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An HSI Report: The Impact of Animal Agriculture on Global Warming and Climate Change

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Abstract

The farm animal production sector is the single largest anthropogenic user of land, contributing to soil degradation, dwindling water supplies, and air pollution. The breadth of this sector's impacts has been largely underappreciated. Meat, egg, and milk production are not narrowly focused on the rearing and slaughtering of farm animals. The animal agriculture sector also encompasses feed grain production which requires substantial water, energy, and chemical inputs, as well as energy expenditures to transport feed, live animals, and animal products. All of this comes at a substantial cost to the environment.

One of animal agriculture's greatest environmental impacts is its contribution to global warming and climate change. According to the Food and Agriculture Organization (FAO) of the United Nations (UN), the animal agriculture sector is responsible for approximately 18%, or nearly one-fifth, of human-induced greenhouse gas (GHG) emissions. In nearly every step of meat, egg, and milk production, climate-changing gases are released into the atmosphere, potentially disrupting weather, temperature, and ecosystem health. Mitigating this serious problem requires immediate and far-reaching changes in current animal agriculture practices and consumption patterns.

Global Warming and Climate Change

Global warming is one facet of climate change and refers to an average increase in global surface temperature.[1] Climate change, by contrast, refers to statistical changes in weather over time[2] and can include long-term changes in rainfall, wind, temperature, or other patterns.[3]

The planet is continually warming. Temperature readings taken around the world in recent decades, as well as scientific studies of tree rings, coral reefs, and ice cores, show that average global temperatures have risen substantially since the Industrial Revolution began in the mid-1700s.[4] This trend has not shown signs of stopping. Each of the most recent three decades, the 1980s, 1990s, and 2000s, has been warmer than the last, and than all other decades on record.[5] The five warmest years ever recorded have all occurred since 1998, and there has been a mean surface temperature increase of about 0.6°C (1.08°F) in just the last 30 years.[6] The Intergovernmental Panel on Climate Change (IPCC) predicts that, relative to 1980-1999 levels, temperatures will rise 1.8-4.0°C (3.2-7.2 °F) by 2090-2099.[7,8]

The impacts of increasing temperatures are widespread. Worldwide, glaciers are in retreat, the tundra is thawing, sea ice is melting, sea level is rising, and some species are rapidly disappearing.[9] Sea-ice reductions translate into loss of polar bear habitat, putting the species at risk of extinction.[10] The U.S. Geological Survey reportedly identified "a definite link between changes in the sea ice and the welfare of polar bears…As the sea ice goes, so goes the polar bear."[11]

There have been increasing occurrences of some extreme weather events since 1950. For example, there have been more heavy precipitation events, more heat waves, and an expansion of drought-affected areas. Since the 1970s, there have been increases in hurricane intensity.[12] The IPCC further predicts changes to a variety of extreme weather events in the future, including the likelihood of more hot nights and more floods in many regions.[13]

Some natural occurrences, such as changes in solar output and volcanic eruptions, can affect climate change;[14] however, "the leading international body for the assessment of climate change"[15] concluded in its Fourth Assessment Report (AR4)that a majority of the increase in temperature over the second half of the 20th century is likely due to human activities.[16,17] In fact, the IPCC[*] found with "high confidence" that human-induced warming has already impacted "many physical and biological systems."[18] The panel warned that human-induced warming could have "abrupt or irreversible" effects. [19]

Since publication of the AR4, even more evidence has been gathered linking human activity to climate change. For example, a 2010 study implicated anthropogenic climate change in Arctic sea-ice reductions, precipitation changes on global and regional scales, increased ocean salinity in part of the Atlantic, as well as temperature change in the Antarctic—the only continent on which climate change had not been attributed to human influence as of the AR4.[20] Recent studies are also able to attribute climate change to human influence on increasingly smaller scales.[21]

Beyond the Environment: Drought, Hunger, and Conflict

The effects of climate change vary greatly by region.[22,23,24,25] While wealthy, developed countries are mainly responsible for the historic buildup of climate changing gases, as well as high per capita emissions,[26] leading global development organizations recognize that the poor in lower income countries are most vulnerable to climate change.[27] The IPCC predicts a growth of drought-affected areas, lower water availability for large numbers of people, and that events such as heat waves, drought, and storms will lead to more death and disease, especially for those not in the position to adapt[28]—such as the more than 1 billion people worldwide who "live in extreme poverty on less than US$1 a day."[29]

The poorest of the poor tend to live in high-risk areas, such as coasts, and are less able to withstand the effects of climate change on water supplies or food sources.[30] Communities reliant on subsistence farming will be among the hardest hit. "Studies have consistently shown," says Robert Watson, former chair of the IPCC and now a senior scientist with the World Bank, "that agricultural regions in the developing world are more vulnerable, even before we consider the ability to cope."[31] Henry Miller of Stanford University has reportedly said that "like the sinking of the Titanic, catastrophes are not democratic…A much higher fraction of passengers from the cheaper decks were lost. We'll see the same phenomenon with global warming."[32]

Drought will bring obvious human suffering. According to the IPCC, by 2020, up to 250 million people may experience water shortages, and in some African nations food production could fall by half.[33] The IPCC also warns that warming temperatures could result in food shortages for 130 million people across Asia by 2050. The report suggests that a 3.6°C (6.5°F) increase in mean air temperature could decrease rain-fed rice yields by 5-12% in China. In Bangladesh, says the IPCC, rice production could fall approximately 10% and wheat by one-third by 2050.[34]

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[*] The IPCC and Al Gore, Jr., former Vice President of the United States, were jointly awarded the Nobel Peace Prize for 2007 "for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change." Nobel Foundation. 2007. The Nobel Peace Prize for 2007. October 12. http://nobelprize.org/nobel_prizes/peace/laureates/2007/press.html. Accessed April 23, 2008.

