CORNELL
AGRICULTURAL ECONOMICS
STAFF PAPER

Biological Emissions and North-South Politics

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Jan. 1991

91-1

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Abstract

Emissions of methane from bovine animals have been estimated elsewhere at approximately 60 million tons per year, 15% of global methane releases. This estimate is misleading for two reasons: it ignores the differences in atmospheric residence time between carbon dioxide and methane, and it overlooks the biological and chemical cycling that occurs. The result is an overemphasis of the role of this methane as a greenhouse gas. This is demonstrated by showing the carbon withdrawal and emission cycle for a representation of the one billion global livestock animals. In terms of cost effectiveness, this method shows energy efficiency and fossil fuel switching to be more efficient policies than biological methane reduction. Finally, implications for negotiations of climate change accords are discussed.

I. Introduction

The Montreal Protocol was the first substantive international agreement to reduce future emissions of a potent family of greenhouse gases, the chlorofluorocarbons.[1] Initiatives are currently underway to forge agreements on other greenhouse gases. Negotiating strategies range from drafting agreements on single gases, such as carbon dioxide (CO_2), to forging comprehensive agreements which establish composite allowable emission levels for several or all known greenhouse gases.

Historically, attention focussed on CO_2 as the primary greenhouse gas. More recently, concern shifted to the other gases, such as methane (CH_4), nitrous oxides, chlorofluorocarbons, and tropospheric ozone.[2] One reason for this increased interest is their comparative growth rates: while CO_2 concentrations increased by 4.6% from 1975 to 1985, concentrations of methane increased by 11.0% and concentrations of several of the chlorofluorocarbons more than doubled.[3] This is of further concern since many of these gases are more effective than CO_2 on a per molecule basis at trapping infrared radiation. As a result, Ramanathan reports that the non-CO_2 gases contributed approximately 50% to the warming effect for the period 1975-1985.[4]

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[1]The Montreal Protocol's primary purpose is to eliminate chemicals which break down stratospheric ozone, resulting in increased ultraviolet radiation reaching the earth's surface.

[2]In the lower atmosphere, the troposphere, ozone acts as a greenhouse gas, trapping infrared radiation. In the upper atmosphere, the stratosphere, ozone screens out harmful ultraviolet radiation.

[3]V. Ramanathan, "The Greenhouse Theory of Climate Change: A Test by an Inadvertent Global Experiment", Science, Vol. 240, April 15, 188, pp. 293-299.

[4]Ramanathan, p.296

Partially as a result of the widespread recognition of these other gases, there has been increased interest in comprehensive agreements. Theoretically, the way such an agreement might work would be to establish an index to weight the global warming potential of each greenhouse gas, similar to the ozone-depleting potential index contained in the Montreal Protocol.[5] One possible weighting scheme, suggested by the U.S. Department of State[6], would assign each unit (such as each molecule) of CO_2 a rating of 1, each unit of methane (CH_4) a rating of 25, and each unit of CFC-12 a rating of 20,000. A reduction goal would then be established giving each country broad latitude as how best to meet the target given its particular needs and cultural values. Consider one view of how this approach might work:

> "Some nations might be able to reduce CO_2 emissions below their limit, such as through substitution of non-fossil fuels, but be unable to reduce CH_4 output (e.g., a nation importing oil and dependent on rice crops, but endowed with untapped solar power opportunities). Those nations would meet their net limits by reducing CO_2 more rapidly than CH_4; requiring them to limit each gas by the same amount would prove much more costly (perhaps in terms of lower economic growth, higher taxes, or reduced rice production) and would leave additional affordable CO_2 reductions unexploited. Other nations might find themselves in the opposite situation, able to afford to limit CH_4 more than CO_2 (e.g., a nation dependent on coal reserves) but able to modify the diet of its ruminant animal husbandry."[7]

Through a discussion of the sources of methane, and in particular the emissions from bovine animals, this paper demonstrates potential problems with implementation of the State Department proposal. Four central questions arise.

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[5]Montreal Protocol, Annex A: Controlled Substances.

[6]U.S. Department of State, "Materials for the Informal Seminar on U.S. Experience with 'Comprehensive' and 'Emissions Trading' Approaches to Environmental Policy", Washington, D.C., February 3, 1990.

[7]Dept. of State, pp. 15-16.

