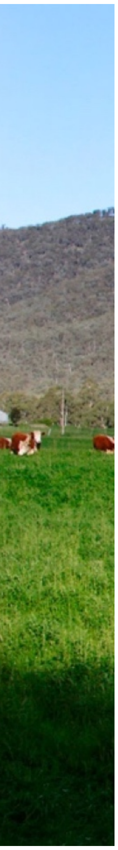
Cattle and the climate: Why industrial production is not the solution to emissions from beef and dairy farms



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A Guidance Memo for the
Tiny Beam Fund

Summary

This Guidance Memo summarizes current scientific thinking about greenhouse gas emissions from different forms of cattle production, including issues that are particularly relevant to low- and middle-income countries (LMICs). It aims to provide the information needed to enable confident, science-based communication with policymakers and others involved in reducing emissions from animal agriculture in LMICs.

It is commonly believed that intensifying beef and dairy production can reduce the emissions created as each unit of milk or meat is produced. This is a logical argument that, broadly speaking, is supported by a number of studies. However, although intensification can potentially benefit both the global climate and the livelihoods of people in LMICs, how effective it is in practice depends on where and how it is implemented. Local conditions can mean that a strategy that is helpful in one situation is counterproductive in another.

Moreover, cattle production is part of a complex and interconnected global food system, and this can lead to unexpected outcomes. For example, cutting emissions in one location can cause them to increase elsewhere, and the economics of intensive production might even cause total, worldwide emissions to rise. Assumptions that intensification will automatically reduce the global climate impact of cattle production are too simplistic.

It is also important to be clear that intensification is not synonymous with industrialization. Intensification refers to an increase in production for each unit of inputs (such as feed or fertilizer), whereas industrialization is a particular means of intensifying production that is characterized by large-scale, high-throughput facilities, with animals fed controlled diets in confined housing. Some intensification strategies involve industrializing production, but many others, such as improving pasture quality or animal health, do not.

Industrial cattle production causes environmental and social problems and oversight in LMICs is weak. Industrializing in a given situation *may* reduce emissions, but this is far from guaranteed. Given that lower-impact strategies for decreasing emissions are available, adopting industrial methods is a risky and unnecessary response to the carbon footprint of cattle in LMICs.

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Introduction

Some individuals working on issues related to animal agriculture in low- and middle-income countries (LMICs) have expressed concern about a widespread perception that pasture-raised ruminants have a higher climate impact than industrially-raised animals. It appears that the "mainstream narrative" outside the scientific community centers on methane produced by enteric fermentation and manure, and that potentially climate-friendly, non-industrial production methods are overlooked or discounted. Concerns have also been raised that carbon footprint models used by scientists neglect important factors such as greenhouse gases (GHGs) from the production of feed for animals in industrial systems, and high levels of emissions from manure management in industrial facilities.

This Memo aims to clarify the current state of science regarding GHG emissions from cattle production, so that misunderstandings among policymakers, corporate executives, and others can be confidently countered. It addresses the following questions:

- What has the scientific community concluded about the climate impacts of different forms of cattle (beef and dairy) production in LMICs?
- What is still controversial, uncertain, or simply unknown?

We begin by introducing some foundational concepts: how cattle production gives rise to emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O); how these gases behave in the atmosphere; and the importance of distinguishing between *emissions intensity* and *total emissions*. We also clarify the difference between *industrialization* and *intensification*, terms that may not be used in the same way by scientists and lay people. We then explain how emissions from cattle production are quantified, and describe some sources of error and uncertainty in those calculations.

These sections provide the foundation for the next, in which we discuss areas in which scientists have reached consensus, and areas that are still under debate, including some issues that are specific to LMICs. The Memo concludes with a set of talking points that can be used when interacting with those who believe that industrializing cattle production is an appropriate response to the problem of GHG emissions from LMICs.

Essential Background

Sources of Greenhouse Gas Emissions in Cattle Production

The main greenhouse gases that are emitted during beef and dairy production are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These gases are generated at many points along the chain of production.

In general, CO_2 emissions result from land conversion or degradation and from use of fossil energy (for growing, processing, and transporting feed crops, for example)[1]. As a rule (with many exceptions), industrial production emits relatively large amounts of CO_2 compared to other systems. Grass-based production can also be responsible for very high CO_2 emissions if forest is cleared to make room for grazing, as the carbon contained in trees, plants, and soil is rapidly returned to the atmosphere (Cederberg et al. 2011).

CH_4 is emitted by the animals themselves (through "enteric fermentation", the breakdown of plant material by micro-organisms in the digestive system) and sometimes by their waste. In general, grazing animals eat fibrous plant materials that lead to relatively high CH_4 emissions compared with animals that are fed maize, soy by-products, and similar foodstuffs. However, the liquid manure storage that is common in industrial facilities can also release large amounts of CH_4.

N_2O mainly results from processes that occur when manure and fertilizer are applied to soil, either by humans or by grazing animals. N_2O emissions from soil and manure involve numerous chemical reactions and biological processes that can vary greatly over small areas and on short timescales, making it difficult both to accurately measure N_2O in the field and to simulate it on a computer. This gas is recognized as a major source of uncertainty in GHG emissions inventories (Oenema et al., 2005; Reay et al., 2012).