As grazing areas dry up in sub-Saharan Africa, pastoralists will be forced to travel farther to find food and many animals will likely starve. In particular, cattle, goats, camels, sheep, and other animals who depend on access to grazing areas for food will suffer from hunger and dehydration.[35]

Conflicts among pastoral communities are also likely to rise along with temperatures. As water supplies dry up, farmers and herders are living out an ancient struggle over land and water resources. One startling example is in Sudan's Darfur region. There, the effects of climate change and population growth, including dwindling water supplies and diminishing arable land, have reportedly created an untenable and devastating situation. Farmers and herders have taken up arms, fighting to gain and maintain control of increasingly scarce water and land.[36]

A 2007 report by the UNEP cites environmental degradation as a catalyst for the ongoing conflicts in Darfur and other parts of Sudan. Among its critical concerns are land degradation and desertification, which are tied to increases in farm animal populations: "Vulnerability to drought is exacerbated by the tendency to maximize livestock herd sizes rather than quality…In addition, an explosive growth in livestock numbers—from 28.6 million in 1961 to 134.6 million in 2004—has resulted in widespread degradation of the rangelands."[37] An almost unprecedented scale of climate change in the region is also a source of conflict due to the stress its effects impose on communities whose livelihoods depend on agriculture. [38]

Not confined to Sudan, these same battles are being fought with greater frequency in several other African nations, including Chad and Niger. [39] UN Secretary-General Ban Ki-moon has cited climate change as one factor that led to the Darfur conflict[40] and also reportedly stated that "the danger posed by war to all of humanity—and to our planet—is at least matched by the climate crisis and global warming," noting that global warming can lead to natural disasters, trigger droughts, and cause other changes that "are likely to become a major driver of war and conflict."[41]

Causes of Global Warming and Climate Change

As discussed, changes in climate can be influenced by both natural and human factors.[42] One natural warming phenomenon is the greenhouse effect. The greenhouse effect is a blanketing effect by which atmospheric greenhouse gases keep the earth's surface warm. Clouds, aerosols, and parts of the earth's surface reflect about one third of the sun's light that reaches the earth.[43] Energy that reaches the earth is absorbed by the surface,[44] and is then re-radiated back towards space as heat energy.[45] Greenhouse gases (GHGs), in turn, essentially trap some of this re-radiated energy within the atmosphere, raising the earth's surface temperatures.[46]

Three important greenhouse gases are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).[47] In naturally occurring quantities, these gases are not harmful; their presence in the atmosphere helps to sustain life on the planet by trapping some heat near the Earth's surface. Since the industrial revolution, however, atmospheric concentrations of all three of these important GHGs have increased significantly due to human activities, contributing to global warming and climate change.[48,49] Between 1970 and 2004, greenhouse gas concentrations rose about 70%.[50] Although the ocean absorbs some of the human-induced carbon emissions,[51] greenhouse gas concentrations continue to rise and oceanic uptake of carbon dioxide appears to be slowing.[52]

While the most important human-influenced GHG may be carbon dioxide, methane, and nitrous oxide are also extremely important for climate change.[53] The global warming potential (GWP), or power, and lifetime in the atmosphere of each of these gases differs. CO_2 has been assigned a value of one GWP, and the warming potentials of other gases are expressed relative to its power.[54] According to the IPCC, 1 tonne[*] of methane has the warming effect of around 25 and 72 tonnes of CO_2 over 100- and 20-year periods, respectively. [55] A 2010 study shows that methane is likely significantly more potent.[56] Further, methane's relatively short atmospheric lifetime compared to carbon dioxide (≈ ten years[57,58] vs. ≈ centuries to millenia[59]) means that reducing methane emissions would have a more immediate and significant impact on mitigating climate change than just reducing CO_2 emissions.[60]

[*] One tonne is one metric ton, or 1,000 kg.

Nitrous oxide is another extremely potent greenhouse gas and remains in the atmosphere for 114 years.[61,62] N_2O is 298 times as potent as CO_2 over 100 years.[63]

Gas	Atmospheric Lifetime	Global Warming Potential (20 years)	Global Warming Potential (100 years)
Carbon dioxide (CO_2)	Centuries to Millennia	1	1
Methane (CH_4)	≈10 years	72	25
Nitrous oxide (N_2O)	114 years	289	298

Animal agriculture is a major emitter of all three of these major GHGs.[64] The FAO's November 2006 report, "Livestock's Long Shadow: Environmental Issues and Options," found that meat, egg, and milk production are responsible for an estimated 18%, or nearly one-fifth, of human-induced GHGs.[65]

The climate changing impacts of the farm animal sector are projected to be significant for decades to come. A 2010 study in the Proceeding of the National Academy of Sciences found that, based on projected product demand, the sector's GHG emissions may increase 39% by 2050. This was estimated to account for 70% of what is considered a sustainable level of GHG emissions in 2050. In other words, farm animals alone are projected to emit over two-thirds of the amount of GHGs considered safe by 2050.[66]

Global Farm Animal Populations and Production Practices

Farm animals are significant contributors to the production of all three major GHGs,[67] and, as their numbers grow, so do their emissions. As the U.S. Department of Agriculture (USDA) notes, "GHG emissions from livestock are inherently tied to livestock population sizes because the livestock are either directly or indirectly the source for the emissions." [68]

Globally, according to the FAO, 67.5 billion land animals were raised for human consumption in 2008,[69] joined by an untold number of aquatic animals. Presently, grazing and mixed farming methods remain widespread in Africa and parts of Asia,[70] but, beginning in the mid-1980s, the reach of industrialized animal production practices extended into less-developed countries.[71] Since industrialized systems support much larger numbers of animals per unit area than extensive systems,[72] a global shift toward industrial production could result in larger farm animal populations over all. Globally, industrialized systems now produce over half of all pork and about two-thirds of eggs and poultry meat.[73] In China, India, and Brazil, for example, producers are increasingly favoring intensive, industrial production systems[74]over more welfare-friendly practices. "In recent years, industrial livestock production has grown at twice the rate of more traditional mixed farming systems and at more than six times the rate of production based on grazing," according to a 2007 report about GHG emissions from agriculture.[75]

This inhumane and environmentally unsustainable trend toward industrial practices views farm animals as production units and focuses nearly exclusively on productivity as the sole output of these industries.[76] Emphasizing productivity can often be at odds with animal welfare, as intensified agricultural production practices of today typically confine animals in cages, crates, and pens without adequate space for animals to experience most natural behavior.[77] In addition to these impacts on animal welfare, farm animals are inefficient in converting feed to edible protein.[78] "If animals are considered as 'food production machines'," a team of Swiss and Italian scientists concluded, "these machines turn out to be extremely polluting…and to be very inefficient."[79]

