Columbia Law School Environmental Law Clinic

Livestock and Climate Change - Annotated Bibliography

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INTRODUCTION

Over the past two decades, efforts to address climate change have primarily focused on reducing carbon dioxide (CO_2) from fossil fuel combustion. The potential contribution of livestock production to climate change has been largely overlooked. Recent scholarship suggests that activities related to livestock production constitute a significant proportion of anthropogenic greenhouse gas (GHG) emissions. Although estimates of livestock's contribution to our overall GHG emissions range broadly—from 18% to 51%—there is no question that this impact warrants serious consideration from policy makers.

Moreover, based on projections of population growth and income growth, the consumption of livestock products is expected to double by 2050. As livestock systems intensify and expand to meet this demand, emissions will also increase substantially. Given the level of uncertainty related to current emission estimates, future consumption estimates, potential efficiency gains, and the large diversity of livestock production systems, there are no precise estimates of future emissions from the livestock sector. Nonetheless, there is broad consensus that a business-as-usual approach, in which livestock production continues to increase to meet demand, with only moderate efficiency gains over time, is unsustainable, and that urgent measures—including a reduction in the global demand for livestock productions—will be required to mitigate emissions from this sector.

This bibliography compiles recent scholarship on the interaction between global livestock production and climate change. Section I identifies resources that provide a general overview of the subject, and are therefore recommended as a starting point for research. Section II addresses scholarship relating to the demand, consumption and production of livestock products, including quantitative projections of current and future production, as well as qualitative assessments of the conditions which cause demand growth in this sector. Section III reviews current estimates of GHG emissions from livestock production, and assessments of the methodologies used to obtain those estimates. Section IV discusses the potential impacts of climate change on the livestock system, how livestock systems may adapt to these impacts, and the implications for future production. Finally, Section V reviews policy recommendations from scholars and international organizations for mitigating emissions from livestock production.

In each Section, resources are arranged by sub-topic and then by date.

I. GENERAL INFORMATION

The following resources provide a general overview of the interaction between livestock production systems and climate change. We recommend these as a starting point for research. Sub-section A describes some key reports that are cited by other sources throughout this bibliography, and sub-section B describes additional documents and compilations that provide a broad overview of this topic. To the extent that some of these resources discuss specific issues in depth (such as demand projections or emissions estimates), they are also discussed in later sections of this bibliography.

A. Significant Reports from the International Community

FOOD AND AGRICULTURE ORGANIZATION (FAO), WORLD LIVESTOCK 2011: LIVESTOCK IN FOOD SECURITY (A. McLeod ed., Rome, FAO 2011).

This is the most recent report from the FAO regarding the global livestock sector. It expands upon the FAO's 2009 report on the "State of Food and Agriculture", which examined the multiple roles played by livestock in the food security of the poor.[1] Although the report does not focus on the environmental or climate change impacts of livestock production, it does contain the FAO's most recent data on the current global production and consumption of livestock products, including a highly detailed overview of regional and country-specific consumption patterns. For a complete overview of the FAO's statistics, see the discussion in Section II at page 9.

Robert Goodland and Jeff Anhang, *Livestock and Climate Change: What if the key actors in climate change are cows, pigs, and chickens?* (Worldwatch Institute 2009).

This study responds to FAO (2006) estimates of emissions from the livestock sector,[2] arguing that the FAO has significantly undervalued the impact of livestock on climate change. Based on a lifecycle analysis of livestock production, the authors find that emissions from this sector constitute *51% of anthropogenic GHG emissions*. The study identifies emissions which were uncounted, overlooked, and/or misallocated by the FAO report, and thus is a key piece of research for anyone interested in this subject. For more information on Goodland and Anhang's findings, see the discussion in Section III at page 41.

[1] *See*, FOOD AND AGRICULTURE ORGANIZATION (FAO), THE STATE OF FOOD AND AGRICULTURE - LIVESTOCK IN THE BALANCE (2009).

[2] Steinfeld et al. (2006).

HENNING STEINFELD ET AL., LIVESTOCK'S LONG SHADOW: ENVIRONMENTAL ISSUES AND OPTIONS, Food and Agriculture Organization (FAO) Livestock, Environment and Development Initiative (2006).

This report provides an extensive overview of the environmental impacts of global livestock production, and identifies potential technical and policy approaches to mitigating these impacts. It is the most heavily cited study on emissions from the livestock sector to date.

The authors find that the livestock sector is "one of the top two or three most significant contributors to the most serious environmental problems, at every scale from local to global" and that regulating livestock production should therefore "be a major policy focus when dealing with problems of land degradation, climate change and air pollution, water shortage and water pollution and loss of biodiversity."[3] With respect to global warming, specifically, the study finds that livestock-related activities contribute 18% of anthropogenic GHG emissions.

For more information on the emissions estimates from this article, see discussion in Section III at page 39; for recommended solutions, see discussion in Section V at page 89.

FOOD AND AGRICULTURE ORGANIZATION (FAO), WORLD AGRICULTURE: TOWARDS 2015/2030 (2003) and WORLD AGRICULTURE TOWARDS 2030/2050, INTERIM REPORT (2006).

The 2003 and 2006 reports update the FAO study *World Agriculture: towards 2010,* issued in 1995. They assess issues that will come up over the years to 2015 and 2030, for the purposes of developing FAO policy.

In the 2003 report, Chapter 3 of the report discusses prospects for major commodity groups, including livestock. Chapter 5 specifically discusses the livestock sector. Chapters 12 and 13 discuss the impacts of the livestock sector on climate change impacts, as well as the impacts of climate change on livestock in turn. The 2006 interim report discusses the shift towards greater consumption of livestock productions in Chapter 2 and implications for the livestock sector in Chapter 3.

For more information on information from these reports, see the discussion regarding consumption and production at page 18, emissions at page 60, and solutions at page 93.

[3] Steinfeld et al. (2006) at xx.

B. Additional Documents and Compilations

SPECIAL ISSUE: GREENHOUSE GASES IN ANIMAL AGRICULTURE – FINDING A BALANCE BETWEEN FOOD AND EMISSIONS, ANIMAL FEED SCIENCE AND TECHNOLOGY, VOL. 166-167 (2011).

This issue of Animal Feed Science and Technology contains eighty-four different articles about the impact of livestock on climate change and vice versa. The majority of these articles are highly technical reports, which discuss specific modeling techniques for emissions from various livestock-related activities (e.g., using a "non-steady-state chamber methodology" to measure soil N20 emissions) or specific technologies for mitigating methane and other emission releases. Due to their specificity and technical nature, most of these articles are beyond the scope of this bibliography, but nonetheless provide a valuable resource for future scholarship on how to model and mitigate GHG emissions from livestock production.

LIVESTOCK IN A CHANGING LANDSCAPE, VOL. I: DRIVERS, CONSEQUENCES AND RESPONSES (Harold Mooney et al. eds., 2010).

This is Volume I of "Livestock in a Changing Landscape," a report produced by the French Agricultural Research Centre for International development; the FAO and its Livestock, Environment and Development Initiative (LEAD); the Swiss College of Agriculture; the International Livestock Research Institute; the Scientific Committee on Problems of the Environment; and the Woods Institute for the Environment at Stanford University.

The report describes global trends in what the authors refer to as a "livestock revolution" resulting from the globalization, standardization, and industrialization of livestock production practices. It details the overarching causes and consequences of this "revolution", as well as the policy instruments dealing with these issues.

Chapter 1 discusses drivers of change in global agriculture and livestock systems. Chapter 2 discusses trends in consumption, production, and trade in livestock and livestock products. Chapter 3 discusses structural change in the livestock sector. Chapter 4 discusses livestock in geographical transition. Chapter 5 discusses the impacts of livestock on the global carbon cycle. Chapter 6 covers the impact on nitrogen cycles. Chapter 9 discusses impacts of intensive livestock production and manure management on the environment. Chapter 15 discusses the future of pastoralism. Chapter 16 discusses solutions to environmental issues.

LIVESTOCK IN A CHANGING LANDSCAPE, VOL. II: EXPERIENCES AND REGIONAL PERSPECTIVES (Pierre Gerber et al. eds., 2010).

This is the second volume to the report "Livestock in a Changing Landscape." It is a case study volume, aiming to use specific examples to flesh out the general theories posited in the first volume (discussed above). It includes the following chapters:

Chapter 2: "Horn of Africa: Responding to Changing Markets in a Context of Increased Competition for Resources" - This study describes how the pastoral production systems of the Horn of Africa are better-suited to the highly fluctuating environmental conditions of the region. However, these systems are threatened by decreasing resource access, increasing levels of civil strife and weather-related emergencies, and increased population and urbanization, which are causing a shift towards intensive industrial production.

Chapter 3: "West Africa: the livestock sector in need of regional strategies" - West Africa faces increasing land degradation and expansion of cropping. It is also experiencing growing population and urbanization. Intensive systems, mostly in poultry, develop at the periphery of major urban areas

Chapter 4: "India: Growth, Efficiency Gains, and Social Concerns" - Incomes are growing, and so is animal product consumption: India is at the onset of its livestock sector boom. Specialized poultry and dairy operations are springing up at urban centers, though dairy is still dominated by smallholders.

Chapter 5: "Brazil and Costa Rica: Deforestation and Livestock Expansion in the Brazilian Legal Amazon and Costa Rice: Drivers, Environmental Degradation, and Policies for Sustainable Land Management" – Brazil's livestock growth has caused deforestation. Costa Rica has managed to halt and reverse this trend. This chapter compares these two situations and the reasons behind the contrast. In particular, the comparison highlights Costa Rica's successful policies in developing payment for environmental services, and discontinuing direct subsidies to livestock production.

Chapter 6: "China: The East-West Dichotomy" - China is used to illustrate the livestock revolution at its post-climax stage, with the urbanization, intensification, and industrialization effects fully in play. Environmental regulations in response to this are still inadequate.

Chapter 7: "The United States: Trends in the Dairy Industry and Their Implications for Procedures and the Environment" - The US is used to illustrate the post-livestock revolution sector consolidation phase. In particular, it is used to show policy and legislative responses to environmental concerns emerging from the full industrialization of agriculture.

Chapter 8: "Denmark- European Union: Reducing Nutrient Losses from Intensive Livestock Operations" - Denmark and the EU are used as a second example of fully developed countries' pollution reduction strategies, in this case at the stage of waste processing.

Chapter 9: "Nestle: responses of the food industry" - The study of Nestle provides an example of an industry actor's response to changing conditions caused by the "livestock revolution", including changing consumer demands and increasing concerns about sustainability.

Philip K. Thornton & Mario Herrero, *The Inter-linkages between Rapid Growth in Livestock Production, Climate Change, and the Impacts on Water Resources, Land Use, and Deforestation*, Background Paper to the 2010 World Development Report, Development and Climate Change (2010).

This report, prepared as a background paper for the World Bank's 2010 World Development Report, provides a detailed overview of the "linkages between the burgeoning demand for livestock products, the subsequent growth in livestock production, and the impacts that this many have on natural resources, as well as how these may both affect and be affected by climate change in the coming decades."[4] For more information, see the discussion of demand projections at page 25, emissions estimates at page 48, and recommended solutions at page 80.

Nigel Scollan et al., *The Environmental Impact of Meat Production Systems*, Report to the International Meat Secretariat (2010).

This report discusses the environmental impacts, in particular the climate change impacts, of global meat production, in light of predictions that global demand for food may increase by 70% in 2050 as a result of population growth. The report discusses all meat systems, but focuses on the red meat industry, which has the highest impacts per unit of production.

The report notes the key role of livestock production in the global economy: this sector represents a significant proportion (approximately 40%) of earnings from agriculture, employs around 1.3 billion people directly and indirectly, and serves as an important "multifunctional asset" for many vulnerable populations.

For a description of the report's analysis of global livestock demand trends, see page 23; emission impacts, see page 53, and recommended solutions, see page 78.

BRITISH SOCIETY OF ANIMAL SCIENCE, PROCEEDINGS OF THE LIVESTOCK AND GLOBAL CLIMATE CHANGE CONFERENCE (P. Rowlinson, M. Steel & A. Nefzaoui, eds., 2008).

This report contains summaries of articles presented at the Livestock and Global Climate Change Conference in Hammamet, Tunisia (May 17-20, 2008). The conference articles cover a

[4] Thornton & Herrero (2010) at 7.

broad range of topics, including some discussion of how livestock production contributes to climate change. The primary focus, however, is the impact of climate change on livestock production systems and the livelihoods attached to those systems. The articles identify adaptation and mitigation strategies for livestock keepers, with a special emphasis on vulnerable populations and regions (i.e., those areas where livestock keeping is a subsistence activity, and where climate change will have the most acute effects on vulnerable livelihoods). In particular, the articles discuss how animal health can best be maintained in a changing environment, and recommend specific management tools for coping with both the direct effects of climate change and the socio-economic impacts.

II. DEMAND, PRODUCTION and CONSUMPTION of LIVESTOCK PRODUCTS

The following articles discuss historical trends and future estimates of livestock production. The vast majority of scholarship relies on data and estimates from the FAO, although there are several independent attempts to quantify future livestock production.[5]

There is general consensus that the primary drivers of increased demand for livestock products are population growth and increased affluence, and that there is a certain threshold of consumption at which demand will taper off and potentially stagnate. Thus, most of the predicted growth in this sector will occur in developing countries where per-capita consumption of livestock products is still relatively low but per-capita GDP is on the rise.

The FAO estimates that global meat consumption was approximately 266 million tons in 2007, and will reach approximately 373 million tons in 2030 and 465 million tons in 2050.[6] These figures reflect an increase in average annual per capita consumption rates to 47 kg / person / year in 2030 and 52 kg / person / year in 2050, with significant variation between industrialized, transition and developing countries. Collaborating FAO's estimates, Fiala (2008) estimates that global meat consumption will reach approximately 360 million in 2030.

There is, however, significant uncertainty with respect to the future production and consumption of livestock products. Some studies suggest that livestock production will expand more rapidly than FAO estimates, whereas other studies assert that growth in this sector will be slower than predicted due to external constraints on production. For example, the International Food Policy Research Institute (IFPRI) (2004) estimates that per capita meat consumption may actually increase to as much as 70 kg per person per year by 2050. Also, Keyser (2005) predicts that growth rates in livestock production will be higher (e.g., 1.9-2.2% for the period from 2015-

[5] *See, e.g.*, Fiala (2008) and Keyser (2005).

[6] FAO (2003); FAO (2006); Steinfeld et al. (2006).

2030, as opposed to FAO estimates of 1.7%). In contrast, Msangi & Rosegrant (2011) predict that, under a baseline scenario, the global average consumption of meat by 2030 will only be 45.2 kg / capita / year (as compared with the FAO's estimate of 47 kg). The Soil Association (2010) asserts more generally that global food production will probably not increase to the extent predicted by the FAO, but does not promulgate specific estimates regarding future agricultural or livestock production.

A. Demand, Production and Consumption Estimates: Primary Sources

FOOD AND AGRICULTURE ORGANIZATION (FAO), WORLD LIVESTOCK 2011: LIVESTOCK IN FOOD SECURITY (A. McLeod ed., Rome, FAO 2011).

This report contains the FAO's most recent statistics on the global production and consumption of livestock products. The report finds that, in 2007, the total production of livestock products (including pig meat, beef and buffalo meat, eggs, milk, poultry meat, and sheep and goat meat) totaled approximately 1,011 million tons. The total production of meat products (excluding milk and eggs) was approximately 266 million tons. The FAO provides a breakdown of both aggregate and per capita consumption in the following chart:[7]

TABLE 4

CHANGES IN GLOBAL LIVESTOCK PRODUCTION TOTAL AND PER PERSON 1967 TO 2007

ITEM	PRODUCTION *(million tonnes)*			PRODUCTION PER PERSON *(kg)*		
	1967	2007	2007/1967	1967	2007	2007/1967
Pig meat	33.86	99.53	294%	9.79	14.92	152%
Beef and buffalo meat	36.50	65.61	180%	10.55	9.84	93%
Eggs, primary	18.16	64.03	353%	5.25	9.60	183%
Milk, total	381.81	680.66	178%	110.34	102.04	92%
Poultry meat	12.39	88.02	711%	3.58	13.20	369%
Sheep and goat meat	6.49	13.11	202%	1.88	1.97	105%

Source: FAOSTAT.

As evinced by those figures, the FAO finds that livestock production has grown steadily over the past 40 years. The report notes that production levels have expanded most rapidly in East and Southeast Asia, Latin America and the Caribbean, whereas growth in sub-Saharan Africa has been very slow. The report also notes that pigs and poultry, "especially those kept in intensive, peri-urban production systems," are primarily responsible for the rapid per capita growth in livestock products.[8]

[7] FAO (2011) at 14.

[8] FAO (2011) at 13.

The report also identifies the current breakdown of livestock production by system, and animal type in the following table (at page 22 of the original report):

TABLE 6

GLOBAL LIVESTOCK PRODUCTION AVERAGE BY PRODUCTION SYSTEM 2001 TO 2003

	LIVESTOCK PRODUCTION SYSTEM				
	GRAZING	RAINFED MIXED	IRRIGATED MIXED	LANDLESS/ INDUSTRIAL	TOTAL
			(Million head)		
POPULATION					
Cattle and buffaloes	406	641	450	29	1 526
Sheep and goats	590	632	546	9	1,777
			(Million tonnes)		
PRODUCTION					
Beef	14.6	29.3	12.9	3.9	60.7
Mutton	3.8	4.0	4.0	0.1	11.9
Pork	0.8	12.5	29.1	52.8	95.2
Poultry meat	1.2	8.0	11.7	52.8	73.7
Milk	71.5	319.2	203.7	-	594.4
Eggs	0.5	5.6	17.1	35.7	58.9

Source: Steinfeld et al., 2006

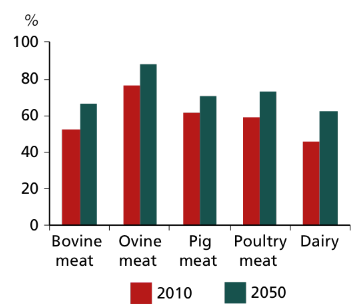
With respect to future demand, FAO summarizes its current projections (which are the same as the 2006 estimates) in the following table (at page 79 of the report):

TABLE 16

PROJECTED TOTAL CONSUMPTION OF MEAT AND DAIRY PRODUCTS

	2010	2020	2030	2050	2050/2010
			(million tonnes)		
WORLD					
All meat	268.7	319.3	380.8	463.8	173%
Bovine meat	67.3	77.3	88.9	106.3	158%
Ovine meat	13.2	15.7	18.5	23.5	178%
Pig meat	102.3	115.3	129.9	140.7	137%
Poultry meat	85.9	111.0	143.5	193.3	225%
Dairy not butter	657.3	755.4	868.1	1 038.4	158%
DEVELOPING COUNTRIES					
All meat	158.3	200.8	256.1	330.4	209%
Bovine meat	35.1	43.6	54.2	70.2	200%
Ovine meat	10.1	12.5	15.6	20.6	204%
Pig meat	62.8	74.3	88.0	99.2	158%
Poultry meat	50.4	70.4	98.3	140.4	279%
Dairy not butter	296.2	379.2	485.3	640.9	216%

PERCENT OF TOTAL CONSUMPTION IN DEVELOPING COUNTRIES



Source: FAO, 2006c. Some calculations by authors.
Note these figures are based on World Population Prospects: The 2002 Revision.

Siwa Msangi and Mark W. Rosegrant, *Feeding the Future's Changing Diets: Implications for Agriculture Markets, Nutrition and Policy*, Paper No. 3, 2020 Conference: Leveraging Agriculture for Improving Nutrition and Health, February 10-12, 2011; New Delhi, India (2011).

This paper explores the key drivers of change in food systems, with a particular emphasis on demand-side drivers such as changing diets. The paper finds that economic growth in developing countries is having a significant impact on the global structure of food demand, and is driving strong growth in per capita and total meat consumption. This, in turn, has lead to significant increases in the demand for cereal products grown for feed.

Using IFPRI's IMPACT model, the paper provides predictions of meat and cereal consumption to 2030. The authors find that meat consumption reveals a "dynamic picture of behavioral change over the medium to long term."[9] Based on their predictions, per capita meat consumption will continue to increase in high-income countries, such as the United States, and will increase more rapidly in developing economies, including China, Brazil, and other countries in East Asia, Latin America, North Africa and the Middle East. The authors note that the "booming East Asian economies such as China show remarkable growth in meat consumption over the 2000-2030 period, though the projected levels of per capita consumption remain below Latin America's 2030 levels." [10] In Sub-Saharan Africa and South Asia, the total per capita consumption levels are predicted to remain relatively small. The authors findings are illustrated in the following table.[11]

Table 1—Per capita meat consumption under baseline and alternative scenarios for high-income (HIC) countries, Brazil and China (kg per capita per year)

	2000	2030 baseline	2030 HIC Low-Meat	% chg from baseline in 2030	2030 HIC+BrzCh Low-Meat	% chg from baseline in 2030
USA	121.3	130.7	64.7	*-50%*	64.7	*-50.5%*
China	49.4	73.5	83.6	*14%*	36.3	*-50.7%*
India	4.8	8.6	9.9	*15%*	12.9	*48.9%*
Brazil	73.0	88.8	103.3	*16%*	43.7	*-50.8%*
E. Europe & C. Asia	41.9	49.8	41.1	*-17%*	48.7	*-2.1%*
High Income countries	85.7	93.3	46.7	*-50%*	47.0	*-49.6%*
Sub-Saharan Africa	10.9	14.5	16.6	*15%*	21.2	*46.7%*
Rest of Developing*	18.2	25.3	27.2	*7.5%*	34.0	*34.5%*
World	37.1	45.2	42.1	*-7%*	36.5	*-19.2%*

Note: "Rest of Developing" excludes China and Brazil.
Source: IMPACT model projections

9 Msangi & Rosegrant (2011) at 4.

10 *Id.*

11 *Id*. at 6.

The authors also note that price changes will accompany changes in per capita consumption, and provide price estimates of key commodities for high-income countries, Brazil and China. Under the baseline scenario, the authors predict that the price of beef will increase from $1971/mt in 2000 to $2031/mt in 2030, the price of pork will decrease from $899/mt in 2000 to $848/mt in 2030, the price of lamb and goat will increase form $2831/mt in 2000 to $2875/mt in 2030, and the price of poultry will decrease from $1245/mt to $1174/mt. Thus, under the baseline scenario, meat prices will not drastically change. However, under the low-consumption of meat scenarios, meat prices are expected to decrease more significantly by 2030.

The paper concludes that a strong shift towards healthier diets and lower consumption of livestock products will subsequently decrease the price of livestock products and thus have positive implications for global food security. The paper further finds that reducing high meat consumption in fast-growing countries such as China will have an even bigger impact than reducing meat consumption in OECD countries.

Sanderine Nonhebel & Thomas Kastner, *Changing Demand for Food, Livestock Feed and Biofuels in the Past and in the Near Future,* 139 LIVESTOCK SCIENCE 3 (2011).

This article analyzes historical trends in the consumption of livestock and cereals, and extrapolates future growth in global demand.

Looking at historical data, the authors find that a “saturation level” for meat consumption is reached at approximately 10,000 GK$ per capita--at this threshold, animal product consumption levels remain at 35%. Accordingly, in high-income areas such as the USA and Western Europe, consumption of animal products has not greatly increased over the past 15 years. The authors estimate that the ~ 1 billion people who live in developed countries consume approximately 100 kg of meat per person per year, requiring approximately 400 kg of cereals. Their aggregate consumption is therefore 100 megatons of meat per year, requiring 400 megatons of cereal production. Because these countries have reached “saturation levels”, the authors estimate that demand will not increase over the next 25 years. (See Figure 4 on next page).

In contrast, fast growing economies, i.e., “transition economies”, such as China and India, have experienced a significant increase in animal product consumption. In China, for example, the consumption of animal products per person has doubled in the past 15 years. The authors estimate that the largest growth in livestock demand will occur in these transition economies, where the average GDP per capita is expected to increase from approximately $2,000 to $10,000 in the next 20 years (GDP growth rates of 6%). Based on this increase, the animal product consumption in these countries would reach saturation levels (~ 35% of total calories consumed) by 2030. The authors estimate that this will increase the per capita demand to 100 kg of meat (400 kg of cereals) per year, same as the current rate for developed countries. Taking into account that approximately 2 billion people live in transition economies, the projected aggregated demand for these countries is 200 megatons of meat, requiring 800 megatons of feed.

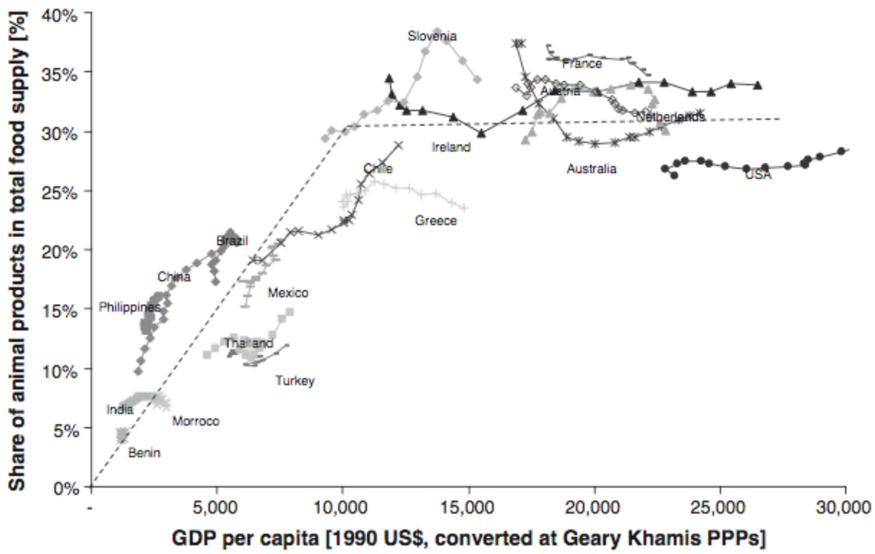


Fig. 4. The relative consumption of animal origin food products (share in total calories consumed) in relation to GDP per capita. The dotted line shows the relation between GDP and consumption of animal products used in this paper. Data are for the years 1990–2005.
Sources: FAOSTAT (2007) and GGDC (2007).

With respect to the approximately 3 billion people who live in developing countries, the authors do not anticipate any major change in meat consumption due to slow economic growth. Given that the value of demand for livestock products and subsequent feed demand are thus estimated to be "0", the total demand projections in this article may be substantially lower than the real picture.

Overall, the article indicates that global meat consumption will rise to approximately 300 MT (requiring 1200 MT of cereal production) in approximately 20 years or once transition economies reach saturation levels. However, the authors acknowledge that their modeling technique "involves large simplifications" and is premised on the assumption that meat consumption will not increase in developed countries.[12] This explains why the 300 MT figure is substantially less than FAO estimates.

Soil Association, *Telling Porkies: The Big Fat Lie About Doubling Food Production* (2010).

This report, prepared by the Soil Association (a UK non-profit focused on sustainable food production), disputes the validity of FAO projections of future food production. Specifically, the report contests two key figures—that global food production will increase 50% by 2030 and double by 2050 in order to meat future demand.

[12] Nonhebel & Kastner (2011) at 8.

The report notes that these figures have come to play a significant role in framing the current policy debates around food, and have been used to justify arguments in favor of intensifying food production systems in order to meet demand. This is problematic due to the deleterious environmental effects associated with intensified production systems.

First, the report identifies the basic assumptions underlying the estimates of future food production:

- Increases in global population and economic growth
- Increased per capita consumption of calories in developing countries
- Continuing growing imports of food by developing countries
- Structural changes in diets of people in the developing world (nutrition transition) to include more meat and dairy products[13]

Although these assumptions are generally true, the actual extent of population growth, economic growth, etc. is entirely debatable. In many instances, scientists may be overestimating growth—for example, by failing to account for the negative impacts of climate change on increases to population and/or per capita GDP.