Grasslands can in some circumstances act as a carbon *sink*, absorbing more GHGs than they emit. Based on this, ambitious claims have been made (generally outside the peer-reviewed scientific literature) about how eating pasture-raised meat "can solve global warming". Box 1 summarizes how carbon sequestration works and explains why, although it can play a role in mitigating climate change, grazing is not a panacea.

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[1] *CO_2 is generally only considered relevant when it is a product of fossil fuel use or is released by processes such as a one-way conversion of forest to other land uses. CO_2 that is released by, say, animal respiration is generally considered part of a short-term carbon cycle (atmospheric CO_2 → absorbed by plants → eaten by animals → respired back to atmosphere) that does not change the net amount of CO_2 in the atmosphere.*

BOX 1: Carbon Sequestration on Grazing Lands – A Greenhouse Gas Sink?

When plants die, the carbon they have transferred from the atmosphere into their tissues can become part of the soil organic carbon pool. Some of that carbon is quickly decomposed by microbes and CO_2 returned to the atmosphere, but a portion may be relatively resistant to decomposition and able to remain in the soil for many years. When the stock of stable soil carbon is increased in this way, carbon sequestration is said to be taking place.

Whether carbon sequestration actually takes place, and how much carbon is sequestered, depends on complex interactions between numerous factors including rainfall, temperature, vegetation, and soil properties. Grazing animals can affect the carbon balance through several mechanisms. One is that grazing can stimulate the growth of roots, which have a more direct route into the soil carbon pool than above-ground plant material. On the other hand, grasslands that are over-grazed have little plant biomass to return to the soil, and can rapidly lose carbon.

Some studies that have tracked soil carbon levels over time on grazing lands have indeed found that large amounts of carbon were sequestered. However, these points are important for following the debate around grazing and carbon sequestration (Garnett et al., 2017):

1. The carbon build-up will not continue indefinitely. The soil will eventually reach an equilibrium in which the amount of carbon that is added equals the amount that is released
2. Sequestration is potentially reversible: sequestered carbon can be re-released under adverse conditions such as drought or overgrazing
3. A grazing system is only a net carbon sink if any sequestered carbon offsets *all* of the GHG emissions from the system, which can be difficult to achieve.

The Distinct Climate Effects of CO_2, CH_4, and N_2O

CO_2, CH_4, and N_2O contribute in different ways to global temperature change. CO_2 has a relatively weak heat-trapping effect but persists for a very long time: 25% of a pulse of CO_2 emitted today will remain in the atmosphere indefinitely (Archer, 2005). CH_4 is more effective at trapping heat than CO_2, but it breaks down through chemical reactions in the atmosphere in little more than a decade. N_2O combines the worst of both worlds, as it is both a powerful greenhouse gas and also fairly long-lived, with an atmospheric lifetime of around 115 years.

Because CH_4 is powerful and short-lived, if we care about temperature changes in the very near future – perhaps to avoid reaching dangerous tipping points in the near term - we will give a high weight to reducing CH_4 emissions. But if we are more concerned about the climate change that will affect our descendants, long-lived CO_2 becomes more important. Almost all scientific papers combine emissions of CO_2, CH_4, and N_2O into a single quantity, "CO_2-equivalents", using conversion factors that assume that 100 years is the relevant timescale. This convention makes it easier to compare different production systems, but it can also obscure important differences between them, such as whether they emit more short-lived CH_4 (typical of pastured animals) or more long-lived CO_2 (characteristic of energy-intensive industrial production and any system that involves deforestation).

Emissions Intensity and Total Emissions

With individual GHGs and with CO_2-equivalents, it is important to distinguish between *emissions intensity* and *total emissions*.

Emissions intensity is the quantity of GHGs released *per unit of something*: a single animal, a hectare of land, a kg of milk, a tonne of carcass weight, a kg of live weight gain, etc. In general, emissions per cow or per hectare are relatively low in LMICs, because cattle tend to be smaller and there tend to be fewer of them in a given area. On the other hand, emissions per kg of milk or beef are often found to be relatively high, because LMIC cattle tend to be less productive. Emissions per cow or per hectare can certainly be important to understand. However, as demand for animal products is rising, emissions per kg of product are usually taken to be the most relevant quantity. *This Memo therefore generally refers to emissions intensity per kg of milk or meat.*

The total quantity of GHGs released depends on both emissions intensity and how much milk, meat, etc. are produced:

Total emissions (kg CO_2-eq) = Emissions intensity (kg CO_2-eq per kg product) x Amount of product (kg)

This distinction has some important implications. For one, a region or production system with low emissions intensity can still produce high total emissions, if it produces a large amount of milk or beef. This is the case for North American beef production, for example: although its emissions intensity per kg of carcass weight is less than half of that of Sub-Saharan Africa, so much beef is produced that North America is responsible for more tonnes of CO_2-equivalents than Sub-Saharan Africa (Gerber et al. 2013). *North American beef systems can be regarded as efficiently producing relatively low-emissions food, or they can equally be viewed as a large source of avoidable emissions.*

Also, decreasing emissions intensity only reduces overall GHG emissions if production does not then rise enough to compensate for that reduction. As we show later, *it is possible that, because of economics and human behavior, cutting emissions intensity can actually lead to higher total emissions*.