Fueling Climate Change: Carbon Dioxide

Carbon dioxide is widely considered the most important human-induced GHG.[80,81] The release of CO_2 into the atmosphere due to human activities, such as the burning of fossil fuels and deforestation, has had the largest impact on the climate relative to all other factors over the last 250 years,[82] and, in 2005, atmospheric carbon dioxide levels were 36%, or about 100 parts per million (ppm) higher than 250 years before, rising to 379 ppm.[83]

CO_2 has the most significant anthropogenic warming impact in the atmosphere[84] for two reasons: 1) the sheer volume of its emissions and 2) its persistence in the atmosphere. Carbon dioxide remains in the atmosphere for centuries or millennia.[85] This is such that today's CO_2 emissions, including those produced by animal agriculture, may remain in the atmosphere in 2100 and beyond.[86,87]

The farm animal sector contributes approximately 9% of annual anthropogenic CO_2 output. The largest sources of CO_2 from animal agriculture come not from the animals themselves, but from the inputs and land-use changes necessary to maintain and feed them.[88]

Fertilizer and Feed Production

Burning fossil fuel to produce fertilizers used in feed production releases significant amounts of CO_2. Indeed, a main input in modern farm animal production is artificial nitrogenous fertilizer, vast amounts of which are used in the cultivation of farm animal feed.[89] This fertilizer is primarily applied to corn, but also to other feedcrops like soybeans, barley, and sorghum.[90] Worldwide, more than 97% of soymeal and over 60% of barley and corn go to feed farm animals.[91]

Most of that fertilizer is produced in factories dependent on fossil-fuel energy.[92] Manufacturing nitrogenous fertilizer requires around 1% of the global energy supply,[93] and an estimated 41 million tonnes of CO_2 is emitted each year from fertilizer production exclusively for feed crops.[94]

China, the world's largest producer of grain,[95] emits the greatest amount of CO_2 from this process, releasing nearly 14.3 million tonnes annually. The United States, the world's second-largest grain producer,[25] emits just under 12 million tonnes, while Canada, France, Germany, and the United Kingdom each emits 2.2-3.3 million tonnes of CO_2 per year as a result of fertilizer production for feed crops.[96]

Energy Use

Maintaining intensive animal production facilities, as well as growing the associated animal feed, may emit 90 million tonnes of CO_2 per year due to requirements such as electricity and diesel fuel.[97] This is in contrast to extensive systems that have low or negligible comparative on-farm fossil fuel use.[98] The FAO estimates that on-farm fossil fuel consumption in intensive systems likely produces more CO_2 emissions than does the manufacturing of chemical fertilizer for feed production. The fossil fuel needed varies by animal: A typical U.S. factory farm in the 1980s used approximately 35 megajoules (MJ) of energy per kg of a chicken, 46 MJ per kg of a pig, and 51 MJ per kg of cattle.[99]

Electricity use in intensive farms makes up a large part of this energy expenditure, especially for ventilating, heating, and cooling monogastric operations, such as pig or chicken meat production facilities.[100] But, according to the FAO, feed production accounts for over half of the energy used for animal agriculture systems.[101] This does not include the energy used to make fertilizer (discussed above), but the energy used for seed, herbicides, and pesticides, as well as the fossil fuel needed for farm machinery used to produce feed.[102]

Transportation and Processing

As agriculture becomes increasingly globalized, meat, eggs, milk, and live animals are transported farther than ever before. Approximately 45 million cattle, pigs, and sheep are traded around the world each year,[103] and millions more are transported over long distances within a country's own borders.[104] In addition to the human health and animal welfare implications of transporting live animals between different cities and countries, and the potential for spreading animal disease,[105] live animal transport likely consumes large quantities of fossil fuels and contributes to climate change.

Transporting feed, and processing and transporting animal products, may emit tens of millions of tonnes of CO_2 per year.[106] While the FAO did not include consideration of live animal transport in its calculations, its report did find that transporting feed and animal products to the destinations where they will be consumed emits approximately 0.8 million tonnes of CO_2 per year.[107]

Soybeans and soybean cakes used for feed are shipped from Brazil to Europe, and estimated annual emissions of CO_2 from just this single trade route are some 32,000 tonnes. The annual trade of meat between countries results in 500,000-850,000 tonnes of CO_2.[108]

The FAO estimates that CO_2 emissions from animal processing total several tens of millions of tonnes per year.[109] Processed animal products typically come from intensive systems,[110] although energy costs vary widely depending on the product.[111] Processing meat from sheep, according to one study, is very energy costly, with 10.4 megajoules (MJ) used per kg of carcass compared to the energy required for processing beef, which uses 4.37 MJ per kg.[112] Processing eggs, too, is energy intensive, with more than 6 MJ used per dozen eggs.[113]

Changing the Landscape: GHG Emissions from Deforestation, Land Degradation, Soil Cultivation, and Desertification

Land uses are continually changing. Around the world, animal agriculture is often an important cause of these changes.[114] Farm animals and meat, egg, and dairy production facilities cover one-third of the planet's total surface area and use more than two-thirds of its agricultural land, inhabiting nearly every country.[115] As the number of farm animals escalates, so do their impacts on forests, soils, and ecosystems.

Expanding farm animal production plays a major role in deforestation, turning wooded areas into grazing land and cropland for the production of feed.[116] But this destruction comes at a cost beyond the loss of the forests. According to the FAO, animal agriculture-related deforestation may emit 2.4 billion tonnes of CO_2 into the atmosphere each year.[117] Tropical forests act as carbon sinks, sequestering carbon and preventing its release into the atmosphere.[118] Thus, deforestation releases large amounts of carbon, both from soil and vegetation.[119] As animal product consumption grows, grazing land, soybean monocultures, industrial feedlots, and factory farms encroach on forests.[120]

Animal agriculture's role in deforestation has been especially devastating in South America, where expansion of pasture and arable land at the expense of forests has been the most prevalent. "[T]he continent [is] suffering the largest net loss of forests and resulting carbon fluxes," the releases of stored carbon from vegetation and soil into the atmosphere.[121]

