimate methane from animals in the United States, where production is predominantly intensive and industrial. This atmospheric evidence suggests that the commonly-repeated assertion that industrial animal production is drastically lower than extensive production may therefore be over-exaggerated.

This does *not* mean that extensive animal production has fewer GHG emissions. What it does mean is that, when it comes to direct emissions, the gap between emissions from extensive and intensive production is likely smaller than commonly reported.

Despite intensive systems being more efficient on average, some forms of extensive beef production are known to have fewer emissions than intensive beef production systems, even according to bottom-up models (Swain et al. 2018, and references therein). Low-emission extensive systems typically exist in areas with particularly fertile soils and warm, wet climates that permits long growing seasons. These conditions allow for high-quality pastures that feed cattle more efficiently (Eshel et al., 2018), leading to lower emissions. However, because these high-efficiency, low-production extensive systems are in uniquely suitable environments, they do not and cannot apply to extensive, pastoral systems everywhere.

3.4.2 Differences between intensive and extensive systems in crop demand, land use, and indirect emissions

Intensive management tends to reduce agricultural land requirements overall. Moving cattle from pasture to grain-fed systems requires more grain to be raised on croplands than extensive management, but because this grain replaces the need for grass and forages, the overall land use is lower.

Cattle in the US have a high land footprint, but their footprint is lower than most other countries (Poore and Nemecek, 2018). Hypothetically shifting the US back towards exclusively grass-fed beef production would require up to 270% more land if Americans did not reduce their consumption (Hayek and Garrett, 2018). Crops are a more energy-rich form of feed than grass, and can fatten cattle more efficiently than pasture. *Although pastoral beef production would reduce cropland use, this would be more than compensated for by the need for additional pastureland.*

Even though *direct* emissions from intensive animal systems may commonly be underestimated, *indirect* emissions associated with feed and deforestation are almost certainly smaller in intensive systems. Extensive grazing comes at a cost, especially in tropical forested ecosystems such as the Brazilian Amazon, as native forests are destroyed for more extensive grass production. Improving feed efficiency helps limit deforestation, provided improved efficiency does not in turn lead to more demand. Intensifying by raising more animals on less land, improving pasture productivity and quality, and feeding cattle grain can mitigate indirect GHG emissions (Lamb et al., 2016) even if the direct emissions reduction is not as high as commonly assumed by bottom-up models.

However, two problems commonly arise with intensifying production. The first problem is that *improving the resource efficiency of production can also improve its profitability, leading to more expansion, deforestation, and emissions*. This is referred to as "Jevons Paradox". Avoiding this paradox relies on coupling efficient production with better environmental governance, including stringent forest protection (Ceddia et al., 2014) and curtailing meat demand. The second problem is that *intensification can encourage confinement*. In these cases, potential land-savings and GHG benefits need to be weighed against drawbacks such as worsening animal livelihoods, point source water pollution from consolidated manure, and increased antibiotic usage leading to antibiotic resistance.

3.4.3 Summary of differences between emissions from intensive and extensive production

To conclude, (1) global GHG emissions from animal agriculture, which predominantly come from *extensive* production, are well-predicted by models. (2) Direct emissions from US animal production, which is predominantly *intensive*, are often higher than bottom-up models predict, but (3) that does not mean that intensive systems have greater emissions than extensive systems. Rather, (4) *extensive production does have higher emissions than intensive production, but the gap between them is likely narrower than is often reported.*

4. The role of animal production in economic development and climate change

4.1 Limits of intensification are not being discussed

Top-down atmospheric evidence suggests that intensive forms of animal production do not offer the degree of GHG savings commonly accepted by the environmental and sustainable development research communities. *This important information is completely absent in the environmental science and global development literature. Suggestions to intensify animal production are still ubiquitous, and these suggestions may influence policy.*

Researchers have suggested supplementing native or local feeds in pastoral systems with higher-quality feeds produced and transported from other regions (Steinfeld et al., 2006; Thornton and Herrero 2010) for more than a decade. Suggestions to intensify feeding regimens as a means to reduce GHG emissions have not since changed (e.g. Wang et al., 2017; Swain et al., 2018; Grossi et al., 2019). While these changes likely would reduce land use overall, they would likely achieve less mitigation than assumed, while leading to further industrialization of food systems and its attendant social and environmental tradeoffs.