Industrial Production, Intensification, and Productivity

In the popular media and among lay people, a clear distinction is often made between "industrial" beef and dairy production, and contexts in which cattle are raised more "naturally" (pasture-based, grass-fed, organic, traditional, smallholder, etc.). Some scientific studies directly address industrial production methods, but research papers and reports also commonly refer to intensification and productivity in cattle production systems. "*Industrial*", "*intensification*", and "*productivity*" are overlapping but not identical concepts, so it is important to define these terms.

Industrial production systems have been described as "Large-scale and market-oriented livestock production systems that rely on fully enclosed housing, high capital input requirements (including infrastructure, buildings and equipment) and purchased non-local feed or on-farm intensively-produced feed" (Gerber et al., 2013). These systems involve "high-throughput production to grow thousands of animals of one species… for one purpose" (Pew Charitable Trusts, 2008).

Agricultural *intensification* is "an increase in agricultural production per unit of inputs (which may be labour, land, time, fertilizer, seed, feed or cash)" (FAO, 2008). In beef and dairy production, intensification can take many forms. For example:

- Improving pasture quality and providing shade and clean water, to increase milk production or weight gain
- Using cattle breeds that more efficiently convert feed into milk or meat
- Increasing fertilizer inputs to improve yields of crops used for animal feed
- Feeding precisely-formulated rations of highly-digestible feedstuffs to cattle in feedlots, to increase rates of weight gain
- Using pharmaceutical technologies (steroid implants, hormones, antibiotics, etc.) to raise the efficiency at which animals convert feed into meat or milk.

These intensification methods would increase *productivity*, the quantity of output per animal or per herd over some time period (e.g. kg of milk per cow per year).

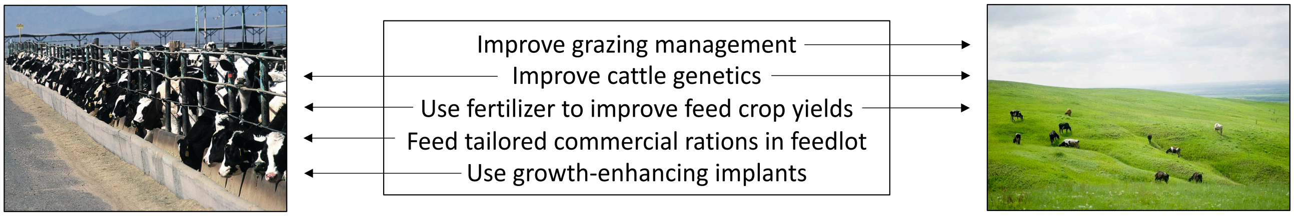

Figure 1: Intensifying beef and dairy production and improving cattle productivity may lower GHG emissions per kg of milk or meat. Some intensification strategies involve industrializing production (left), but many others do not (right), or can be used in a range of production systems. Image credits: Jeff Vanuga, USDA NRCS; Alexey Komarov (CC BY 3.0).

Industrial systems are highly intensified, but – as the above examples show - intensification does not necessarily imply industrialization (see Figure 1). Intensification can involve a transition from one production system to another (e.g. pastoral to industrial), but it can also mean improving an existing system (Gerssen-Gondelach et al., 2017). *When confronted with an argument that cattle production must be intensified, it is important to clarify what method(s) of intensification is/are intended.*

Quantifying Emissions

To compare emissions from cattle production systems, or to examine the effects of intensifying an existing system, the various GHG sources/sinks must be quantified. This relies on several levels of data-gathering and modeling (Figure 2).

First, empirical (real-world) data have to be collected for individual emission processes. In the case of enteric CH_4, for example, cows can be trained to stand in an enclosed respiration chamber, or can wear portable devices that collect the gases they exhale. As CH_4 emissions depend on cattle diets, genetics, etc., these experiments need to be carried out in as wide a range of situations as possible.

Because of financial and logistical constraints, however, experimental data cannot be obtained in all possible contexts. This means that the available data must be used to create estimates or models that can be used in circumstances where measurements do not exist. These models and estimates can be very simple, or rather complex. At one extreme, simple “emission factors” have been generated: continuing with the CH_4 example, an African multi-purpose cow emits roughly 31 kg CH_4 per year (IPCC 2006). At the other extreme, sophisticated models calculate CH_4 emissions tailored for specific situations by simulating the many physical, chemical and biological processes that occur in ruminant digestive tracts.