In 2005 the FAO found that cattle ranching is one of the main causes of forest destruction in Latin America. The FAO predicted that by 2010, more than 1.2 million hectares of forest will be lost in Central America, while 18 million hectares of South American forest will disappear, in large part, because of clearing land for grazing cattle.[122]

According to a 2004 report by the Center for International Forestry Research (CIFOR), rapid growth in the exportation of Brazilian beef has accelerated destruction of the Amazon rainforest. The total area of forest lost increased from 41.5 million hectares in 1990 to 58.7 million hectares in 2000. In just ten years, reports CIFOR, an area twice the size of Portugal was lost, most of it to grazing land.[123] "In a nutshell," says David Kaimowitz, Director General of CIFOR, "cattle ranchers are making mincemeat out of Brazil's Amazon rainforests."[124] Brazil is the fourth-largest GHG emitter, largely because of agricultural burning in the Amazon, which contributes some 70% of the country's emissions.[125]

Soybean and corn production for animal feed is also leading to the rapid clearance of tropical forests.[126] Mato Grosso, the state that has led Brazil in both deforestation and soybean production since 2001,[127] lost approximately 36,000 km^2 of forest to intensive mechanized agriculture between 2001 and 2004.[128,129] In just five months, from August through December 2007, Brazil lost more than 3,200 km^2 of forest in the Amazon at least partly due to illegal farming and ranching, as high prices for cattle, soybeans, and corn led farmers and ranchers to plant more crops and raise more animals.[130,131] Because of this rapid deforestation, in late January 2008, Brazilian President Luiz Inácio Lula da Silva convened an emergency meeting of cabinet ministers to call for increased monitoring of the most affected regions.[132]

Other important ecosystems are jeopardized by soy production, while about 97% of global soymeal goes to farm animals.[133] According to the World Wildlife Fund (WWF), half of Brazil's soy production occurs in the Cerrado region.[134] The world's most biologically diverse savannah, the Cerrado is the size of Alaska and the second-largest major biome in Brazil.[135,136] Nevertheless, it is among the country's least protected ecosystems.[137] According to WWF, the region's animal species "are competing with the rapid expansion of Brazil's agricultural frontier, which focuses primarily on soy and corn. Ranching is another major threat to the region, as it produces almost 40 million cattle a year."[138]The Cerrado's traditional land use of extensive cattle ranching on natural pastures maintained most of the region's natural vegetation; however, changes in government policies, including credit subsidies for technological advances, have made soybean farming more profitable than extensive cattle ranching. Although the Cerrado's natural vegetation typically stores less carbon per hectare than a rainforest, land use conversion still results in biodiversity losses, increased soil erosion, and substantial carbon emissions.[139]

To address emissions from deforestation, the international environmental organization Greenpeace reportedly worked with the McDonald's Corporation to pressure the largest soy traders in Brazil to observe a two-year moratorium on the purchase of any soy from newly deforested areas.[140] Cargill, the multinational company that was supplying McDonald's with Brazilian soy to be used as chicken feed, assisted in persuading fellow soy traders to agree to the moratorium. As one Cargill official reportedly noted, "The moratorium will give everyone time to plan how to better control the farming and protect the forest." [141] But this is a small dent in a much larger problem. According to Greenpeace, in 2008, two years after the McDonald's campaign began, 75% of Brazil's GHG emissions were still coming from deforestation and land-use changes; unsustainable expansions of crops like soy, as well as cattle ranching, were at the heart of these emissions, making Brazil the fourth largest climate polluter in the world if including land-use change emissions.[142,143]

Like forests, soils can serve as carbon sinks. In fact, the estimated total amount of carbon currently stored in soils is 1,100-1,600 billion tonnes—more than twice the carbon in vegetation or in the atmosphere.[144] Human disturbances (primarily agriculture), however, have significantly depleted the amount of carbon sequestered in the soil. The FAO reports that the Scientific Committee on Problems of the Environment (SCOPE), an interdisciplinary group of natural and social scientists, estimates that 50% of carbon in soils on the North American Great Plains has been lost over the last century due to burning, erosion, harvesting, grazing, or by vaporizing into the air.[145] The FAO estimates that animal agriculture-related releases from cultivated soils worldwide may total 28 million tonnes of CO_2 annually.[146]

In particular, conventional tillage practices (scraping the soil with machinery) both lower the organic carbon content of the soil and produce significant CO_2 emissions. The FAO estimates that 18 million tonnes of CO_2 are emitted annually from cultivating corn, soybean, and wheat on approximately 1.8 million km^2 of arable land to feed animals raised for meat, eggs, and milk.[147]

The animal agriculture sector can also play a significant role in desertification due to overgrazing and trampling of rangelands by farm animals.[148] Desertification tends to reduce the productivity and amount of vegetative cover, which then allows CO_2 to escape. The FAO estimates that animal agriculture-induced desertification of pastures may release up to 100 million tonnes of CO_2 per year.[149]

Converting forests to grazing area does not just lead to increased CO_2 emissions. Land use changes for animal agriculture also greatly reduce methane oxidation by soil micro-organisms such that methane is released into the atmosphere rather than being utilized. Grazing lands can even become net sources of methane when soil compaction from animal traffic limits the diffusion of gas.[150]It should be noted, however, that in certain grasslands, animal traffic may limit the release of natural nitrous oxide emissions.[151] Detailed accounting of nitrous oxide and methane emissions from the farm animal sector follows.

Artificial Fertilizer and Manure: Nitrous Oxide Emissions

Nitrous oxide is a GHG of great importance.[152] In addition to its large GWP, N_2O plays a role in depleting the ozone layer. [153] Its concentration in the atmosphere has grown approximately 16% since 1750,[154] and the molecule persists in the atmosphere for 114 years.[155]

Animal agriculture accounts for 65% of global anthropogenic N_2O emissions.[156] Approximately 9% of those emissions result from applying artificial fertilizer to feed crops.[157] As discussed above, synthetic fertilizer is used to produce high-energy, concentrate animal feed, such as corn.[158]

Farm animal manure also produces nitrous oxide, accounting for nearly 82% of nitrous oxide emissions from farm animals globally.[159] Animal manure accounts for 6% of U.S. agricultural nitrous oxide emissions.[160]

In the United States alone, cattle, pigs, chickens, turkeys, and other animals raised on factory farms generate approximately 455 million tonnes of manure.[161]When used to fertilize crops, manure enriches the soil and is a key input to healthy, sustainable farms and landscapes. The quantities of manure produced on factory farms, however, exceed the amount of land available to absorb it, transforming manure from a valuable agricultural resource into hazardous waste that threatens soil, water, and air quality.[162]

For more information on the environmental and health impacts of factory farm manure and nitrogen fertilizer, please see, "An HSUS Report: The Impact of Industrialized Animal Agriculture on the Environment."