The first question concerns the difference between the instantaneous radiative effect used by Ramanathan and the total long term effect. A molecule of CH_4 has an instantaneous effect 25 times greater than a molecule of CO_2, but also has a much shorter atmospheric lifetime, decaying to CO_2 in 10-14 years. Does ignoring this fact overemphasize the importance of methane as a greenhouse gas?

The second question concerns the importance of the origin of the different gases. Is methane released from a cow really the same as methane released from the mining and transmission of natural gas? In the latter case, new carbon is being added to the atmosphere, whereas methane from bovine animals includes carbon that was once in the atmosphere.

Third, what is it likely to cost to reduce emissions of CO_2 compared to CH_4? Comparatively little is known to date about the costs of reducing methane emissions from bovine animals. Recent estimates are presented which raise the question of whether CH_4 emission reductions would make economic sense.

Finally arises a question touching on North-South politics. An international agreement which focusses on reductions in CO_2 emissions would put the largest burden of responsibility on industrialized countries, who to date have been responsible for a large percentage of the increased atmospheric CO_2. However, by including other gases, such as methane, then the emissions of methane from the animal population and rice paddies of developing countries become much more important.[8] Is this what the U.S. and other industrialized countries are really pursuing by pushing for a comprehensive agreement?

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[8]It is, of course, true that an agreement regulating carbon dioxide alone would effect the future growth rates of energy usage in developing countries. However, an agreement on methane would have to impact current agricultural practices in these same countries.

II. Sources of Methane

Reaching agreement on meaningful reduction strategies for any greenhouse gas requires a thorough understanding of the sources and sinks for that gas. Consider the sources of methane, Table 1. The largest source is natural wetlands and bogs where methane is continuously formed through anaerobic decomposition of organic matter. Other sources include: rice paddies; enteric fermentation (the intestinal fermentation which occurs in animals such as cows); biomass burning; coal mining; the drilling, venting, and transmission of natural gas; and termites. Few, if any, of these sources, seem susceptible now to accurate data estimates of emissions, effective regulation, or monitoring of plans for emissions reductions. However, the State Department targets both rice production and ruminant animals as possible methane reduction sources in its proposal.[9]

Cows, actually bovine animals in general, are a source of methane emissions that is poorly understood. While estimates of the magnitude of this source exist, it is not a precise number, and certainly not uniform among bovine animals, but depends on such factors as temperature, and feed quality and quantity.[10] One would have to question how an agreement to limit this source would be monitored.

The next section clarifies the process of methane production among ruminants and attempts to reconcile estimates by various authors in terms of quantities of methane produced.

II.a. Ruminant Production of Methane

The process begins with the ingestion of plant material.

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[9]Dept. of State.

[10]A recent article in the New York Times typifies the increased focus on methane from bovine animals. The article cites "bovine flatulence" as a significant source of methane, accounting for "...up to 400 liters of methane [per animal] per day." See M. O'Neill, "Cows in Trouble: An Icon of the Good Life Ends Up on a Crowded Planet's Hit Lists", New York Times, Sunday, May 6, 1990, Section 4, p.1.

Table 1: Sources of Methane. Annual emissions of methane into the atmosphere, in millions of tons.

Source	**Quantity**	**% of Total**
Natural Wetlands (includes bogs, swamps, tundras)	126.5	21.3
Rice Paddies	121.0	20.3
Enteric Fermentation (ruminant animals)	60.5	14.8
Biomass Burning (includes fuel wood, agricultural burning, forest fires)	60.5	10.2
Gas Drilling, Venting, Transmission	49.5	8.3
Termites	44.0	7.4
Landfills	44.0	7.4
Coal Mining	38.5	6.5
Oceans	11.0	2.1
Fresh Waters	5.5	1.1
TOTAL	**594.0**	**99.4**

Source: Cicerone and Oremland. "Biogeochemical Aspects of Atmospheric Methane." 1988

The stomach, referred to as the rumen, rather than relying on enzymes to break down the plant material, relies on microorganisms which ferment the material, resulting in volatile fatty acids, methane, and CO_2.[11] The gases are removed by belching (not through flatulence, as commonly thought), with a gas composition of approximately 27% CH_4, 65% CO_2, and traces of

[11]M. Wolin, "The Rumen Fermentation: A Model for Microbial Interactions in Anaerobic Ecosystems", in Advances in Microbial Ecology, M. Alexander, ed., Vol 3, Plenum Press, New York, 1979, p. 49.

other gases.[12] The basic reactions are:

$$HCO_2OH \longrightarrow CO_2 + H_2$$

$$4H_2 + CO_2 \longrightarrow CH_4 + 2H_2O$$

There are two widely quoted sources on methane quantities produced by ruminants. The two sources are discussed and compared below.