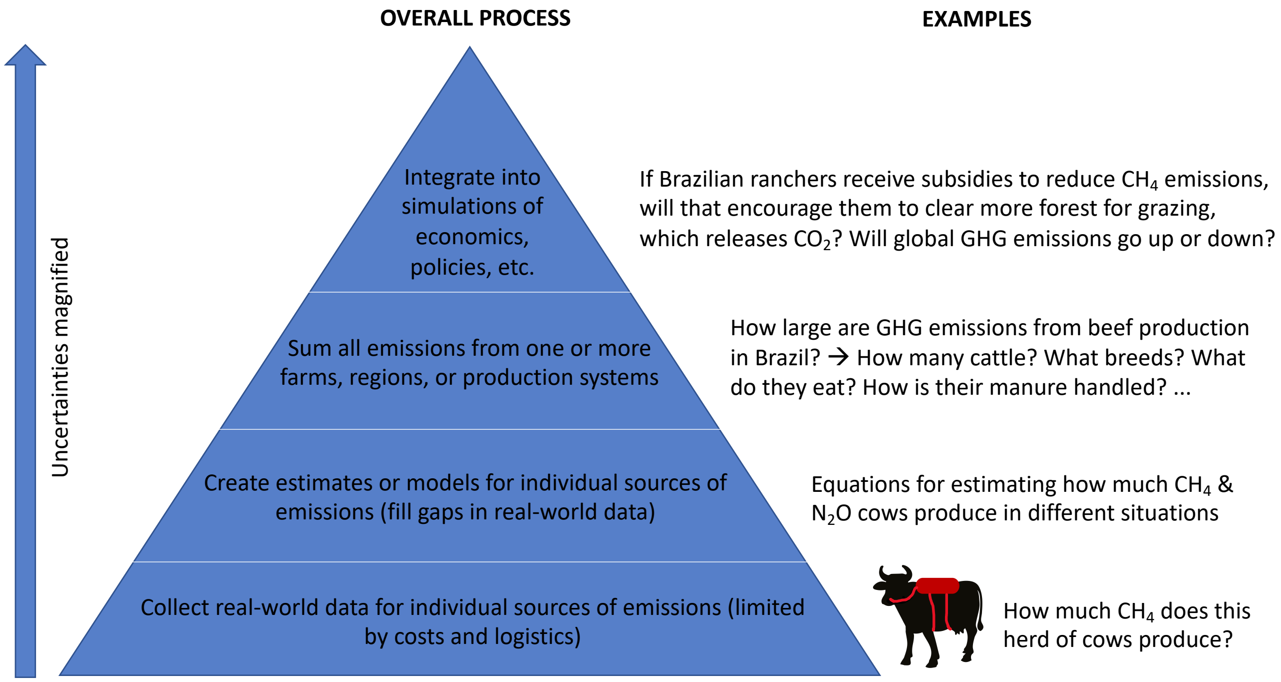

Figure 2: Stages involved in quantifying GHG emissions from beef and dairy production. These steps involve many research groups, have been worked on over years or decades, and are continually being refined, updated, and debated.

Using the data or models available for individual emission processes, the next step is to sum up all the emissions from a whole farm, region, or production system. This is accomplished through a lifecycle analysis/assessment (LCA) or similar modeling approach[2]. Because there are so many potential emissions sources, and they can vary so much with environmental conditions, cattle characteristics, farm management, etc., performing an LCA or running a farm or system model requires a substantial amount of information about the farm or system being evaluated (Box 2).

Finally, the information gathered from LCAs or similar models can be integrated into complex simulations that attempt to show how changing policies, demographics, or economic factors will affect total GHG emissions from a region or production system. Each step in this process incorporates data from the previous one, meaning that *the uncertainties in emissions estimates are magnified on moving from field/laboratory experiments to simulating the global food system*.

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[2] The methodology generally used in research papers is much more inclusive than the IPCC approach to national emissions accounting, in which only domestic emissions from enteric fermentation and manure are allocated to each country's livestock sector.

BOX 2: Collecting data for a lifecycle assessment – an example

O'Brien et al., (2012) performed an LCA to compare the environmental impacts of grass-based and confinement dairy farms in Ireland. The data they gathered included the number of milking cows, their milk production (including fat and protein content), body weight, replacement rate, feed consumption, and the amount of fertilizer used on the farms. For each feed ingredient, its amount and national origin had to be evaluated, and emissions factors estimated for the fuel and fertilizer used to produce it (as well as land use change emissions in the case of the soy and palm products used in the feed).

Methane emissions from the confined cows in the O'Brien study were calculated using a model that "requires data on animal weight, body weight change, animal activity, feed digestibility, milk production and composition, and replacement rate of cows". Emissions from manure depended on factors such as the amount of time the animals spent indoors, and varied with the time of year. Clearly, there are many decisions to be taken when compiling data for an LCA, and different scientists often make different choices, potentially leading to somewhat different results (Baldini, Gardoni, & Guarino, 2017).

The State of the Science

Numerous research papers and reports argue that intensification and productivity improvements in beef and dairy systems are needed to reduce the climate footprint of the sector, especially in LMICs (Gerber et al., 2013; Gerssen-Gondelach et al., 2017; Hagemann et al., 2011; Havlík et al., 2014; Valin et al., 2013). These arguments are logical and broadly supported by evidence, especially if it is accepted that rising global demand for animal products must be met. At the same time, studies also find that *the climate benefits of intensification depend on the local context and the methods used to intensify, and intensification can actually be counterproductive in some circumstances*. This section first outlines the rationale for intensification in general, and for industrialization in particular, then examines some of the factors that complicate the picture.

Evidence Supporting Intensification and Industrialization

Globally, enteric fermentation and manure are the largest sources of emissions (Gerber et al., 2013), which means there are several reasons why intensification and productivity improvements should reduce emissions. For instance:

- Improving the efficiency with which feed is converted to milk or body mass means that less of the carbon and nitrogen in the feed is converted into CH_4 and N_2O
- Cattle that grow faster can be slaughtered younger, so they emit less CH_4 and produce less manure over their lifetimes
- When cattle reach higher slaughter weights, fewer animals are needed to produce a given quantity of meat, and fewer "unproductive" parent animals are required to produce replacement calves
- The earlier a dairy cow gives birth and starts lactating, the less time she spends emitting CH_4 and producing manure as a non-producing heifer
- Feeding a more digestible diet (such as grain) both increases milk and meat yield and reduces CH_4 emissions from the rumen microbes that break down roughage (such as grass)

In addition, intensifying production means that less land is needed to produce the same amount of milk or meat, so the GHG releases caused by deforestation can – in theory – be avoided. Broadly speaking, emissions models support these arguments: Gerber et al., (2011) calculated that, *as milk output per cow increases from the very low levels characteristic of LMICs, emissions intensity decreases sharply. However, their work also showed that the positive effects then start to level off, with further increases in productivity yielding diminishing returns*.