Ruminant Digestion and Manure Management: Methane

Methane has at least 25 times the GWP of carbon dioxide,[163] and its concentrations increased by approximately 150% between1750 and 2005; in 2005 the atmospheric concentration of methane was about 1775 parts per billion, or much higher than the highest levels measured for the last 650,000 years.[164] Globally, farm animals are one of the most significant sources of anthropogenic methane, responsible for 35-40% of methane emissions worldwide.[*] [165,166]

Ruminants, such as cattle, sheep, and goats, usually have a stomach divided into four chambers[167] and emit methane during digestion,[168] which involves microbial (enteric) fermentation of fibrous feeds and grains.[169] An adult cow emits 80-110 kg of methane annually.[170] Approximately 86 million tonnes of methane are released globally each year from enteric fermentation alone.[171]

Emissions from enteric fermentation vary by country but are significant. In Africa, methane emissions from enteric fermentation rose from 190 Teragrams (Tg)[*] CO_2-equivalent per year in 1990 to 222 Tg CO_2-equivalent per year in 2000 "because of a 17% increase in the ruminant population."[172] In the U.S., enteric fermentation is responsible for about 25% of anthropogenic methane emissions.[173] In 2004, estimates for methane emissions

[*] There are also natural sources of methane, including wetlands, non-wetland soils, termites, oceans, and freshwater bodies. (U.S. Environmental Protection Agency. 2006. Where does methane come from? http://www.epa.gov/methane/sources.html. Accessed April 23, 2008.) .
[*] One teragram equals one million tonnes.

from enteric fermentation totaled 21.17 million tonnes in Central and South America, roughly 12 million tonnes in India, and nearly 9 million tonnes in China. The rest of Asia was responsible for just over 8 million tonnes.[174]

Methane is also emitted from manure. The FAO shows that pig production contributes the largest share of emissions from manure, followed by dairy operations. Methane emissions from pig manure represent nearly half of total global farm animal manure emissions. China has the largest country-level methane emissions in the world with 3.84 million tonnes; Western Europe produces 4.08 million tonnes, North America 3.39 million tonnes, and Central and South America 1.41 million tonnes. [175] In the US, manure management contributes about 8% of anthropogenic methane emissions.[176] Globally, methane released from animal manure totals nearly 18 million tonnes annually.[177]

Between 1990 and 2008, methane emissions from manure management in the U.S. rose 54%, mostly due to 50% and 91% rises, respectively, from pig and dairy cow manure—an elevation that the nation's EPA attributes, at least in part, to the shift towards rearing pigs and cows in larger facilities that use liquid manure management systems, which have more potential for methane emissions than dry manure management systems.[178]

Under anaerobic conditions, methane and nitrous oxide are released when bacteria digest animal waste. Most of this methane comes from large, open-air lagoon or holding tank systems where farm animal waste is stored under anaerobic conditions, and which were developed in the 1960s to manage waste.[179] As industrial methods of pig and dairy production become the standard worldwide, methane emissions from manure lagoons are likely to increase.

Manure that is not stored or managed in lagoon systems, but utilized in a dry form such as in stacks or drylots for fertilizer on fields, does not produce significant amounts of methane.[180, 181] Storage of manure under anaerobic conditions—like those present in lagoons—will produce large amounts of methane but suppress nitrous oxide emissions. In contrast, composting and piled storage of manure will promote aerobic decomposition, increasing nitrous oxide emissions while suppressing methane emissions.[182]

Mitigating the Animal Agriculture Sector's Role in Climate Change

Direct and immediate actions are required to mitigate and prevent the problems associated with climate change. According to the IPCC, a temperature rise exceeding about 3.5°C (6.3°F) could result in the extinction of 40-70% of the world's assessed species.[183] Such a rise in temperatures and their devastating impacts are inevitable, however, if we continue "business as usual."[184] Producers, consumers, and policy makers throughout the world must examine and respond to the contributions of today's meat, milk, and egg production to GHG emissions and climate change.

Transforming Agriculture: Practices to Reduce Impacts

To date, most mitigation and prevention strategies to reduce GHG emissions from animal agriculture have focused on technical solutions, such as increasing the efficiency of farm animal production and feed crop agriculture. Researchers at several universities are investigating the possibility of reformulating ruminants' diets with new feeds to reduce enteric fermentation and consequent methane emissions.

The amount of methane produced by animals and their manure is largely determined by the animals' feed quality, digestive efficiency, body weight, age, and amount of exercise.[185,186] "In general, lower feed quality and/or higher feed intake leads to higher CH_4 emissions," and different species and management systems have differing feed intakes.[187] Cattle confined in feedlots, for example, fed a very high-energy grain diet produce manure with a "high methane-producing capacity," whereas cattle raised on pasture, who eat a low-energy diet of grasses and other forages, may produce manure with roughly 50% of the methane-producing potential compared with animals raised in feedlots.[188] However, this does not necessarily correlate to greater overall GHG emissions per kilogram of product. For example, one U.S. study found that feedlots resulted in lower

GHG emissions per kilogram of product than that finished by pasture.[189] An Irish study, however, found that cows raised for beef in an extensive system produced less GHGs per cow and per kilogram of live weight.[190] As discussed in more detail later, there is not yet a clear answer for what system results in the least overall GHGs per kilogram of product.