Recommendations to intensify production are founded on assumptions that (1) rising animal-derived food demand is inevitable in low- and middle-income countries, or that plant-based diets and plant-based meat alternatives can only offset a fraction of demand (Searchinger et al., 2018; Swain et al., 2018), and (2) intensifying production has a high potential to mitigate GHGs. *Neither of these assumptions are necessarily true.*

Some have even gone so far as to promote more meat. A recent analysis of animal emissions in China recommends increasing per-capita production of animal products (Yu et al., 2018), claiming that improved efficiency will offset the increase in production and provide net methane emission reductions overall. Intensifying beef production in tropical middle-income countries (Swain et al., 2018) has also been recommended. *These suggestions are informed only by bottom-up methods to quantify animal methane emissions, not by substantial top-down atmospheric evidence that intensive animal production systems likely emit more methane than commonly assumed.*

The benefits of intensification vary case by case. In cases that intensifying animal production leads to other negative impacts, marginal GHG cost savings may not be worthwhile. It should not be assumed that intensification is always sustainable.

4.2 Case study: intensification in East and Southeast Asia

What are the implications for GHG emissions in low- and middle-income countries that are intensifying their animal production?

Intensification in East and Southeast Asia (ESA) region, which includes mainland China, is expected to reduce marginal emissions substantially (Wang et al., 2017; FAO, 2018; Yu et al., 2019). Even though total demand is increasing, the emissions of each unit of production are assumed assumed to decrease over time (Figure 2A). In the future, total animal emissions are expected to increase slightly by 2030, then gradually go down until they return to early 2000's levels by 2050 (Figure 2B). *These projections, however, come from bottom-up emissions estimates may overestimate the benefit of intensification* (FAO, 2018).

If direct emissions are instead more in line with top-down estimates (scaled up by 65%, the average detected by top-down estimates, provided in Table 1), emissions per unit of meat and dairy will not decrease as drastically over time (Figure 2C). Total animal emissions in the region could reach 1.71 $GtCO_2eq$ by 2050, 22% higher than previously predicted (Figure 2D). This is not a definitive prediction; it is merely an illustrative example, demonstrating that *intensifying animal production in the future <u>may not</u> be an effective approach to controlling overall GHG emissions, especially if demand continues to grow.*

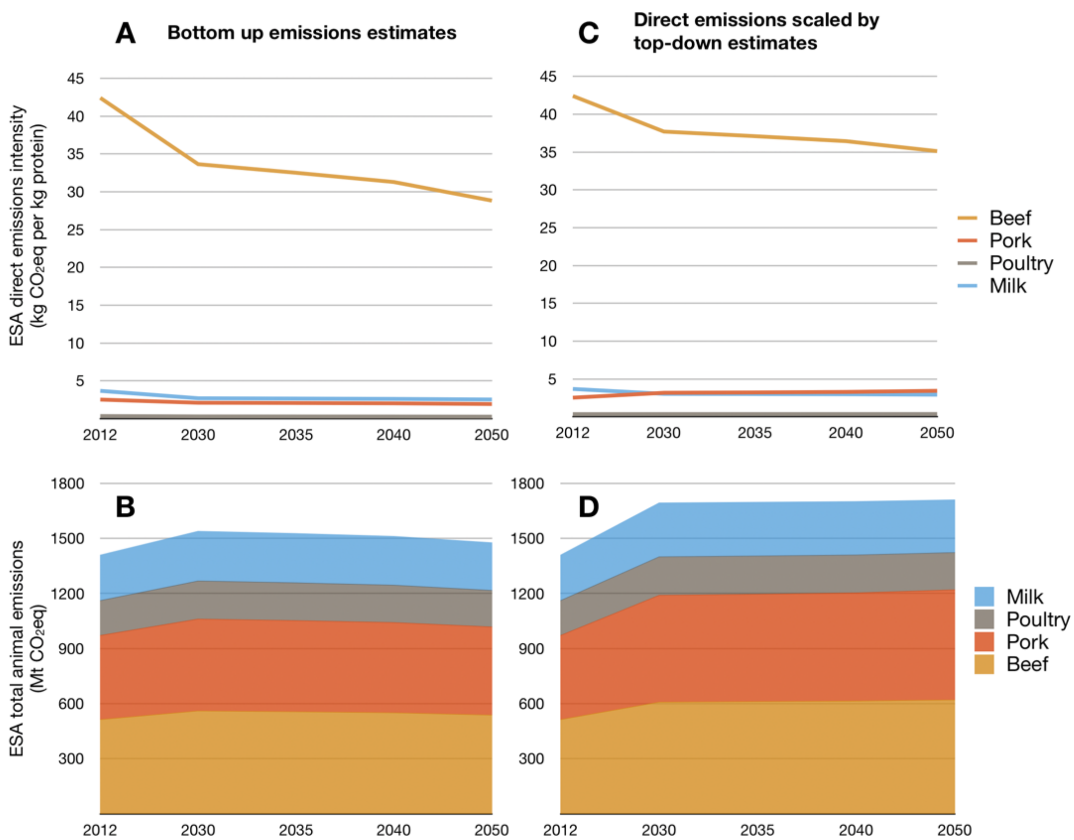

Figure 2. Present and future emissions intensities and total emissions from animal production in East and Southeast Asia (ESA), as estimated by bottom-up emissions models (**A-B**) and direct emissions from intensive production adjusted by a scale factor (1.65) derived from the average of top-down emissions estimates in the US (**C-D**).