The first, and probably more widely quoted source, is Crutzen, Aselmann, and Seiler[13]. Crutzen, et al, utilize an energetic approach to calculating world-wide methane emissions. They first examine feeding practices in three representative countries, the U.S., Germany (representative of Europe) and India (representative of developing countries). They then take available estimates of energy losses due to methane releases as a function of feed quality and quantity and estimate average emission rates. Table 2 demonstrates their calculations for the U.S. For example, milk cows, which comprise 10% of U.S. cattle, consume an average of 10150 feed units per day. A feed unit is defined as equivalent to the amount of energy contained in 1 lb of corn. The gross energy intake is equivalent to 230 MJ.[14] Of this amount, approximately 5.5%, or 12.65 MJ, of energy is lost by the belching of methane. Assuming that 1 kg of methane is equivalent to 55.65 MJ, this implies an annual emission of 83 kg/animal. For the other two types of bovine animals, feed and range cattle, Crutzen, et al, estimate annual methane releases of 65 and 54 kg respectively. These estimates imply a weighted average of 58 kg of methane per animal per year. Note that this

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[12] T. Miller, "Methanogenic Ecosystems" to be published as "Microbial Production and Consumption of Greenhouse Gases", by American Society for Microbiology, draft, May, 1990, p. 3.

[13] P. Crutzen, I. Aselmann, and W. Seiler, "Methane Production by Domestic Animals, Wild Ruminants, Other Herbivorous Fauna, and Humans", Tellus 38B, 1986, pp. 271-284. This is the source cited by Wuebbles and Edmonds (in Primer on Greenhouse Gases) and Abrahamson (in Challenge of Greenhouse Warming).

[14] 1 megajoule (MJ) = 948 Btu

Table 2: Estimated methane emissions by U.S. cattle				
Type of Cow	**Feed Units**	**Daily Energy Intake (MJ)**	**Methane Yields (%)**	**% of Population (%)**
Milk cows	10150	230	5.5	12.5
Feed cattle	6650	150	6.5	12.5
Range cattle	4800	110	7.5	77.5

number does not include consideration of the methane content of animal feces.

For developing countries, Crutzen, et al, adopt an average feed consumption of 60.3 MJ[15], much lower than even the range cattle in the U.S., and a methane loss of 9% due to the low quality of feed. Based on these numbers, they estimate an annual methane production rate of 35 kg per animal in the developing world.

Using FAO data of world cattle population of 1.2 billion cattle, 53% of which are in developing countries, and 47% in the developed world including Brazil and Argentina, they conclude that the global methane release to the atmosphere from cattle totals 54 Tg annually, or 59.4 million tons[16], 10 percent of all annual emissions of methane.

The other widely cited estimate of ruminant methane emissions is Cicerone and Oremland.[17] However, their source is Meyer Wolin at the New York State Department of Health. Wolin

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[15]Crutzen, p. 274.

[16]Crutzen, p. 274. One Teragram (Tg) = 1.1 million tons.

[17]R.J. Cicerone and R.S. Oremland, "Biogeochemical Aspects of Atmospheric Methane", Global Biogeochemical Cycles, Vol 2, no. 4, December 1988.

estimates that the amount of methane produced per day in a 500 kg cow averages about 200 liters per day.[18] Liters of gas are easily converted to kilograms via:

$$pV = nRT$$

Assuming a pressure of 1 atm[19], and a temperature of 39 degrees Celsius:

$$(1\ \text{atm})(200\ \text{liters}) = (n)(.0821\ \text{liter atm}/^{\circ}\text{K mole})(312^{\circ}\text{K})$$

which, when solved for n, the number of moles of gas, implies that 200 liters of methane contains 7.8 moles of methane. Since one mole of methane contains 16 g of methane, 200 liters reduces to .125 kg/day or 45.6 kg/year.