Some studies have found that industrialization, specifically, can reduce emissions intensity. In one such paper, Capper (2012) calculated the emissions due to three US beef systems: "Conventional" (calves started on pasture then finished in feedlots using growth-enhancing technologies such as steroid implants and hormone supplements), "Natural" (feedlot finishing without growth-enhancing technologies), and "Grass-Fed" (animals on pasture throughout their lives). In this model, Conventional beef had the lowest climate footprint and Grass-Fed the highest, for reasons similar to those given above.

Methods and Context Matter

While there are logical arguments for intensifying production, intensification strategies need to be adapted to the local context. A few examples: Feeding maize to cattle can reduce CH_4 emissions, but CO_2 released by tilling the soil can outweigh the benefits – depending on the soil type and crop rotation (Vellinga & Hoving, 2011). In New Zealand, high-input dairy farms have the lowest carbon footprint in some regions but the highest in others (Reisinger, Ledgard, & Falconer, 2017). Both improving pastures and using feedlots lowered emissions in a study in Brazil, but the mitigation potential of each strategy was limited because only relatively low-production beef cattle could withstand the heat, humidity, and diseases in that region (Cardoso et al., 2016).

A Missing Piece: Carbon Sequestration in Grazing Systems

Many modeling studies do not include the possible effects of soil carbon sequestration (Box 1). However, this is increasingly recognized as an important ingredient in emissions calculations. To give one recent example, Stanley et al. (2018) used measurements of soil carbon from grazing experiments on a research farm in an LCA that compared US feedlot- and grass-finished beef. The industrial system had lower emissions if carbon sequestration was ignored, but the situation was reversed when the carbon absorbed by the grazing system was included in the calculation.

The sequestration rate measured by Stanley and co-authors was unusually high and, for the reasons explained in Box 1, carbon sequestration is unlikely to decisively shift the balance in favor of grazing systems in all situations (see Garnett et al., 2017). Nevertheless, *carbon sequestration in grazing systems is a relatively new and active area of research that may challenge some previous conclusions about industrial vs grass-based production*.

Emissions in High-Income Countries May be Underestimated

As well as the experiments and modeling discussed above, GHG emissions can also be measured from towers, aircraft, and satellites. There are fewer of these measurements and they rely on simulating how gases move in the atmosphere, but they provide a useful check on the results obtained via modeling. *The data suggest that the emissions gap between LMICs and HICs is smaller than previously believed, and that the benefits of industrialization have been overestimated*. The reasons for the discrepancy between the two methods are hotly debated at present, but some researchers argue that the data and models used to calculate emissions as described in the previous section simply contain too many assumptions and uncertainties to give accurate results (Miller, Michalak, & Wofsy, 2014). The Guidance Memo by M. Hayek provides a more in-depth explanation of this issue.

Different Timescales Can Favor Different Systems

Researchers are finding that, because of the different lifetimes and warming potentials of CH_4, N_2O, and CO_2, *the timescales used for evaluating the global warming effects of emissions can change which kind of production system has the lowest climate footprint*: low-input grazing systems tend to be favored on long timescales (centuries), while high-input production can be less damaging on shorter ones (Pierrehumbert & Eshel, 2015; Reisinger et al., 2017). This work highlights the fact that emissions modeling involves value judgments about climate change timescales that are often not explicitly recognized.

System Boundaries Can Determine Outcomes

Emissions modeling also requires making decisions about where to draw the boundaries of the system, and what influencing factors to include. These decisions can have a significant effect on the conclusions that are drawn.

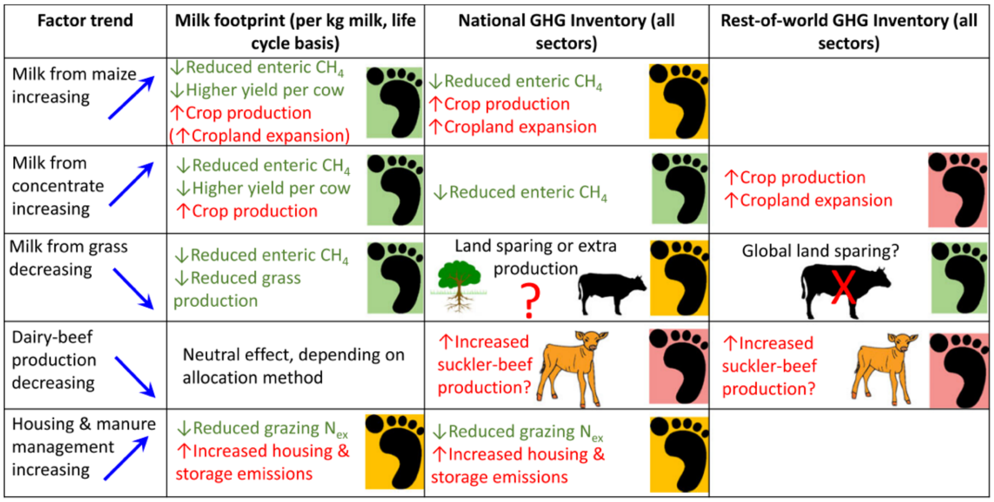
Capturing remote land-use change

Improving productivity in one location may have the consequence of increasing emissions in another. This was the case in a study of dairy production in Ireland that compared emissions from grass-based and confinement dairies (O'Brien et al., 2012). Although *on-farm* emissions per kg milk were greater in the grass-based dairy, *total* emissions were higher in the confinement system. This was because the confinement dairies fed a larger amount of concentrates containing palm and soybean ingredients, leading to CO_2 emissions from land-use change (LUC) in Malaysia and Brazil.