The report then identifies "four key problems" with the popular projections of future food production, including:

(1) Our diet in the developed world is causing serious disease and obesity problems and these are now stating to increase in the developing world.
(2) The data used to measure food security focuses attention on the level of agricultural production without considering access to food, distribution, and affordability, which are all important in ensuring that people do not go hungry.
(3) The projections assume that the developing world continues to import growing quantities of staple food stuffs—in fact, increasing local production of staple foods is vital in ensuring food security.
(4) According to these scientists, meeting these projected food demand targets will not solve food insecurity anyways.[14]

The authors note that if food production actually increases to the extent predicted by the FAO (50% increase in food production by 2030 and 100% increase by 2050), this does not mean that we would be feeding the hungry, but rather would be likely to cause major new epidemics of diet-related health problems, such as heart disease, Type 2 diabetes and some forms of cancer. Thus, "[m]any of those misusing the statistics in the FAO paper to argue for massive increases in food production in both UK and globally, appear to be unaware that they are in effect condemning many in developing countries to ill-health and early deaths."[15]

The paper provides a more in-depth critique of both the assumptions underlying these statistics and the manner in which they are being used for political purposes (to advocate for

[13] Soil Association (2010) at 3.

[14] *Id*.

[15] *Id*.

increased and intensified food production). One key problem is the lack of information regarding the sources of the two figures—i.e., how exactly the FAO has reached this determination. The report concludes that there is "considerable uncertainty" about the basis of these figures, and notes that FAO's current data suggests that the increase between 2005 and 2050 might be 70% but not 100%.

Mark Rosegrant, Maria Fernandez and Anushree Sinha, *Looking into the future for agriculture and AKST*, Chapter 5 in IAASTD Global Report (2009).

This chapter, written as part of a global report from the International Assessment of Agricultural Knowledge, Science and Technology for Development, examines future potential growth in the agricultural and livestock sectors. Some of the key findings in the chapter include:

- Quantitative projections of price and production indicate a tightening of world food markets, with increasing resource scarcity, adversely affecting poor consumers.
- Improved agricultural knowledge, science and technology (AKST) can help to reduce the inevitable tradeoffs between agricultural growth and environmental sustainability at the global scale.
- Growing water constraints will have a major impact on future production, and will be a major driver for future AKST.
- Continuing structural changes in the livestock sector, driven mainly by rapid growth in demand for livestock products, will bring about profound changes in livestock production systems.
- Expected climate changes are likely to affect agriculture, requiring attention to harmonizing policies on climate mitigation and adaptation with others on agriculture and forest land for bioenergy and on forestry for sequestration.

With respect to livestock specifically, the paper finds that there are "substantial growth opportunities… for livestock producers in the developing world" but that the "availability of animal feed will… affect both the rate and extent of this growth, since competition is growing between animal and aquaculture feeds that both use fishmeal and fish oil."[16] In addition, "declining resource availability could lead to degradation of land, water, and animal genetic resources in both intensive and extensive livestock systems."[17]

The authors find that, historically, livestock production has responded to increased demand by increasing herd size (animal population), and predict that this trend will continue in the coming decades. For example, the grazing intensity of grassland-based systems (number of animals per ha of grazing land) is projected to double globally, and possibly quadruple in sub-Saharan Africa.

[16] p. 308

[17] p. 308

The authors also provide specific predictions with respect to the global expansion of livestock populations. Between 2000 and 2050, the authors predict that the global population of bovines will increase from approximately 1.5 billion to 2.6 billion, sheep and goats will increase from 1.7 billion to 2.7 billion; pigs will increase from 0.9 billion to 1 billion; and poultry will increase 16 billion to 34.5 billion.

Nathan Fiala, *Meeting the demand: An estimation of potential future greenhouse gas emissions from meat production*, 67 Ecological Economics 412 (2008)

Fiala uses an economic elasticity model to forecast the future global demand for meat, disaggregated by beef, chicken and pig products. He forecasts that actual consumption of meat products will be as follows:

Table 4 – Actual consumption by meat product in 2000 and forecasts for 2010, 2020 and 2030 in 1000 metric tons.[18]

Product	**2000**	**2010**	**2020**	**2030**
Beef	59,606	66,485	72,751	78,506
Chicken	59,240	84,241	106,635	124,566
Pig	89,961	113,860	135,563	155,995
Total	208,807	264,586	314,949	359,067

Fiala's figures do not include consumption of other meat products or dairy products.

HENNING STEINFELD ET AL., LIVESTOCK'S LONG SHADOW: ENVIRONMENTAL ISSUES AND OPTIONS, Food and Agriculture Organization (FAO) Livestock, Environment and Development Initiative (2006).

The FAO identifies several factors which shape demand for and production of livestock products, including (1) population growth, (2) income growth; and (3) other demographic shifts, such as age structure and urbanization. The report emphasizes the key role that growing incomes play in the increased demand for livestock products, as illustrated in the chart on the following page.[19]

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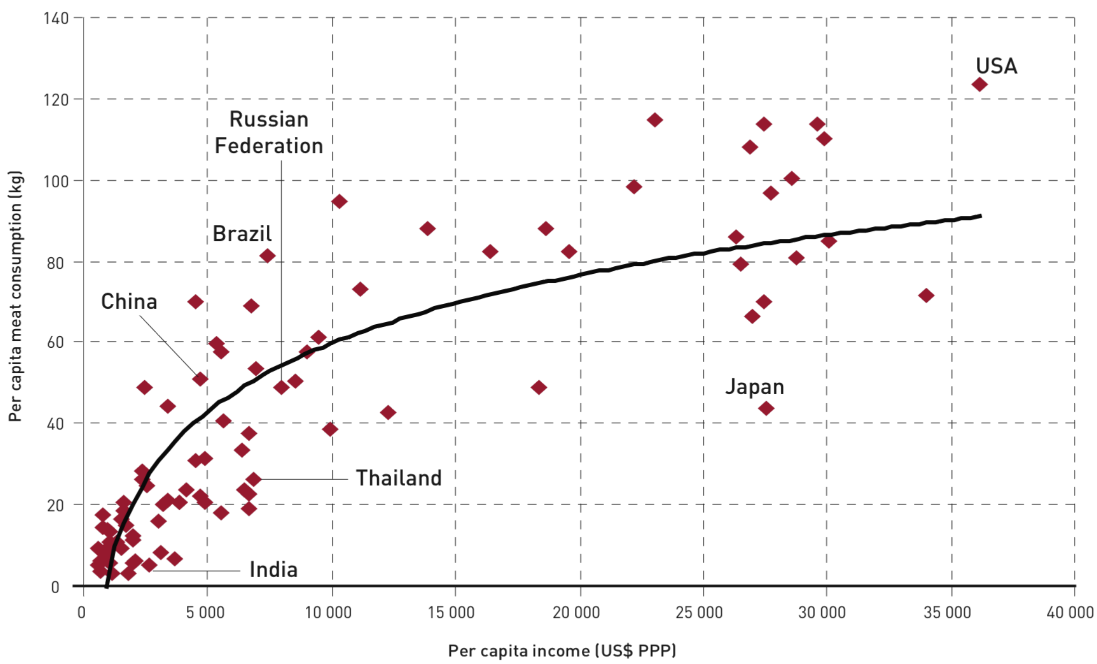
[18] Fiala (2008) at 417.

[19] Steinfeld et al. (2006) at 9.

Figure 1.4 The relationship between meat consumption and per capita income in 2002



Note: National per capita based on purchasing power parity (PPP).
Source: World Bank (2006) and FAO (2006b).

Accounting for current trends in livestock production (in particular, that total meat supply tripled from 47 million tons to 137 million tons from 1980 to 2002, representing an increase in annual per capita consumption of meat from 14 kg to 28 kg), the FAO estimates that livestock production and consumption will significantly increase in the next several decades. Specifically, the report estimates that total meat consumption will be 252 million tons in developing countries and 121 million tons in developed countries by 2030. These findings are summarized in the following table:[20]

Table 1.5

Past and projected trends in consumption of meat and milk in developing and developed countries

	Developing countries					Developed countries				
	1980	1990	2002	2015	2030	1980	1990	2002	2015	2030
Food demand										
Annual per capita meat consumption (kg)	14	18	28	32	37	73	80	78	83	89
Annual per capita milk consumption (kg)	34	38	46	55	66	195	200	202	203	209
Total meat consumption (million tonnes)	47	73	137	184	252	86	100	102	112	121
Total milk consumption (million tonnes)	114	152	222	323	452	228	251	265	273	284

Source: FAO (2006a) and FAO (2006b).

[20] Steinfeld et al. (2006) at 15.

The report further estimates that global meat production will increase to 465 million tons in 2050.

In addition, the report projects that livestock consumption will increase most in developing countries where per capita GDPs are increasing and the per capita consumption of livestock products has not already maxed out.

Claudia Ringler, *Global Food, Feed, Fiber and Bioenergy Demand Prospects: Implications for Natural Resources—Drawing on the Millennium Ecosystem Assessment*, International Food Policy Research Institute (2006).

This report estimates increases in total food consumption per person using the International Food Policy Research Institute (IFPRI)'s "IMPACT" models. The report predicts that per capita demand for livestock products will increase "much more rapidly worldwide, driven by strong income growth and increasing preference for livestock products."[21] Specifically, the report estimates that annual per capita consumption of meat will increase from 36 kg in 1997 to 70 kg in 2050 under the "Global Orchestration (GO)" scenario, which the author describes as a scenario with a "globally connected society that focuses on global trade and economic liberalization" which "takes a reactive approach to environmental problems."[22] Under alternative scenarios, the increase in meat consumption may be far more limited—ranging from 41 kg to 43 kg of per capita meat consumption in 2050—although the aggregate impact of this increase on production would still be significant in light of population growth.

FOOD AND AGRICULTURE ORGANIZATION (FAO), WORLD AGRICULTURE: TOWARDS 2015/2030 (2003) and INTERIM REPORT (2006).

Chapter 5.2 of the 2003 report, and Chapters 2.3 and 3.3 of the 2006 update discuss increases in global demand for livestock products.

The rising share of animal products in the diet is evident in developing countries. Even though calories derived from cereals have increased in absolute terms, as a share of total calories they continue to fall, from 60% in 1961/63 to an expected 50% in 2030. Similarly, the contribution of other traditional staples (potatoes, sweet potatoes, cassava, plantains and other roots) fell from second largest contributor to dietary calories (10%) in 1961/63 to lowest (6.2%) by 1997/99. In industrial countries, cereals contribute significantly less as a share of calories consumed – around 34% – while the contribution of animal products has remained stable at around 23%.

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[21] Ringler (2006) at 4.

[22] *Id*.

In industrial countries, the consumption of animal proteins increased in the 1960s and 1970s from 44 to 55 g/capita/day. After this, animal protein consumption remained fairly stable. In developing countries, however, although the level of consumption of animal proteins increased steadily from 9 g/capita/day in 1961/63 to 20 g/capita/day in 1997/99, there is still significant potential for increases.

In the 2003 report, for the period from 1997/99 to 2030, annual meat consumption in developing countries was projected to increase from 25.5 to 37 kg per person, compared with an increase from 88 to 100 kg in industrial countries. Consumption of milk and dairy products was projected to rise from 45 kg/person/year to 66 kg in developing countries, and from 212 to 221 kg in industrial countries. For eggs, consumption was projected to grow from 6.5 to 8.9 kg in developing countries and from 13.5 to 13.8 kg in industrial countries.

The 2006 interim report updates these projections. It provides the following estimates for per capita consumption (kg / person / year) of livestock-related food products:

		Industrial	**Transition**	**Developing**	**World Average**
Meat	2030	99	59	38	47
	2050	103	68	44	52
Dairy	2030	223	179	67	92
	2050	227	193	78	100

The difference between the 2003 and 2006 figures is the result of updated data, as well as the shift from analyzing developed vs. developing countries to analyzing industrial, transition and developing countries.

Chapter 2.3 of the interim report also provides a breakdown of projected per capita consumption of food products by region (e.g., sub-Saharan Africa, Latin America and Caribbean, etc.).[23] Similarly, Section 5.2 of the 2003 report discusses regional variation in livestock product consumption, reflecting preferences based on availability, relative prices and religious and taste preferences.[24]

Both the 2003 report and 2006 interim report note that the figures showing increased production and consumption over the 1980s and 1990s are substantially caused by sectoral growth in China. Without China, the world meat consumption average would have actually stagnated in the 1980s and 1990s. The report does note that this phenomenon is due in large part to the fall of communism and the disappearance of subsidies in "transition economies". The reports also find that the "upward" trends in meat consumption are disproportionately influenced

[23] FAO Interim Report (2006) at 30.

[24] Table 3.9 shows consumption of dairy products per capita by global region in the periods 1967/69, 1987/89, 1997/99, and then projected in 2015 and 2030; Table 3.10 shows consumption of meat per capita by global region, as well as by type of meat, in the periods 1967/69, 1987/89, 1997/99, and then projected in 2015 and 2030; Table 5.2 shows livestock production separated by commodity (bovine meat; ovine meat; eggs; etc), and then into region, and then comparing industrial vs. transition countries, in the periods 1967/69, 1987/89, 1997/99, and then projected in 2015 and 2030.

by increased consumption of poultry.

In addition, both reports point out that there has been a deceleration in the growth rate of animal product consumption.[25] Again, this is linked to the downward bias caused by the transition economies. It is also caused by continuing poverty in low-income countries, near-saturation of consumption in developed economies, policies of high domestic meat prices in some countries, health and food safety reasons, and cultural and religious factors determining what kinds of meat are consumed.

Section 3.3.2 of the 2003 report and section 3.3 of the 2006 interim report predict changes in consumption patterns for the future. The 2003 report concludes that meat consumption growth rates are likely to stagnate while dairy consumption will continue to rise; whereas the 2006 report finds that "per capita meat consumption in the developing countries is likely to grow at much slower rates than in the past, mainly because the great push given to consumption growth in the past by China and Brazil will not be playing the same role in the future" the result being that the aggregate meat consumption [in developing countries] may grow in the next 30 years half as rapidly as in the preceding three decades."[26] With respect to transition and industrial countries, the report finds only limited prospects for demand growth.

The 2006 interim report concludes that this projected slowdown in meat production is based on the following assumptions: "(a) relatively modest further increases in per capita consumption in industrial countries, (b) growth rates in per capita consumption in China and Brazil well below those of the past, (c) persistence of relatively low levels of per capita consumption in India, (d) persistence of low incomes and poverty in many developing countries."[27] Even under these assumptions, the report finds that the slower growth rate will still produce "large absolute increases (some 465 million tons must be produced annually by 2050, the great bulk of which in the developing countries)."[28] This figure is predicated on estimated growth rates of 1.7% for the period from 2000-2030, and 1.0% from 2030-2050. As a point of reference, the 2003 report concluded that world meat production would increase to a total of 376 million tons in 2030, based on a growth rate of 1.9% for the period from 1995-2015, and 1.5% for the period from 2015-2030.[29]

The reports also contain detailed information on regional variation in consumption of livestock products, noting that, in addition to population and income, this variation reflects traditional preferences based on availability, relative prices and religious and taste preferences. Section 3.3.2 of the 2003 report discusses future consumption patterns prospects for different regions, concluding that meat consumption growth rates are likely to stagnate while dairy consumption will continue to rise. The report finds that:

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[25] See Table 3.11 in FAO (2003).

[26] FAO Interim Report (2006) at 49.

[27] FAO Interim Report (2006) at 51.

[28] FAO Interim Report (2006) at 51.

[29] FAO (2003) at 162.

- Sub-Saharan Africa has maintained stably low consumption levels of animal products over the last 30 years. This is likely to remain stable over the next few decades.
- In the *Near East and North Africa,* the contribution of animal products to the relatively high calorie consumption is small, just 8.7% in 1997/99. The contribution of animal products (primarily poultry meat and milk) to total calorie intake will increase to 11.4% by 2030.
- In *Latin America and the Caribbean* (excluding Brazil), consumption of animal products (meat) historically has been higher than in other developing country groups and is predicted to increase further. Currently, animal products provide 16.6% of the dietary energy, but meat consumption per capita is still only about 60% of that of industrial countries, implying that there is scope for further growth.
- *Brazil* is unusual in terms of its large and increasing dietary contribution of animal products (18.8% in 1997/99). The gap between Brazil and the rest of Latin America is expected to widen. Meat consumption per capita, at present over three-quarters the level of industrial countries, is projected to reach the level of the latter by 2030. Per capita milk consumption, at present just over half the level of industrial countries, is projected to reach three-quarters of the industrial countries' consumption by 2030.
- In *South Asia* (excluding India), there has been a slow but steady growth in animal product consumption. This increase is mostly the result of an increase in the contribution of milk, already high at a per capita level 50% above the average for developing countries, together with an increase in the contribution of poultry meat. The contribution of eggs is well below the developing country average.
- In *India,* the relative contribution of animal products to diets is predicted to increase up to 2030 largely as a result of increases in the consumption of milk and milk products.
- In *East Asia* (excluding China) there is also a steady increase in the contribution of animal products to the diet. However, unlike South Asia, this increase is a result of the contribution of meat, predominantly pork.
- In *China,* the projected rapid rise in the contribution of animal products to dietary energy from 15 to 20% between 1997/99 and 2030 will be mainly on account of a substantial increase in the contribution of pork and poultry. Per capita consumption of milk is very low and projected to remain so (rising from 7kg p.a. in 1997/99 to 14kg in 2030). By contrast, egg consumption in China is very high – more than double the average for developing countries and even above the industrial country average – and will rise from 15 kg/person/year in 1997/99 to 20 kg in 2030.

The 2003 report also discusses variations in production systems. It finds that crop-livestock production systems, or mixed farming systems, are still the most common ways of raising ruminant livestock. 1996 FAO figures estimated such systems as providing over 65% of global beef supply, 69% of mutton and 92% of cow milk.

Grazing-based systems are experiencing a decreased market share relative to other types of production system. This is because the availability of rangelands is decreasing, through arable land encroachment, land degradation, conflict, etc.

The strongest structural trend in livestock production has been the growth of intensive, vertically integrated, intensive establishments close to large urban centers. In recent years, industrial livestock production grew at twice the annual rate of the more traditional mixed (i.e., livestock/crop production) farming systems (4.3 against 2.2%), and at more than six times the annual growth rate of production based on grazing (0.7% based on 1996 figures).

In general, more industrial growth has occurred in production of pigs and chickens than of ruminants, because pigs and chickens are more efficient at converting cereals into meat, and require less land. This effect is most pronounced in Asia, where there is a shortage of land but an abundance of relatively cheap labor.

Finally, both the 2003 and 2006 reports discuss changes in the international meat trade.[30] Global trade in meat products grew rapidly over the 1990s, because of factors including reduced market barriers and increasingly specialized consumer preferences. The report predicts that this will continue to rise in the future. This is not mentioned in the reports, but longer-range exports will obviously cause increased emissions.

M.A. Keyzer, M.D. Merbis, I.F.P.W. Pavel, C.F.A. van Wesenbeeck, *Diet shifts towards meat and the effects on cereal use: can we feed the animals in 2030?* 55 ECOLOGICAL ECONOMICS 187 (2005).

This article argues that current projections of global meat and feed demand may underestimate future consumption patterns for two main reasons: (1) demand projections are based on income extrapolation with an assumed demand elasticity; (2) feed requirements per unit of meat are taken to be fixed. Rather than relying on those assumptions, the authors propose a "structural specification [of meat demand] that includes a dietary shift towards meat as per capita income increases" and which "account[s] for a shift from traditional to cereal intensive feeding technologies."[31] Using this framework and relying on "commonly assumed growth rates of per capita income," the authors project that meat and subsequent feed demand will be "significantly higher" in the next 30 years than is currently projected.

The authors base their quantitative analysis of global meat and feed demand on three assumptions: (1) that per capita meat demand will depend primarily on per capita income, and it is therefore necessary to account for the differences in per capita income *within* countries; (2) the "Engel curve" that links per capita consumption is a non-linear relationship, as the poor segments tend to abstain from meat consumption until their income reaches a lower threshold,

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[30] See FAO (2003), Table 3.12 for figures of tons of meat exported in 1964/66, 1974/76, 1984/86, and 1997/99; See Table 3.13 for figures of how much meat (in tons) was exported and imported by the respective top exporters and importers of meat, broken down into type of meat/dairy products.

[31] Keyzer et al. (2005) at 187.

while rich consumers become satiated at a higher threshold; and (3) the rise in meat demand will require additional supply of feed that cannot be met with traditional crop-residue and pasture-based technologies, requiring a shift towards intensive feeding technologies.

In light of these three factors, the authors project annual growth rates of aggregate meat cereal demand under several possible scenarios. Their findings are as follows:

Table 2
Scenario outcomes: annual growth rates of meat and cereal feed demand (in percent)

Income growth per capita	Annual growth rates aggregate meat demand		Feed technology	View	Annual growth rates of aggregate cereal feed demand	
	1997–2015	2015–2030			1997–2015	2015–2030
High	3.0	2.2	Ratio residuals/	Optimistic	1.1	1.5
			cereal feed fixed	Pessimistic	2.8	2.0
			Residual growth	Optimistic	1.6	3.5
			on trend	Pessimistic	5.6	4.2
			Residual and grazing	Optimistic	1.3	4.0
			area growth on trend	Pessimistic	6.0	4.7
Low	2.3	1.9				

Table 3
Annual growth rates of aggregate meat consumption (in percent)

	High growth rates		Low growth rates		FAO (2003)	
	1997–2015	2015–2030	1997–2015	2015–2030	97/99–2015	2030
Sub-Saharan Africa	3.0	2.9	2.8	2.5	3.4	3.7
Near East/North Africa	4.1	3.2	3.4	2.8	3.6	2.9
South Asia	5.8	3.9	4.4	3.7	3.8	4.0
East Asia	4.9	2.6	3.7	2.6	2.5	1.6

Source: FAO (2003) and own projections.

The authors also note that the energy demands for these growth scenarios will be significant--under the high growth scenario, in 2030, the energy requirement to produce meat totals 15.7 billion GJ, or 4.37 billion GWH, "which significantly exceeds the total electricity production of the US in 1997 of 2.67 billion GWH" (assuming that 40 MJ/kg of meat are required).[32]

B. Interpreting Demand, Production and Consumption Estimates

Nigel Scollan et al., *The Environmental Impact of Meat Production Systems*, Report to the International Meat Secretariat (2010).

This report summarizes and discusses recent estimates with respect to current production and future demand for livestock products, for the purposes of informing the policy of the International Meat Secretariat (IMS). The report finds that, over the past 20 years, livestock production has "rapidly responded to the growing demand for meat, particularly in developing

[32] Keyzer et al. (2005) at 194, fn. 10.

countries."[33] The majority of this increase has been in monogastrics, primarily poultry and pig meat. The report relies primarily on data from the FAO (2009) and Thornton & Herrero (2010) indicating that livestock production will double to 470 million tons by 2050, mainly from pigs and poultry, and primarily in transition and developing countries where per capita income is on the rise (see chart, next page).[34]

The report also notes that, historically, the growth in livestock production has "largely been achieved through increased livestock numbers rather than enhanced output per animal (yield)" and that the major productivity increases have occurred in "some pig, poultry and dairy cattle systems but more rarely in beef and sheep."[35] The authors conclude that mitigating environmental concerns will require a shift towards improving yield rather than expanding numbers.

Table 1.1 Production of livestock products by region, 1980 and 2007 (million tonnes) (adapted FAO, 2009)

Region/Country Group/Country	Meat		Milk		Eggs	
	1980	2007	1980	2007	1980	2007
Developed Countries	88.6	110.2	350.6	357.8	17.9	18.9
Developing Countries	48.1	175.5	114.9	313.5	9.5	48.9
World	136.7	285.7	465.5	671.3	27.4	67.8

Table 1.2 Production of main categories of meat for 2007 (million tonnes; values in parenthesis are percentage of total production for that species; adapted from FAO, 2009)

	Pigs	Poultry	Cattle	Sheep and Goats	Total
Developed Countries	39.5 (36)	37.0 (34)	29.4 (27)	3.2 (3)	109.1
Developing Countries	76.0 (45)	49.8 (29)	32.5 (19)	10.8 (6)	169.1
World	115.5 (42)	86.8 (31)	61.9 (22)	14.0 (5)	278.2

[33] Scollan (2010) at 10.

[34] *Id*.

[35] *Id*. at 4.

Philip K. Thornton & Mario Herrero, *The Inter-linkages between Rapid Growth in Livestock Production, Climate Change, and the Impacts on Water Resources, Land Use, and Deforestation*, Background Paper to the 2010 World Development Report, Development and Climate Change (January 2010).

This paper compiles demand estimate from Steinfeld et al. (2006) and FAO (2006) to predict the long-term growth in meat and milk consumption from 1980 – 2050.[36]

Table 2. Past and projected trends in consumption of meat and milk in developing and developed countries. Data for 1980-2015 from Steinfeld et al. (2006) and for 2030-2050 from FAO (2006).

		Annual per capita consumption		Total consumption	
		Meat (kg)	**Milk (kg)**	**Meat (Mt)**	**Milk (Mt)**
Developing	**1980**	14	34	47	114
	1990	18	38	73	152
	2002	28	44	137	222
	2015	32	55	184	323
	2030	38	67	252	452
	2050	44	78	326	585
Developed	**1980**	73	195	86	228
	1990	80	200	100	251
	2002	78	202	102	265
	2015	83	203	112	273
	2030	89	209	121	284
	2050	94	216	126	295

The authors note that, in addition to population growth, rising per capita incomes, cultural issues and ethical issues will impact patterns of demand for livestock products. Furthermore, constraints on resource availability will cause prices to rise, also impacting demand.

The report then attempts to extrapolate how production systems will adapt to meet demand. According to Rosegrant et al. (2009), in developing countries, 90% of production growth over the past decade has come from increases in herd sizes. Thus, the authors predict that, although "significant improvements in animal yields [e.g., efficiency] are projected, growth in numbers will continue to be the main source of production growth."[37]. The predicted increases in livestock populations are illustrated in Table 3 on the following page.

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[36] Thornton & Herrero (2010) at 12.

[37] *Id*. at 19.

Table 3. Bovines, sheep and goats, pigs and poultry numbers for the reference run, by region (billion head). Rosegrant et al., 2009.

BOVINES	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
CWANA	0.124	0.162	0.192	0.218	0.237	0.248
ESAP	0.578	0.745	0.911	1.055	1.165	1.209
LAC	0.349	0.430	0.507	0.566	0.610	0.627
NAE	0.268	0.288	0.306	0.311	0.304	0.282
SSA	0.179	0.219	0.253	0.273	0.278	0.270
Globe	1.498	1.844	2.170	2.423	2.593	2.636

SHEEP & GOATS	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
CWANA	0.403	0.491	0.556	0.597	0.614	0.601
ESAP	0.723	0.871	1.008	1.115	1.184	1.210
LAC	0.116	0.136	0.154	0.168	0.175	0.174
NAE	0.195	0.218	0.235	0.244	0.244	0.231
SSA	0.271	0.346	0.406	0.443	0.459	0.457
Globe	1.707	2.061	2.359	2.566	2.677	2.673

PIGS	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
CWANA	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
ESAP	0.539	0.622	0.669	0.664	0.627	0.558
LAC	0.080	0.096	0.110	0.119	0.123	0.122
NAE	0.274	0.295	0.307	0.304	0.290	0.262
SSA	0.019	0.024	0.029	0.032	0.034	0.034
Globe	0.912	1.038	1.115	1.121	1.076	0.978

POULTRY	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
CWANA	1.449	1.677	1.901	2.108	2.306	2.424
ESAP	7.478	10.112	12.979	15.712	18.168	19.687
LAC	2.286	2.893	3.531	4.151	4.762	5.245
NAE	4.180	4.677	5.180	5.542	5.780	5.750
SSA	0.784	0.991	1.170	1.306	1.407	1.445
Globe	16.178	20.350	24.760	28.819	32.423	34.551

CWANA Central and West Asia and North Africa
ESAP East and South Asia and the Pacific
LAC Latin America and the Caribbean
NAE North America and Europe
SSA Sub-Saharan Africa

Mario Herrero, Philip K. Thornton, Pierre Gerber, and Robin S. Reid, *Livestock, livelihoods and the environment: understanding the trade-offs*, 1 CURRENT OPINION IN ENVIRONMENTAL SUSTAINABILITY 111 (2009).