For a world total, multiplying 45.6 kg/animal/year times 1.2 billion bovine animals, yields 55.9 Tg per year, essentially equal to the Crutzen estimate (54 Tg). Hence it seems that there is fair agreement among these two sources.

An estimate of up to 400 liters per day was referenced in the New York Times.[20] This number is probably the upper limit of what could be released during a 24 hour period. Milk cows in the U.S. come closest; using Crutzen's estimate of 83 kg/yr implies approximately 360 liters per day. Recall, however, that this is but 10% of the U.S. herd size.

III. The Importance of Ruminant Methane in the Global Methane Cycle

The next question is to quantify the effect of methane emissions of this magnitude on climate change. Several recent articles contend that the combined effect of several of the trace gases, CFCs, N_2O, and CH_4 could rival the effect of the most often mentioned greenhouse gas, carbon dioxide. These articles

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[18]Wolin, p. 68.

[19]Terry Miller, Wadworth Center for Laboratories and research, New York State Department of Health, Albany, N.Y., personal communication, June, 27, 1990.

[20]O'Neill, p. 1.

stem from the earlier mentioned Ramanathan numbers. They suggest that methane's role is approximately 18% of the total, Figure 1.[21]

These numbers are misleading for two reasons. First they ignore the differences in atmospheric residence times of the gases and second they ignore the source of the gases, and whether any cycling of gases occurs. These reasons are considered in turn.

IIIa. Consideration of Atmospheric Residence Times

In a recent article in Nature, Lashof and Ahuja,[22] note that most weighting schemes basically ignore the difference in atmospheric residence times for the different gases. They note, for example, that methane, with a residence time of 14.4 years, (versus some 230 years for CO_2) is eventually oxidized to CO_2 and H_2O.[23] Rather than the instantaneous forcing index of 25-44 suggested by others, Lashof and Ahuja suggest an index which weights CH_4 at 3.7 times CO_2 on a molar basis.[24] Lashof and Ahuja conclude that if one uses their proposed index, then "carbon dioxide emissions alone account for 80% of the contribution to global warming of current greenhouse gas emissions"[25], Figure 2. Their analysis suggests that the primary emphasis for greenhouse gas reductions should really remain on CO_2. This conclusion is even more important in light of the recent amendments to the Montreal Protocol which call for a phase out of most chlorofluorocarbons by the year 2000. If one

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[21]Ramanathan.

[22]D. Lashof and D. Ahuja, "Relative Contributions of Greenhouse Gas Emissions to Global Warming", Nature, 344, 5 April 1990, pp. 529-531.

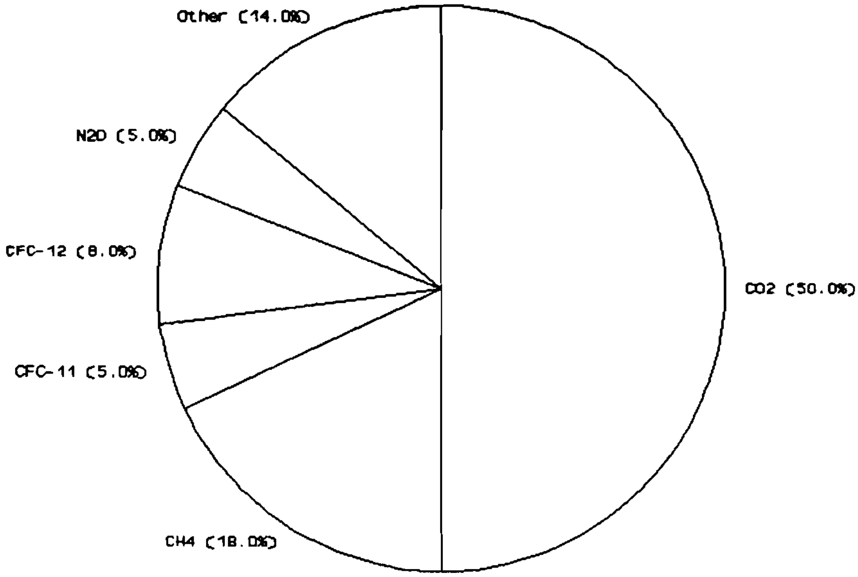
[23]Lashof, p. 530.