Increasing the digestibility of pasture for grazing ruminants may be an expedient way of reducing methane emissions from enteric fermentation, but this measure must also be accompanied by a reduction in animal numbers.[191, 192] The European Environment Agency has echoed this sentiment, stating that the "main driving force of CH_4 emissions from enteric fermentation is the number of cattle."[193]

Another proposed feed-related remedy is a fist-sized, plant-based pill that, along with a special diet and strict feeding times, is intended to reduce the methane produced by cattle.[194] Winfried Drochner, the lead researcher on this supplement, believes that by reducing excessive fermentation and regulating the metabolic activity of rumen bacteria, beef and dairy producers can reduce the amount of methane emissions from both the cattle themselves and their manure.[195]

Feed composition is not the only husbandry practice being examined within the climate change context. One suggested mitigation strategy to control GHG emissions from beef production is to shorten intervals between calving by one month. While this may result in less animal waste and less required feed, as cows would birth the same number of calves in a shorter amount of time and be culled at an earlier age,[196] it would likely impose additional physical stress on the animals and impair their welfare.

Another technical mitigation strategy reportedly being adopted by some large-scale producers is the use of anaerobic digesters to isolate the methane from farm animal manure and use it to power generators on-site or sell the energy to local electric companies.[197]

The U.S. EPA estimates that anaerobic digestion systems are feasible at approximately 7,000 pig and dairy operations in the United States and, through the AgStar program and the Methane to Markets Partnership, provides technical assistance and financial incentives to encourage the use of these systems both domestically and globally.[198,199]

According to the U.S. EPA, existing systems provide enough renewable energy to power more than 20,000 average U.S. homes and have reduced annual methane emissions by about 1.5 million tonnes of CO_2-equivalent.[200] In 2007, the USDA agreed to contribute $1.5 million USD towards manure digester projects at three operations in Ohio, which respectively confine 580,000 chickens, 10,000 beef cattle, and 3,800 dairy cows.[201] Projects in development in Southeast Asia, aided by the World Bank and U.S. EPA, are estimated to prevent annual emissions of 4,536 tonnes of CO_2-equivalent per 20,000 pigs.[202]

Despite their benefits for mitigating GHG emissions, this technology is more likely to benefit larger operations than smaller-scale farms. According to *EnergyBiz Insider*, "Typically, a minimum herd of 300 dairy cows or 2,000 swine is needed to make such a system feasible."[203] A representative of Microgy, a now bankrupt New Hampshire-based company that operated renewable gas facilities using anaerobic digestion of animal and food industry waste,[204] reportedly echoes the benefits this technology offers to large-scale producers: "[T]he market is really unlimited. It's only limited by how many cows and hogs you have in feedlots."[205] Incentivizing more large-scale, industrial production by subsidizing anaerobic digesters also carries with it the threat of growing the farm animal population at a rate by which emissions would be greater than without subsidized anaerobic digester projects.

Smithfield Foods, the world's largest pork producer,[206] had reportedly invested more resources in biogas collection to meet its CCX goals. At its Tar Heel pig slaughtering plant in North Carolina, for example, Smithfield is using methane generated by its wastewater treatment system as boiler fuel. In Michigan, the company is burning methane from a 10 million-gallon anaerobic manure lagoon in place of using natural gas energy. Two of the company's other facilities are also making biofuels out of animal fats and oils.[207]

One Swedish company, Svenska Biogas, is going one step further than manure digesters and extracting residual methane from slaughter plant waste such as cows' stomachs, intestines, udders, livers, kidneys, and blood. Depending on the size of the animal, the company can extract 80-100 kg of methane. Annually, the company is making use of 54,000 tonnes of this waste from cows, pigs, and chickens.[208]

Other agricultural companies are focusing on similar efforts. Seaboard Foods, the second largest U.S. hog producer,[209] has a long list of environmental initiatives that mainly focus on animal waste treatments but they do not seem to be systemized across all of their production farms. These efforts include things such as using animal fats to create biodiesel, for which they have even created a corporate subsidiary, High Plains Bioenergy, to manage these efforts.[210] They also have a seven-stage microbial treatment for animal wastes on at least one farm accompanied by planted vegetation around all waste lagoons to improve soil quality.[211] Tyson Foods has teamed up with oil giant ConocoPhillips and Syntroleum, a fuel technology company, to create renewable diesel using fats from beef, pork, and poultry byproducts. Production is expected to yield as much as 662-946 million liters per year.[212,213] The companies claim their renewable diesel meets all federal standards for ultra-low-sulfur diesel.[214] Tyson Foods has aligned themselves with the principles of ISO 14001, the U.S. EPA Climate Leaders program, and have even begun using a carbon footprint inventory among other initiatives. They have also set several environmental goals including water conservation, waste reduction, increased recycling, and decreasing packaging of their products.[215]

Some researchers have noted the ostensible resource efficiency of monogastric farm animals like chickens, who require less feed, which correlates with lower water, and land use for feed.[216] Nonetheless their production still has significant environmental impacts, including methane and nitrous oxide emissions from their manure[217] and carbon dioxide emissions from the transport of pig and poulty products.[218]

Developing feedlot rations to reduce emissions from enteric fermentation, using animal waste and carcasses to generate fuel, or selectively purchasing feed crops from less devastated forested regions may be innovative ways of reducing GHG emissions; however, these strategies do little to address the other environmental problems inherent in industrialized meat, egg, and milk production, and may serve to increase the global farm animal population and further intensify farming practices, thereby exacerbating the myriad social, environmental, and animal welfare problems associated with industrial farm animal production.

Transforming Agriculture: Extensive and Organic Practices

When evaluated purely from a climate change perspective, organic and extensive production systems may be more efficient than other systems under some circumstances. Organic agriculture has the potential to sequester carbon and mitigate emissions, according to the International Federation of Organic Agriculture Movements (IFOAM).[219,220] But there are numerous and conflicting studies on this issue for beef and dairy production.