This article discusses the growing demand for livestock products, and how this will impact the "key global trade-offs arising between livestock rearing, human well-being, and environmental sustainability."

The authors identify the characteristics that make livestock is a key global commodity: (1) livestock systems occupy 45% of the global surface area, and also have serious land use impacts from feed production and related activities; (2) these systems are a significant global asset, with economic value of at least $1.4 trillion; (3) these systems are organized in long market chains which employ at least 1.3 billion people globally, and directly support livelihoods of at least 600 million poor smallholder farmers in the developing world; and (4) livestock products contribute 17% to global kilocalorie consumption and 33% to protein consumption globally.

The article discusses the implications of increased livestock consumption in the context of consumption estimates from Thornton & Herrero (2010) and Rosegrant et al. (2009). The article relies upon the following estimates of per capita meat and milk consumption in 2050.[38]

Table 1 – Projections of demand for livestock products in the developed and developing world (adapted from Thornton and Herrero, data from Rosegrant et al.)

		Annual per capita consumption		**Total consumption**	
		Meat (kg)	Milk (kg)	Meat (Mt)	Milk (Mt)
Developing	2002	28	44	137	222
	2050	44	78	326	585
Developed	2002	78	202	102	265
	2050	94	216	126	295

The authors also cite projections by Bouwman et al. (2005), which indicate that 30% more grass will be required to meet this increased demand for meat and milk.[39]

The authors note that these increases in consumption will have positive impacts in the developing word – including improvements in cognitive development and mortality rates – as the per capita consumption in 2050 is still well-below the current consumption in developed

[38] Herrero et al. (2009) at 112.

[39] A. F. Bouwman et al., *Exploring Changes in World Ruminant Production Systems*, 84 AGRICULTURAL SYSTEMS 121 (2005).

countries. In contrast, the increase in per capita consumption in the developing world will have primarily negative impacts on human health, including increased rates of obesity, cancer and heart disease. In light of these demand trends, the authors recommend a "two-pronged" approach to confronting livestock's environmental impacts, which involves (1) reducing demand for livestock products in the developed world, and (2) sustainably intensifying production to meet demand in the developing world.

The article also compiles statistics on current production trends in developed vs. developing countries, to extrapolate future patterns. For example, the authors note that:

- Developing countries already produce 50% of the beef, 41% of the milk, 72% of the lamb, 59% of the pork and 53% of poultry globally,[40] and that these shares are likely to increase significantly by 2050.
- In developing countries, mixed extensive and intensive crop-livestock systems produce 65%, 75% and 55% of the bovine meat, milk and lamb, and that these types of systems are "of particular importance from a food security and livelihoods perspective because over two-thirds of the human population live in these systems and apart from livestock products, they also produce close to 50% of the global cereal share."[41]
- Globally, industrial pork and poultry production account for 55% and 71% of overall pork and poultry production, [42] respectively, and that these systems will account for over 70% of the increases in meat production to 2030, especially in America and Asia.

The authors note the adverse environmental effects of intensive systems, and cite to recent research[43] suggesting that a shift towards integrated mixed farming systems (in North America, specially) could "still maintain high and profitable levels of production and at the same time have noticeable beneficial environmental impacts such as increased carbon sequestration, increased efficiency in use of resources, and recycling of nutrients."[44]

Andrew W. Speedy, *Global Production and Consumption of Animal Source Foods*, Animal Production and Health Division, Food and Agriculture Organization of the United Nations (FAO), 133 JOURNAL OF NUTRITIONAL SCIENCE 4048S (2003).

This article interprets statistics and information on global livestock production and the consumption of animal source foods from the FAO statistical data. This data shows that

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[40] For these figures, the authors relied on data from Rosegrant et al. (2009); Steinfeld et al. (2006); and M. Herrero et al., *Drivers of change in crop-livestock systems and their potential impacts on agro-ecosystems services and human well-being to 2030*. CGIAR Systemwide Livestock Program (2009).

[41] Herrero et al. (2009) at 112.

[42] For these figures, the authors relied on Steinfeld et al. (2006).

[43] M. P. Russelle, M. H. Ents & A. J. Franzluebbers, *Reconsidering integrated crop-livestock systems in North America*, 99 Agronomy Journal 325 (2007).

[44] Herrero et al. (2009) at 113.

livestock production is growing rapidly, the greatest increase being in the producing and consumption of poultry and pigs, as well as eggs and milk.

The data also demonstrates a very uneven pattern of consumption, and extreme divergence in growth patterns. In rich countries where meat consumption is already high, there is very little growth in consumption. In extremely poor countries, in particular certain African countries, consumption per capita is actually declining from an already low level as population increases. The majority of growth in consumption is occurring in developing economies like China, Brazil and India. When China and Brazil are included in calculations, meat production in these developing countries rose from 50 million Mt in 1980 to 180 Mt in 2000. If China and Brazil are excluded, then meat production grew from 27 million Mt in 1980 to only 50 million Mt. in 2000. The author notes that China, especially, has experienced "spectacular growth" in pig production, and that "[i]f China's growth in meat consumption in the last decade, which is an increase of ~2 kg/person/y... were to continue for much longer, the country would soon surpass the per capita consumption of the industrial countries, an untenable prospect."[45]

Interpreting this data, the author finds that the main determinant of per capita meat consumption appears to be per capita income, but that there is a certain threshold at which meat consumption levels off. The quantitative findings are illustrated in the graph below:

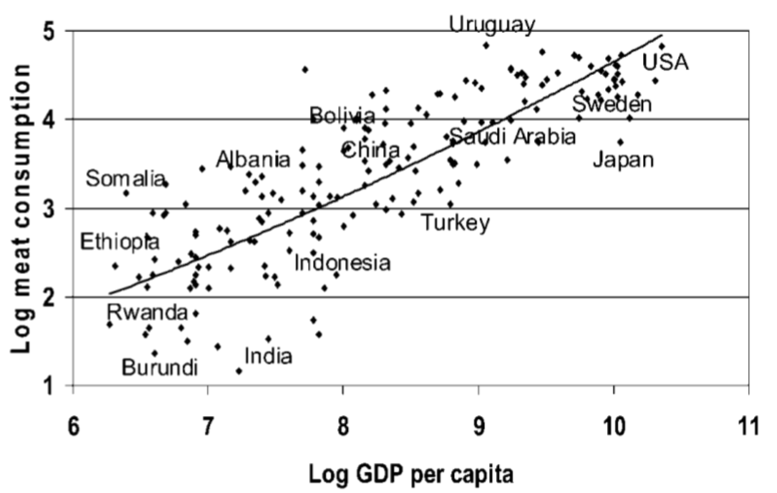

FIGURE 11 Per capita meat consumption in relation to GDP.

[45] Speedy (2003) at 4049S.

C. Qualitative Discussion of Demand, Production and Consumption Patterns

Peter Havlik et al., *Production system based global livestock sector modeling: Good news for the future*, paper presented at the European Association of Agricultural Economics (EAAE) 2011 Congress, "Change and Uncertainty: Challenges for Agriculture, Food and Natural Resources (August 30 to September 2, 2011).

This paper argues that productivity gains in livestock production will allow the livestock sector to meet demand by 2030 without a significant increase in environmental impacts or price. Specifically, the authors rely on evidence of productivity gains in the crop sector over the last several decades, which have enabled that sector to satisfy increased demand under decreasing real prices, with little additional land. The authors argue that, if livestock production systems are allowed to freely adapt to economic and resource constraints, the increase in per hectare productivity will allow the industry to satisfy the 2030 demand for ruminant products with less land than in 2000, and with livestock prices remaining stable.

The authors note, however, that adaptation in the livestock sector is a condition for sustainable future development, and should be taken into account by policy-makers. In particular, policy should seek to overcome specific barriers to adaptation, including economic, infrastructural, physical and institutional constraints.

Philip K. Thornton, *Livestock Production: Recent Trends, Future Prospects*, 365 PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B 2853 (2010).

This article discusses how livestock demand growth has been driven by human population growth, income growth and urbanization, and describes the production response in different livestock systems. Thornton finds that production will be increasingly affected by competition for natural resources, particularly land, water and feed, as well as the need to operate in a carbon-constrained economy. In light of these constrains, developments in breeding, nutrition and animal health will play an important role increasing total productive output and the efficiency of production systems. Thornton also notes that demand could be "heavily moderated by socio-economic factors such as human health concerns and changing socio-cultural values."[46]

Thornton asserts that the most significant challenges will be in developing countries, where livestock demand is increasing rapidly. Meeting this increased demand will require the modification of production techniques, including: (1) carcass weight growth, (2) intensification of livestock production, (3) new breeding techniques, (4) development and diffusion of more

[46] Thornton (2010) at 2853.

efficient technologies. Thornton notes that there are considerable opportunities to increase productivity in developing countries, in particular through modified breeding techniques.

Thornton further notes that, even with efficiency gains, the prices of meats, milk and cereals (feed) are likely to increase in the coming decades, potentially slowing demand growth. Other factors that may mitigate the increasing demand for livestock products include: (1) competition for land and water resources, (2) increased costs due to climate change adaptation needs, (3) changing socio-cultural attitudes, and (4) ethical concerns about the impact of livestock production on the environment and individual animals.

John Kearney, *Food Consumption Trends and Drivers*, 365 PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETy 2793 (2010).

This article discusses food consumption trends and projections to 2050. With respect to livestock products, Kearny estimates that consumption of meat will "increase moderately" (primary reflecting increases in poultry and pork intake), the consumption of eggs will continue to rise and the consumption of milk will continue to fall.[47] Specifically, Kearny finds that although there has been a rapid increase of meat consumption in Asia generally and China specifically, as well as Brazil, it is unlikely that India and countries in Africa will see similar increases due to economic and cultural factors. Thus, since the developed world, Brazil and China have already reached relatively high levels of per capita meat consumption, the overall demand for meat products will probably decelerate over the next 40 years.

Wei Zhao and Patrick Schroeder, *Consumption and production: Trends, challenges and options for the Asia-Pacific region*, 34 NATIONAL RESOURCES FORUM 4 (2010).

This paper discusses general trends in consumption and production in Asian developing countries and emerging economies. The authors find that the main challenge for Asian economies will be addressing the unsustainable consumption patterns of urban consumers, and recommends a shift towards green economic development and a "sustainable consumption and production" (SCP) approach.

The authors note that the SCP approach has been developed and implemented in Europe, North America and Japan over the past 30 years, with significant gains in resource productivity (i.e., "eco-efficiency"). The "vision" of this approach is to "achieve absolute decoupling of economic growth and human well-being on the one hand, and resource consumption and greenhouse gas emissions on the other."[48] The authors cite several barriers to the global realization of the SCP approach: (1) the inability of markets to successfully disseminate cleaner technologies, (2) subsidies for fossil fuels and resource-intensive industries, (3) the globalization

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[47] Kearny (2010) at 2796.

[48] Zhao & Schroeder (2010) at 5.

of value chains which has resulted in the outsourcing of polluting and inefficient industrial production, and (4) increasing levels of household livestock consumption.

The authors assert that the SCP approach requires "lifecycle thinking aiming to transform the consumption and production patterns of goods and services along the value chain" in order to understand the total footprint of production-consumption patterns and to identify "hot spots", e.g., those areas responsible for the highest output of greenhouse gases.

In addition to technologically and economically viable methods of improving the eco-efficiency of livestock production, the authors emphasize that "more efforts need to be directed towards addressing unsustainable consumption issues." [49] This is particularly important as the consumption patterns of consumers in the newly industrialized Asia-Pacific region are "now converging with those of western industrialized countries", where the average citizen consumes 3x as many resources as a citizen in a developing country. [50] The authors note that urban per capita emissions are much higher that rural emissions, and that targeting urban consumers will therefore be key in addressing global warming concerns.

Robert A. Kanaly et al., *Energy Flow, Environment and Ethical Implications for Meat Production,* Ethics and Climate Change in Asia and the Pacific (ECCAP) Project (Bangkok 2010).

This report discusses the environmental, energy, water, public health and socioeconomic effects of meat production, with an emphasis on livestock's role with respect to climate change. The primary purpose of the report is to encourage countries that are contemplating the creation, expansion, or integration of more intensive or industrialized modes of meat production to consider the possible future impacts of their investments, so as to dissuade these countries from expanding their reliance on the livestock sector.

The report identifies some of the key problems with industrialized livestock production, to illuminate why investments in this sector may be a poor choice going forward. For example, the report notes that, in developed countries, "it is understood that the perceived success of intensive meat production systems have been largely dependent upon the availability of relatively cheap fossil fuel energy as a foundation for their various modes of production."[51] Accordingly, countries can expect that intensive livestock production will become less economically viable as fossil fuel prices continue to rise.

The report also describes the "numerous negative externalities [of livestock production] that have serious and wide-ranging environmental, socioeconomic and public health consequences."[52] These externalities include GHG emissions that are contributing to global

[49] Zhao & Schroeder (2010) at 6.

[50] Zhao & Schroeder (2010) at 6.

[51] Kanaly et al. (2010) at 1.

[52] *Id*.

warming, as well as deleterious impacts to water quality, land quality and other natural resources. Many of these problems are linked to the energy intensity of livestock production (i.e., the high level of energy inputs necessary to produce a kg of meat or dairy products). Thus, as the livestock sector expands and intensifies to meet global demand, the externalities associated with livestock production will increase accordingly.

The report details some of the past and current trends in livestock production, noting a marked shift towards intensive meat production systems worldwide. As noted above, the ability of countries to transition to industrial livestock production has been predicated on the availability of cheap fossil fuel. In addition, the report finds "mounting evidence from the developed countries… that these systems have not operated in environmentally, economically and socially responsible manners through extensive negative cost externalizations."[53] Given this trajectory, the report finds it would be "prudent for developing and developed countries in Asia [where demand for livestock products is rapidly increasing] to consider alternative means of development in the meat production sectors before investing portions of their limited energy, economic and environmental resources in these systems."[54]

Much of the discussion focuses on Asia, which is "projected to undergo unprecedented growth and transformation in the coming years" for which "access to large amounts of energy in various forms will be necessary, and evaluation of the most efficient use of valuable energy flows while minimizing costly negative externalities that will affect public health and environment are priorities for responsible economic planning."[55] Thus, in Asia and elsewhere, it makes good sense to transition away from energy-intensive modes of livestock production. Rather, countries can pursue less intensive livestock production systems, or identify alternatives to livestock products that require significantly fewer energy inputs (e.g., legumes and soy).

In addition, the report conducts an ethical analysis of livestock production, both from a humanitarian perspective (recognizing a right to adequate access to food, and that all people should be free from chronic hunger and food insecurity), as well as the viewpoint of animals and what constitutes cruelty.

The report concludes with a number of policy options, including a proposed for internationally developed codes of good practice and codes of ethics that would address the environmental, ethical and socio-economic problems associated with intensive animal production systems.

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[53] Kanaly et al. (2010) at 2.

[54] *Id*.

[55] *Id*. at 2-3.

D. Case Studies – Analyzing the Livestock Sector in Specific Countries

The following policy papers were prepared by researchers at Brighter Green, as part of a series called "Climate Change and the Globalization of Factory Farming: Brazil, China, Ethiopia, and India." The papers document the globalization of industrial animal agriculture in Brazil, China, Ethiopia and India, focusing primarily on climate change impacts, but also discussing additional environmental, food security, equity, livelihood and animal welfare impacts of industrialization.[56]

Mia MacDonald and Justine Simon, *Cattle, Soyanization, and Climate Change: Brazil's Agricultural Revolution* (Brighter Green 2011).

This paper discusses Brazil's expanding livestock sector, which produced approximately 37% of global meat exports in 2011. The authors find that, in order to meet the rising international and domestic demand for livestock products, Brazil's livestock sector has significantly increased the number of animals, production facilities, and processing and transport capacity.

The production of poultry, pork, veal, and eggs has intensified to meet demand in Brazil. However, intensified feedlots for cattle are still rare. Only 5% of Brazilian beef is produced in feedlots. That said, the authors also find that much of the pasture used for grazing cattle has been created in areas of great biological diversity, including the Amazon rainforest and the Cerrado (Brazilian savannah), both of which are "enormously important to the global climate."[57] Thus, grazing also has significant environmental impacts.

Some of the most significant sources of emissions associated with cattle production include those released when forests are burned, and the lost sequestration opportunity during the period that land is dedicated to grazing. The paper further finds that 75% of Brazil's GHG emissions are the "result of deforestation and changes in land use to pave the way for production of livestock and crops."[58] Emissions from the livestock sector are rapidly increasing, and cattle production is a major contributor. The paper cites one study, which estimates that *half of Brazil's GHG emissions came from the cattle sector,* based solely on emissions from deforestation and burning to create pasture land, and enteric fermentation. Thus, the actual proportion of emissions from cattle production may be even higher when all parts of the cattle supply chain are included.

The authors also cite World Bank Figures, which estimate that, between 1995 and 2010, deforestation reduced Brazil's "carbon stock" (the amount of carbon stored in natural resources such as trees and soil) by 6 billion metric tons, which is equivalent to *roughly two-thirds of all*

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[56] These policy papers are all available at: http://brightergreen.org/brightergreen.php?id=24.

[57] MacDonald & Simon (2011) at 1.

[58] *Id*. at 2.

the GHGs produced globally each year. Thus, the authors conclude that the Brazilian government should prioritize emissions reductions from the cattle sector.

After providing an overview of Brazil's livestock sector, the paper explores whether Brazil can protect its biodiversity and natural resources and meet its stated climate change targets, even while it produces, consumes and exports more livestock products. The authors conclude with several policy recommendations for Brazil's livestock sector:

- Brazilian government should prioritize the reduction of GHG emissions from the cattle sector;
- The government should modify incentives and subsidies to discourage deforestation via burning;
- Economic models should account for sequestration potential in the Amazon and Cerrado regions;
- The government should put a price on major GHGs, including carbon dioxide and methane;
- Externalities of industrial agriculture should be fully accounted for, priced, and paid by producers, including land degradation and forest loss;
- Other avenues of economic development (aside from livestock development) should be explored.

The authors also offer a number of more specific recommendations for reducing the environmental impacts of livestock activities in Brazil.

Mia MacDonald and Sangamithra Iyer, *Skillful Means: The Challenges of China's Encounter with Factory Farming* (Brighter Green 2011).

This paper documents China's rapid increase in the consumption and production of meat and dairy products, and the subsequent impacts of rapid industrialization of the livestock sector. The authors note that meat consumption in China has quadrupled since 1980, reaching approximately 54 kilograms per person, annually, by 2011. China is currently the world's largest producer of both pigs and poultry meat, and the world's largest producer of agricultural products more generally.

The paper describes the deleterious environmental impacts of the expanding livestock industry in China, finding that China's livestock produce 2.7 billion tons of waste a year, which is now one of the leading sources of water pollution. The paper further finds that livestock has significantly contributed to an increase in China's per capita emissions of carbon dioxide, which have more than doubled from 2.1 tons of CO_2 equivalent in 1990 to 5.1 tons in 2011.

The paper also discusses how production has intensified in China to meet demand. Currently, most of China's livestock are still produced on small and medium sized farms, primarily mixed systems. However, the proportion of livestock produced in factory farms is gradually increasing. The authors note that there is much inertia for intensification, as many stakeholders believe this is the most efficient way to increase production, and that "it will be difficult to convince the Chinese government or people to move away from the intensive model."[59]

The paper concludes that China is developing more rapidly than any other nation in global history, and that it will be difficult to predict the full impacts from this phenomena. It is clear that environmental impacts from livestock production are significantly increasing, and that this is quite problematic. However, it is unclear how China can best mitigate these impacts while ensuring food security. The authors provide several policy recommendations including:

- China's government should undertake a multi-sector analysis of the nature and impacts of industrial animal agriculture, to better understand the relative merits of intensification;
- The government should redefine its conception of short and long-term food security, so that it doesn't give priority to a meat-centered diet;
- Government subsidies that support the expansion of industrial-scale livestock operations should be ended;
- Externalities from animal agriculture, such as GHG emissions, water pollution and land degradation, should be paid for, in full, by the industry and/or specific factories that case them;
- Political openness should be encouraged;
- The government should support ongoing dialogue on these issues;
- The growing environmental movement in China should consider the issue of intensive animal agriculture in research and advocacy-based activities.

Mia MacDonald and Justine Simon, *Ethiopia's Complex Relationship with Livestock* (Brighter Green 2011).

This paper discusses the livestock sector in Ethiopia, which has been gradually expanding, but without a substantial positive impact on the livelihoods of most Ethiopians.

Ethiopia is the world's tenth largest producer of livestock. It has the largest livestock population of any African country, and is the continent's top livestock producer and exporter. In 2008, Ethiopia had approximately 49 million cattle, nearly 50 million sheep and goats, and 35 million chickens. These populations have grown substantially in the last ten years. Between 1998 and 2008, the total population of cattle increased by 29%, sheep increased by 86%, goats increased by 109% and chickens increased by 6%.

However, even while production has increased, livestock consumption in Ethiopia remains at very low levels. The average Ethiopia eats 8.3 kilograms of meat per year, which is one-tenth the levels of consumption in the United States. Thus, the paper finds that Ethiopia's export potential is the primary driver of growth in this section. Meanwhile, Ethiopia continues to deal with famine and malnutrition despite increased livestock production. In light of these

[59] MacDonald & Iyer (2011) at 6.

problems, Ethiopia's export of food—including livestock products—is somewhat controversial among Ethiopian civil society groups and international non-governmental organizations.

Most of the livestock in Ethiopia are still raised by small-scale farmers and pastoralist, but production systems are gradually intensifying. For example, the Ethiopian government has taken steps to commercialize the poultry industry, which has lead to intensification of this sector. A key problem for intensification is the lack of productive land for growing feed. Thus, some international donors are working to support the continuation of small-scale livestock production rather than intensified production.

The paper also discusses how the effects of global warming may impact livestock production in Ethiopia. It finds that the "effects of global climate change on Ethiopia Drought and desertification are two key problems which could significantly hinder livestock and other food production in Ethiopia. Thus, livestock production is particularly vulnerable in the context of climate change, and reliance on livestock may actually undermine the livelihoods of Ethiopians.

The paper concludes by providing recommendations to the Ethiopian government, donor partners, and civil society groups. For example, the paper recommends that the government adopt long-term plan for achieving food security, develop a comprehensive plan for expanding domestic production of non-livestock food products for Ethiopian people, and identify new means for rural Ethiopians to store wealth apart from livestock. In addition, the paper recommends that all stakeholders should collaborate on the implementation of large-scale ecosystem restoration projects, and re-assess the policies and practices that lead to land degradation, desertification, further aridity and increase the risk of drought, in the context of global warming. Finally, the paper recommends raising awareness about climate change, its impacts on livestock production, and what this will mean for the livelihoods of Ethiopians.

Mia MacDonald and Sangamithra Iyer, *Veg or Non-Veg? India at the Crossroads* (Brighter Green 2011).

This paper discusses the rising domestic consumption of meat and dairy products in India, attributing the increased demand for these products primarily to the rapid expansion of India's middle class. The paper notes that India is now one of the world's largest producers of livestock products, and that it has the world's biggest dairy herd, comprised of approximately 300 million cows and buffalo. India is already the world's largest consumer of milk, and the domestic demand for dairy products is growing by 7-8% per year. India is also the world's fourth largest producer of eggs and fifth largest producer of poultry. As of 2010, India's poultry market is expanding more rapidly than markets in Brazil, China, the U.S., the European Union and Thailand.

Animal products are still relatively cheap in India, due to the scale of production, lack of taxation, reliance on low waged labor and limited government regulation. The low costs also provide a competitive advantage in international markets for animal products. For example, India produces eggs at a lower cost than any other country, and the cost of producing poultry are the second lowest in the world.

The majority of India's animal products are consumed domestically, but international trade in this sector is growing. India is also seeing increased trade with respect to the grain and oil meals used in livestock feed. The Indian government hopes that India will "become a key player in the global meat market."[60] Accordingly, the government is encouraging foreign investment in India's agribusiness and livestock sectors. In 2011, the government announced that foreign direct investment for intensive livestock operations with 100% foreign ownership would be welcome and permitted in India.

Thus, despite predictions that Indians will never consume as many animal products as citizens of the U.S. and China due to their cultural and culinary traditions, the livestock sector is rapidly expanding in this country, In addition to export potential and rising incomes, India is experiencing rapid population growth that will also lead to marked increase in the consumption of livestock products.

With respect to GHG emissions, the paper finds that India is the fifth largest emitter of GHG emissions in the world, and that livestock are a significant source of those GHGs. For example, India's emissions of methane from livestock are larger than any other country's. In 2007, India's livestock sector produced approximately 334 million tons of CO_2 equivalent. Methane produced from enteric fermentation was responsible for approximately 63.4% of GHG emissions from India's livestock sector, approximately 212 million tons of CO_2 equivalent.

The paper discusses the various components of India's livestock sector with more depth, and concludes with a number of policy recommendations. In particular, the paper recommends that the Indian government should reconsider its policies with respect to the livestock sector and its role in the global livestock economy. Rather than focus on livestock production, the paper recommends that the government "make it a national priority to ensure food security for all Indians through access to a varied, nutrient-dense, plant-based diet, with a particular focus on addressing extremely high rates of child malnutrition."[61] The paper also provides additional, more specific recommendations on how the government and civil society groups can achieve environmental and humanitarian goals while reducing the country's reliance on livestock production.

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[60] MacDonald & Iyer (2011) at 2, citing India's National Meat and Poultry Processing Board.

[61] *Id*. at 36.

III. EMISSIONS FROM LIVESTOCK PRODUCTION

It is difficult to quantify the total emissions from livestock-related activities, due to the lack of precise data, the varied nature of livestock production systems across the globe, and the challenge of identifying all life-cycle activities and their respective emissions. The FAO (2006) estimates that the livestock sector is responsible for 18% of anthropogenic greenhouse gas emissions worldwide, whereas Goodland & Anhang (2009) believe that this figure is too low, because it underestimates demand, under-tallies emissions from certain activities and completely omits emissions from other categories, and that the correct estimate is closer to 51%. This section first provides an overview of those two competing studies, and then reviews additional literature which discusses the possible contribution of livestock to GHG emissions and the methodologies used to develop such estimates.

A. Quantifying Emissions from Livestock Activities: FAO Report (2006) and Response from Goodland & Anhang (2009)

HENNING STEINFELD ET AL., LIVESTOCK'S LONG SHADOW: ENVIRONMENTAL ISSUES AND OPTIONS, Food and Agriculture Organization (FAO) Livestock, Environment and Development Initiative (2006).

This 2006 report from the FAO provides the most comprehensive and extensively cited statistics on current emissions from livestock production and future predictions.

The FAO estimates that the livestock sector is responsible for 18% of greenhouse gas emissions, or approximately 7.1 billion tons of CO_2 equivalent. This includes 9% of anthropogenic CO_2 emissions, 37% of anthropogenic methane (which have a global warming potential (GWP) that is 23x that of CO_2), 65% of anthropogenic nitrous oxide (GWP is 296x CO_2), and 64% of anthropogenic ammonia emissions (which contribute significantly to acid rain and acidification of ecosystems).