Another recent study also found that LUC increased emissions, but for somewhat different reasons. Styles et al. (2018) investigated the effect of increasing milk production by raising the amount of maize and concentrates in dairy cows' diets, and found that this indeed reduced the *direct GHG emissions from dairies in the UK*. However, there were two downstream effects that could increase *total, worldwide emissions*.

First, the extra land required to produce maize and concentrates came from converting UK grassland into arable land. Tilling grassland releases carbon, so increasing crop production added to GHG emissions. Second, in the higher-production dairies, fewer cows were needed to satisfy the demand for milk, so fewer dairy calves were available to meet demand for beef. If the UK grassland "spared" from grazing was used for low-intensity beef production and/or reforested, beef demand was met through imports from Brazil, where deforestation to produce extra pasture caused total GHG emissions to increase (Figure 3).

These examples show the importance of making the boundaries of the modeled system wide enough to capture effects that are exported to other parts of the world/food system. The Styles paper also illustrates the difficulty of doing so: the final GHG balance in their model depended on assumptions about how land is used in the UK (and Brazil), which depends on factors such as policies, economic conditions, and consumer preferences. In addition, the O'Brien study demonstrates that the local context and the specific methods used to increase



Factor trend	Milk footprint (per kg milk, life cycle basis)	National GHG Inventory (all sectors)	Rest-of-world GHG Inventory (all sectors)
Milk from maize increasing ↗	↓Reduced enteric CH_4 ↓Higher yield per cow ↑Crop production (↑Cropland expansion) 🟩	↓Reduced enteric CH_4 ↑Crop production ↑Cropland expansion 🟨	
Milk from concentrate increasing ↗	↓Reduced enteric CH_4 ↓Higher yield per cow ↑Crop production 🟩	↓Reduced enteric CH_4 🟩	↑Crop production ↑Cropland expansion 🟥
Milk from grass decreasing ↘	↓Reduced enteric CH_4 ↓Reduced grass production 🟩	Land sparing or extra production ? 🟨	Global land sparing? X 🟩
Dairy-beef production decreasing ↘	Neutral effect, depending on allocation method	↑Increased suckler-beef production? 🟥	↑Increased suckler-beef production? 🟥
Housing & manure management increasing ↗	↓Reduced grazing N_{ex} ↑Increased housing & storage emissions 🟨	↓Reduced grazing N_{ex} ↑Increased housing & storage emissions 🟨	

N_{ex}=N excretion; green=positive effect (reduces footprint); red=negative effect (increases footprint); amber=uncertain net effect.

Figure 3: Conceptual illustration of the possible effects of intensifying UK dairy production, at the scale of the farm, nation, and world. Intensification tends to reduce emissions on the farm (green footprints, second column), but this may be at the expense of increasing global emissions (red footprints, fourth column). From Styles et al. (2018).

production can make a significant difference to emissions. Unlike in the land-rich USA (Capper 2012), industrialization in Ireland involved importing feed from regions undergoing rapid LUC, so the overall effect was to increase emissions.

Including economic effects

In theory, intensifying production should reduce the climate footprint of milk and meat because (1) it leads to lower emissions per kg of product (especially CH_4), and (2) less land is needed for the same production, reducing the pressure to clear forests for grazing or cropping land. In practice, *economics and human behavior can mean that intensification is not as helpful as expected – and may even be counterproductive* (Lambin & Meyfroidt, 2011; Paul et al., 2019). One reason is that efficient production tends to be more profitable, which can encourage farmers to increase production, offsetting some or all of the emissions "saved" by intensification. If intensified production leads to cheaper and more abundant animal products, consumer demand may also increase, again prompting a rise in total production. Deforestation can also increase as livestock production intensifies, if existing producers decide to expand their operations or new ranchers are attracted to the area.

The importance of these forces (known as the "rebound effect", or "Jevons' paradox") in livestock production is highly debated, with different studies reaching very different conclusions (Cohn et al., 2014; Kaimowitz & Angelsen, 2008; Müller-Hansen et al., 2019; Valin et al., 2013). Nonetheless, the debate emphasizes the importance – and complexity – of including both biophysical and human factors when trying to simulate changes in an intricate, interconnected system like worldwide food production. It also highlights that *good governance and well-crafted policies are needed to ensure that intensification does not lead to unintended consequences*.

A wild card: the fate of former grazing lands

Moving from pastoral to industrial cattle systems in LMICs may reduce the emissions intensity of meat and milk production, but it is important to consider how the current grazing land might be used in such a scenario. It has been proposed that, if some of the land were allowed to "re-wild", termites and wild ruminants, which both produce CH_4, would re-occupy some of the ecological niches vacated by domestic cattle (Manzano & White, 2019). This is a rather speculative suggestion that has not yet been thoroughly tested, but it underscores the complexity of the problem and the need for a full systems understanding.