Multiple studies show organic dairy production is comparable to conventional production in terms of GHG emissions. Three European[221,222,223] studies all show similar total GHG emissions from varying production systems, including organic, extensive, and conventional. A 2010 study modeled emissions from organic and conventional farms for four different geographical locations in Austria and found that organic systems emitted, on average, 11% fewer GHGs per kilogram of milk than conventional systems.[224] Since some of the systems used soybean meal from South America, this study took land-use change emissions into account. However, it did not evaluate deforestation emissions, which may make organic systems even more efficient relative to the conventional systems.[225,226]

Studies on organic or extensive beef production also show varying results. Some studies indicate the potential for organic or extensive production to be as GHG-efficient as conventional production. An early study comparing the U.S. intensive feedlot system to an African pastoral system showed that the pastoral system had lower emissions per kilogram of product. When accounting for forgone carbon sinks, this difference was even greater.[227] A study of two German farms with integrated crop production showed that the organic system had lower emissions over a given area, but emissions from organic production were found to be "probably higher" per kilogram of product.[228] This study used a relatively low, German-specific emission factor for methane from the slurry manure system in the non-organic farm (15% vs. the suggested IPCC factor of 35% at that time),[229] which, while possibly appropriate given the location, may have influenced results against the organic farm. The German study stands in contrast to an Irish study that showed lower emissions per unit product in organic production.[230]

An Australian study published in 2010, which does not appear to account for carbon sequestration potential, found varying results both between its study locations and when comparing its results to other studies. For example, emissions from beef varied by year and system. A table attempting to compare the results to other studies showed widely varying results around the world, with the African pastoral system, from the study mentioned above, emitting the lowest amount of GHGs from beef production.[231] A comparison of various life cycle assessments, however, is problematic.[232]

A 2010 life cycle assessment of beef production in the Upper Midwestern U.S. found feedlot-finished beef to be more GHG efficient per live-weight kilogram than grass-finished beef.[233] However, this result can change based on the assumptions, and clearly more research is needed. For example, if taking into account certain carbon sequestration rates "for improved pastures" and "pastures recently converted to management-intensive grazing," the results reverse. In that case, "grass-finished beef would be 15% less greenhouse gas intensive than feedlot-finished beef []."[234] Further, this study noted that for all beef production systems the gross chemical energy return on investment, i.e. how efficient it is to raise cows for beef, was 2% or less.[235] In other words, as the authors note: "none of the systems analyzed can be described as ecologically efficient relative to most other food production strategies."[236]

While GHG emissions are a key environmental consideration when evaluating different production systems, other environmental factors also need to be taken into account. Organic agriculture, for example, has greater potential to foster biodiversity than conventional agricultural systems, which rely on more external inputs. Organically managed agricultural land tends to be more bio-diverse, supporting a range of grasses and species, including songbirds, earthworms, and soil microorganisms.[237]

It is also important to note that a higher level of animal welfare is associated with organic production.[238,239,240] One dairy life cycle assessment took this directly into account and found that the organic system was preferable both to a conventional and extensive system from an animal welfare perspective.[241] The 2010 Austrian study mentioned above states that "[o]verall, pasture-based systems can be considered not only as animal friendly but also as favorable from the point of view of GHGE, as they are emitting less GHG than any other housing systems."[242]

Transforming Agriculture: Carbon Offsets and Exchanges

At least two major animal agribusiness corporations hoped to offset their GHG emissions by joining the Chicago Climate Exchange (CCX). The Exchange was the world's first and North America's only voluntary, legally binding GHG emissions registry, reduction, and trading program. Smithfield Foods, the world's largest pig producer, and agribusiness giant Cargill both joined the Exchange in 2007.[243,244] In Smithfield's 2009/2010 Annual Report, they announced a 4% decline in overall GHG emissions for 2007 to 2009.[245] Cargill boasted a 7.8% reduction in GHG emissions for 2008, their latest verified reporting year.[246] Cargill has also set a goal to improve their GHG intensity by 5% by 2015.[247] As part of the CCX, Smithfield had the opportunity to purchase carbon credits through the CCX Carbon Financial Instrument to meet their target.[248] However, Smithfield, Cargill and other corporations will now have to set and meet their targets without the help of the Chicago Climate Exchange. The member's commitments expired in 2010 and the program was shut down.[249]

Like carbon trading programs, carbon offsets allow companies and other emitters to compensate for their own emissions by investing in measures to reduce emissions elsewhere or to engage in other, unrelated actions to prevent, sequester, or displace CO_2 emissions.[250,251] Criticisms of offset programs abound, chief among them being the idea that, in some instances, they may only be symbolic, rewarding emitters for measures that would have been taken despite participation in an offset program.[252,253]

Established within the Kyoto Protocol, the Clean Development Mechanism (CDM) is a funding mechanism financed by the international community designed to subsidize offsets and ensure that projects (1) actually reduce emissions and (2) are "additional" activities that would not have otherwise been undertaken.[254] For example, a power plant in a developed country that finds it difficult to reduce its own emissions can buy credits to support new emissions-reducing projects in a developing country like India.

Under the CDM, such projects can earn certified emissions reduction (CER) credits which "can be traded and sold, and used by industrialized countries to a meet a part of their emission reduction targets under the Kyoto Protocol."[255] The signatories to the Kyoto Protocol run the CDM through the CDM Executive Board, which oversees these projects.[256] One such project was registered in 2006 by V.P. Farms in Thailand, a swine production farm.[257] Although this project is considered small-scale by CDM standards, V.P. Farms plans to use the manure of 88,000 pigs.[258]

Industrial animal agribusiness corporations in several developing countries have already initiated projects under the CDM. For example, one proposed CDM project was for a confined pig production operation in Brazil to install anaerobic digesters which could be used to generate electricity from methane.[259] However, the animals in industrial animal production facilities, whether they install digesters or not, produce large amounts of manure and other wastes that have deleterious environmental impacts other than GHG emissions.[260,261] Furthermore, in Brazil and other parts of South America, tropical rainforest and grasslands are being destroyed by ranching and the construction of slaughter plants,[262] and for soy production for farmed animal feed.[263,264]

Transforming Agriculture: Making Climate-Friendly Food Choices

As consumers become increasingly concerned about climate change and global warming, they are choosing more environmentally friendly products, such as energy-efficient appliances, compact fluorescent light bulbs, solar panels, and hybrid vehicles. While these are all important measures toward increasing energy efficiency and curbing GHG emissions, replacing and reducing animal product consumption are also very effective strategies for mitigating the impacts of climate change.