With respect to the GHG emissions released by such activities, the report finds that livestock respiration makes up only a "very small part of the net release of carbon that can be contributed to the livestock sector" and that the bulk of emissions are released indirectly by other channels, including:

(1) burning fossil fuel to produce mineral fertilizers used in feed production
(2) methane release from the breakdown of fertilizers and from animal manure
(3) land-use changes for feed production and for grazing;
(4) land degradation;
(5) fossil fuel use during feed and animal production; and

(6) fossil fuel use in production and transport of processed and refrigerated animal products.[62]

The report analyzes each of these impacts, and provides country- and region-specific estimates of the emissions generated by these processes. The FAO's estimates are summarized in the following table.[63]

Table 3.12

Role of livestock in carbon dioxide, methane and nitrous oxide emissions

Gas	Source	Mainly related to extensive systems (10^9 tonnes CO_2 eq.)	Mainly related to intensive systems (10^9 tonnes CO_2 eq.)	Percentage contribution to total animal food GHG emissions
CO_2	**Total anthropogenic CO_2 emissions**	**24 (~31)**		
	Total from livestock activities	**~0.16 (~2.7)**		
	N fertilizer production		0.04	0.6
	on farm fossil fuel, feed		~0.06	0.8
	on farm fossil fuel, livestock-related		~0.03	0.4
	deforestation	(~1.7)	(~0.7)	34
	cultivated soils, tillage		(~0.02)	0.3
	cultivated soils, liming		(~0.01)	0.1
	desertification of pasture	(~0.1)		1.4
	processing		0.01 – 0.05	0.4
	transport		~0.001	
CH_4	**Total anthropogenic CH_4 emissions**	**5.9**		
	Total from livestock activities	**2.2**		
	enteric fermentation	1.6	0.20	25
	manure management	0.17	0.20	5.2
N_2O	**Total anthropogenic N_2O emissions**	**3.4**		
	Total from livestock activities	**2.2**		
	N fertilizer application		~0.1	1.4
	indirect fertilizer emission		~0.1	1.4
	leguminous feed cropping		~0.2	2.8
	manure management	0.24	0.09	4.6
	manure application/deposition	0.67	0.17	12
	indirect manure emission	~0.48	~0.14	8.7
Grand total of anthropogenic emissions		**33 (~40)**		
Total emissions from livestock activities		**~4.6 (~7.1)**		
Total extensive vs. intensive livestock system emissions		**3.2 (~5.0)**	**1.4 (~2.1)**	
Percentage of total anthropogenic emissions		10 (~13%)	4 (~5%)	

Note: All values are expressed in billion tonnes of CO_2 equivalent; values between brackets are or include emission from the land use, land-use change and forestry category; relatively imprecise estimates are preceded by a tilde.
Global totals from CAIT, WRI, accessed 02/06. Only CO_2, CH_4 and N_2O emissions are considered in the total greenhouse gas emission.
Based on the analyses in this chapter, livestock emissions are attributed to the sides of the production system continuum (from extensive to intensive/industrial) from which they originate.

62 Steinfeld et al. (2006) at 86.

63 *Id*. at 113.

The report also provides a detailed overview of land-use practices related to livestock production, specific types of livestock systems (e.g., mixed farming systems vs. grazing systems), and the geographic concentration of livestock practices. The report finds that production patterns are shifting, both geographically (as production grows more concentrated and moves towards population centers and feed sources) and structurally (as production becomes more vertically integrated). There has also been a shift towards poultry and pig meat relative to ruminant meat, and towards grain- or concentrate-based diets rather than "low-value feed". The report finds that the aggregate effect of these shifts in production practice is to increase, rather than decrease, the environmental impacts of the livestock sector.

Robert Goodland and Jeff Anhang, *Livestock and Climate Change: What if the key actors in climate change are cows, pigs, and chickens?* (Worldwatch Institute 2009).

Based on an analysis of the life cycle and supply chain of domestic animals raised for food, this report concludes that the contribution of livestock to climate change is substantially larger than FAO figures (18%). Goodland & Anhang estimate that livestock actually produces approximately 51% of anthropogenic GHG emissions, or 32,564 million tons of CO_2 equivalent per year. In reaching this figure, they assert that the FAO underestimated demand for livestock products, under-tallied emissions from certain activities, and omitted emissions from other categories.

To reach this figure, the authors identify livestock related GHG emissions which were uncounted, overlooked, and/or misallocated by the FAO report. These include:

Emissions Source	Annual GHG emissions (CO_2e) - million tons	Percentage of worldwide total
FAO Estimate	7,516	13.7
Overlooked respiration from livestock	8,769	13.7
Overlooked land use	≥ 2,672	≥ 4.2
Undercounted methane	5,047	7.9
Uncounted - 4 other categories	≥ 5,560	≥ 8.7
Misallocated in current GHG inventories - 3 categories	≥ 3,000	≥ 4.7
Total	≥ 32,564	≥ 51.0

Based on these projections, the authors assert that taking action to replace livestock production would achieve quick reductions in atmospheric GHGs and could also mitigate the ongoing world food and water crises. Specifically, the authors recommend that a 25% reduction in livestock products worldwide could be achieved between the 2009 and 2017, resulting in a 12.5% reduction in global atmospheric GHG emissions. The authors note that this reduction would be "almost as much as is generally expected to be negotiated in Copenhagen."[64]

Undercounted and Misallocated Emissions - Goodland & Anhang identify a number of specific "under-counted" and "misallocated" emissions from livestock activities which produce approximately 5,560 and 3,000 million tons of CO_2e per year, respectively. The four under-counted sources in the table above included: (1) the increase in livestock products from 2002-2009 (FAO's estimate relied on 2002 figures); (2) adjustment for undercounting in official statistics of livestock production; (3) current estimates of emissions statistics for various livestock species (FAO relied on citations from 1964, 1982, 1993, 1999 and 2001); and (4) adjustment for inefficiency of livestock operations in developing countries (FAO report relied on efficiency of operations in Minnesota).

The three categories of misallocated emissions in the table above include: (1) emissions from livestock related deforestation; (2) emissions from fish farming; and (3) emissions attributable to the use of livestock products such as cooling livestock products (fluorocarbons), cooking livestock products, disposal of livestock waste products, production, distribution and disposal of livestock byproducts and packaging, and the carbon-intensive medical treatment of zoonotic illnesses and human illnesses related to livestock products.

Overlooked Respiration from Livestock - As evinced by the chart above, a key difference in the two studies is that the FAO omitted emissions from respiration whereas Goodland & Anhang include them. This decision obviously has a major impact on how livestock's impact on the atmosphere will be understood, since the emissions from "overlooked respiration" identified by Goodland & Anhang are greater than the total emissions from livestock production identified by the FAO.

The FAO omits respiration because it is not considered a "net source" of CO_2. The assumption is that the amount of CO_2 exhaled by livestock is roughly equivalent to the carbon sequestered in the feed grown for and consumed by livestock. Thus, this carbon is part of a short-term carbon cycle that does not contribute to global warming.

Goodland & Anhang argue, however, that the FAO's approach is flawed, because livestock are a human invention, and the CO_2 exhaled by livestock is not part of the natural carbon cycle. The authors explain:

> [W]hile over time an equilibrium of CO_2 may exist between the amount respired by animals and the amount photosynthesized by plants, that equilibrium has never been static. Today, tens of billions more livestock are exhaling CO_2 than in pre-industrial days,

[64] Goodland & Anhang (2009) at 15.

while Earth's photosynthetic capacity (its capacity to keep carbon out of the atmosphere by absorbing it in plant mass) has declined sharply as forest has been cleared.[65]

Thus, there is no longer a true balance between sequestration and respiration. Goodland & Anhang also note that by ignoring GHGs attributable to livestock respiration, we will not manage these GHGs and their amount will increase. In finding that CO_2 from livestock respiration accounts for 21% of anthropogenic GHGs worldwide, Goodland & Anhang rely on 2005 estimate from Alan Calverd, a British physicist, that livestock exhale approximately 8,769 million tons of CO_2 per year.

Overlooked Land Use **–** Goodland & Anhang assert that the FAO has overlooked at least 2,672 million tons of CO_2e from land use changes associated with livestock production. They find that the FAO estimate includes the "relatively small" amount of emissions from land use changes each year, but omits the annual GHG reductions from photosynthesis that are foregone by using 26% of the land worldwide for grazing livestock and 33% for growing feed.[66] They find that "leaving a significant amount of tropical land used for grazing livestock and growing feed to regenerate forest could potentially mitigate *as much as half (or even more) of all anthropogenic GHGs*."[67] Thus, it is important to account for the foregone sequestration opportunities from lands dedicated to livestock-related uses, in order to prioritize the reclamation of such lands.

Undercounted Methane **-** With respect to undercounted methane emissions, Goodland & Anhang use the 20-year global warming potential (GWP) for CH_4, which is 72; whereas the FAO uses a 100-year GWP of 23. This methodological difference explains the discrepancy in their figures.

Brook & Russell (2009), supra page 54, also address this issue, noting that the GWP of methane is significantly higher when calculated over a 20-year timeframe and discussing the implications of this difference. They estimate that, in Australia, livestock produce approximately 3 million tons (Mt) of methane, which would be calculated as the equivalent of 63 Mt of CO_2e using a 100-yr GWP. But using the 20-yr GWP, instead, livestock production produces the equivalent of 216 Mt of CO_2 emissions—*more than half the atmospheric heating caused by emissions from all Australia's coal fired power stations.* Brook & Russell also find that the choice between a 20-year and 100-year GWP has a significant impact on how we calculate we calculate the relative emissions intensity of different food sources.

Given these discrepancies, Brook & Russell recommend that public information campaigns and policy makers should reconsider the use of 100-yr GWPs, which have "given methane a very low public profile even though it is the second most important greenhouse gas after CO_2."[68] This issue is of particular importance because shorter-lived climate forcers,

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[65] Goodland & Anhang (2009) at 12.

[66] *Id*. at 13.

[67] *Id*.

[68] Brooks & Russell (2009) at 39.

particularly methane, represent a significant proportion of livestock-related GHG emissions, and enteric fermentation from livestock is the biggest anthropogenic source of methane.

B. Quantifying Emissions from Livestock Activities: Additional Discussion

M. Herrero et al., *Livestock and Greenhouse Gas Emissions: The Importance of Getting the Numbers Right*, 166-167 JOURNAL OF LIVESTOCK SCIENCES 779 (2011).

The purpose of this article is to identify the "significant methodological differences and uncertainties" which explain the broad range of current estimates for livestock's contribution (10-51%). In particular, the authors examine the main discrepancies between FAO's 2006 Report ("Livestock's Long Shadow"), which estimated that livestock contributes 18% of global GHG emissions, and the response from Goodland & Anhang (2009) published by the Worldwatch Institute, which estimated that livestock contributes 51% of global GHG emissions.

The authors assert that there are certain deficiencies in the Goodland & Anhang (2009) study. In particular, the authors argue that the Goodland & Anhang's methodology was flawed it "oversimplified the issue with respect to livestock production" by "emphasi[zing] the negative impacts without highlighting the positives."[69] The authors compare the substantive differences in the two reports as follows:

Exclusion of carbon dioxide emissions from livestock respiration: FAO (2006) omitted such emissions from their analysis, whereas Goodland & Anhang (2009) included them. The authors assert that the FAO approach was appropriate. Specifically, they note that, under 2006 Intergovernmental Panel and Climate Change (IPCC) inventory guidelines (IPCC 2006), and under the Kyoto protocol CO_2 from livestock production is not considered a net source of CO2 because (1) the "amount of carbon in feed consumed and CO emitted by livestock are considered to be roughly equivalent and part of a short-term carbon cycle… [which] does not lead to a net increase in the concentration of atmospheric CO_2 within relevant time horizons;" and (2) any differences that do exist between carbon consumed and CO_2 emissions are "small when overall global rangeland and forage productivity are considered as a carbon sink" and a "significant body of evidence… suggests that grasslands and their growth more than offset CO2 emissions from livestock."[70] The authors conclude that, whatever the exact numbers may be, "if respiration is accounted for, then CO_2 absorption related to the growth of forage and feed should also be considered in the overall carbon cycle analysis."[71]

Emissions from land use and land use change: The authors determine that FAO (2006) estimates "may have been conservative in many aspects" but that Goodland & Anhang (2009)

[69] Herrero et al. (2011) at 780.

[70] *Id*.

[71] *Id*.

used an oversimplified and flawed methodology to reach their own estimates of livestock emissions from land use and land use changes. Specifically, Goodland & Anhang used a "consequential approach" that relies upon a "what-if scenario"—it "quantifies the amount of carbon that would be sequestered if existing grazing lands were allowed to revert to forest, and then attributes the lost opportunity for carbon sequestration to livestock."[72] The FAO report, in contrast, "bases its analysis on actual land use trends, thereby allocating carbon losses resulting from *current* changes in land use to livestock."[73]

The authors conclude that, although it is "important to consider different future possible uses for land" the approach adopted by Goodland & Anhang (2009) is "methodologically inconsistent" because it does not "quantify the lost opportunity for carbon sequestration that results from other forms of land use"—if they did, the "overall anthropogenic GHG emissions would be higher, and livestock-related impacts would need to be seen as a percentage of this overall higher figure."[74] The authors also find that Goodland & Anhang (2009) failed to consider the practical realities of what would happen to grazing land if it was not used for livestock production, given that the key drivers of land use change are not necessarily ensuring maximum productivity or mitigating environmental impact, and that there is a present "lack of economic incentive to conserve or maintain natural resources" in most areas.[75]

The authors do agree with Goodland & Anhang, more generally, that FAO (2006) estimates for emissions from land use changes were deliberatively conservative.

Global Warming Potential of Methane: Goodland & Anhang (2009) use the 20-year global warming potential (GWP) for CH4, which is 72; whereas FAO (2006) used a 100-year GWP of 23—which explains some of the discrepancy in their figures. The authors note that the FAO estimate may be low (the IPCC has revised the 100-year estimate to 25) and that, given the short-term radiative forcing potential from methane, using a shorter time horizon may be appropriate (thus supporting Goodland & Anhang's methodology). The authors also note, however, that 100-years is the more commonly used timeframe for comparing and prioritizing mitigation practices (thus supporting FAO's methodology). The authors conclude that the selection of a time horizon is "not only a scientific issue, but a political one" and that this decision should be explicitly addressed in any scientific study.[76]

Attribution of greenhouse gases to livestock and others: The authors explain that Goodland & Anhang (2009) also identified a number of GHG sources which are currently excluded from the FAO and other reports, such as: cooking in open fires, waste management, use of toxic chemicals, and the packaging and use of cold chains. The authors find that "[m]ethodologies for estimating and adequately attributing these kinds of emissions to specific

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[72] Herrero et al. (2011) at 781.

[73] *Id*.

[74] *Id*.

[75] *Id*.

[76] Herrero et al. (2011) at 782.

sectors are still under development and have not been vetted by the international scientific community."[77]

The authors note, however, that Goodland & Anhang were correct in finding that the FAO assessment omits GHG emissions related to the preparation of animal products, and furthermore, that the FAO's estimates for emissions from land use change, transport and processing were deliberatively conservative and constrained by data availability.

With respect to Goodland & Anhang's determination that the FAO's 18% estimate was outdated (because it relied on older, smaller figures of total livestock production), the authors agree generally with this proposition. However, the authors find that Goodland & Anhang "erroneously assume[d]" that a 12% increase in the global tonnage of livestock products would directly translate into a proportionate increase in GHG emissions, because this assumption ignores the fact that livestock production systems can and have become more efficient.

Finally, with respect to the overall figures of animal population—in particular, Goodland & Anhang's assertion that the FAO undercounted poultry—the authors find that this assertion "stems from a misinterpretation on the part of Goodland and Anhang (2009) who confound "poultry biomass" for production of poultry meat." The authors further note that "despite some shortcomings of the FAO statistics, FAO still remains the only globally recognized source of data on agriculture."[78]

The article concludes that the magnitude of the discrepancy between emissions estimates from Goodland & Anhang (2009) and FAO (2006) illustrates the need to improve and standardize the methodology for calculating GHG emissions. In particular, "we need to define the magnitude of the impact of livestock on climate change, but… we also need to understand their contribution relative to other sources" in order to make the best choices among competing mitigation options. Thus, although Goodland & Anhang (2009) correctly determined that the FAO statistics are "conservative" and potentially omit certain emissions which should be attributed to livestock production, their overall estimate of livestock-related emissions (51%) is highly questionable because it often relies on assumptions and rather than actual data, fails to fully substantiate its assumptions and methodologies, and fails to address the discrepancy between its assessment and current standards for calculating GHG emissions.

The authors recommend that we continue to reevaluate emissions estimates, but that future studies "need to be part of an ongoing process… one that is to be conducted through transparent, well established methodologies, rigorous science, and open scientific debate."[79]

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[77] *Id*.

[78] *Id.*

[79] Herrero et al. (2011) at 782.

Robert Goodland & Jeff Anhang, *Response to Livestock and Greenhouse Gas Emissions: The Importance of Getting the Numbers Right*, by Herrero et al., 172 ANIMAL FEED SCIENCE AND TECHNOLOGY 252 (2012) at 253.

In this article, Goodland & Anhang respond to the critique from Herrero et al. (2011). Goodland & Anhang defend their methodology for calculating GHG emissions from the livestock sector on the following grounds:

Inclusion of Livestock Respiration: Goodland & Anhang assert that the conception of "net emissions" utilized by the FAO is based on an outdated conception of the carbon cycle, in which photosynthesis balances respiration.[80] That model made sense only when there were "roughly constant levels of respiration and photosynthesis on Earth."[81] Now, however, respiration has "increased exponentially with livestock production (now more than sixty billion land animals per year)."[82] Meanwhile, "increased livestock and feed production accompanied by large scale deforestation and forest-burning have caused a dramatic decline in the earth's photosynthetic capacity, along with large and accelerating increases in volatization of carbon in soil."[83] Thus, the respiration of all organisms exceeds the capacity of photosynthesis to absorb such carbon.

Overlooked Land Use - Goodland & Anhang assert that the "what if" scenario is appropriate, and accords with practices of other international environmental institutions. The Kyoto Protocol, for example, "relies in all its parts on 'what-if' scenarios; that is, measurements of theoretical prospective carbon emissions and absorptions."[84] Goodland & Anhang also note that they used "minimal" figures to predict the lost opportunity for carbon sequestration in land set aside for grazing and feed production.[85] In other words, they were deliberatively conservative in order to account for uncertainty regarding alternative land uses—e.g., whether grazing land would otherwise be reforested or put to some other use.

Global Warming Potential of Methane - To defend their use of a 20-year GWP for methane, Goodland & Anhang assert that the IPCC has long supported the use of a 20 year timeframe for methane, and cite to an article by Dyer et al. (2011), which found that the 20-year accounting period may be a better reflection of the time scale for the GWP of methane, due to the growing urgency of global warming.

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[80] Robert Goodland & Jeff Anhang, *Response to Livestock and Greenhouse Gas Emissions: The Importance of Getting the Numbers Right*, by Herrero et al., 172 ANIMAL FEED SCIENCE AND TECHNOLOGY 252 (2012) at 253.

[81] *Id*.

[82] *Id*.

[83] *Id*.

[84] *Id*. at 254.

[85] *Id*.

Wedderburn-Bishop, G. & L. Pavlidis, *Livestock production and shorter-lived climate forcers,* World Preservation Foundation (2011).

This report, written by scientists at the World Preservation Foundation, details the global livestock sector's contribution to emissions from shorter-lived climate forcers. Emissions from three such forcers – methane, black carbon and tropospheric ozone – have a larger annual CO_2 equivalent impact than emissions from CO_2 itself. The authors find that livestock production is the primary anthropogenic source of emissions from all three of these agents. Mitigating emissions from these sources could significantly reduce short-term (decades-level) climate change, "allowing time for necessary longer term CO_2 abatement measures to take effect."[86]

Wedderburn-Bishop & Pavlidis advocate reductions in deforestation (and the open fires associated with it) for livestock production as a relatively low-cost, high-yield approach to mitigating short-term climate change. Reforestation and soil carbon accumulation also have the positive long-term effects of reducing legacy CO_2. The authors believe "the climate impacts of this one industry [livestock production] offer a unique opportunity to stem global warming, giving the scientific and political communities time to work on longer term solutions." [87]

Philip K. Thornton & Mario Herrero, *The Inter-linkages between Rapid Growth in Livestock Production, Climate Change, and the Impacts on Water Resources, Land Use, and Deforestation*, Background Paper to the 2010 World Development Report, Development and Climate Change (January 2010).

In Section 4, the article specifically highlights the effects of increased livestock production on climate change. The article discusses figures from Steinfeld et al. (2006)—estimating that livestock activities contribute approximately 18% of total anthropogenic emissions, taking into account emissions from the five major sectors for GHG reporting (under the IPCC framework): energy, industry, waste, land use plus land-use changes plus forestry, and agriculture. The article notes that the 18% overall figure does not include respiration, as the IPCC does not account for this (the rationale being that the CO_2 absorbed by the plants that are consumed to be approximately equivalent to that emitted by livestock respiration.)

The authors also note that this figure will probably grow due to the increasing use of fossil fuels to manufacture fertilizer used in feed production, in feed and animal production, in land-use changes, and in the processing of transportation of livestock-products. The authors conclude that, "[a]s farming systems become more intensive and industrialized in places, CO_2

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[86] Wedderburn-Bishop & Pavlidis (2011) at 2.

[87] *Id*.

emissions will increase, corresponding to increasing shifts away from the solar energy harnessed by photosynthesis to fossil fuels."[88]

Nathan Pelletier & Peter Tyedmers, *Forecasting potential global environmental costs of livestock production 2000-2050,* 107 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES 18371 (2010).

In this study, Pelletier and Tyedmers (environmental scientists at Dalhousie University, Halifax) compare global livestock data from 2000 to projections for 2050, focusing on livestock's impacts on three environmental issues: climate change, plant biomass usage, and reactive nitrogen mobilization. (This summary will concentrate on climate change.) They project that by 2050, the sustainability thresholds for all three issues will be nearly met or even exceeded by the contributions of livestock production alone. In response, the authors emphasize the need for governments to reel in livestock industry growth.

Livestock production volume will double from 2000-2050, due to population growth and per capita demand increases. According to Pelletier and Tyedmer's models and FAO's scenarios, GHG emissions from meat and dairy production will simultaneously increase by 39%. However, emissions vary greatly by animal product type. For example, the authors estimate that if all marginal beef production past 2000 levels was replaced by poultry production, that 39% increase in emissions could be reduced by 5-13%.

According to the authors, agriculture directly contributes 10-12% of anthropogenic greenhouse gas emissions (IPCC 2007), or anywhere from 17-32% if land use change is included. A complete supply-chain analysis attributes 31% of the EU's GHG emissions to the food sector. However, a 2006 FAO report attributes 14% of anthropogenic climate change to livestock production alone, or 18% with land use change included (FAO 2006).

58% of human-collected biomass was dedicated to livestock production in 2000. The inefficient conversion of this biomass to animal protein increases the per-calorie carbon footprint of meat products. Pelletier and Tyedmers endorse the "vigorous [pursuit]" of increased feed conversion efficiency, citing vast improvements over the last few decades. However, they believe that technological limits necessitate a "shift in production away from ruminants and toward lower impact species such as poultry."[89] This shift should be encouraged by subsidies, taxes and regulation. Well-managed fisheries and aquaculture are promising options as well, but have their own negative externalities.

The authors argue that per capita animal product consumption must drop 19% by 2050 in order to maintain 2000 anthropogenic GHG emissions levels, which is feasible in developed nations, where meat is currently consumed at twice the USDA-recommended rate. (The

[88] Thornton & Herrero (2010) at 51.

[89] Pelletier & Tyedmers (2010) at 18373.

objectivity of USDA recommendations is not discussed.) However, the effects of Bennett's Law – which states that, as per capita income increases, so does per capita meat consumption – must be curbed in developing countries as well.

Alexander Popp et al., ***Food consumption, diet shifts and associated non-CO2 greenhouse gases from agricultural production,*** **20 GLOBAL ENVIRONMENTAL CHANGE 451 (2010).**

Popp et al, scientists at the Potsdam Institute for Climate Impact Research, research the non-CO_2 greenhouse gas emissions of animal agriculture, and with good reason: they found that most of global agriculture's 15% contribution to anthropogenic emissions is attributable not to CO_2 but methane and nitrous oxide. The authors stress the importance of projecting future emissions from agriculture, but acknowledge the difficulty of predicting demand trends. The uncertainty of future supply and demand is the main cause of the diversity of agricultural GHG emissions predictions, which range from 6700 to 10,150 metric tons CO_2-equivalent by 2020. Their response to this challenge is a land use model (MAgPIE: Model of Agricultural Production and its Impact on the Environment) that incorporates socioeconomic and environmental information to project future agricultural non-CO_2 GHG emissions.

The MAgPIE model analyzes food, feed, and livestock production types across 10 economic areas. It includes in its calculations regional crop yield, hydrology, vegetation, and economic conditions. It predicts a 63% increase in non-CO_2 agricultural emissions until 2055, with great variability in total emissions and their sources between different regions. Specifically, CH_4 emissions will increase by 57% and N2O by 71%. Popp et al. offer detailed projections for the distribution of emissions and their sources in each region. These sources include enteric fermentation, manure, and rice farming for CH_4, and soil and manure for N_2O. The authors' several scenarios yielded distinct results:

- Baseline scenario (animal product intake per capita remains static) – non-CO_2 emissions increase from 5314 CO_2-equivalent in 1995 to 8690 until 2055.
- Increased meat scenario – non-CO_2 emissions increase by 76% over the baseline scenario until 2055. All sources of N_2O and CH_4 increase except for CH_4 from rice farming and N2O from soil, which both decrease by 11%.
- Decreased meat scenario (25% meat demand reduction per decade) – non-CO_2 emissions fall 51% in 2055 compared to the baseline scenario.
- Increased meat scenario with technical mitigation – non-CO_2 emissions fall 36% below increased meat scenario in 2055. However, this still leaves an overall 13% increase in emissions.
- Decreased meat scenario with technical mitigation – non-CO_2 emissions drop to 2519 CO_2-equivalent in 2055.

Popp et al. compared MAgPIE's conclusions to those of a 2006 US-EPA study that assumes a similar "Baseline" scenario with static dietary preferences. The EPA report projects increases of

21% for CH4 and 32% for N2O from 1995 to 2015, while MAgPIE projects 27% and 33%, respectively. MAgPIE's "Increased meat scenario" predictions also lined up with similar studies. (pp. 458)

Agriculture contributes 47% of methane's and 58% of nitrous oxide's anthropogenic emissions. Most of this CH4 results from ruminant enteric fermentation, although some is emitted by rice agriculture and manure storage.

Like Pelletier and Tyedmers (2010), Popp et al. conclude that technological improvements are needed, but ultimately less effective than changes in food consumption. They emphasize the need to address meat consumption in developing countries even more than Pelletier and Tyedmers, citing Stern 2006's finding that developing nations are responsible for nearly three quarters of global agricultural emissions.

Pierre Gerber et al., *Greenhouse gas emissions from the dairy sector: A life cycle assessment,* Food and Agriculture Organization of the United Nations [FAO] (2010).

This FAO report is a follow-up to 2006's *Livestock's Long Shadow*, which was the first study to estimate global livestock greenhouse gas emissions. (Its full supply-chain analysis determined that livestock production accounts for about 18% of global anthropogenic emissions.) Gerber et al. employ a Life Cycle Assessment (LCA) to examine the impacts of dairy production in particular. Their two objectives are to isolate the dairy sector's contribution to gross livestock emissions and pinpoint "GHG hotspots" along the dairy food chain at which significant emissions reductions can be made. Along the way, they also calculate the emissions attributable to meat production from dairy cattle.

The LCA is quite thorough. Carbon dioxide, methane and nitrous oxide emissions are all featured in a "food chain approach" that includes emissions from:

- Input production (feed, etc.)
- Dairy production, including manure and other byproducts
- Land use change (most notably, deforestation for soybean plantations)
- Dairy product transport
- Processing

Furthermore, the study investigates the GHG emissions from different production systems (ranging from grass-fed to factory farming) and agro-ecological zones across the globe.