4.3 Guidance on addressing rising meat and dairy demand in a warming world

The climate impacts of growing demand for meat and dairy have worrying implications for global warming.

Most countries have not committed to reducing non-CO_2 gases, including methane and nitrous oxide from animals (Climate Action Tracker, 2019).

If countries address CO_2 from fossil fuels, but meat and dairy consumption continues to grow, animal agriculture could take up almost half of the allowable GHG budget for 1.5°C threshold of warming by the year 2030 (Harwatt, 2018). These findings come from bottom-up models that underestimate emissions from increasingly prevalent intensive production systems. Growth in meat and dairy consumption is therefore likely to be more incompatible with limiting global warming than commonly reported.

In countries and local governments that have not committed to reducing methane and nitrous oxide emissions from agriculture (e.g. China, New Zealand), *pressure should be placed on these governments to adopt methane reduction targets*. Even without such targets, efforts to reduce meat and dairy production and demand are critically important.

In places where methane reduction has been committed to (e.g. California, Mexico, Germany, Côte d'Ivoire), the information in this guidance memo can be used to *push back against policies that attempt to mitigate GHGs primarily through intensification*. Policies should primarily reduce demand.

The overall narrative that intensification is best for reducing environmental impacts has the potential to shape policy, but this narrative can be interrupted. *Policymakers should be informed that intensification's potential for limiting GHG emissions is limited.*

Intensification may be effective in particular circumstances, especially in regions where *indirect* emissions are large, provided demand is limited and (in no specific order) the intensification strategy is (a) accompanied by *strong environmental conservation policies* (b) improves farmer livelihoods and *does not lead to industry consolidation that can crowd out smaller producers* (c) *does not entail confinement that harms animal welfare and promotes disease and antimicrobial resistance*. All of the above and more is required to ensure that intensification is done sustainably and with limits to animal confinement, geographic expansion, and unsustainable growth of meat and dairy markets.

5. Conclusions and suggestions for sustainable economic transitions

The challenge of a warming world requires all economic sectors to change their strategies from business-as-usual.

This guidance memo has shown that business-as-usual in animal agriculture, which has consisted of making production more efficient over time, may not result in the expected level of emissions reductions, and will certainly not result in sufficient GHG reductions to limit global warming within safe levels.

In developing strategies that substantially address GHG emissions reductions, *moving back to pastoral animal production is not an effective environmental strategy*, as it can demonstrably worsen environmental impacts, particularly land use and the indirect emissions associated with agricultural expansion. This does not vindicate industrial systems either, which can have many other social and environmental harms.

The best changes to animal food production with the fewest tradeoffs would make already-existing pastoral systems more sustainable and efficient without relying on industrialization to do so. These strategies must be married with other conservation strategies, such as forest protection, which can limit unsustainable growth of production.

The most certain way to limit GHG emissions and other environmental impacts is by reducing meat and dairy production.

It is also necessary to help farmers diversify and incorporate profitable, regionally-appropriate, and sustainable agricultural products. Often, farmers require help in the form of investments in regional infrastructure to make shifting production, storage, and transportation of plant-based agricultural goods less burdensome (Garrett et al., 2017a).

Several strategies may exist for helping farmers transition to lower meat and dairy. Incorporating more crops into extensive animal production, which has the potential makes pastoral production more efficient, can increase output of plant-based goods like timber, beans, and cocoa. Production systems with both animals and crops are referred to as "integrated crop-livestock systems" (Garrett et al., 2017b). In other cases, farmers may benefit more by substituting animals entirely with crops. In the cases of lower-quality "marginal" grazing land for cattle, crops cannot be produced at all. Ranchers in marginal lands could profit from other forms of economic activity besides agriculture, such as solar or wind energy production. In all cases, local producers should be incorporated in planning and decision-making to invest in transitioning production.

All of the above efforts to transform animal agriculture and move producers towards other forms of production must be coupled with limiting demand. Lower demand can avoid environmental tradeoffs of shifting from one form of animal production to another (Hayek and Garrett, 2018). It is also possible to mitigate more GHG through changing demand than improving the efficiency of production (Smith et al., 2013).

Lastly, governments should take seriously the need to monitor and limit emissions from animal agriculture. When sufficient concern around monitoring and reducing agricultural GHG has been mobilized, bottom-up emissions models should not be used in their present state to monitor progress. For governments with ample resources, emissions should be measured from the atmosphere using top-down approaches to determine success and provide an accountability mechanism for hitting targets to reduce emissions.

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