Issues Specific to Low- and Middle-Income Countries

Before about 2010, few emissions calculations for cattle production in LMICs had been carried out. Since then, at least 16 have been published for milk production and considerably more for beef. Almost all of the beef studies relate to Brazil, and most of these consider different methods of pasture management (as most Brazilian beef comes from grazing animals, although feedlot finishing is rapidly expanding; Vale et al., 2019).

On the whole, the LMIC beef studies paint a similar picture to the HIC research: LCAs predict that intensification (particularly improvements to grazing management) generally reduces emissions; avoiding deforestation is critical; and local context and specific methods make a difference to outcomes. Much of the work on the rebound effect (above), in which lower emissions intensity can lead to higher total emissions, relates to Brazil and other Latin American countries.

Little of this research directly compares industrial and non-industrial beef production. One study found the carbon footprint of feedlot-finished beef in Uruguay to be lower than that of cattle finished on rangeland or improved pastures (Modernel, Astigarraga, & Picasso, 2013), but two others concluded that, in Brazil, improved pastures performed at least as well as feedlots in this respect (Cardoso et al., 2016; Pashaei Kamali et al., 2016). Modernel and co-authors calculated that, despite its lower GHG emissions, the feedlot system had the highest impacts in other environmental impact categories (fossil energy use, soil erosion, nutrient imbalances, and pesticide contamination risk). *While some studies conclude that industrialization can reduce GHG emissions, industrialization also risks causing or exacerbating other environmental problems*.

The LMIC milk studies highlight two particular issues that are explained in the following sections: the different functions of cattle in LMICs compared to HICs, and lower levels of emissions in detailed, farm-scale studies than are found by global models.

The many functions of smallholder cattle

Animals in smallholder systems often perform many more functions than cattle on industrial farms, and this complicates the way in which emissions are divided between ("allocated to") multiple products from a farm.

A European dairy farm, for example, produces essentially two products: milk and meat (from "surplus" calves and culled cows). This means that, to calculate GHG intensity per kg of milk, some emissions must be subtracted from the total and allocated to meat production (i.e., milk emissions = total emissions – meat emissions). In African smallholder systems, however, cattle provide many goods and services: meat, milk, manure to sell, burn, or use as fertilizer, draught power, insurance, social status, wealth storage, etc. If industrial milk gets emissions "credit" for also producing meat that would otherwise be obtained in some other way, it makes sense that smallholder milk production should also be credited for these other products.

Researchers have started to develop methods for allocating emissions between a mixture of tangible and intangible, market and non-market products, and *splitting the emissions in this way can reduce the GHG intensity of smallholder milk production to levels very similar to those of industrial dairies* (Weiler et al., 2014). Scientists in LMICs point out that productivity improvements would probably mean reducing the size of the herd (if the same total production were maintained), which may lead to the loss of some services that are essential to small farmers (Garg et al., 2016; Udo et al., 2016). *In principle there are many development benefits to increasing cattle productivity in LMICs, but intensification strategies must be compatible with the needs, desires, and constraints of the farmers themselves.*

Low-emissions farms in LMICs

Detailed case studies of smallholder and grass-based milk production in LMICs tend to find emissions intensities that are much lower than those presented in the widely-quoted 2013 FAO report on livestock emissions (Gerber et al. 2013), and at the very low end of the ranges found in more recent FAO dairy research (FAO and GDP, 2018). For example, Udo et al. (2016) estimated values of 1.3 – 2.3 kg CO_2-eq per kg milk for Kenyan smallholder dairies (depending on farm type and allocation method), compared to the FAO estimate of 9 kg CO_2-eq per kg milk for Sub-Saharan Africa in general.

These striking differences are partly due to allocating emissions between multiple products and services as discussed above, but that is not the whole story. Other possibilities include (1) a bias towards including unusually data-rich, well-managed farms in research studies (Lizarralde et al., 2014); (2) the omission of land-use change in some work (Gaitán et al. 2016); and (3) the use of detailed, on-farm data that more accurately represents the studied farms than the regional statistics used by the FAO (Garg et al., 2016).

Although differences in methodologies make it difficult to compare emissions numbers in detail, at a minimum these findings suggest that *there are smallholder and grazing dairy farms in LMICs that already have a low climate footprint*. Given that practices on existing farms are probably within reach of other local farmers (given appropriate assistance), *they could well be better models for low-emissions production than new, industrial systems that have many negative social and environmental side-effects*.

Why Researchers Disagree

Clearly, the issue of how best to deal with GHG emissions from cattle production is still highly debated. This is partly because accurately quantifying emissions is simply a difficult task: the biological, physical, and chemical processes involved are complicated, interrelated, and not always well-understood, and the data needed for the calculations are not always available or reliable. Projecting emissions into the future requires complex models that integrate many different biophysical and human factors, relying on assumptions that may or may not be valid.

In addition, differences in factors as diverse as climate, soils, and the multiple roles of animals mean that solutions that work in one context may be ineffective or harmful in another. Broad, global studies have difficulty capturing these effects, while detailed, local studies often cannot be generalized. Further complicating matters, the changing climate may itself alter emissions from agriculture. As one team acknowledged, each paper "contribute[s] to our necessarily evolving and increasingly nuanced understanding of beef production and food system sustainability issues generally" (Pelletier, Pirog, & Rasmussen, 2010). No single piece of work is conclusive.