Allocating emissions to different livestock goods, services and byproducts (i.e. waste) can be problematic. When these factors cannot be allocated on physical grounds, the authors separate them on economic grounds. Table 2.1 on the following page summarizes the allocation techniques used in the assessment, and Table 4.1 summarizes the authors' conclusions regarding GHG emissions from milk and meat production.

Table 2.1. Summary of the allocation techniques used in this assessment

Products	Source of emissions	Allocation Technique
Milk	All system related emissions	Protein content
Meat	All system related emissions	Protein content
Manure	Emissions from storage	100 % to livestock system
Manure	Emissions from application	Sub-division: when crop or crop residue is used for feed in the livestock system. *See grass, feed-crops and residues below.*
Animal draught power		Sub-division:
Grass and feed-crops	Emissions related to cultivation and application of manure and chemical fertilizer	100 % to livestock
Crop residues, by-products and concentrate components	Emissions related to cultivation, application of manure and chemical fertilizer, processing, transport, land use change (only soybean)	Economic allocation (in the case of crop residues digestibility as a proxy)
Capital functions		Not taken into account

It is important to note that the report does not calculate GHG emissions from certain sources, including:

- "Capital goods," such as farm machinery, etc.
- On-farm milking and cooling
- Pharmaceutical production, such as antibiotics, antimicrobials, etc.
- Packaging disposal

The authors' conclusions are summarized in the following table:

Table 4.1. Milk and meat production and related GHG emssions – global averages

Commodities	Total production (Million tonnes)	GHG emissions (Million tonnes CO_2-eq.) *	GHG emissions (kg CO_2 .eq. per kg of product) *	Contribution to total anthropogenic emissions in 2007 (%) *
Milk: production, processing and transport	553	1 328	2.4	2.7
Meat: produced from slaughtered dairy cows and bulls (carcass weight)	10	151	15.6	0.3
Meat: produced from fattened surplus calves (carcass weight)	24	490	20.2	1.0

* [±26 percent]

In addition to the emissions data shown above, Gerber et al. provide numerous graphs and charts detailing the attribution of GHG emissions to particular dairy goods (e.g. milk, cheese, whey, etc.), regional processing differences, trade flows, etc. Finally, their uncertainty analysis quantifies their doubts regarding the results.

Nigel Scollan et al., *The Environmental Impact of Meat Production Systems*, Report to the International Meat Secretariat (2010).

The second section of this report discusses the emissions produced by the livestock industry. It identifies the sources of GHG emissions, the stages of the process at which they occur, and the proportionate contribution of livestock emissions to global emissions totals.

The report finds that livestock agriculture is the "world's largest use of land resources, and engages very closely with landscape management, biodiversity, soil conservation and holistic functioning of agri-ecosystems." It identifies the major impacts of livestock production as air pollution (including GHG emissions), land degradation, water depletion and pollution, and loss of biodiversity.

The report notes that there is "considerable debate" as to the quantity of GHG emissions from livestock production, and cites to values both above and below the FAO estimates (18% of total global anthropomorphic GHG emissions). The authors explain that emissions estimates from this sector are bound to be uncertain due to overly-simplified methods of quantifying such emissions: "[s]imple generic coefficients applicable to all animals are commonly used which takes no account of differences in production efficiency between species and systems."[90] As a result, current emission factors are reported as having an uncertainty of +/- 30-50%. The report notes that the specificity of emissions reporting in this sector will "likely improve" and that it is "important that uniform inventory procedures are adopted in all countries" in order to accurately quantify livestock-related emissions and avoid displacement of emissions.[91]

The authors also note that the "range of uncertainty does not obviate the need for the sector to be proactive in the debate in deriving improved measurements and providing solutions that are practical and achievable by the industry."[92]

The report employed Life Cycle Assessment (LCA) as its main approach for quantifying environmental impacts, including emissions, form the livestock sector. Under this approach, the authors found that production of 1kg of beef used the most land and energy and had the highest global warming potential, followed by 1kg of pork, chicken, eggs and milk.

With respect to the specific sources of GHG emissions from livestock production, the report finds that ruminant systems are dominated by CH_4 from enteric fermentation and N_2O

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[90] Scollan (2010) at 5.

[91] *Id*.

[92] *Id*.

from manures, with the balance shifting from CH4 towards N2O as the systems become more intensive. The report finds that "[m]ost of the emissions of both CH_4 and N2O arise on farm, with only 3% from meat processing, 5% for transportation and 12% from consumer activities."[93]

Though it employs LCA, the report does not discuss emissions caused by land use changes and agricultural practices (for food production).

Barry Brook & Geoff Russell, *Global Warming Beefed Up: Meat's Carbon Hoofprint*, 80 AUSTRALASIAN SCIENCE 37 (2009).

This article discusses the methane emissions impact of meat production in Australia, and finds that current estimates for livestock's contribution to global warming are artificially low due to the international community's reliance on a 100-year timescale for calculating the Global Warming Potential (GWP) of GHG emissions. The authors note that the GWP for methane—one of the key emissions from livestock production—is significantly higher when calculated over a 20-year timeframe (72 times the impact of CO_2) as opposed to a 100-year timeframe (23-25 times the impact of CO2), as illustrated in the graph below:[94]

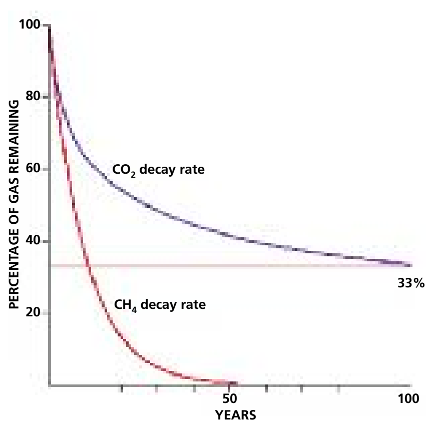

Figure 1. Amount of carbon dioxide (CO_2) and methane (CH_4) that remains in the atmosphere as a function of time.

The authors note the importance of reducing CO_2, because it stays in the atmosphere for so long, but also find that reducing methane and other GHG emissions is extremely important for two reasons: (1) methane is a very powerful GHG with a relatively short lifetime, so methane reductions can impact the radiation balance relatively quickly; and (2) "while CO_2 emission reductions are complex and costly because they cut across so many economic sectors, mitigation of methane emissions is generally far simpler" because we can target livestock industries.[95] Furthermore, in both Australia and the rest of the world, enteric fermentation from livestock (predominantly ruminants) is the biggest anthropogenic source of methane.

The authors estimate that, in Australia, livestock produce approximately 3 million tons (Mt) of methane, which would be calculated as the equivalent of 63 Mt of CO_2e using a 100-yr GWP. But using the 20-yr GWP, instead, livestock production produces the equivalent of 216 Mt of CO_2 emission*s—more than half the atmospheric heating caused by emissions from all*

[93] Scollan (2010) at 5.

[94] Brook & Russell (2007) at 37.

[95] *Id*. at 38.

Australia's coal fired power stations. Accordingly, the authors recommend targeting the livestock sector in order to reduce the radiation imbalance quickly.

The authors also note that the choice between a 20-year and 100-year GWP has a significant impact on how we calculate the relative emissions intensity of different food sources, as illustrated in the following table:[96]

Table 1. Emission intensity of some common foods expressed as kilograms of carbon dioxide-equivalent (CO_2-e) released into the atmosphere for each kilogram of production. For foods that produce copious amounts of methane, the 20-year figures are substantially higher than over a 100-year time frame. Source: Australian Greenhouse Office

Food	kg CO_2-e/kg (20 years)	kg CO_2-e/kg (100 years)
Beef	111.1	55.5
Sheep meat & wool	96.3	32.7
Pig meat	10.5	3.5
Rice	2.4	0.74
Poultry	1.3	0.38
Wheat	0.35	0.32

Given these discrepancies, the authors recommend that public information campaigns and policy makers should reconsider the use of 100-yr GWPs, which have "given methane a very low public profile even though it is the second most important greenhouse gas after CO_2."[97]

Nathan Fiala, *Meeting the demand: An estimation of potential future greenhouse gas emissions from meat production*, 67 ECOLOGICAL ECONOMICS 412 (2008).

This article forecasts future global demand for meat products, including beef, chicken and pig products (discussed in Section II at page 12). Using these figures, Fiala then estimates the potential GHG emissions that will be produced in meeting this demand.

Fiala predicts that Confined Animal Feeding Operations (CAFOs)—which are the fastest growing form of meat production in developing nations—will be substantially expanded in order to meet demand. Problematically, the author notes that when indirect GHG emissions are included in analysis, CAFOs produce nearly twice the GHG emissions as the African pasture system (14.8 kg CO_2 equivalent per kg of beef, compared to 8.1 kg CO_2).[98]

To simply his calculations, Fiala assumes that "all meat [is] produced in the same method as the US CAFO system and there [is] no deforestation]"—a scenario in which 1 kg of Beef would produce 14.8 kg of CO_2 equivalent, 1 kg of Pig would produce 3.8 CO_2 equivalent, and 1

[96] Brook & Russell (2007) at 39.

[97] *Id*.

[98] Fiala (2008) at 416-417, citing Subak (1999).

kg of Chicken would produce 1.1 kg of CO_2 equivalent. Fiala's estimates are illustrated in Table 6, on the following page.

Table 6 – Estimate of total greenhouse gases in million tones of CO_2 equivalent for each commodity (at p. 418)

Product	**2000**	**2010**	**2020**	**2030**
Beef	882	984	1077	1164
Chicken	62	96	121	142
Pig	338	427	509	586
Total	1287	1507	1707	1891

Based on these figures, Fiala recommends that beef production, in particular, be reduced, and more generally that we should focus production on more efficient sources of protein such as soybeans.

Gowri Koneswaran & Danielle Nierenberg, *Global farm animal production and global warming: Impacting and mitigating climate change,* 116 Environmental Health Perspectives 578 (2008).

Koneswaran and Nierenberg, scientists at the advocacy groups the Humane Society of the United States and Worldwatch Institute,[99] offer a full supply-chain analysis of the GHG emissions from meat, egg and milk production. They include in their calculations energy inputs ranging from animal rearing and slaughter to feed production and transport, water consumption, waste storage and disposal, various farm energy expenditures, final product transport, and so forth.

According to a 2008 FAO report, about 56 billion animals are raised and slaughtered yearly. This number is expected to double by 2050, potentially leading to a doubling in livestock GHG emissions as well. The climate footprint of animal agriculture already exceeds that of transportation globally.

The report finds that animal agriculture is accountable for:

- 9% of global CO_2 emissions annually, due mostly to feed crop production (and its inputs), farm energy consumption, feed and animal product transport, and land use change.

[99] Because these are advocacy groups, the authors' biases should be kept in mind. Their extended discussion of livestock living conditions further illustrates their perspective.

- 35-40% of global CH4 emissions annually. (Popp et al. claim 47%.)

The authors provide several recommendations for decreasing livestock sector emissions:
- "Enhanced regulation" to monitor farms' emissions.
- True pricing of environmental services, to incentivize the internalization of negative externalities.
- Research into new ruminant diets that reduce direct emissions from the animal and its manure. For instance, organic grass-fed cattle "may emit 40% less GHGs and consume 85% less energy than conventionally produced beef." The other climate effects of free-range beef are not examined.
- Implementation of anaerobic digesters for manure, as discussed in Amon et al.

Henning Steinfeld and Tom Wassenaar, *The Role of Livestock Production in Carbon and Nitrogen Cycles*, 32 ANNUAL REVIEW OF ENVIRONMENTAL RESOURCES 271 (2007).

Steinfeld and Wassenaar compare GHG emissions from extensive production systems, in which there are limited use of external inputs, and intensive production systems, which rely on external inputs such as feed. They find that intensive systems have higher requirements for fossil fuel at all stages of the production process, but have less impact on land-use changes than extensive modes of production, except through the expansion of crop land for feed production.[100]

Extensive Systems - The authors identify the following sources of GHG emissions from extensive livestock systems:

(1) Savannah burning – This is "not [usually] considered to result in net CO_2 emissions, because emitted amounts of carbon dioxide (CO_2) released in burning are recaptured in grass regrowth" but does release important amounts of other gases, including NOx, CO, CH_4 and aerosols, many of which lead to the production of tropospheric ozone.[101] In addition, "high concentrations of cloud condensation from the burning of biomass stimulate rainfall production and affect large-scale climate dynamics."[102]

(2) Desertification of pastures – Desertification results from overgrazing or mismanagement, and results in a net release of carbon to the atmosphere. The authors estimate that the total CO_2 emissions from the desertification of pastures currently amounts to approximately 100 million tons of CO_2e per year.

(3) Pasture expansion into forest – The conversion of forest into pasture releases considerable amounts of CO_2 into the atmosphere. Steinfeld and Wassenaar estimate that

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[100] Henning Steinfeld and Tom Wassenaar, *The Role of Livestock Production in Carbon and Nitrogen Cycles*, 32 ANNUAL REVIEW OF ENVIRONMENTAL RESOURCES 271 (2007) at 279.

[101] *Id*. at 275.

[102] *Id.*

emissions from conversions of forests to pastures release approximately 1.7 billion tons of CO_2 per year.[103]

(4) Enteric fermentation – Livestock, particularly large ruminants such as cattle, produce methane emissions during digestion through a process known as "enteric fermentation." Steinfeld and Waasenaar estimate that the net CH_4 released through enteric fermentation totals approximately 86 million tons per year.[104]

(5) Nitrous oxide from manure –Steinfeld and Wassenaar estimate that manure from extensive systems releases approximately 1.3 million tons of N_2O to the atmosphere annually, which constitutes approximately 0.6 billion tons of CO_2e.

Intensive Systems **–** Steinfeld and Wassenaar identify the following emission sources for intensive systems:

(1) Fossil fuel use – Intensive production systems have higher requirements for fossil fuel at all stages, including (a) manufacturing fertilizer for feed production, which produces an estimated 40 million tons of CO_2 annually; (b) on-farm fossil fuel use, which produces an estimated 60 million tons of CO_2 annually for feed production (a "conservative estimate") and 30 million tons of CO_2 annually for direct livestock rearing; (c) transportation and processing, emissions from which are roughly estimated at "several tens of million tons of CO_2" for production and 800-850 thousand tons of CO_2 for transportation.[105]

(2) Cropland expansion into forest – Although intensive systems involve fewer direct land use changes, the authors estimate that the expansion of cropland into forest produces approximately 0.7 billion tons of CO_2 per year.

(3) Carbon loss from soils cultivated to produce feed – Most of the carbon loss from soil occurs at the original conversion of natural cover into managed land, but soils continue to release large amounts of carbon for a long time after conversion. Steinfeld and Wassenaar estimate that this loss produces an additional 18 million tons of CO_2 annually in temperate regions and 10 million tons of CO_2 in tropical regions.

(4) Methane released from animal manure – Although intensive production systems are only responsible for a small proportion of N_2O emissions from manure, they produce a significant quantity of CH_4 emissions from manure. Manure deposited directly on land, or otherwise handled in a dry form, does not produce significant amounts of CH_4 (hence no significant contribution from extensive production systems). However, substantial amounts of CH_4 are released from the anaerobic decomposition of manure when it is managed in liquid form, such as lagoons or holding tanks, which are typical for most intensive and industrialized livestock systems. Citing FAO figures, Steinfeld and Wassenaar estimate that intensive systems produce approximately 17.5 million tons of CH_4 annually.

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[103] Steinfeld & Wassenaar (2007) at 276.

[104] *Id*. at 277.

[105] *Id*. at 280.

(5) Nitrogen emissions from feed-related fertilizer, leguminous crops, and stored manure – Steinfeld and Wassenaar estimate that fertilizer used in the production of feed for livestock use produces approximately 0.4 million tons of N_2O per year (0.2 billion tons of CO_2e), and 3.1 million tons of NH_3 (ammonia) per year. Leguminous feed cropping produces an additional 0.5 million tons of N_2O (0.2 billion tons of CO_2e) per year. Finally, manure from extensive systems produces approximately 0.5 million tons of N_2O (0.2 billion tons of CO_2e) per year.

B. Amon et al., *Methane, nitrous oxide and ammonia emission during storage and after application of diary cattle slurry and influence of slurry treatment,* 112 AGRICULTURE, ECOSYSTEMS AND ENVIRONMENT 153 (2006).

In this study, Amon et al. (professors of agriculture and ecology in Austria) investigate and attempt to quantify the CH4, NH3, and N2O emissions from liquid manure stores, or "slurries." The authors consider the differential impacts of various slurry treatments. Slurries were stored in tanks for 80 days and then applied to grasslands, all the while being monitored for emissions.

The majority of the emissions (in terms of CO_2-equivalent) were traced to methane emissions during storage and nitrous oxide emissions in the field. Amon et al. aimed to mitigate emissions by reducing "slurry dry matter and easily degradable organic matter content." They tested several different methods for decreasing emissions, including slurry separation, anaerobic digestion, slurry aeration, and straw cover.

Table 2
Slurry characteristics at the beginning and at the end of the storage of differently treated dairy cattle slurry

	N_t (g (kg FM)$^{-1}$)	NH_4-N (g (kg FM)$^{-1}$)	C_t (g (kg FM)$^{-1}$)	DM (% FM)	Ash (% DM)	pH
Untreated						
Start	3.96	1.57	35.36	9.24	21.36	7.11
End	3.25	1.82	20.05	5.74	28.58	7.80
Separated (liquid phase)						
Start	4.00	1.48	21.09	5.97	30.45	7.30
End	3.66	1.73	14.31	4.15	31.57	7.88
Separated (solid phase)						
Start	5.12	0.93	80.68	20.94	16.04	7.72
End	7.56	0.08	80.90	24.23	33.55	8.41
Biogas						
Start	3.17	2.13	20.38	5.57	26.48	7.65
End	2.48	1.55	13.28	4.16	31.01	7.78
Aerated						
Start	3.90	1.93	32.74	8.78	23.69	7.25
End	3.84	1.64	26.73	7.84	25.05	7.55
Straw cover						
Start	3.89	1.66	32.34	9.07	22.79	7.40
End	3.85	1.30	24.80	7.53	23.77	7.58

The authors conclude that emissions can be mitigated most effectively by decreasing methane emissions during storage. To achieve this, slurry dry matter and easily degradable organic matter content must be reduced. Most ammonia emissions, however, occur in the grassland after manure application, and so must be mitigated in the field. Simple methods for ammonia emissions reduction include careful timing of application, decreased slurry dry matter content, and "low trajectory application." Slurry separation reduces net CO_2-equivalent emissions, but also increases ammonia emissions, resulting in other environmental problems. Conversely, anaerobic digestion reduces emissions without affecting ammonia emissions, leading Gerber et al. to recommend that it be applied on commercial farms. Moreover, if good manure composting is practiced and enough oxygen is provided, emissions of all kinds can be reduced.

FOOD AND AGRICULTURE ORGANIZATION (FAO), WORLD AGRICULTURE: TOWARDS 2015/2030 (2003).

Chapters 12 and 13 include some discussion of the livestock industry's contribution to climate change. Specifically, Table 12.1 assesses agriculture's production of different types of greenhouse gases, divided into different types of agricultural activity including livestock-related activities. It states that tropical forest clearance and land use change were major factors causing carbon dioxide emissions in the past, but are likely to play a smaller role in the future as compared to methane and nitrous oxide. The warming potential of methane is about 20 times more powerful than carbon dioxide. About 15% of methane emissions come from livestock. In the UK and Canada the share is over 35%.

C. <u>Comparing Emissions Impacts from Different Livestock Systems and Products</u>

A. Bernues, R. Ruiz, A. Olaizola, D. Villalba, I. Casasus, *Sustainability of pasture-based livestock farming systems in the European Mediterranean context: Synergies and trade-offs*, 139 LIVESTOCK SCIENCE 44 (2011).

This paper discusses low-input pasture-based farming systems (meat sheep and beef cattle) located in mountainous and other less productive areas of the European Mediterranean basin.

The authors argue for a more sophisticated system-specific approach to studying sustainability in livestock production, because there is so much variety across different systems in terms of consumption of resources and production of emissions. It is unfair to lump this type of farming together with large-scale industrial farming when talking about the effects of the livestock industry on climate change.

The authors present several ways in which pasture-based livestock farming is more environmentally friendly than large-scale industrial farming. Firstly, it is more responsive to changing eating habits in Europe, in particular reduced demands for red meat and increased demands for ethical and local production. Secondly, pasture-based farming can protect landscape and biodiversity, and prevent environmental hazards like forest fires and erosion. Also, because the land is already cleared, it does not result in any further deforestation. Furthermore, it uses much less fossil fuel and emissive fertilizer than intensive industrial farming does. The authors also argue that emissions from manure can more easily be alleviated in pasture-based farming than in intensive industrial systems. Moreover, these methane emissions can be at least partially offset by the carbon sequestration of grassland soils in a pasture-based system. Improved grassland management practices can contribute further to this effect. Lastly, they generally do not compete with food production for human nutrition, given that the land they use is typically not fertile enough for human food production.

The authors also note, however, that pasture-based farming uses fibrous diets of low energy density that increase methane production. At the moment, there are no cost-effective methods for achieving substantial reductions in emissions from grazing systems. Furthermore, pasture-based agriculture is more vulnerable to climate-change impacts.

The authors suggest several options for responding to these challenges, such as increasing diversification of practices and products, reducing the use of chemical fertilizers, increasing productivity, and improving energy efficiency.

The authors conclude that any attempt to address the connection between livestock farming and the environment should appreciate the strategic role played by pasture-based systems, rather than casting the entire livestock industry in a uniform negative light. This is particularly important in terms of the upcoming Common Agricultural Policy (CAP) reform in 2013.

M. de Vries & I.J.M. de Boer, *Comparing environmental impacts for livestock products: A review of life cycle assessments,* 128 LIVESTOCK SCIENCE 1 (2010).

De Vries and de Boer, animal scientists at Wageningen University in the Netherlands, analyzed 16 studies that assess environmental impacts from livestock products (beef, pork, chicken, eggs and milk). These peer-reviewed studies are compared along 5 parameters: "study from an OECD (Organization for Economic Cooperation and Development) country, non-organic production, type of LCA (life cycle analysis) methodology, allocation method used, and definition of system boundary."[106] The authors found consistent results for climate change factors as well as land and energy usage across these studies. Unfortunately, the effects of land use change and human-animal land competition are not included in their calculations.

[106]de Vries & de Boer (2010) at 1.

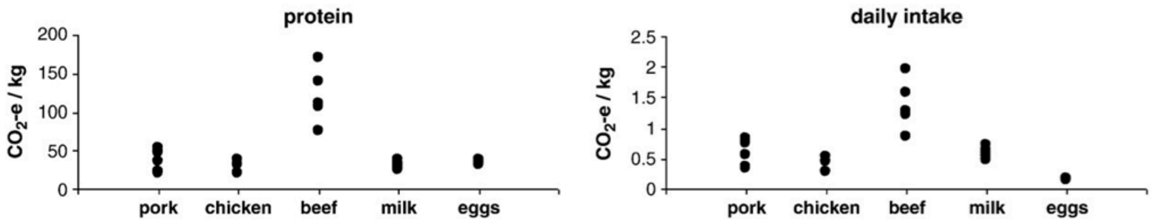

Fig. 6. Global warming potential for livestock products, in CO_2-e per kg of protein or per average daily intake of each product.

The majority of the average OECD diet's global warming potential (GWP) and land use is due to beef consumption. GWP from beef production is split roughly equally between N_2O and CH_4 emissions, whereas most GWP from monogastric livestock is attributed to N_2O. However, "for all livestock products, CO_2 appears to be the least important greenhouse gas."[107]

Milk, pork, chicken and eggs share similar (or at least not consistently different) environmental impacts per kg protein. Only one of the 16 reports analyzed directly compare the impacts of meat and other animal products, so the authors hope that additional research will challenge these results.

Per kg protein, beef has the largest overall environmental impact of any meat product, followed by pork and chicken. De Vries and de Boer attribute the differential impacts of these products to variation within three factors:

- Feed conversion efficiency
- Enteric CH4 emissions – these differ greatly between ruminant (cows, sheep and goats) and monogastric (poultry and pigs) livestock
- Reproduction rates

Jonathan Vayssieres et al., *Comparing Energy Use Efficiency and Greenhouse Gas Emissions for Livestock Products*, 1 ADVANCES IN ANIMAL BIOSCIENCES 506 (2010).

This article summarizes the results of a case study of 165 livestock farms on the tropical island of La Réunion, which included production systems for dairy milk, beef, pork, chicken and rabbit. The authors note that La Réunion farming systems are high input systems as compared with European ones. The study calculates the efficiency of various livestock products based on (1) direct emissions, mainly CH_4 from enteric fermentation, and CH_4 and N_20 from stored or laid out manure, based on the IPCC methodology; (2) indirect energy consumption and GHG emissions (mainly CO_2) based on specific consumption data for water, fuel, electricity and gas. For industrial processes, the authors relied on European life cycle inventories and added extra energy costs and CO_2 emissions to account for energy consumed for transport to Europe. Using this data, the study estimates efficiency with respect to nutritional needs—specifically, the study

[107] de Vries & de Boer (2010) at 7.

calculates: (1) the amount of food energy produced per kg of fossil energy consumed, and (2) the quantity of GHG emissions per kg of protein produced.

The results of the study were as follows:[108]

Table 1 *Technico-environmental performances for different livestock productions in La Réunion (2007)*

	Feed conversion efficiency (kg concentrate/kg product)	Energy use efficiency (kg crude energy/kg fossil energy)	Part of fossil energy consumptions linked to animal rationing (%)	GHG emissions (kg CO_2-eq./kg protein)	Coefficient of variation (%)	Part of enteric CH_4 in total GHG emissions (%)
Milk (dairy)	0.79	0.37	55.3	87.3	24.5	26.2
Beef (suckling)	4.00	0.19	31.9	239.7	66.5	65.5
Beef (fattening)	5.48	0.42	53.3	104.7	27.3	40.1
Pork	3.23	0.62	77.0	35.9	18.7	6.1
Chicken	2.19	0.36	75.3	25.9	15.6	1.8
Rabbit	3.99	0.15	58.8	83.2	28.8	2.3

Based on these results, the authors conclude that milk is an environmentally friendly product; that red meat should be substituted with white meat.

The authors note that certain environmental consequences were excluded from the analysis, including CO_2 emissions associate with land use changes (e.g., deforestation for cultivation of feed crops and the on-farm carbon storage on grasslands (which is greater for beef production).

Lucas Reijnders and Sam Soret, *Quantification of the environmental impact of different dietary protein choices,* 78 American Journal of Clinical Nutrition (suppl) 664S (2003).

Reijnders and Soret (environmental scientists at the University of Amsterdam and Loma Linda University School of Public Health, respectively) quantitatively compared the environmental impacts of different protein sources and presented their findings at the Fourth International Congress on Vegetarian Nutrition in 2002. Their study does not include calculations of direct livestock emissions, but their analyses of land use and agricultural fossil fuel inputs are relevant.

Land Use: The average gram of animal protein requires the input of 10 grams of vegetable protein, although this varies greatly by species. The authors offer the following feed conversion (to protein) efficiency rates, although opinions vary on energy conversion statistics:

- Broilers: 18%
- Pork: 9%
- Beef: 6%

[108] Vayssieres et al. (2010) at 506.

Fossil Fuels: If the rest of the world engaged in systems of agriculture as energy-intensive as America's, all of the planet's proven oil reserves would be consumed in 12 years by agricultural production and consumption alone. This is largely due to the prevalence of animal agriculture in the USA. According to the authors, "attributing all energy inputs to the production of foodstuffs," vegetable protein (typically soybean) production is 2.5-50 times more fossil-fuel efficient than meat protein production.

David Pimentel and Marcia Pimentel, "Sustainability of meat and plant-based diets and the environment" 78 AMERICAN JOURNAL OF CLINICAL NUTRITION 660 (2003).

This article calculates the fossil fuels and area of land required to produce a meat-based versus lacto-ovo-vegetarian diet. The results are as followed:

Protein consumption: Both meat-eaters and lacto-ovo-vegetarians consume about twice the recommended daily allowance for protein, which is 56 g. The average amount for the lacto-ovo-vegetarian diet is 89 g per day. The meat-based diet comes out at112 g per day.