[24]Lashof, p. 529.

[25]Lashof and Ahuja's estimate of 80% is for "the total contribution of CO_2, including net CO_2 produced from emissions originating as CO and CH_4." See Lashof, p. 531.

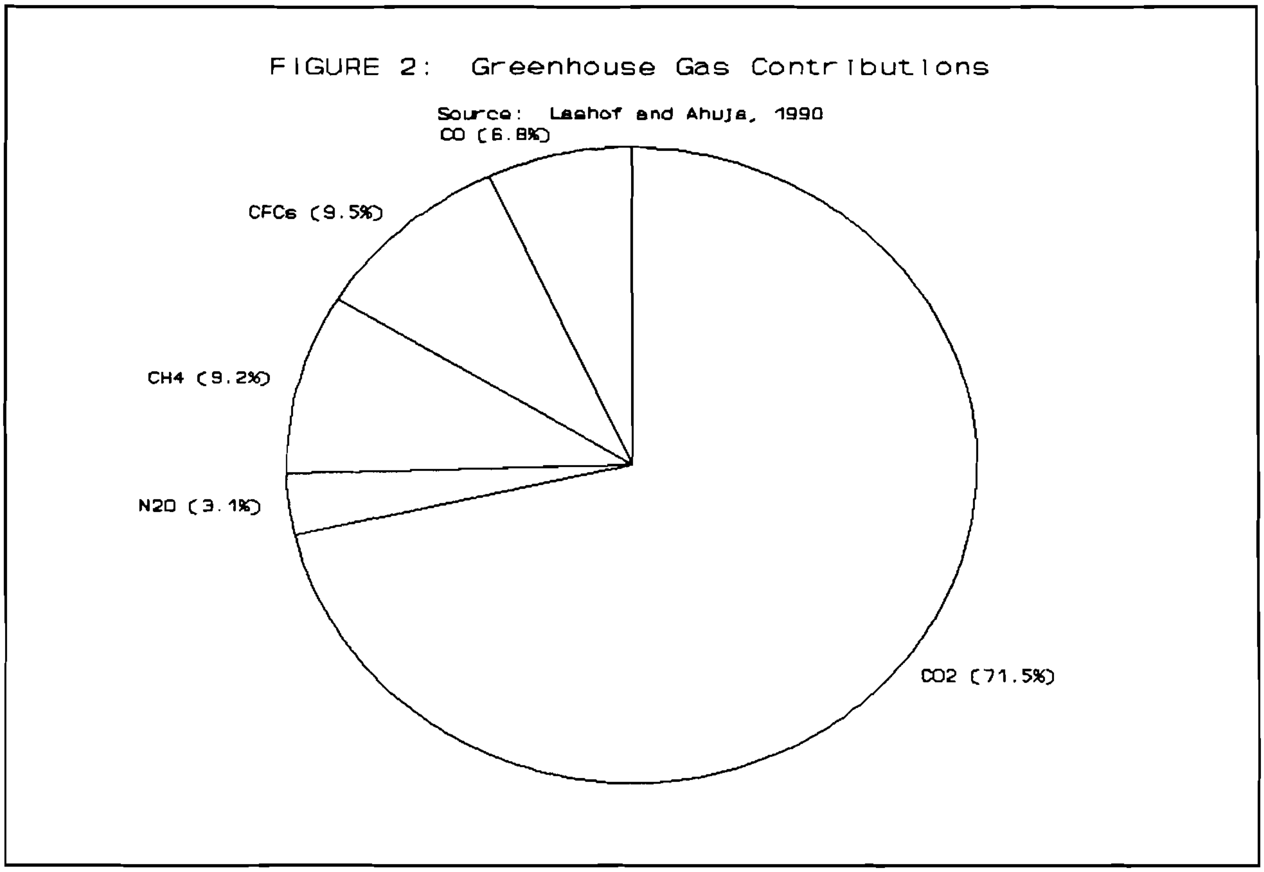
FIGURE 1: Greenhouse Gas Contributions

Source: Ramanthan, 1989



assumes that this phase out will occur, then the total effect attributable to CO_2 approaches 90%.