Replacing meat, eggs, and dairy products with plant-based foods—even by simply incorporating more animal-free foods into one's diet—is also an effective strategy to reduce GHG emissions from animal agriculture and to reduce its other harmful impacts. Numerous studies support this conclusion globally. One study shows that, in the U.S., choosing vegetable-based meals over red meat and dairy one day a week is equivalent to driving 1860 kilometers, or 1160 miles, less per year. The reduction improves to the equivalent of an impressive 13,000 kilometers, or 8,100 miles, for a complete shift to a vegetable-based diet.[265] A 2010 study in *Agriculture, Ecosystems, and Environment* found that the production, processing, transport and preparation of an Indian, non-vegetarian meal including mutton collectively emitted 1.8 times the GHGs as that of a vegetarian meal without dairy products.[266]

The benefits of choosing more animal-free foods does not end with the climate. A 2007 article in the *European Journal of Clinical Nutrition* notes that "vegetarian and vegan diets could play an important role in preserving environmental resources and in reducing hunger and malnutrition in poorer nations."[267] Similarly, a 2007 position paper by the American Dietetic Association states that dieticians "can encourage eating that is both healthful and conserving of soil, water, and energy by emphasizing plant sources of protein and foods that have been produced with fewer agricultural inputs."[268]

Numerous environmental and non-profit organizations echo this call. The Organic Consumers Association encourages consumers to seek out locally produced, seasonal organic foods, as well as vegetarian fare to combat climate change.[269] The Natural Resources Defense Council has released an Eat Green guide that encourages people to choose "more fruits, vegetables, and grains" and to limit red meat consumption.[270] Environmental

Defense devotes one page on its website to tips for "Fighting Global Warming with Food," primarily addressing the benefits of reducing meat consumption.[271] Greenpeace's online "Green Living Guide" includes a piece about the environmental impacts of meat production and suggests consumers "go vegetarian or simply cut down on the amount of animal products you consume."[272]

Reducing consumption of meat, eggs, and dairy products is critical to control GHG emissions from animal agriculture and to mitigate its other harmful impacts, especially as we move to the future. In January 2008, IPCC Chair Rajendra Pachauri reportedly urged consumers to eat less meat to fight global warming, one among a few lifestyle changes he said the IPCC was "afraid" to advocate earlier.[273] As researchers wrote in the *American Journal of Clinical Nutrition* in 2003, "skepticism has been directed at supporting the increased demand for animal products in the diet of the economically advantaged persons of the world," noting "a direct link between dietary preference, agricultural production, and environmental degradation."[274] Human health, in addition to environmental health, also benefits from eating fewer animal products. An article published by *The Lancet* in September 2007 advocates a reduction in meat consumption to 90 g per person per day (roughly the equivalent of a single beef hamburger patty), both to reduce GHG emissions and to promote better human health. According to the authors, "the unprecedented serious challenge posed by climate change necessitates radical responses…For the world's higher-income populations, greenhouse-gas emissions from meat-eating warrant the same scrutiny as do those from driving and flying."[275] Finally, a 2010 study in the *Proceedings of the National Academy of Sciences* projected a 39% rise in emissions from animal agriculture by 2050.[276] Individuals can help mitigate this increase by choosing more plant-based foods.

Accountability of Policy Makers

Governments and international policy makers must better regulate the GHG emissions from industrialized animal operations. The U.S. Supreme Court declared in April 2007 that the nation's EPA has the authority to regulate carbon dioxide and other heat-trapping emissions from vehicles as pollutants.[277,278] The same regulations should be in place for other sectors—including animal agriculture—that emit GHGs into the atmosphere. Such policies will require greater and better monitoring of large animal-feeding operations, as well as moratoriums on the construction of new industrial farm animal production facilities.

One important policy option is to accurately price environmental services, such as a stable climate and clean air. "Most frequently natural resources are free or underpriced, which leads to overexploitation and pollution," write animal agriculture experts at the FAO, concluding that "[a] top priority is to achieve prices and fees that reflect the full economic and environmental costs, including all externalities."[279]

The authors of the FAO's "Livestock's Long Shadow" call attention to the need to establish accurate pricing within the animal agriculture sector "by selective taxing of and/or fees for resource use, inputs and wastes."[280] Such a system could reward farmers for environmental services, such as protecting forests and biodiversity, so that logging to make land available for grazing cattle or cultivating feed crops is not the only viable financial option for ecologically fragile regions. As it stands now, the prices of inputs for raising livestock are relatively low, resulting in inefficiencies and overuse. The FAO argues for adequate pricing of resources like water to correct the distortion.[281] Policy options for correcting the externalities include compensating producers who benefit the environment and taxing those who do not.[282]

Consider the following example from Costa Rica: According to a 2004 study published in the *Proceedings of the National Academy of Sciences*, pollination services provided by native bees inhabiting the forest near a coffee plantation total $62,000 USD. In other words, the bees from a nearby forest provide a valuable economic resource that, until now, had not been quantified. The researchers found that if the forest were used for other purposes, the value would be much less. For example, if farmers chose to cut down the trees to raise cattle, the total value of that land would be $24,000 USD, two-thirds less than what the forest-dwelling bees provide.[283]

One form of regulation comes in the form of international agreements. The Kyoto Protocol, an amendment to the UN Framework Convention on Climate Change (UNFCCC), was established in 1997 and came into force in

2005. The Protocol's principal component is the establishment of mandatory targets on GHG emissions.[284] It also includes market-based mechanisms, such as the CDM, to help countries meet their GHG emissions reduction targets.[285]

The Kyoto Protocol is set to expire in 2012.[286] In December 2007, negotiators met in Bali, Indonesia, to begin making preparations for a post-Kyoto world.[287] The Bali Action Plan, or Bali Roadmap, calls for a number of actions to curb climate change.[288]

In addition to observing and furthering the goals of international agreements, individual nations can begin developing their own national and regional policies for emissions reductions that also honor other social goals such as animal welfare.

Conclusion

Mitigating the animal agriculture sector's significant yet under-appreciated role in climate change is vital for the health and sustainability of the planet, the environment, and its human and nonhuman inhabitants. Reducing GHG emissions, especially from animal agriculture, is both urgent and critical. "[B]y far the single largest anthropogenic user of land" and responsible for 18% of human-induced GHG emissions,[289] the farm animal production sector must be held accountable for its role in the climate crisis. More innovative approaches in animal agricultural practices and management must be actualized by raising awareness and providing price incentives for farmers and consumers to embrace more sustainable food systems. Individually, incorporating environmentally sound and animal welfare-friendly practices into daily life, including adopting consumptive habits less reliant on meat, eggs, and dairy products, can significantly slow the effects of climate change.

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