Feed Grain Use: The amount of grains fed to US livestock is sufficient to feed about 840 million people who follow a plant-based diet. The US livestock population consumes more than 7 times as much grain as is consumed directly by the entire American population.

The amount of feed grains used to produce the animal products (milk and eggs) consumed in the lactoovovegetarian diet was about half (450 kg) the amount of feed grains fed to the livestock (816 kg) to produce the animal products consumed in the meat- based diet.

Crop land use: Less than 0.4 ha of cropland was used to produce the food for the vegetarian-based diet, whereas about 0.5 ha of cropland was used in the meat-based diet.

Fossil energy use: To produce 1 kcal of plant protein requires an input of about 2.2 kcal of fossil energy. On average, producing 1 kcal of animal protein requires 25 kcal of fossil energy. Broken down: Producing 1 kcal of chicken requires 4 kcal of fossil energy. 1 kcal of turkey requires 10 kcal of fossil energy. Milk has a 14:1 ratio. Pork has a 14:1 ratio. Eggs have a 39:1 ratio. Beef has a 40:1 ratio. Lamb has a 57:1 ratio.

Solution: If these animals were fed only good-quality pasture, the energy inputs could be reduced by about half.

IV. IMPACTS OF CLIMATE CHANGE ON LIVESTOCK PRODUCTION

Livestock production systems do not merely contribute to anthropogenic climate change—they will also be heavily impacted by the rapid change in environmental conditions which will accompany climate change. This section contains an overview of literature describing the potential impacts of climate change on livestock systems and recommending adaptive solutions for livestock keepers.

A. General Discussion of Impacts on Livestock Systems

A. Nardone, B. Ronchi, N. Lacetera, M.S. Raniere, U. Bernabucci, *Effects of climate changes on animal production and sustainability of livestock systems*, 130 LIVESTOCK SCIENCE 57 (2010).

This article describes the potential impact of climate change on animal health and livestock production. The authors identify three primary concerns: (1) projected increases in drought across the world will affect forage and crop production, thus increasing the cost and decreasing the availability of feed; (2) warmer environments tend to impair production (of meat, milk and eggs) as well as reproductive performance, metabolic and health status, and immune responses; and (3) the process of desertification will reduce the carrying capacity of rangelands and the buffering ability of agro-pastoral and pastoral systems. The article notes that the extent of these impacts will depend on two main types of vulnerability: (1) biophysical vulnerability (sensitivity of natural environment to hazards), and (2) social vulnerability (sensitivity and adaptability of human environment)—problematically, the developing word is more vulnerable in both respects.

The authors expect that livestock systems based on grazing and mixed farming systems will be more heavily affected by global warming than industrialized systems, due to increased drought and direct effects of high temperature on animals. This is particularly problematic because these are the predominant systems in developing countries, and the authors anticipate a worse scenario in Africa and some zones of Asia where extensive or pasture based systems remain the norm. With respect to industrialized livestock systems, the authors note that "the indirect effects of global warming, such as soil infertility, water scarcity, grain yield and quality and diffusion of pathogens may impair animal production more than direct effects."[109]

The authors describe how climate change will affect animal health, including direct effects (temperature-related illness and death, morbidity during extreme weather events) and indirect effects (e.g., the influence of climate on microbial populations, distribution of vector-borne disease, host resistance to infectious agents, feed and water shortages, or food-borne diseases). They also discusses the impact of climate change on reproduction, specifically, noting

[109] *Id.* at 58.

that "exposure to elevated ambient temperature decreases fertility" in cattle and pigs especially but also in poultry, rabbits and horses.

Finally, the article discusses the impact of climate change on the production of animal products, and notes several historical events in which heat waves and adverse weather significantly lowered production, resulting in specific monetary losses as high as $1 billion dollars (2006 heat wave in California).

To facilitate adaptation to these impacts, the authors recommend "advanced planning of production management systems, with an understanding of animal responses to thermal stress and ability to provide management options to prevent or mitigate adverse consequences."[110] More specifically, the authors suggest:

(1) optimizing productivity of crops and forage by improving water and soil management;
(2) intensifying livestock production in regions that may actually benefit from climate change (e.g., higher latitudes where rainfall is predicted to increase and where warmer weather may actually increase production);
(3) more efficient use of water (i.e., growing plants and rearing animals in systems demanding less water; selecting species which require less water);
(4) selective breeding of animals that are more resistant to heat effects;
(5) transitioning from pastoral systems and mixed rain-fed systems to intensive, specialized systems (however the authors note that this may have adverse environmental effects, including additional GHG emissions from manure).

P.K. Thornton, J. van de Steeg, A. Notenbaert, M. Herrero, *The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know*, 101 AGRICULTURAL SYSTEMS 113 (2009).

In light of the importance of livestock to vulnerable populations and the disproportionate impact that climate change will have on these populations, this article identifies a research agenda for development organizations and other interested stakeholders.

The article first provides an overview of livestock systems in the developing world, identifying a variety of potential classifications including: (1) geographic classifications: arid/semiarid; humid/sub-humid, and tropical highlights/temperature; and (2) production classifications: solely livestock systems (grass-land based systems and landless livestock production systems) and mixed systems (rain-fed mixed faming systems and irrigated mixed farming systems)

The article then discusses the potential impacts of climate change on livestock, identifying seven specific categories of impacts:

110 (Îd. At 4, citing Nienaber and Han, 2007.)

(1) Feed production: the article identifies several studies with conflicting data, which suggest that atmospheric CO_2 concentration and higher temperatures can inhibit the quantity and quality of feed production, but may also increase yields under certain conditions. Although higher CO_2 levels may increase yield, the authors note that "many studies show that temperature and rainfall changes in the future will modify, and often limit the direct CO_2 effects on plants. All of these impacts are "clearly site dependent", e.g., at higher latitudes rising temperatures may prolong the growing season whereas in lower latitudes, such temperatures will result in more water stress for plants. The authors note that in grasslands, there is a strong relationship between drought and animal death and that increased temperatures will decrease precipitation in these areas.

(2) Heat stress: the authors identify conflicting studies which suggest that the impact of increased temperatures on livestock may be major or minor, and find that there is "considerable value in better understanding the match between livestock populations, breeds and genes with the physical, biological and economic livestock" and that this information will be especially valuable in adaptive planning.

(3) Water: the article finds that water scarcity will be a key issue as temperatures rise, especially for vulnerable populations, and that the "uneven distribution" of water availability is especially problematic. The article finds that the impacts of climate change on water supply is difficult to estimate and will be site-specific, and furthermore that the impacts of supply changes on livestock systems in developing countries are not well-studied.

(4) Livestock diseases and disease vectors: as with other issues, the article finds that the impacts of climate change on infectious disease burdens are extremely complex. The authors identify two ways in which climate change will impact disease vectors: (1) changing bio-climatic conditions such as increased temperature and rainfall, and (2) increase in extreme events, such as flooding. The authors note that higher temperatures may increase the rate of development of pathogens or parasites, but may also have a negative impact on pathogens that are heat-sensitive. Perhaps more problematically, changing conditions, such as increased temperatures or drought, can increase the susceptibility of host subjects to infection.

(5) Biodiversity impacts: the authors note that the loss of biodiversity, much of which can be attributed to global livestock production, but also as a result of rising temperatures and other climactic changes, is of particular concern. Although difficult to measure, the loss of animal and plant genetic resources is irreversible and these "non-renewable resources" have extremely high value for adaptive strategies. The authors also note that pastoralists and smallholders are the guardians of much of the world's livestock genetic resources, and that a great deal can and must be done to preserve such resources.

(6) Systems and livelihoods: the article discusses how the "livestock revolution", the "green agriculture movement" and other systemic changes (e.g., more crops being grown for bio-fuel) have thus far impacted global livestock production. The article notes several studies into how climate change is impacting systems in unexpected ways—e.g., in marginal areas of Southern Africa, reductions in length of the growing period and the increased rainfall variability

is driving systems to a conversion from a mixed crop-livestock system to a range-land based system, as farmers find growing crops too risky in those marginal environments. Noting that only limited research has been done in this field, and the importance of identifying systems that can withstand climatic changes, the authors assert that a comprehensive, systems-oriented assessment would be useful.

(7) Indirect impacts: the article notes that the most significant indirect impact of climate change on livestock systems will be its impact on human health, which will inevitably alter the capacity of livestock keepers in developing countries.

The article summarizes “key knowledge gaps” in the following table:

Table 2: Some of the knowledge gaps of climate change impacts on livestock-based systems and livelihoods in the tropics and subtropics

Area	**Gap**
Feeds: quality and quantity	Rangelands (LG): primary productivity impacts, species distribution and change due to CO_2 and other competitive factors, estimation of carrying capacities Mixed systems (MR, MI): localized impacts on primary productivity, harvest indexes and stover production
Heat stress	What is the extent of the problem, in a developing context?
Water	Surface and groundwater supply, and impacts on livestock Effective ways to increase livestock water productivity
Diseases and disease vectors	How may the prevalence and intensity of key epizootic livestock disease change in the future? How may climate change affect disease as systems intensity (particularly MR, MI, LL systems?)
Biodiversity	‘Ecological biodiversity’: what will happen to numbers of species as systems change? Animal breed biodiversity: can the animal genetic resources that might be useful in the future be specified?
Livestock systems	Localized impacts on livelihoods How will systems evolve in the future? Magnitude and effects of systems changes n ecosystems good and services
Indirect impacts	How do human health impacts of climate change intertwine with livelihood systems and vulnerability?

In conclusion, the report identifies a "typology of adaptation options' (citing Kurukulasuriya and Rosenthal, 2003) which should be considered:

(1) Micro-level adaptation options, including farm production adjustments such as diversification and intensification of crop and livestock production; changing land use and irrigation; and altering the timing of operations.

(2) Income-related responses—such as crop, livestock and flood insurance schemes, credit schemes, and income diversification opportunities

(3) Institutional changes, including pricing policy adjustments such as the removal or putting in place of subsidies, the development of income stabilization options, agricultural [including agricultural support and insurance programs; improvement in (particularly local) agricultural markets, and the promotion of inter-regional trade in agriculture.

(4) Technological developments, such as the development and promotion of new crop varieties and livestock feeds, improvements in water and soil management, and improved animal health technology.

FOOD AND AGRICULTURE ORGANIZATION (FAO), WORLD AGRICULTURE: TOWARDS 2015/2030 (2003).

Chapter 13 of the report discusses two primary sources of damage to the livestock industry from climate change impacts. The first is grasslands in some developing countries deteriorating progressively as a result of increased temperature and reduced rainfall. However, this is less of a concern as it is expected to happen more slowly, by which time much livestock production will be via intensive industrial systems and not grasslands.

Of more concern is the rise in temperature, which will cause heat stress to livestock in warm countries.

There are also direct impacts from sea level rise.

Lastly, there are indirect impacts through effects on resources availability, notably water resources and increase in pests.

B. Recommendations for Adapting Livestock Systems to Climate Change

Philip K. Thornton & Mario Herrero, *The Inter-linkages between Rapid Growth in Livestock Production, Climate Change, and the Impacts on Water Resources, Land Use, and Deforestation*, Background Paper to the 2010 World Development Report, Development and Climate Change (2010).

The authors recommend that short-term adaptation activities should focus on risk-management for existing producers, whereas long-term approaches should focus on climateproofing development. The authors find that there are various ways in which livestock producers can respond to climate change, but that these will require adequate exchange of information about weather patterns, climate effects, impacts to crops and livestock, and methodologies / technologies for improving resilience. For example, livestock keepers can change the mix of livestock species or otherwise change the herd composition, and lessons from practitioners who have already engaged such strategies will assist others.

M. Blummel, I.A. Wright and N.G. Hegde, *Climate Change Impacts on Livestock Production and Adaptation Strategies: A Global Scenario,* Lead Paper for National Symposium on Climate Change and Rainfed Agriculture, February 18-20, 2010, Central Research Institute for Dryland Agriculture (CRIDA).

This article identifies strategies for adapting livestock systems to climate change, both to improve the resistance of livestock systems to climate shocks and to reduce GHG emissions, including:

(1) Feed production: noting the particular impact that CC will have on feed growing operations as well as the significant emissions produced by growing feed, the article recommends focusing feed production on more efficient feed sources—i.e., sources that will be more efficiency converted into "microbial biomass' (the source of protein) and short chain fatty acids, with lower production of CO_2 and CH_4. Specifically, this can be achieved by increasing the proportion of concentrate in the diets. However, there are drawbacks associated with the production of concentrated feed which may cancel out the benefits, and that natural resource usage of land, water and biomass may be more efficient where livestock production is based on byproducts such as crop residues or on biomass harvest—through grazing and otherwise—from areas not suitable for arable land.

(2) Anaerobic bacteria: given the potential drawbacks of concentrated feed usage, the article notes that research is currently being done on the potential use of anaerobic bacteria, capable of breaking fiber, which could be introduced into the digestive system of ruminants.

(3) Water: the article recommends improving the efficiency of water usage in both feed growing operations and livestock production.

(4) Breeding: the article recommends selective breeding of animals that are more resistant to temperature changes and disease. In particular, the availability indigenous breeds, which have co-evolved in land systems and are better adapted to marginal conditions / climatic shocks, will be essential for successful adaptation. The article also notes that the "adaptive challenge will be to improve productivity traits while maintaining adaptive traits" since these are often in competition (i.e., better resistance to temperature fluctuations or drought, but smaller meat yield). The article concludes that the "preservation of existing animal genetic diversity as a global insurance measure against unanticipated change" is especially important.[111]

[111] (See p. 138-139, and FAO World Animal Genetic Resources Report (2007).)

(5) Feeding: the article recommends well-fed animals to increase productivity (i.e., improve the intake of feed, nutrient density of the diet, or preferably, a combination of both). Citing a 2005/2006 case study in India, the authors note that the daily milk yield of cross bred, local cows and buffalo could be increased through the use of more nutritious feed and higher quantities of feed—recommends that improving the productivity of each animal reduces the amount of methane produced per liter of milk and reduced overall maintenance costs / energy expenditures.

(6) Livestock and Human Health: The article describes how climatic changes will effect the vector of various diseases, in particular tropic and sub-tropic diseases, such as animal trypanosomes (spread by Tsetse flies) which are common in livestock (ruminants, equids, and pigs) and can also infect humans. The authors identify a need to improve resilience through selective breeding, maintaining diverse animal stock, and specific practices (e.g., preventing animals from being aggregated around water points where diseases spread easily).

Louise O. Fresco, *Challenges for food system adaptation today and tomorrow*, 12 ENVIRONMENTAL SCIENCE AND POLICY 378 (2009).

This article discusses the challenge of adapting plant, animal and food systems to changing temperature, nutrient and water conditions. The author notes the need for a "sustainable food system" which is productive and responsive to changing demands, resource efficient, place explicit limits on GHG emissions, and reduces vulnerability to climate change impacts. With respect to livestock production, the author recommends a variety of adaptive solutions, including:

(1) The return of semi-urban agriculture, at least as intensive vegetable or poultry production concentrated on the roofs of industrial or office buildings with excess heat stored in aquifers or used as additional heating.

(2) Systemic recycling of plant nutrients from urban waste

(3) Meeting future protein needs from new species lower down the food chain such as algae.

(4) Meat substitutes from soy or lupins.

More generally, the author also notes the important role of multifunctional food systems in improving efficiency and reducing vulnerability to climate change impacts.

Claudia Pelizaro, Kurt Benke & Victor Sposito, *A Modeling Framework for Optimisation of Commodity Production by Minimising the Impact of Climate Change*, 4 APPLICATION OF SPATIAL ANALYSIS 201 (2011).

This article presents a modeling framework to identify the regions under threat of productivity decline due to climate change impacts, and alternative crops and their locations that can better cope with various climate change scenarios. The authors developed the framework by combining three approaches: (1) regional land suitability analysis, (2) uncertainty analysis and (3) analysis of the optimal distribution of crops across regions. The authors then applied the proposed framework to a case study in the South West Region of Victoria, Australia, to identify "optimal" agricultural commodities and crop allocations in the region.

The framework could potentially be used to identify optimal locations and cereals for livestock feed purposes.

Irene Hoffman, *Climate change and the characterization, breeding and conservation of animal genetic resources*, Animal Production and Health Division, Food and Agricultural Organization of the United Nations (FAO) (2010).

This report discusses the potential impact of climate change on livestock species, and the importance of maintaining breed diversity in the context of rapid change and uncertainty. The report describes how breeding practices may be adjusted for both adaptation and mitigation purposes--e.g., responding to higher temperatures, lower quality diets and greater disease challenges, as well as reducing emissions.

Given that such adjustments in breeding practices are inevitable, and must respond to uncertain conditions, the report finds that securing the "option value provided by animal genetic diversity" is an essential objective. To achieve this objective, the report recommends (1) better characterizing and defining breeds, production environments and associated knowledge; (2) the compilation of more complete breed inventories; (3) improved mechanisms to monitor and respond to threats to genetic diversity; (4) more effective *in situ* and *ex situ* conservation measures; (5) genetic improvement programs which identify adaptive traits in high-output breeds and performance traits in locally adapted breeds; (6) increased support for developing countries in their management of animal genetic resources; and (7) wider access to genetic resources and associated knowledge.

C. Region and Country-Specific Analysis

J. Wang, J. Huang & S. Rozelle, *Climate Change and China's Agricultural Sector: An Overview of Impacts, Adaptation and Mitigation*, International Centre for Trade and Sustainable Development (ICTSD) Issue Brief No. 5 (May 2010).

This paper discusses the impacts of climate change on China's agricultural sector, and activities that are currently being undertaken to mitigate emissions and adapt to environmental changes. The paper notes that agricultural production activities account for more than 15% of China's total greenhouse gas emissions, including nearly 90% of nitrous oxide emissions, and 60% of methane emissions.

Section 3.3 of the report deals with climate change impacts on livestock, specifically. The report notes that spring droughts in the grasslands, induced by steadily rising temperatures, are becoming more serious and thus the productivity of these pastures has been steadily decreasing.

The report also discusses the contribution of agricultural practices to climate change emissions, but only briefly touches on the specific contribution of livestock production--noting that agricultural emissions of methane mainly come from the keeping of ruminant animals, and that the total emission from methane from ruminant animals in 1994 was 10,182 thousand tons of CO_2 equivalent (59.2% of the total methane emissions from China's agricultural sector). The report does not specify what percentage of emissions come from cereals specifically produced for livestock feed.

S. Seo & R. Mendelsohn, *The Impact of Climate Change on Livestock Management in Africa: A Structural Ricardian Analysis*, Center for Environmental Economics and Policy in Africa (CEEPA) Discussion Paper No. 23 (2006).

This report conducts quantitative analysis the potential economic impacts of climate change on livestock production systems in Africa. The study uses a "structural Ricardian model" to project choices made by livestock keepers in the face of changing climate conditions—in particular, the study determines a range of possible outcomes for: (1) which species will be selected, (2) the number of animals per farm, and (3) net revenue per animal. The authors use this information to project to potential sensitivity of African animal husbandry to climate changes, and finds that all three factors (species selection, number of animals, net revenue) are "highly dependent on climate." In particular, the study projects that, as climate changes:

> "[N]et income across all animals will fall but *especially across beef cattle*. The fall in net income causes African farmers to reduce the number of animals on their farms. The fall in relative revenues also causes them to shift away from beef cattle and towards sheep

> and goats. All farmers will lose income but the most vulnerable farms are large African farms that currently specialize in beef cattle."[112]

The study also identifies differences in how small and large livestock production systems will respond to climate change, noting that small farms have an advantage because they are diversified, relying on dairy cattle, goats, sheep, and chickens. In contrast, large farms will be most significantly impact because they tend to specialize in dairy and beef cattle.

***Climate Change Vulnerability and Adaptation in the Livestock Sector of Mongolia*, Final Report Submitted to the Assessments of Impacts and Adaptations to Climate Change (AIACC), Project No. AS 06 (2006).**

This report discusses the potential ecological and economic impacts of climate change on the livestock sector of Mongolia, identifies key vulnerabilities, and recommends a list of adaptation options. Some of the key adaptation objectives include: improving integrated pasture management, strengthening the productivity of individual livestock (through breeding and management practices), enhancing livelihoods in rural communities, and increasing food security.

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[112] Seo & Mendelsohn (2006) at 7.

V. SOLUTIONS

This section of the annotated bibliography will present a cross-section of the literature on mitigation options and policy solutions for GHG emissions from livestock. *Livestock's Long Shadow* provides an initial, sweeping overview of the mitigation landscape. Articles based on consumer-driven demand reduction outline dietary and ethical approaches to mitigation, and technical articles illuminate how mitigation is actually achieved from the farm perspective. Finally, sample legislation is provided to demonstrate what a successful national policy aimed at mitigation of livestock GHG emissions might look like.

A. <u>General Articles</u>

Joyce D'Silva and John Webster, eds., *The Meat Crisis: Developing Sustainable Production and Consumption* (2010).

Stefan Wirsenius and Fredrik Hedenus, "Policy Strategies for a Sustainable Food System: Options for Protecting the Climate"

This concise article, which focuses on the European Union, starts out by suggesting that both supply side (e.g. direct subsidies) and demand side (e.g. taxes on animal food) policies will be needed. Demand-side is crucial because of the overall low potential for technological solutions in the short-term.

This article suggests and thoroughly dissects the implementation of a GHG-weighted consumption tax on animal food (an output tax). These taxes are weighted according to the average production of emission intensities for the food category – so, for example, a tax on ruminant products would be around ten times higher than the tax on poultry. This would stimulate substitution towards less emission-intensive diets. This tax is similar to long-existing taxes on fuel, which are meant to decrease consumption and increase efficiency. Land would be made available by substitution away from emissions-intensive animal products such as cattle would leave land open, which the authors suggest should be used for bio-energy, rather than remaining unused. This would further increase the emissions gains from a consumption tax.

The consumption tax is superior to a tax on emissions themselves because of the difficulty of monitoring emissions sources. Further, a consumption tax does not have a distortionary effect between domestic production and imports, which an emissions tax does. A consumption tax also does not cause "carbon leakage" – where worldwide carbon does not decrease, but rather is shifted elsewhere – like an emissions tax does. However, a major disadvantage of a GHG-weighted consumption tax is that it does not provide an incentive to reduce emissions with new technology or improved practices. A GHG-weighted consumption tax might also cause an increase in poultry consumption, which would offset some gains from a decrease in ruminant consumption, however this is unclear given the sparse data on cross-price elasticities.

Note: a similar article was subsequently published by these authors in Climatic Change 108 (2011).

Lang et al., "Meat and Policy: Charting a Course through the Complexity"

Drawing upon "ecological public health" and integrating biological, social and cultural dimensions of meat and climate change, this article takes a more theoretical posture. In mapping the terrain of the problem the authors address the environment, public health, political economy, culture and national identity, and ideology and philosophy. In order to breach the current chasm between scientific reality and policy, which has been perpetuated by the productionist policy framework of the last half-century, the authors argue that a shocking event akin to mad cow disease might be necessary.

In terms of policy recommendations, the article charts, from the "softest" policy to the most restrictive, a list of options: advice, labeling, education, public information, endorsement and sponsorship, welfare support, product/ compositional standards, licensing, subsidies, competition rules, taxes and financial measures, bans, and rationing. Specific policies mentioned include use of the power of public procurement (i.e. in hospitals, schools or prisons), the trans-fat bans in Denmark and New York City, and surcharges on meat parallel to the traffic congestion charge in London for car use.

Robert Goodland, *How the Food Industry Can Reverse Climate Change Quickly and Profitably*, Global Forum for Food and Agriculture, International Green Week, Berlin, January 14-16 (2010).

In this paper, Goodland briefly discusses the impacts of livestock on climate change, and identifies business opportunities for the food industry to mitigate these impacts. Given the urgent nature of climate change, Goodland notes the imperative of working directly with industries to promote change, rather than simply petitioning governments to enact policy changes.

Goodland asserts that, as with other GHG emissions, GHGs attributable to livestock should be considered as impacts managed or owned by the industry or sector that emits them. He also notes that, because the livestock industry is situated within a larger food industry that will be deleteriously impacted by climate change there is a "compelling commercial motivation for the food industry to manage the impacts of these emissions."[113]

With respect to specific mitigation opportunities, Goodland asserts that the food industry has a clear interest in producing alternatives to livestock products that will produce fewer emissions. Goodland identifies four incentives for individual food companies to respond to the risks and opportunities applicable to the food industry at large. These include: (1) individual food

[113] Goodland (2010) at 5.

companies already suffer from disruptive climate events, so it is within their self-interest to act to slow climate change; (2) livestock production will be most heavily impacted by the rising demand for and price of oil (as oil supply declines), and thus there is an incentive to begin replacing livestock products with cheaper alternatives; (3) the cost of meat is also anticipated to rise due to increased demand and forced reductions in supply (caused by natural phenomenon such as climate change, as well as policy decisions that will put a price on carbon and other externalities), providing yet another incentive for replacing livestock with cheaper alternatives; and (4) food companies can produce and market alternatives to livestock products that taste similar, but are easier to cook, less expensive, and healthier—thus, with public acceptance, these alternatives could actually become more profitable and/or popular than livestock products.

Goodland discusses a number of possible alternative products, which he calls "meat and dairy analogs," including products made from soy, wheat gluten and rice. He asserts that such analogs could be easily substituted into people's diets and food culture (e.g., heavily used recipes). Goodland further notes that achieving high growth in analog consumption will require a "significant investment in marketing, as meat and dairy analogs will be new to many consumers."[114]

Goodland concludes that the risk of business-as-usual production outweigh the risks of change for this industry, and thus that the food industry now has a clear business incentive to transition from livestock to alternative products.

Henning Steinfeld and Pierre Gerber, *Livestock production and the global environment: Consume less or produce better?* 107 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES 18237 (2010).

This article assesses the potential of productivity growth, triggered by demand growth and resource scarcity, to mitigate the environmental impact of livestock production, including GHG emissions.

The authors find that the productivity (measured in global protein output per standing livestock biomass) of ruminant species has been relatively stable over the past two decades, whereas productivity of monogastrics (pig and poultry) has increased at an annual rate of 2.3%. These productivity gains have resulted from the "broad application of science and advanced technology in feeding and nutrition, genetics and reproduction, and animal health control as well as general improvements in animal husbandry."[115] The authors also note that feed productivity is an important factor in overall livestock productivity, and that nearly 90% of increased global crop production has resulted from productivity gains rather than area expansion.

In light of these statistics, the authors find that the "shift to monogastric species and continued productivity growth has the potential to considerably reduce environmental impact *per*

[114] Goodland (2010) at 7.

[115] Steinfeld & Gerber (2010) at 18237.

unit of product, but given the projected increases in demand, *aggregate impact is poised to grow further*."[116] In order to achieve actual reductions in impact, "livestock production needs to be intensified in a responsible way (i.e., be made more efficient in the way that it uses natural resources and generates harmful emissions)."[117] The authors note that additional deforestation is *not* necessary to meet livestock demand, if gains are achieved through intensification of current production, given the low-intensity levels of production in much of Latin America where most livestock-associated deforestation occurs.

Ultimately, the authors find that a dual approach, which targets *both* production systems (to achieve efficiency gains) and consumption trends will be necessary to effectively reduce the environmental impact of livestock.

Nigel Scollan et al., *The Environmental Impact of Meat Production Systems*, Report to the International Meat Secretariat (2010).

The third and fourth sections of this report discuss the contribution of the meat and livestock industry to greenhouse gas mitigation. This can be done in two ways: (1) increasing the efficiency of the livestock production system itself, and (2) directly targeting the source of the emissions. The advantage of the first route is that it brings the double benefits of increased profits to the producers, making it a "win-win" situation.

The report notes that historical gains in livestock production have primarily been achieved through increased livestock numbers, rather than enhanced output per animal (yield), and that such trends must be reversed in order to accommodate for increased demand while mitigating environmental impacts.