Consider the following calculation which uses the proposed Lashof and Ahuja criteria to illustrate two greenhouse gas reduction goals. The first is reducing methane production by reducing cattle populations; the second is reducing CO_2 emissions by increased lighting efficiency. One could phrase the question as: how does a cow compare to a light bulb in terms of global warming effect? The answer is that one cow has the same warming effect as a 75 Watt light bulb operating continuously for one



year[26], Figure 3. This suggests that a policy of replacing 75 W incandescent light bulbs in industrialized countries with new 18 W compact fluorescent bulbs would go much further towards reducing future climate change impact than trying to regulate bovine emissions in developing countries.

III.b. Consideration of the Carbon Cycle

A second commonly overlooked fact is the source of the methane. Is this methane released from bovine animals equivalent

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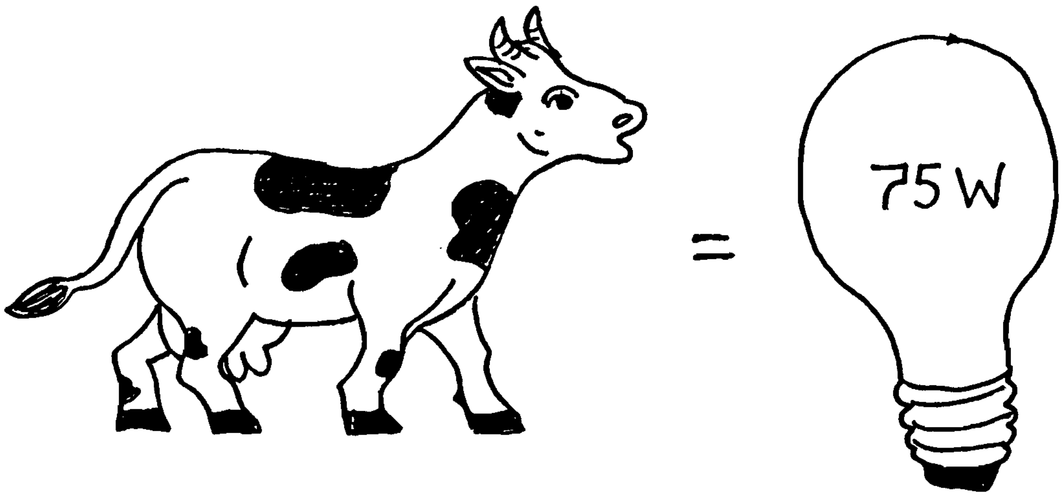
[26]The calculations are straightforward. Assume one U.S. cow emits 58 kg of methane per year. This is equivalent to 3625 moles of methane. Applying the Lashof index of 3.7, the emissions per cow have the same impact as 13,413 moles of CO_2. Next, note that the conversion of one kg of coal to electricity results in 2.1 kwhr of electricity and 41.66 moles of CO_2. Therefore, 12,413 moles of CO_2 is the end product of producing about 676 kwhr of electricity, approximately the power consumed by one 75 Watt light bulb operated for one year.

Figure 3: Bovine animals versus light bulbs as sources of reducing future climate change.



1 Cow emitting 58 kg methane/yr

75 Watt light bulb operated 24 hrs/day for one year

to the methane released from other sources, such as natural gas production? The following example illustrates the importance of considering both the atmospheric residence times and the source of carbon.

This example looks at the carbon cycle for a 500 kg beef cow in steady state, meaning the mature animal, Table 3. The cow in this example consumes 9 kg per day (dry weight) of silage with an approximate carbon content of 40%. Inputs of carbon amount to approximately 3600 g. In steady state, the total input and output of carbon fluxes must balance, column 1. Through normal respiration, 2095 g of carbon immediately return to the atmosphere. Of the remaining quantities, approximately 173 g are returned in the form of CO_2 and 94 g in the form of CH_4 through belching and 1238 g are deposited on the ground in the form of

Table 3: Daily Carbon and Greenhouse Gas Cycles. All figures in g/day. Assumes a 500 kg beef animal in steady state.				
INPUTS:	**Carbon**	**CO_2**	**CH_4**	**GHG Equiv.**
Approximately 9 kg/day silage (dry weight)	**3600**	**13200**		**13200**
OUTPUTS:				
Carbon in CO_2 -- belching	173	634		634
Carbon in CH_4 -- belching	94		125	1275
Carbon in manure (1238 g)				
Carbon released as CO_2	309.5	1135		1135
Carbon released as CH_4	309.5		413	4200
Carbon into soil	619			
Carbon in CO_2--respiration	2095	7682		7682
Carbon in urine	neg.			
Totals	**3600**	**9451**	**538**	**14926**

manure.[27]