On a deeper level, the way in which the problem is viewed, and the solutions that are considered, depend on a researcher's training, background, expertise, research partners, funding, and worldview. Some research teams will consider only biophysical issues, others will attempt to include economic or policy effects, and yet others will point out ethical considerations such as asking for emissions reductions from people who have contributed little to climate change so far. Research in food and agriculture is always touched by beliefs, which may or may not be consciously recognized, about matters such as whether science, technology, and markets can solve humanity's problems, and how we should relate to nature, animals, and each other (Garnett, 2014).

Arguments Against Industrial Cattle Production in Low- and Middle-Income Countries

The emissions-related arguments for intensification and industrialization were presented above. Here, the evidence that complicates and contradicts that picture is condensed into a set of concise counter-arguments that can be used in discussions with those who believe that industrialization of animal agriculture in LMICs is the right way to counter climate change.

1. Intensification is not equivalent to industrialization

Increasing productivity does not require adopting industrial production methods. The FAO's 2013 assessment of global emissions from livestock production states that mitigation "can be achieved within existing systems; this means that the potential can be achieved as a result of improving practices rather than changing production systems (i.e. shifting from grazing to mixed or from backyard to industrial)" (Gerber et al., 2013). For example, improving grazing management can increase productivity (by providing more and better quality forage), reduce CH_4 emissions (by providing lower-fiber forage), and potentially lead to soil carbon sequestration. *Most of the climate benefits of intensification occur when very low production levels are modestly improved, so it doesn't make sense to incur all the problems of industrial animal production in return for marginal reductions in emissions*.

2. Industrialization will not necessarily reduce emissions per kg of milk or meat

The effect of intensification on emissions intensity depends on the method(s) used to improve productivity, and the context in which they are used. For instance, it is possible to increase milk output per cow by replacing forage with soybean or palm by-products. However, if forested land was cleared to grow the crop (releasing CO_2), fertilizer is used in its production (releasing N_2O), and/or the cattle are kept in energy-intensive industrial facilities, the overall effect may be to *increase* emissions per kg of milk or meat. In addition, there is some evidence that emissions from industrial systems are in fact higher than has been estimated in the past.

Given the many environmental and social problems of industrial animal production, advocates of intensification via industrialization should be able to demonstrate that the specific system that they propose will genuinely reduce GHG emissions per unit product. In addition, as regulation of industrial food animal production is weak in many LMICs and non-compliance appears common (Lam, Fry, & Nachman, 2019), they should also provide evidence that the system will actually be operated as they describe.

3. Reducing emissions per kg of milk or meat will not necessarily reduce total emissions

Reducing GHG emissions intensity may cause higher *total* emissions. Mitigation measures have to be made attractive to farmers, and one way of doing that is to subsidize them or otherwise demonstrate that they are profitable. If cattle production becomes more profitable, then total production may increase enough to outweigh the reduction in GHG emissions per kg of product. Similarly, if more efficient production causes prices to fall, overall demand and consumption may rise. *Improving farm productivity and profitability can certainly be good goals for LMICs, especially for the smallholder farmers who supply much of the food in these countries. However, efforts to intensify production need to be accompanied by policies that are carefully designed to avoid unintended consequences*.

4. The harmful side-effects of industrialization outweigh any potential benefits

Industrializing animal production in an attempt to reduce emissions is very likely to lead to other problems, such as pollution of waterways with nitrogen and phosphorus and bacteria from manure. This can cause human illnesses and toxic algal blooms, and impair the ability of water bodies to support the fish and other aquatic life that ecosystems and livelihoods depend on. These problems are particularly acute when animals are confined in feeding areas where they produce more waste than the surrounding land can absorb. The papers and reports that advocate for intensification generally acknowledge the existence of these problems in industrial production but rarely give recommendations for solving them. *Given that climate benefits can be achieved by improving the management of existing, non-industrial systems, industrializing cattle production to reduce GHG emissions is a risky, high-cost, and unnecessary strategy.*

5. The real solution is to reduce consumption of animal products in high-income countries

Instead of asking "how can we change the ways in which meat and milk are produced in LMICs so that we can meet rising demand without causing dangerous climate change?", we should ask "how can we achieve a level of animal production and consumption that meets everyone's nutritional needs without causing dangerous climate change?". As scientists have pointed out, "GHG emissions from livestock and their impacts are relatively modest when compared with the contribution that livestock make to the livelihoods of hundreds of millions of poor people" (Herrero et al., 2009), while people in HICs consume more animal protein than they need (Sans & Combris, 2015).

Numerous studies have concluded that the environmental (and especially, climate) impacts of animal products are greater than those of plant-based foods (e.g. Hedenus, Wirsenius, & Johansson, 2014; Popp, Lotze-Campen, & Bodirsky, 2010; Stehfest et al., 2009). Fortunately, human nutritional needs can be met while reducing current global levels of animal production, with smaller numbers of livestock making use of feed sources – such as grasslands – that are not directly useful to humans (Berners-Lee et al., 2018; Röös et al., 2017).

Acronyms

GHG: Greenhouse gas
HIC: High-income country
LCA: Lifecycle analysis, lifecycle assessment
LMICs: Low- and middle-income countries
LUC: Land-use change (e.g. deforestation)

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