The report further notes that the environmental impacts of livestock production are dependent on the system of production and its intensity, and that negative impacts can be mitigated through the use of extensive systems and efficient manure management.

Thus, the report recommends that emissions per unit of livestock production can be decreased either by: (1) increasing the efficiency of production systems, or (2) directly targeting the source of emissions - the animals. Specifically, the first objective could be achieved through the use of intensive systems and on-farm technologies such as anaerobic digestion (AD), and the second objective could be achieved by changing the diet of livestock or genetically improving livestock (or feed crops) through breeding processes.

The report discusses three different policy approaches for reducing emissions from livestock production: (1) market-based approaches; (2) command and control; and (3) voluntary systems. The report describes these as follows:

(1) *Voluntary codes of practice.* The report prefers these to direct government

[116] Steinfeld & Gerber (2010) at 18237 (emphasis added).

[117] *Id.*

intervention. It sees this option as a first step to more interventionist measures if the voluntary steps do not turn out to be enough.

(2) *Command-and control.* Such a system would simply require farmers by law to comply with certain specified activities. The report is less favorable about this option, because it does not allow farmers to use their own specialist knowledge the way a voluntary code does. However, the report acknowledges that command-control systems may be required where governments need certainty in outcomes, or where they need to be perceived as applying an even-handed policy approach.

(3) *Market-based approaches.* The two most common types are emissions tax and pollution permit trading systems (AKA cap-and-trade). Emissions taxes are rarely used in practice, because of the practicalities of monitoring emissions and collecting the tax. Cap-and-trade systems are usually preferred as more feasible. They have an additional advantage over tax-based systems in that they allow an overall cap to be set on emissions. However, they have faced problems in the recent economic slowdown.

The report favors market-based approaches over command-and-control approaches, as they afford the most flexibility to individual producers and have the potential to bring about reductions in emissions at lowest unit costs per ton of CO_2 abated. The authors note that the use of marginal abatement cost curves (MACCs) has revealed certain measures that are actually "win-win" and that these could be realized through a market-based approach to regulating carbon. The report also recommends de-coupling support from direct production and moving it towards support of environmental objectives--for example, by using a subsidy scheme to incentivize mitigation activity.

Finally, the report notes the importance of policy to incentivize demand-side mitigation, as well as supply-side mitigation. The authors find that efforts to increase awareness of environmental and human health impacts of livestock consumption are becoming more mainstream, for example, through discussion of carbon footprints. The authors also note that there is an "arguable" case for attributing emissions on a consumption basis, rather than a production basis--but ultimately concludes that although such an approach is "ethically compelling" it would be "politically unattractive" and difficult to implement.

The report concludes with a portfolio of specific policy options, which it recommends that the International Meat Secretariat (IMS) support, including:

(1) development of more precise methods of calculating livestock emissions in national GHG inventories;

(2) enhancing capabilities of relevant stakeholders to monitor and report emissions from livestock production;

(3) improving production efficiency, in particular through the use of "win-win" methods and technologies, i.e., those that both lower emissions and reduce production costs;

(4) preparing the livestock industry for carbon pricing constraints and constraints on water resources;

(5) the IMS playing a "leading role" in securing an international framework agreement on sustainable livestock production.

Obstacles to these solutions are also discussed. The article mentions the restrictions on the use of certain materials (e.g. growth promoters) and technologies (GM) in certain parts of the world. Also, some of these technologies are too expensive for developing countries. Lower-cost solutions must be developed to address growth in meat demand from the developing world.

Philip K. Thornton & Mario Herrero, *The Inter-linkages between Rapid Growth in Livestock Production, Climate Change, and the Impacts on Water Resources, Land Use, and Deforestation*, Background Paper to the 2010 World Development Report, Development and Climate Change (January 2010).

The report finds that there is substantial economic potential for the mitigating of GHG emissions from livestock. The article notes that several existing technologies have exhibited mitigation potential in this sector, including:

(1) improved crop and grazing land management to increase soil carbon storage
(2) restoration of cultivated peaty soils and degraded lands
(3) improved rice cultivation techniques
(4) improved manure management to reduce methane emissions
(5) improved nitrogen fertilizer application techniques to reduce nitrous oxide emissions;
(6) improved energy efficiency in general.

Although the report finds that many of these options "already exist" it also notes that there are a number of obstacles to implementing these technologies and methodologies, which are "related to incentive systems, institutional linkages, policy reforms, monitoring techniques for carbon stocks and appropriate verification protocols."[118]

Robert Goodland, *Forests, Fisheries, Agriculture: A Vision for Sustainability,* Expert consultation on greenhouse gas emissions and mitigation potentials in the agriculture, forestry and fisheries sectors (FAO 2009).

This report discusses the impacts of livestock on climate change, and provides a menu of recommendations for how global policy-makers can address these impacts. Noting the emissions estimates from Goodland & Anhang (2009)—finding that global livestock activities are responsible for at least 51% of anthropogenic GHG emissions—Goodland asserts that current mitigation measures "no longer suffice, and broadly avoiding emissions attributable to livestock becomes critical."[119]

[118] Thornton & Herrero (2010) at 64.

[119] Goodland (2009) at 2.

As a threshold issue, Goodland asserts that large steps will be required in order to switch from exploiting natural capital to conserving and regenerating natural capital. In order to do this, "the productivity of agriculture must quickly be boosted, with inefficient food production replaced by more efficient alternatives."[120] Goodland further notes the importance of improving efficiency in light of predicted climate change impacts on feed and livestock production. For example, Goodland cites studies predicting a 10% decline in wheat and rice yields for each one-degree centigrade rise in temperature above the norm during growing seasons.

Goodland asserts that the "emissions attributable to livestock should be considered as impacts managed or owned by the industry or sector that emits them."[121] Because livestock are only one part of the global food industry, and because this industry will be heavily impacted by climate change, Goodland notes that there is a "compelling commercial motivation for the food industry to manage the impacts of these emissions, as soon as they are fully understood." [122] Goodland further asserts that this incentive to manage livestock emissions may become more apparent when the food industry realizes that there are "pragmatic business opportunities that would balance the impacts—namely, to produce better alternatives to livestock products." [123]

However, barriers still exist to the realization of benefits associated with switching production from livestock to alternative food sources. Goodland provides a number of "constructive next steps" for moving forward with this transition. Specifically, Goodland recommends:

- Governments should work with the FAO to provide assistance to support small- and large-scale livestock producers with pursuing alternative livelihoods, managing emissions from livestock production, and adapting to climactic changes;
- Governments and the livestock sector should support efforts that are underway to clarify the amount of GHG emissions attributable to the lifecycle and supply chain of livestock products—and one key topic for clarification should be reasonable measures of the biomass of livestock raised worldwide.
- The livestock sector, governments and the FAO should realize that reforestation is a top priority, and should thus map the areas most ripe for reforestation on a technical and economic basis.
- The livestock sector should partner with leading companies in the food industry to promote the production and marketing of better alternatives to livestock products.
- Governments, producers and the FAO should promote improved nutrition for the poor, and should undertake measures to improve food security and efficiency of production, such as the identification of disease-resistant and drought-proof seeds.

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[120] Goodland (2009) at 3.

[121] *Id*. at 6.

[122] *Id*.

[123] *Id*.

Goodland also provides a number of other industry-specific recommendations for addressing emissions from global food production activities, and reducing the overall proportion of nutritional needs that are met through livestock products.

Tara Garnett, *Livestock-related greenhouse gas emissions: impacts and options for policy makers*, 12(4) ENVIRONMENTAL SCIENCE AND POLICY 491 (2009).

This article provides argues for policy strategies that combine GHG mitigation with measures to improve food security. Garnett lays out four categories of policy solutions: (1) improving productivity; (2) changing the management system; (3) managing the outputs; and (4) reducing livestock numbers (see Garnett 2007 for more detail). In this article the focus is on two strategies – modifying livestock diets to improve productivity, and reducing overall numbers reared – viewed through the lens of three perspectives – "second order impacts, opportunity costs, and need." These two options reflect different perspectives on tackling livestock emissions – the first is technology-oriented, and the second emphasizes behavior change.

With regard to modifying livestock diets, the article criticizes the conclusion in recent articles that diets rich in concentrates such as cereal and oilseeds increase milk output thus reducing methane per unit of output. Garnett notes that these studies have ignored the second order impact of land clearance.

Raising fewer livestock is crucial given that technological improvements are unlikely to even cancel out increase in demand. This article supports a global equality approach whereby the developed world reduces per capita consumption to the point where it equals the consumption in developing worlds in 2050. The article also describes the "ecological leftovers" approach, which takes ecological capacity as the ultimate constraint on livestock production and consumption. "Ecological leftovers" assesses what land and byproducts are available for livestock that are genuinely unsuited to other purposes and uses this as an absolute limitation.

The article concludes by noting that the twin policy goals of ensuring food security and reducing GHG emissions should be explicitly married at every level of decision-making. The author suggests that the "full panoply of policy tools will need to be deployed—fiscal, regulatory, and voluntary" and that more research is needed, including: what areas should be classified as "leftovers," breeding to increase resilience and productivity, the use of biofuels with land use, and government nutrition recommendations.

Helena Paul et al, *Agriculture and Climate Change: Real Problems, False Solutions,* Report Published for the Conference of the Parties of the UN FCCC in Copenhagen (December 2009).

This article is a useful counterpoint to the conventional wisdom that intensification of livestock production is an important mitigation path for livestock-related greenhouse gas emissions (as presented in *Livestock's Long Shadow*, for example). The authors cite reliance on subsidies, "biosecurity," and antibiotics, as well as animal welfare issues, as indicators the lack of feasibility of commercial livestock operations. Another strike against intensification is the threat that it poses to the synergies of extensive livestock systems – for example, maintenance of nitrogen cycle balance. Extensive systems also help support grasslands, which have evolved to co-exist with livestock, and the important natural carbon sinks they provide. The authors believe "[i]t would be a climate policy mistake to allow destroying grasslands for more crop land for more feed for ever more livestock."

The authors come to the familiar conclusion that due to "subsidies, tax breaks, cost of epidemic control, and the huge externalized cost of environmental destruction and certain diseases of civilization" that there truly is "no such thing as cheap meat," and mitigation policies such as intensification are naively hopeful. Hinting at a tax policy, the authors note that "[p]rices for animal products that reflected the real costs would address unreasonable consumption."

In sum: "Far fetched proposals like changing the bacteria that help to turn grass into food within the ruminants' stomachs aim at reducing methane emissions, but will not reduce the number of cattle, excessive Northern consumption and the destruction of grassland as well as other carbon sinks."

Mario Herrero, Philip K. Thornton, Pierre Gerber, and Robin S. Reid, *Livestock, livelihoods and the environment: understanding the trade-offs*, 1 CURRENT OPINION IN ENVIRONMENTAL SUSTAINABILITY 111 (2009).

This article discusses the production requirements of livestock systems in light of estimates that the total demand for livestock may nearly double by 2050. The authors recommend reducing livestock product demand in certain regions, regulating industrial livestock production, and capitalizing on efficiency gains in livestock systems (e.g., the potential for sustainable intensification of mixed systems, and the potential for ecosystems services payments in rangeland systems) in order to balance competing demands of livestock production, livelihoods and environmental protection.

In particular, the authors note the importance of recognizing vast differences in the level of consumption of livestock products between rich and poor countries, and recommend that policy encourage demand reductions in those areas where there is excessive consumption of animal products. The authors find that "meeting the demand for livestock products in future carbon-constrained markets will require a mixture of adaptation and simple, effective and transparent mitigation strategies."[124] The authors identify three potential ways to mitigate GHGs from livestock:

(1) **Direct reductions of GHG emissions**, by (a) managing demand in particular in developed countries, through adequate regulations, incentives, policies and possible carbon quotas; (b) intensifying the diets of animals, so that they consume more nutrients and produce less methane, (c) controlling animal numbers and shifting breed choices, and (d) reducing GHG through effective manure management.

(2) **Using livestock systems to sequester carbon**, specifically storing soil carbon in rangelands or in silvo pastoral systems through locally-tailored management practices;

(3) **Offsetting livestock GHG emissions,** by using corps and residues from agricultural lands as a source of fuel (the authors assert that emissions from these fuel sources are of recent atmospheric origin, and thus the net benefit of bio-energy sources is equal to the fossil-derived emissions displaced, less any emissions from producing, transporting and processing.) The authors also note that CO_2 emissions can be avoided by "agricultural management practices that forestall the cultivation of new lands now under forest, grassland, or other non-agricultural vegetation", and that "biogas from manures can be used to offset energy use in livestock systems."[125]

More fundamentally, the authors recommend the implementation of policy solutions to reduce demand where there is excessive consumption of animal products, and to de-intensify certain systems (those which are particularly inefficient or environmentally harmful) through policies and payments for eco-systems, while simultaneously intensifying livestock production in sustainable ways through the effective use of technology and other efficiency-enhancing mechanisms.

Robert Goodland and Jeff Anhang, *Livestock and Climate Change: What if the key actors in climate change are cows, pigs, and chickens?* Worldwatch Institute (December 2009).

Given the urgency of addressing climate change, the authors recommend targeting industry directly, rather than "recommending policy changes to governments, which may or may not eventually lead to change in industry."[126] The authors find that an "individual food company" has at least three incentives to respond to the risks and opportunities afforded by climate change: (1) these companies already suffer from disruptive climate change events, so it is in their self-interest to slow climate change; (2) increasing fuel costs--in particular oil--will make it more expensive to produce and process livestock products; and (3) food companies "can produce and

[124] Herrero et al. (2009) at 117.

[125] *Id*. at 118.

[126] Goodland & Anhang (2009) at 15-16.

market alternatives to livestock products that taste similar, but are easier to cook, less expensive, and healthier, and so are better than livestock products."[127]

Debra L. Donahue, *Elephant in the Room: Livestock's Role in Climate and Environmental Change*, 17 MICHIGAN STATE JOURNAL OF INTERNATIONAL LAW 95 (2008).

The policy section of this article adds nuance to the FAO's conclusions about emissions from livestock production. Specifically, the article details the potential benefits of payment for environmental services (PES) as applied to livestock production systems.

The authors begin by acknowledging that pastoralism in many areas is crucial to human survival, but that pastoral grazing causes degradation. The article therefore suggests simultaneously promoting the welfare of pastoralists and environmental objectives by increasing productivity and providing alternatives to pastoralism. Thus, the focus of this article is on the policy tool that "holds great promise," namely "[p]aying pastoralists to maintain or enhance ecosystem services," which could increase income while reducing livestock production. Donahue then draws a distinction between two different applications of PES.

The first application is in the context of high-income, industrialized countries, where there is widespread degradation of government land leased to farmers for grazing. Donahue, like the FAO, concludes that these "marginal" lands should be taken out of livestock production as a "seminal first step." Donahue believes this important step could be done under existing law, and would significantly mitigate climate change by promoting increased carbon sequestration. Further, because livestock are a source of stress in these ecosystems, removing livestock would greatly help the lands cope with the impacts of climate change. For example, "[p]aying [ranchers in the western U.S.] to produce native seed and plants for desperately needed range rehabilitation projects" is "far more sensible than subsidizing public land grazing, given its minor contribution to meat production and substantial environmental externalities." Citing the "stewardship" payments proposed by Professor David Farrier, Professor Donahue also argues that PES would be preferable to compensating landowners for land use restrictions.

Second, in developing countries, PES would be a complement to reducing extensive livestock production and would provide a means for improving the practices of pastoralists. Those engaged in small-scale extensive production could receive PES for planting trees or shrubs, establishing shelter belts, collecting seed, or protecting steep slopes, areas with fragile soils, or water sources. The income received from PES could exceed income obtained from livestock production on marginal lands.

Other PES programs could be tailored for private lands – landowners could be compensated for eradicating and controlling weeds, establishing and maintaining perennial vegetation, slowing soil erosion, and protecting riparian areas. "Special nature districts," as

[127] Goodland & Anhang (2009) at 16.

advanced by Professor Christopher Elmendorf, offer a means of implementing PES programs at local and regional scales, and could provide a framework for taxes and regulation.

Financing mechanisms for PES should be broader and more flexible than the system suggested by the World Bank. Donahue draws a parallel to the emerging carbon market and suggests expanding the limited scope of the Kyoto CDM to include PES. Other funding sources include a carbon tax, taxes on certain land uses, and government subsidies, but the primary focus should be on reallocating subsidies for livestock.

The article also collects existing scholarly work on PES, including Balmford, 2002; Elmendorf, 2003; Farrier, 1995; and Lipper *et al.*, 2006.

Pete Smith et al, *Greenhouse gas mitigation in agriculture*, 363 PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY: BIOLOGICAL SCIENCES 789 (2008).

This article is valuable for its extensive data and tables, and for its examination of methodology and comparisons to all previous calculations. The article is also very useful for its extensive references – the authors have nearly six pages of citations to a wide range of important mitigation studies.

For mitigation strategies based on management of grazing land and pasture improvement, the authors suggest particular attention to grazing intensity, nutrient management, fire management, species introduction, and increased productivity.

In terms of livestock management, this article recommends practices for reducing methane emissions based on three general categories: "improved feeding practices, use of specific agents or dietary additives, and longer term management changes and animal breeding." For improved feeding practices the authors note that methane emissions can be reduced by feeding more concentrate, adding oils to the diet, improving pasture quality, especially in less developed regions, and optimizing protein intake to reduce N excretion and nitrous oxide emissions. Specific agents and dietary additives, mostly aimed at suppressing methanogenesis, include: ionophores, halogenated compounds, probiotics, propionate precursors, vaccines against methanogenic bacteria, and bovine somatotrophin (bST) and hormonal growth implants.

For manure management the authors suggest reducing emissions from manure stored in lagoons or tanks by cooling or covering the sources, or by capturing the methane. They also mention anaerobic digestion for maximizing retrieval of methane as an energy source.

Table 3 provides a very useful summary of "biophysical reduction potential" (which means increasing the proportion of an animal's enteric methane production). The table is broken down based on the specific technique, and gives the potential methane savings for each "agro-ecological zones" and from each type of livestock (cattle, sheep, and buffalo). These estimates were derived using a model similar to that suggested by the EPA, and were adjusted for (i) the proportion of the animal's life where the practice was applicable, (ii) the technical adoption feasibility in a region, (iii) the proportion of animals in a region to which the measure can be applied, and (iv) non-additivity of simultaneous application of multiple measures. Only measures considered feasible for a region were applied in that region. Based on the data in Table 3, the authors conclude that "there may be no universally applicable list of mitigation practices, but that any proposed practices will need to be tuned to individual agricultural systems present in specific climatic, edaphic and social settings."

Table 5 provides the estimated marginal cost of implementing each mitigation practice (in US$ per ton of CO_2-equivalent). At low prices, the dominant strategies are those consistent with existing production such as change in fertilizer application or diet formulation. Higher prices, on the other hand, elicit land use changes that displace existing production, such as biofuels and afforestation. The portfolio of mitigation strategies also varies over time owing to the limited ecological capacity of the sequestration related strategies, as well as the limited market penetration potential of capital intensive strategies like biofuels. The factors determining the level of implementation are discussed in detail in Smith et al. 2007.

In sum, the global technical mitigation potential from agriculture by 2030, considering all gases, is estimated to be approximately 5500–6000 Mt CO_2-eq. yrK1, with cumulative economic potentials of 1500–1600, 2500–2700 and 4000–4300 Mt CO_2-eq. yrK1 at carbon prices of up to 20, up to 50 and up to 100 US$ t CO_2- eq.K1. In other words, agriculture could offset, at full biophysical potential, about 20% of total annual CO_2 emissions, with offsets of approximately 5, 9 and 14% at CO_2-eq. prices of up to 20, up to 50 and up to 100 US$ t CO_2-eq.K1. It is crucial to note that of these mitigation potential totals, approximately 89% is from reduced soil emissions of carbon dioxide, whereas only approximately 9% is from mitigation of methane and approximately 2% is from mitigation of soil nitrous oxide emissions. The authors also stress that the main benefits of mitigation actions taken now will emerge over decades.

Last, Table 7 compares the estimates of agricultural GHG mitigation potential by 2030 with previous estimates from a range of academic studies and other sources.

Anthony J. McMichael, John W. Powles, Colin D. Butler, Richardo Uauy, *Food, livestock production, energy, climate change, and health*, 5 ENERGY AND HEALTH 1253 (2007).

This article discusses the health effects of disparate livestock consumption—obesity and associated health consequences in developed countries vs. under-nutrition in developing countries—and recommends a "international contraction and convergence strategy" to both improve public health and reduce GHG emissions from livestock production. Specifically, an effective contraction and convergence policy would seek to: (1) reduce GHG emissions per unit of meat or milk produced; (2) reduce consumption of meat and milk in high-income countries, and (3) taper the rise in consumption of meat and milk in developing countries.[128]

In particular, the article finds that the global average meat consumption is 100 g per person per day, "with about a ten-fold variation between high-consuming and low-consuming

[128] McMichael et al. (2007) at 1261.

populations." The authors propose a consumption target of 90 g per person per day, distributed more evenly among populations, with no more than 50 g per day from read meat from ruminant (methane-producing) animals such as cattle, sheep, and goats. Achieving this target would require "substantial reduction of meat consumption in industrialized countries and constrained growth in demand in developing countries."[129] The authors recommend removing state subsidies for animal feed in high-intake countries as an initial step towards this policy.

The authors find that achieving this target by 2050 would potentially stabilize emissions from the livestock sector, assuming a 40% increase in global population and no advance in livestock-related GHG reduction practices. It could also substantially improve global health, but only if there is convergence, i.e., a "substantial contraction" of meat consumption in high-income countries and an increase in consumption in low-intake populations.[130] The authors emphasis the need for affirmative policy action to ensure convergence, in light of studies which indicate that climate change will likely increase the inequality between low-income and high-income countries' food production and consumption. The article asserts that emphasizing international equity and focusing on a contraction and convergence policy is the "most defensible—and therefore the most politically feasible—model for restricting emissions arising in relation to consumption of meat and dairy products.

In addition, the article lists several options for reducing GHG emissions *per unit of animal production*, including: "(1) sequestering carbon and mitigating carbon dioxide emissions by reduction and reversal of deforestation arising from agricultural intensification and by restoration of organic carbon to cultivated soils and degraded pastures; (2) reducing methane emissions from enteric fermentation… through improve efficiency and diets; (3) increasing the proportion of chickens, monogastric mammals, and fish in the flow of animals grown for human consumption; (4) mitigation emissions of methane through improved management of manure and biogas; and (5) mitigating emissions of nitrous oxide via more efficient use of nitrogenous fertilizers."[131] The article notes that recent studies suggest that the "available mitigation technologies could reduce missions per unit of animal product by up to 20% at fairly low costs."[132]

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[129] McMichael et al. (2007) at 1254.

[130] *Id.*

[131] *Id*. at 1260.

[132] *Id*.

Henning Steinfeld and Tom Wassenaar, *The Role of Livestock Production in Carbon and Nitrogen Cycles*, 32 ANNUAL REVIEW OF ENVIRONMENTAL RESOURCES 271 (2007).

Steinfeld and Wassenaar review mitigation options to reduce Carbon and Nitrogen emissions form livestock's land use, production and animal waste. The authors identify the following "technical options" to mitigate carbon and nitrogen losses:

(1) Sequestering carbon and mitigating carbon dioxide emissions, primarily by slowing, halting and eventually reversing deforestation, as well as improved grassland management, and the use of silvo-pastoral systems in the humid tropics.

(2) Reducing methane emissions from enteric fermentation by adjusting animals' diets (increasing the digestibility of feedstuff), improved nutrition, selective breeding and general husbandry practices;

(3) Mitigating methane emissions through improved manure management and biogas systems;

(4) Mitigating nitrogen loss, both through improved feeding practices and by storing manure in enclosed tanks during storage and improved practices for returning waste to the land, to increase the amount of nitrogen that re-enters the soil rather than entering the atmosphere.

Henning Steinfeld *et al.*, *Livestock's Long Shadow: Environmental Issues and Options*, The Livestock, Environment and Development (LEAD) Initiative, FAO (2006).

This important report dedicates Chapter 6 to "Policy Challenges and Options," and Chapter 3.5 is dedicated to mitigation options for climate change specifically.

Chapter 6 discusses general principles for policymaking. It emphasizes that policy intervention is based on the concept of market failures, and the negative externalities and the inefficiencies that they create. To that end, the report gives several general policy recommendations. First, the choice of policy instruments should be based on efficiency – where the difference between social benefits and social costs is maximized. Second, all policy should focus on maximizing participation amongst all involved stakeholders. Third, design and implementation must have the right mix and sequencing of policy measures. Fourth, that "command and control" style regulations are less likely to work in developing countries, whereas economic instruments are better suited to developing countries. Last, policy can and should be a significant driver of technological advance insofar as it forces more efficient use at more accurate prices.

The authors also suggest specific policy instruments to reduce the environmental impact of livestock generally: (1) limiting livestock's land requirements, (2) correcting distorted natural resource prices, (3) strengthening land titles, (4) pricing water realistically, (5) removing subsidies, (6) trade liberalization, (7) regulations, (8) supporting intensification and promoting research, (9) institutional development, and (10) awareness building, education, and information.

- Limiting livestock's land requirements means supporting geographic transition toward a contraction of the land used for pasture and the land devoted to producing feed for livestock. This means careful intensification of existing grazing and arable land, where yield increases can be achieved, which will free up land for carbon sequestration.
- Correcting distorted prices means taking externalities into account in price. The authors suggest a land tax to encourage more accurate prices and more productive use of land. Livestock prices are distorted by non-productive uses including using livestock to help secure land titles and using livestock to store wealth under common property regimes, which lead to overgrazing and destruction of carbon sinks.
- Removing subsidies can reverse the environmental impact of livestock by reducing scale of production, amongst other changes. Subsidies incentivize monoculture and use of environmentally sensitive land. Subsidies can also create a technology "lock-in," where technological change is prevented because of the cost-effectiveness of otherwise inefficient input use. The authors cite to across the board removal of subsidies by New Zealand in the 1980s as evidence of the benefits of doing away with subsidies.
- The authors note that if we are to meet increasing demand there may not be a way around intensification. The article suggests that precision feeding and improved genetics offer the promise of significant reductions of greenhouse gases. Switching from ruminants to poultry in "concentrate-based systems" is an example. Intensification is also suggested for the production of feed crops.

With respect to **carbon dioxide** emissions specifically, the focus should be on addressing issues of land use and land degradation since the livestock sector has great potential for carbon sequestration, particularly with improved pastures.

- There is an urgent need to reverse deforestation, or at least consciously plan the process, especially in the Amazon. Some think intensification on the best land is the only available option, and could be achieved by increased fertilizer inputs, but this may not be socio-politically possible.
- Other ways of achieving intensification include using higher-yielding and better-adapted varieties, better land and water management, improved cultivars, irrigation, organic and inorganic fertilization, management of soil acidity, integrated pest management, double-cropping, and crop rotations.
- Soil sequestration could also generate a large net benefit (the IPCC suggests that improved soil practices allow soil carbon to increase by 0.3 tons per hectare per year). Other "non-conventional" soil mitigation practices include: conservation tillage and erosion reduction. Conservation tillage means leaving at least 30% of crop residue on the soil surface after planting. This leads to higher soil organic carbon and less machinery usage. This practice is gaining widespread adoption. Organic farming has produced similar results. (Note: a later return to intensive tillage negates any gains.)