In sum, of the original carbon ingested, 66% is returned almost immediately to the atmosphere, some of it as methane. The remainder of the carbon is dumped on the ground in the form of manure. Of course, the manure too breaks down releasing both CO_2 and CH_4 to the atmosphere. Patterson estimates a carbon to CH_4

[27]Assumes 34.4% carbon content of manure. See H. Tunney, "Agricultural Wastes as Fertilizers", in Handbook of Organic Waste Conversion, M. Bewick, editor, New York, Van Nostrand Reinhold, 1980, pp. 1-35.

conversion rate for manure of approximately 10% per year[28]; for this example, it is assumed that approximately 50% of the manure eventually decomposes returning 619 g of carbon to the atmosphere, half as CO_2, half as CH_4. The remainder is added to the soil.

Consider the overall effect of this carbon cycle in terms of greenhouse gas effect. Columns 2 and 3 indicate the quantities of CO_2 and CH_4 cycled. The last column indicates the greenhouse gas equivalence of the various components of the cycle, using the weighting factors of Lashof and Ahuja. The results are enlightening: while 14,926 greenhouse equivalent units are released to the atmosphere, 13,200 units are removed from the atmosphere, for a net increase of just 13%.

The variable of greatest uncertainty in this calculation is the manure decomposition rate. If one assumes that only 35% of the manure is allowed to decompose, rather than 50%, then the inputs and outputs virtually balance in terms of greenhouse effect.

This is an example of recycled carbon. The net effect of each unit of methane from bovine animals is definitely less than that of a unit of methane emitted through fossil fuel combustion or leakage. In the latter case, we are adding the combined effect of approximately 10-14 years of methane followed by the effect of approximately 200 years of carbon dioxide, whereas the former case involves only the increased infrared trapping effect of the 14 years of methane.

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[28] J. A. Patterson, "Potential Methane Emissions from Animal Manure", in Proceedings of Workshop on Greenhouse Emissions from Agricultural Systems, IPPC-RSWG, Subgroup on Agriculture, Forestry, and Other Human Activities, Dec. 1989.

IV. Cost Estimates of Various Greenhouse Gas Reduction Goals

Table 4 presents cost estimates for four different strategies to reduce greenhouse gas emissions. Three strategies, increased lighting efficiency,[29] fuel switching,[30] and tree plantations[31], target CO_2 emissions. The fourth is an estimate by Adams, Chang, and McCarl[32] for reducing CH_4 emissions by altering the diet of ruminant animals.

The estimate by Adams, et al, of $351 per ton CO_2 equivalent (in the form of CH_4) is quite high compared to the other alternatives presented, and in general those found in the literature for CO_2 reduction strategies. While this estimate is the result of preliminary work, if further work confirms the magnitude of this reduction strategy, it will be further evidence of the difficulty of pursuing any CH_4 reduction strategies which target bovine animals.

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[29]This estimate is based on replacing continuously operated 75 W incandescent light bulbs with 18 W compact fluorescents. Assumes an average electricity cost of $.064/kwhr, incandescent cost of $.75, and compact fluorescent cost of $15.99.

[30]This number represents the difference in fuel costs for fossil steam plants operating with natural gas rather than coal. Assumes coal cost of $1.44/MBTU, natural gas costs of $2.32/MBTU.

[31]Assumes a growth ratio of six tons per acre per year; cost estimates includes site preparation, weed control, planting costs, land rental costs, fertilizer, harvesting, and removal of trees from the site. Also assumes the use of Short Rotation Intensive Culture (SRIC) which utilizes fast-growing trees on managed plantations. See Chapman, D. and T. Drennen, "Equity and Effectiveness of Possible CO_2 Treaty Proposals", Contemporary Policy Issues, July 1990, pp. 16-28.

[32]Richard M.Adams, Ching-Cheng Chang, and Bruce A. McCarl, "The Role of Agriculture in Climate Change: A Preliminary Evaluation of Emission Control Strategies", Draft, presented at the Conference on Global Change: Economic Issues in Agriculture, Forestry and Natural Resources. Washington, D.C. November 19-21, 1990. Adams, et al, estimate that to reduce emissions of methane by altering ruminant diets would cost between $2,250 to $4,900 per ton of methane. This was converted to greenhouse gas equivalents by applying the Lashof and Ahuja index and taking an average.

Table 4: Cost Estimates of Various Greenhouse Gas Reduction Goals	
Strategy	**$/$CO_2$ Equivalent Metric Ton**
Compact Fluorescents	-56.00
Fuel Switching (Coal to Natural Gas)	22.00
Tree Plantations	54.00
Cow Diet	352.00

V. The North-South Political Question

The implications of pursuing CO_2 reductions alone versus pursuing a comprehensive approach also raises important questions touching on North-South political questions. For example, which countries should bear the largest burden of responsibility in regards to curbing global warming? Presumably, in negotiating a comprehensive approach, countries would have to settle the question of an appropriate bench mark level of emissions for the different gases. In regards to CFCs, one can imagine disagreement arising over starting levels or credit for past reductions as achieved under the Montreal Protocol. The U.S., the largest single consumer of CFCs,[33] would likely be insistent on gaining recognition and credit for already achieved reductions in CFC levels. Consider the following numerical example of such a claim by the U.S.

U.S. consumption in 1986 of CFC-12 alone was about 140

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[33]The U.S. accounted for 29% of total world-wide consumption in 1986. See Shea, "Protecting Life on Earth: Steps to Save the Ozone Layer", Worldwatch Paper 87, December 1988, p. 25.

million kg.[34] Using a greenhouse gas potency index rating of 20,000, this implies a value of 2.8 trillion CO_2 equivalent units. If one assumes a 90 percent reduction over these levels by the year 2000, the U.S. would most likely insist on a credit of 2.52 trillion units towards its reduction of greenhouse gases. Based on the use of Wyoming sum-bituminous coal (54.6% carbon), this would be equivalent to the CO_2 released from ninety seven 400 MW coal-fired plants, making it look as though the U.S. had already done its share of reducing the risk of future climate change. Meanwhile, those countries with low levels of CFC consumption would not benefit from such a credit. Indeed, it would be these countries, such as India, which would have to make sizeable changes in its methane emissions to capture a similar credit.

Whether intentional or not, the effect of pursuing the comprehensive approach might be a failure to reach any accord. Would India or China, who see the industrialized countries as the prime culprits, agree to something which required reductions in greenhouse gas emissions from their agricultural sector? Perhaps this is the real goal of the U.S.'s policy of pursuing a comprehensive agreement?

VI. Conclusion

This paper compared various estimates of total methane emissions from bovine animals and discussed the relative addition to greenhouse gas warming due to this one source.

Emissions of methane from bovine animals have been estimated elsewhere at approximately 60.5 millions tons per year, 14.8% of global methane releases. This estimate is misleading for two reasons: it ignores the differences in atmospheric residence time between carbon dioxide and methane; and it overlooks the

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[34]Shea, p. 23, reports U.S. per capita use rates of .34, .58, and .31 kg for CFC-11, CFC-12, and CFC-113 respectively. Multiplied by a U.S. population of 241 million results in an aggregate total of 140 million kg of CFC-12.

biological and chemical cycling that occurs. The result is an overemphasis of the role of this methane as a greenhouse gas.

This has important implications for negotiations on future climate change accords. By ignoring these two factors, the role of developing country's total contributions to climate change has been overemphasized. Lashof and Ahuja[22] conclude that carbon dioxide emissions alone account for 80% of the contribution to global warming, significantly higher that the oft cited 50% figure of Ramanathan.[3] Based on Lashof and Ahuja's numbers, an agreement aimed solely at reducing future CO_2 emissions would be an important first step. From a practical standpoint, any agreement regulating methane would be exceedingly difficult to develop, due to the lack of data availability, and measurement and monitoring capabilities.

All of this does not imply that bovine methane emissions should be ignored. Policies for reducing methane emissions which follow from the above calculations include: improving the quality of animal feed; and finding ways to more effectively utilize animal manure, such as through biogas utilization. However, as evidenced by the preliminary results of Adams, et al, such reduction strategies may not be economically attractive when compared to CO_2 reduction strategies.

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