- Improved grassland management is another area where soil carbon losses can be reduced. Overgrazing is the greatest cause of degradation of grasslands and the biggest human influence on soil carbon. Overgrazing can be curbed with improved grazing management, such as optimizing stock numbers and rotational grazing. Other options include fire management and fertilization. Given a policy pricing carbon at $10 a ton, and that a pastoralist in Africa can sequester 0.5 tons of C/ha/y with modest improvements in management, individuals could earn roughly $50 per year, or 15% of the average income.
- Agroforestry is another option for carbon sequestration. Payment schemes for carbon sequestration through silvo-pastoral systems have already proven their viability in Latin American countries.
- Because it takes decades to reach peak carbon uptake rates there will need to be assurances that governments will be supporting sequestration far into the future.
- Though soil sequestration activities were not part of the Clean Development Mechanism (CDM) of the Kyoto Protocol, there are alternate funding options including BioCarbon Fund, Global Environment Facility, Adaptation Fund, and Prototype Carbon Fund.
- In terms of *implementation* for carbon dioxide mitigation, the authors recommend participatory land management programs, rather than top-down or interventionist policies, in order to reduce the risk of farmers opting out of agreements during the long period necessary for many of these land use issues. The authors also suggest using existing local or regional institutions to administer the sequestration program (see Tschakert and Tappan, 2004). This institution would help ensure the wide participation, a fair distribution of costs, coordinate monitoring and verification, and channel benefits in desirable and equitable ways.

With respect to **methane** emissions from livestock, improving the productivity and efficiency of livestock production, better nutrition, and genetics are all options.

- Enteric fermentation – the digestive process for ruminants that emits methane – can be reduced by a number of existing technologies. The basic principle is to increase the digestibility of feedstuff by modifying feed or by manipulating the digestive process.
    - Feed additives are one easy-to-use improvement. Increasing the level of starch or rapidly fermentable carbohydrates reduces excess hydrogen and subsequent methane formation. National strategies of dietary changes for livestock are needed for this option to be successful. EPA gives the following recommendations for production improvement: improving grazing management, soil testing and addition of proper fertilizers, supplementing cattle diets, developing a preventative herd program, providing appropriate water sources and protecting water quality, and improving genetics and reproductive efficiency. More advanced technologies that have not been implemented include: reduction of hydrogen production by stimulating acetogenic bacteria, eliminating certain

protozoa from the rumen, and vaccination to reduce methanogens. One way to improve waste management is improving rumen fermentation efficiency through the use of better quality feed, particularly in India's huge dairy sector.

- Trending toward monogastrics and poultry as a way to reduce methane per unit is crucial.
- Mitigating methane is also possible through improved manure management and biogas. Increasing carbon to nitrogen ratios in food is one option. Storing manure at lower temperatures reduces emissions. Frequent and complete removal of manure from indoor storage pits reduces methane emissions. Deep cooling of manure further reduces emissions, though this requires energy consumption which may offset any benefits. Additional measures include: anaerobic digestion (which produces biogas), flaring/burning, special biofilters, composting, and aerobic treatment. Biogas is 65% methane and 35% carbon dioxide and can be burned directly for heating or light, or in modified internal combustion engines. Biogas has the potential to reduce methane emissions by 75% in warm climates. This tremendous savings is especially suited to systems with covered lagoons, pits, or tanks. Biogas has been spread using subsidies in countries such as China, Vietnam, Thailand, and the Philippines.
- Mitigating human interference in the nitrogen cycle is also important. One important mitigation strategy is raising low animal nitrogen assimilation efficiency through more balanced feeding such as optimizing proteins or amino acids to match the requirements of particular livestock. Improving feeding by grouping by gender and phase of production is another strategy. The use of a tank or maintaining a natural crust on the manure can prevent volatilization of ammonia. Reducing emissions from grazing is important because it constitutes the bulk of nitrous oxide emissions in the livestock context. Excessive losses from manure can be avoided by not overstocking pastures and by not grazing in late fall or winter. Land drainage is another option to reduce nitrous oxide emissions. There is an ever-present trade-off between decreasing methane emissions and the consequent increase in nitrous oxide emissions.

Other policy tools mentioned by the authors include:

- Land taxes that drive land toward the highest productivity as well as deforestation taxes.
- Zoning, which is an effective policy tool where there are "functioning institutional frameworks to assign and police land uses." Particularly, the authors refer to zoning limitations on the size and number of livestock based on the vulnerability of the land. Infrastructure policy is also cited as a powerful determinant for land use, especially conversion of forests into pastures.
- Fuel taxes, such as in Costa Rica where a fuel tax supports the "forest environmental service payment" scheme to promote conversion of degraded pastures for carbon sequestration. Colombia is also working on a similar system.

- In some ecosystems, such as that of northern Tanzania, pastoralism combined with sound wildlife management is the most environmentally friendly agricultural activity. The Wildlife Management Areas (WMAs) of Tanzania are a success story of land use policy.
- Grazing fees are common in Morocco and if priced properly can prevent over-grazing by discouraging use of unproductive animals and by encouraging early de-stocking.
- Certification schemes or regulations to optimally balancing of nutrients, feed conversion with enzymes and synthetic amino-acids, and biogas generation.
- The development and dissemination of slow release fertilizers, tighter emission standards for fertilizer factories, limitations on the use of manure and mineral fertilizers, and application of the nutrient budget approach have all contributed to reducing emissions in developing countries.
- Reconnecting nutrient flows from livestock activities to crops via programs targeted at better geographic distribution and integration of livestock. This helps prevent nutrient loading, which leads to the release of ammonia, methane, and other gases. Zoning regulations and taxes can also be used to discourage high-density livestock production from occurring far from cropland where nutrients can be recycled. Thailand and the Netherlands (where there is tradable manure quotas) are examples of successful geographic distribution policy.
- Policy retiring marginal areas currently used by livestock and turning those areas into stable pasture or forest land.

FOOD AND AGRICULTURE ORGANIZATION (FAO), WORLD AGRICULTURE: TOWARDS 2015/2030 (2003)

Policy solutions for reducing emissions from livestock waste discussed in Chapter 12 include: developing national strategies for livestock waste management to promote voluntary local solutions & disseminate best practices; strengthened mandatory emissions standards; expanded range of economic instruments e.g., pollution taxes; and improved information-sharing between developed and developing countries, including environmental impact assessment (EIA) to ensure that international projects have adequate provision for sound livestock waste management.

The report (in Chapter 13) also discusses potential climate change mitigation benefits of livestock production, in the form of carbon sequestration via soil organic matter. Global estimates of the potential contribution of cropland to carbon sequestration are in the range of 450-610 million tonnes of carbon p.a. for the next 20-30 years (GCSI, 1999). There is considerable uncertainty as to how to calculate this & what is the extent of the potential gains from improved soil management, but the report anticipates including such activities under the Kyoto Protocol CDM.

B. <u>Consumer-Driven Demand Reduction</u>

Arnold Tukker et al., *Environmental impacts of changes to healthier diets in Europe*, 70 ECOLOGICAL ECONOMICS 1776 (2011).

This article recommends a shift to a healthier diet in Europe (and other areas where meat and dairy consumption are heavily consumed) as a strategy for reducing the environmental impacts of food consumption.

The authors estimates the difference in impacts between the European status quo and "three simulated diet baskets" including: (1) a diet in accordance with the universal dietary recommendations, (2) that same pattern but with reduced meat consumption, and (3) a "Mediterranean" diet with reduced meat consumption. The authors specifically choose diets with "positive heath impacts on the basis of generally accepted, authoritative recommendations" which would "contribute to the prevention of chronic diseases like obesity, type II diabetes, cardiovascular diseases and cancer." (p. 1778)

Although each scenario entails only "moderate dietary shifts", the authors estimate that environmental impact reductions of up to 8% are possible under these scenarios. Such reductions would primarily be achieved by replacing about 40% of red meat consumption with chicken, seafood and cereals (the models did not alter dairy consumption). With respect to global warming and greenhouse gas emissions, the study found that the alternative scenarios could reduce global warming impacts from meat and dairy as follows:

Global warming impacts (in kg CO_2e per capita), excluding land use changes.

	Status Quo	Scenario 1	Scenario 2	Scenario 3
Meat and Dairy	1.39E + 03	1.33E + 03	1.08E + 03	1.05E + 03

However, the authors note that shifts in production--whereby the European meat production sector will mostly likely respond by increasing exports to compensate for losses on the domestic meat market--will slightly offset the environmental gains from altered consumption habits.

Erik Stokstad, *Could less meat mean more food?* 327 SCIENCE 810 (2010).

This is a brief article directed at lay readers setting out options for cutting back on meat consumption.

The first solution comes from Lester Brown of the Earth Policy Institute in Washington, D.C., who says that one option to reduce demand would be to raise the price of meat to reflect its true ecological and climate costs. Brown argues that taxes should be tied to a piece of meat's particular carbon footprint. Another option quoted by the article is suggested by Sjur Kasa of the University of Oslo, who suggests removing subsidies for meat producer. A third option comes from Danielle Nierenberg of the Worldwatch Institute in Washington, D.C., who favors campaigns directed at consumers.

Harold J. Marlow et al., *Diet and the environment: does what you eat matter?* 89 AMERICAN JOURNAL OF CLINICAL NUTRITION 1699S (2009).

This article evaluates the relative environmental impacts of vegetarian and non-vegetarian diet in California in terms of agricultural production impacts (e.g., pesticides and fertilizers, water and energy) and finds that a non-vegetarian diet requires substantially greater inputs. Specifically, the non-vegetarian diet required 2.9 times more water, 2.5 times more primary energy, 13 times more fertilizer, and 1.4 times more pesticides than the vegetarian diet. Given these differences, the authors recommend that "many societies, and governments in particular, will have to reconsider the increasing demand for an animal-based diet" and will need to "reassess agricultural subsidies... and divert some of the funding to support additional research, development, and application of sustainable methods of food production."[133] The authors also note that "[o]utreach programs may be necessary to educate and inform people about the health and environmental impacts of a vegetarian diet."[134]

Ramona Cristina Ilea, *Intensive Livestock Farming: Global Trends, Increased Environmental Concerns, and Ethical Solutions*, 22 JOURNAL OF AGRICULTURAL ENVIRONMENTAL ETHICS 153 (2009).

This paper draws on statistics from the FAO (2006) and several other studies in order to demonstrate the effect of intensive livestock on global warming and public health. The author outlines the problems caused by intensive livestock farming and analyzes a number of possible solutions, including legislative changes and stricter regulations, community mobilizing, and consumer-driven reductions in livestock consumption.

Looking at these possible solutions, the author argues that systemic, top-down solutions are not sufficient. Solving the environmental problems caused by intensive livestock farming will require reducing the demand for animal products, which can only be achieved through changes in personal consumption habits. In other words, individual consumers are primarily responsible for reducing their intake of livestock products. The author notes that this is particularly important for driving policy--because politicians "will not pass laws if the public is

[133] Marlow et al. (2009) at 1702S.

[134] *Id*.

not in support of stricter regulations... [w]e need individual citizens to send a clear message to politicians that they are willing to see prices rise and to eat less meat."[135] The author characterizes this as a matter of moral responsibility and an ethical solution to the environmental threat of livestock production.

Matthew Cole et al., *Animal foods and climate change: shadowing eating practices*, 33 INTERNATIONAL JOURNAL OF CONSUMER STUDIES 162 (2009).

This article describes a pilot study, which investigated the connections between day-to-day animal food practices (sourcing, preparing and consuming animal products) and awareness of, and behavior in relation to, environmental issues, among a sample of six UK households. The purpose of the study was to inform further research into designing policy interventions to mitigate climate change.

The results of the study suggested that individual consumers' "beliefs about climate change in general, and the role of animal foods in particular, play very little part in the food practices" of those consumers.[136] The only participant who made consumption decisions based on his awareness of the connection between climate change and consumption of animal products was a single vegan who was "free to choose the foods he pleased without being greatly constrained by food prices or accommodating the domestic preferences of others."[137] Although the other participants expressed interest in environmental issues, they did not express any particular awareness of the connection between animal products and climate change, nor did they modify their consumption habits.

The authors conclude that there is a "generalized lack of awareness of the relationship between animal farming and climate change" but that "the mere awareness of the rational arguments in relation to reduction of animal food are unlikely to be sufficient to significantly change food practices in some, if not most, cases."[138] Thus, NGO or government initiatives to reduce or eliminate animal food consumption will probably have limited effectiveness in changing behavior."[139] However, the authors did note that some participants were ambiguous about the place of animal products in their food practices, and that such ambiguous feelings (regarding health, the environment, and the well-being of animals) may provide an opportunity for consumer-driven demand reductions.

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[135] Ilea (2009) at 163.

[136] Cole et al. (2009) at 165.

[137] *Id*. at 164.

[138] *Id*. at 166.

[139] *Id*.

Robert Goodland, *Environmental sustainability in agriculture: diet matters*, 23 ECOLOGICAL ECONOMICS 189 (1997).

This article advocates for a conversion-efficiency sliding-scale tax on certain kinds of food, based on the "polluter pays" principle. Under such a scheme, the livestock products that convert nutrients with the least efficiency (such as beef) would be highly taxed, whereas the more efficient converters (such as poultry or ocean fish) would be taxed less. This would create different incentives depending on where a population is in terms of wealth and meat consumption. Most people of the world are already at the efficient, low impact end of the food chain and thus would remain mostly as they are after this tax took effect, perhaps with even lower prices. More affluent people now consuming significant quantities of meat would begin to consume lower down the food chain. And last, those people starting to move up the food chain (e.g. China, India) would be incentivized to maintain current consumption patterns. Land allocated to production of products other than food, such as tobacco, would also be taxed heavily; especially where the land used is suitable for food production. This scheme would obviously not support the allocation of public funds (i.e. subsidies) to the least efficient converters, livestock.

C. Articles with a Technical Focus

D.I. Massé, G. Talbot, Y. Gilbert, *On farm biogas production: A method to reduce GHG emissions and develop more sustainable livestock operations*, 166-167 ANIMAL FEED SCIENCE AND TECHNOLOGY 436 (2011).

This article describes the potential contribution of on-farm biogas production to reducing greenhouse gas (GHG) emissions and other environmental impacts related to livestock production. In particular, the study evaluates the use of anaerobic digestion (AD) technologies to process agricultural wastes and provide renewable energy. The primary benefits of AD technologies are that they reduce fugitive GHG emissions from manure storage (primarily CH_4), and create biogass which can be used as a substitute for fossil fuel energy, thus offsetting emissions from coal, oil and natural gas.

The authors also note that AD technologies can have a positive impact on water quality, and may reduce N_2O and NH_3 emissions from land-applied manures. AD may also be useful for reducing environmental impacts and water contamination from morality disposal. Finally, the authors note the agronomic benefits of AD--in particular, that it preserves crop nutrients and thus increases the agronomic value of manure produced using this technology.

Finally, the authors identify several barriers to the application of AD technologies. The primary obstacle is the "high cost of modifying existing farm infrastructure and the additional equipment needed to operate a digester."[140] The authors find that the "high capital costs, low returns on generated energy and technical failures have impeded uptake of AD technology by North American livestock producers." Such barriers are "exacerbated in developing countries."[141]

For example, a study in Thailand (Prasertan and Sajjakulnukit, 2006) found that the primary barriers to AD were: (1) institutional barriers that have resulted in poor coordination among government agencies and the private sector, (2) inadequate governmental policies to support renewable energy, (3) technical barriers due to lack of standards on bioenergy systems and equipment, (4) lack of financial incentives, and (5) lack of confidence of the private sector and local community in energy generated from biomass.

The authors note that promotion of AD technologies will require "co-operation of all involved parties regarding nutrient recycling and biogas utilization in order to increase process profitability."[142] The authors recommend "government support through financial incentives and policies [to] encourage the use of on-farm AD and ensure access to energy distribution systems for surpluses of biogas and/or the electricity produced."[143] The authors also recommend the promotion and provision of efficient technologies for biogas production.

Gert-Jan Monteny, Andre Bannink, and David Chadwick, *Greenhouse gas abatement strategies for animal husbandry*, 112 AGRICULTURE, ECOSYSTEMS AND ENVIRONMENT 163 (2006).

This article provides a very useful overview of the different husbandry-based mitigation options, with citations to many of the leading studies.

Generally, a key to decreasing livestock emissions is increasing the ratio of livestock production to livestock maintenance. For example, this ratio could be improved by faster growth, higher milk yields, shorter dry periods, or an increase in longevity in lactating cows. However, note that only a reduction in the number of animals registers under the IPCC inventory. Other important general strategies include modifying diet, decreasing methanogens and methanogen activity, and of course reducing overall livestock numbers.

The dietary changes most effective at reducing methane emissions for ruminants include, in theory: (a) an increase the level of starch or rapidly fermentable carbohydrates to enhance propionate production, (b) altering the diet concerning feed intake and feed composition to allow for a higher animal productivity, (c) reducing [H] by addition of (unsaturated) fat or stimulation of acetogenic bacteria, and (d) reduction of methanogens or removal of protozoa through

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140 Massé et al. (2011) at 441.

141 *Id*. at 442.

142 *Id*.

143 *Id*.

additives or probiotics. But the authors believe that only (a) and (b) are likely applicable to farming practices today.

For indoor housing of animals, the authors suggest the following techniques to achieve a reduction in methane: (a) reduction of gas production through deep cooling of manure or a substantial reduction of manure pH, (b) removal of the gas source, for example by frequently removing manure from indoor storage pits, and (c) proper management of bedding and manure heaps. The author also discusses biogas production with reference to the Burton studies.

Nitrous Oxide reduction options include (citing Harrison et al., 2003): (1) Choice of fertilizer – nitrate-based fertilizers result in greater emissions than ammonium-based fertilizers. (2) Adding nitrification inhibitors, especially via slurry injection. (3) Land drainage management because water filled pore space of more than 70% results in significant nitrous oxide emissions. (4) Storage of solid manure including addition of high C substrate and compaction of manure heaps. (5) Better N_2O:N_2 ratio achieved by spreading of anaerobically digested slurry (see Amon et al. 2002). (6) Changes in manure housing and management.

B. Amon et al, *Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment*, 112 AGRICULTURE, ECOSYSTEMS AND ENVIRONMENT 153 (2006).

This article compares the net total greenhouse gas emissions from different methods of a very important source of mitigation, manure treatment. The comparison focused on two stages, during manure storage and after manure application. The authors conducted a study with dairy cattle slurry (and also collect results from other studies) on the results of following manure treatments: slurry separation, anaerobic digestion, slurry aeration, and straw cover. In Table 1 the authors identify the problems resulting from slurry storage, spreading, and fertilization. Generally, mitigation of GHG emissions can be achieved by a reduction in slurry dry matter and easily degradable organic matter content.

Beyond the confines of the study, the article provides an overview, and breaks down the different methods currently being used, beginning with the premise that it is advisable to reduce slurry dry matter and carbon content at an *early stage* of manure management. The first mitigation strategy presented is slurry mixing, which is the most commonly applied manure treatment technology. During mixing, the slurry is homogenized in order to evenly distribute nutrients. Next, slurry dilution (with water) reduces ammonia losses after application. However, dilution also results in a significant increase in slurry volume. Another technique is slurry additives, which can work on a physical, chemical or biological level.

The techniques used in the study are also detailed. First, slurry aeration introduces oxygen into the slurry in order to allow aerobic microbes to develop. But aeration results in an increase in ammonia emissions, energy consumption, and the potential for nitrous oxide emissions. With slurry separation, solids are mechanically separated from slurry. Anaerobic digestion is mainly implemented for energy production reasons. Digestion reduces manure carbon and dry matter content by about 50%. Last, straw cover just entails covering manure stores with a layer of chopped straw.

The results of the study, where each number represents total GHG emissions (in kg of CO_2 equivalent), using IPCC global warming potential conversions, are as follows:

Untreated (control)	92.40 kg
Separated	58.50 kg
Digested	37.89 kg
Straw Cover	119.73 kg
Aerated	53.32 kg

The authors therefore conclude anaerobic digestion is the slurry treatment that offers the most environmental benefits, and thus they recommended it for commercial farms. (See B. Amon *et al.*, "Mitigation of greenhouse gas emissions by anaerobic digestion of cattle slurry" (2005) for another similar study with similar results).

The study also broke down emissions by pollutant. Methane emissions from cattle slurry were reduced by *all treatments except* of covering the slurry store with straw. *None* of the treatments was able to reduce ammonia emissions. Nitrous oxide emissions increased with *all* treatments. Nearly all of net total GHGs originated from methane emissions during storage, so manure management abatement measures are most effective if they aimed at methane during storage. Again, this can be achieved by a reduction in slurry dry matter and easily degradable organic matter content.

Rattan Lal, *Carbon Sequestration in Dryland Ecosystems*, 33(4) ENVIRONMENTAL MANAGEMENT 528 (2004).

This article addresses carbon soil sequestration as a mitigation option, and details the significant potential that grazing techniques have to promote carbon storage in soil. The particular focus of this article is drylands, which occupy 47.2% of the world's land area. Grazing is the predominant land use in dryland ecosystems, and adoption of better grazing practices would improve carbon sequestration via two main channels: conservation and better management of surface residue. Conversion of land degraded by cropping to pasture, along with improving pasture management, would enhance soil organic carbon (SOC) concentration and mitigate climate change due to livestock.

Land use and management practices to sequester SOC pertaining to livestock include afforestation with appropriate species, pasture management on grazing land, and conversion of degraded soils to other restorative land uses. Recommended practices for managing grazing lands include controlled grazing at an optimal stocking rate, fire management, and growing improved species. Table 5 provides a breakdown of strategies of pasture and rangeland management for soil carbon sequestration, where they are practiced, and previous scholarly work on that strategy.

More specific techniques are also provided. For example, restoration of pasture using "improved pasture species" such as barrel medic and Mitchell grass, or incorporation of perennial woody legumes into the grazing system, which may enhance SOC by transferring the carbon to sub-soil at lower depths. Reduction in fire frequency may lead to a shift in favor of woody vegetation. Last, bush fallowing – permitting natural vegetation to grow without grazing or biomass removal – can restore soil quality and enhance SOC concentration.

For a more comprehensive discussion, see a book on the topic edited by the author: R.F. Follett, J.M. Kimble, and R. Lal, eds., *The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect*, CRC/Lewis Publishers (2001).

Iqbal et al, *Mitigation of ruminant methane production: current strategies, constraints and future options*, 24(12) WORLD JOURNAL OF MICROBIOLOGY AND BIOTECHNOLOGY, 2747 (2008).

This article offers integrated research investigating animal, plant, microbe and nutrient level strategies that may offer a long-term solution to methane production in ruminants. The article functions mostly as a collection of previous research and an evaluation of the efficacy of various methodologies.

One current mitigation strategy is improving nutrition. The authors cite to two specific techniques – changing the proportion of concentrate within the diet and changing the forage type and quality. Studies have demonstrated that increased fiber-based concentrate use at pasture reduced enteric methane per kilogram of animal, and a positive response to high levels of starch-based concentrate has also been reported. However, the high cost of production for concentrate feeding limits use in low cost systems. In terms of forage, methane production was reduced by increasing dry matter intake, and the use of more digestible forage (less mature and processed) resulted in a reduction of methane. Methane production was also lower with legume than with grass forage. Methane emissions per unit of feed intake can be reduced by use of grass cultivars selected for improved animal performance.

Another current strategy for reducing methane emissions is rumen modification, including defaunation, ionophores, oils, and dicarboxylic acids. The elimination of protozoa from the rumen is termed defaunation. Defaunation techniques used in research include dietary manipulation; synthetic chemicals including copper sulfate and detergents; and natural compounds like vitamin A, non-protein amino acids and ecdysones. Defaunation results in reduced methane production due to reduced fiber digestion, reduced methanogen population associated with protozoa, reduced hydrogen transfer, and increased partial pressure of oxygen on the rumen. Some reports indicate that the reduction of methane production by defaunation is only temporary. Ionophores are polyether antibiotics produced by soil microorganisms that modulate the movement of cations such as sodium across cell membranes. Ionophores affect methane production by increasing feed conversion efficiency, selectively reducing acetate production, inhibiting the release of H2 from formate, and depressing ciliate protozoa population. Cattle studies have shown that ionophore-induced suppression of enteric methane production is short lived. The addition of oils – e.g. coconut oil or linseed oil – to ruminant diets may decrease methane emission by up to 80% in vitro and about 25% in vivo. Addition of fats or oils to the diets of ruminants suppresses methane production via protozoal inhibition, reduction of double bonds in unsaturated fatty acids, increased productivity, enhanced propionate production, and fatty acid toxicity to methanogens (the direct mechanism). However, oil addition reduces fiber digestibility significantly. Dicarboxylic organic acids are potential precursors of propionate which stimulate H2 utilization for reduction of fumarate to succinate during propionate synthesis at the expense of enteric methane.

Future options include animal level (genetic selection), microbe level (probiotics and immunization), nutrient level (hexose partitioning and prebiotics) and plant level mitigation strategies. Further research is needed for all of the following mitigation options. Methane emissions can be reduced by selection of animals with improved genetic merit. For example, genetic variation in feed intake provides a basis for genetic selection. At the microbe level, probiotics – such as yeast – are feed additives that influence rumen fermentation resulting in increased productivity. Yeast cultures reduce methane production by increasing butyrate or propionate production, by reducing protozoan numbers, by promoting acetogenesis, and by improving animal productivity. One possible future pathway to reduce methane output up to 70% is to immunize animals against their own methanogens and protozoa. But much more work is needed to make this technique effective because there are many strains of Archaea in the rumen. Methanogenesis could be altered by increasing the quantity of microbial cells leaving the rumen per unit of carbohydrate consumed, and one possible technique is hexose partitioning. Partitioning alters methanogenesis by changes in the diet, which manipulate the amount of feed carbohydrate going directly into microbial growth as opposed to fermentation. Prebiotics are non-digestible supplements that enhance beneficial intestinal organisms. Last, improvement and breeding of plants also controls methanogenesis.

D. Example Legislation

Australia's "Carbon Credits (Carbon Farming Initiative) Act 2011" No. 101, 2011 (legislation available at: http://www.comlaw.gov.au/Details/C2011A00101) (regulations promulgated under the Carbon Farming Initiative available at: http://www.comlaw.gov.au/Details/F2011L02583).

The legislation, which just received royal assent on September 15, 2011, states that the Carbon Farming Initiative (CFI) is: "An Act about projects to remove carbon dioxide from the atmosphere and projects to avoid emissions of greenhouse gases, and for other purposes." As part of the "Clean Energy Future Plan" passed on November 8th, 2011, the Australia has also committed to a number of complementary land sector measures. One of the stated reasons for the CFI was to help Australia meet its Kyoto obligations. The Carbon Credits Administrator receives applications for emissions offset programs, and may declare a project to be eligible and then allocate credits. Both Kyoto eligible and non-Kyoto projects are counted. For an emissions reducing carbon activity to be eligible under the Carbon Farming Initiative, it must: (1) be within the scope of the CFI, (2) be covered by an approved CFI methodology, (3) be on the Positive List, and, (4) not be on the Negative List. Credits can then be used to offset onsite emissions and can also be sold.

The Department of Climate Change and Energy Efficiency has stated that the following four types of projects could be eligible under the CFI, provided they satisfy the above criteria.

- "Agricultural emissions avoidance projects" and "Introduced animal emissions avoidance projects" including:
    - Projects that avoid emissions of: methane from the digestive tract of livestock (or introduced animal), or methane or nitrous oxide from the decomposition of livestock (or introduced animal) urine or dung,
- "Sequestration offsets projects" that remove carbon dioxide from the atmosphere by sequestering carbon in living biomass, dead organic matter or soil; or remove carbon dioxide from the atmosphere by sequestering carbon in, and avoid emissions of greenhouses gases from, living biomass, dead organic matter or soil.

An initial list of eligible activities includes:

- The exclusion of livestock
- The management of the timing and the extent of grazing, of feral animals
- The capture and combustion of methane from livestock manure
- The reduction of methane emissions through the humane management of feral goats, feral deer, feral pigs or feral camels
- The reduction of emissions from ruminants by manipulation of their digestive processes
- The application of urease or nitrification inhibitors to, or with, livestock manure or fertilizer

A presentation breaking down the legislation is available from the Department of Climate Change and Energy Efficiency at: http://www.climatechange.gov.au/government/initiatives/~/media/government/initiatives/cfi/resources/presentations/CFI_overview_presentation_pdf.pdf.