TABLE B-1 (CONTINUED)
FEED INTAKE AND MANURE PRODUCTION FOR CATTLE

Region	Livestock Category	Sub-Population	Mass (kg)	Feed Digestibility (%)	Energy Intake (MJ/day)	Feed Intake (kg/day)	Category Population %	Manure (kg/h/d dm)	VS (kg/h/d)	B_o (m^3 CH4/kg VS)
Africa & Middle East	Dairy Cattle	Average	275	60%	92.8	5.0	100%	2.01	1.85	0.13
	Non-dairy Cattle	Mature Females	200	55%	73.2	4.0	13%	1.79	1.64	0.10
		Mature Males Draft	275	55%	93.2	5.1	13%	2.27	2.09	0.10
		Mature Females Grazing	200	55%	93.6	5.1	5%	2.28	2.10	0.10
		Mature Males Grazing	275	55%	112.3	6.1	25%	2.74	2.52	0.10
		Young	75	60%	36.2	2.0	44%	0.78	0.72	0.10
		Avg. Non-dairy Cattle	173	57%	70.6	3.8	100%	1.68	1.54	0.10
Asia	Dairy Cattle	Average	350	60%	141.6	7.7	100%	3.07	2.82	0.13
	Non-dairy Cattle	Mature Females Farming	325	55%	113.2	6.1	27%	2.76	2.54	0.10
		Mature Females Grazing	300	60%	105.0	5.7	9%	2.28	2.09	0.10
		Mature Males Farming	450	55%	134.9	7.3	24%	3.29	3.03	0.10
		Mature Males Grazing	400	60%	112.5	6.1	8%	2.44	2.24	0.10
		Young	200	60%	79.3	4.3	32%	1.72	1.58	0.10
		Avg. Non-dairy Cattle	319	57%	106.8	5.8	100%	2.49	2.29	0.10
Indian	Dairy Cattle	Average Dairy Cow	275	55%	117.7	6.4	100%	2.87	2.64	0.13
Subcontinent	Non-dairy Cattle	Mature Females	125	50%	63.8	3.5	40%	1.73	1.59	0.10
		Mature Males	200	50%	83.7	4.5	10%	2.27	2.09	0.10
		Young	80	50%	43.2	2.3	50%	1.17	1.08	0.10
		Avg. Non-dairy Cattle	110	50%	55.5	3.0	100%	1.50	1.38	0.10

Ash content estimated at 8%. Cattle characteristics from Gibbs and Johnson (1993).

TABLE B-2
FEED INTAKE AND MANURE PRODUCTION FOR SWINE AND BUFFALO

Region	Livestock Category	Sub-Population	Mass (kg)	Feed Digestibility (%)	Energy Intake (MJ/day)	Feed Intake (kg/day)	Category Population %	Manure (kg/h/d dm)	VS (kg/h/d)	B_o (m^3CH_4/kg VS)
Developing Countries	Swine	Average	28	50%	13.0	0.7	100%	0.35	0.34	0.29
Developed Countries	Swine	Average	82	75%	38.0	2.1	100%	0.51	0.50	0.45
Indian Subcontinent[a]	Buffalo	Adult Males	450	55%	134.5	7.3	14%	3.28	3.02	0.10
		Adult Females	350	55%	139.0	7.5	40%	3.39	3.12	0.10
		Young	200	55%	74.0	4.0	46%	1.80	1.66	0.10
		Average	295	55%	108.0	5.9	100%	2.65	2.43	0.10
Rest of World[b]	Buffalo	Adult Males	450	55%	134.5	7.3	45%	3.28	3.02	0.10
		Adult Females	350	55%	114.0	6.2	45%	2.78	2.56	0.10
		Young	200	55%	74.0	4.1	10%	1.80	1.66	0.10
		Average	380	55%	119.0	6.5	100%	2.91	2.68	0.10

a Estimates based on data for India.

b Estimates based on data for China.

Ash content taken as 8% for buffalo and 2% and 4% for swine in developed and developing countries, respectively.

Sources: Buffalo characteristics from Gibbs and Johnson (1993). Swine feed intake estimates from Crutzen et al. (1986).

TABLE B-3
MANURE MANAGEMENT EMISSION FACTOR DERIVATION FOR DAIRY CATTLE

Climate	Manure Management System MCFs								
	Lagoon	Liquid/ Slurry	Solid Storage	Drylot	Pasture/ Range	Daily Spread	Digester	Burned for Fuel	Other
Cool	90%	10%	1%	1%	1%	0.1%	10%	10%	1%
Temperate	90%	35%	1.5%	1.5%	1.5%	0.5%	10%	10%	1%
Warm	90%	65%	2%	5%	2%	1%	10%	10%	1%

Region	Dairy Cattle Characteristics			Manure Management System Usage (MS%)									Emission Factors kg CH_4 / hd / yr		
	Mass[a] (kg)	B_o (m^3CH_4/kg Vs)	VS[b] (kg/hd/day)	Lagoon	Liquid/ Slurry	Solid Storage	Drylot	Pasture/ Range	Daily Spread	Digester	Burned for Fuel	Other	Cool	Temperate	Warm
North America	600	0.24	5.2	10%	23%	18%	5%	0%	37%	0%	0%	7%	36	54	76
Western Europe	550	0.24	5.1	0%	40%	18%	0%	19%	20%	0%	2%	1%	14	44	81
Eastern Europe	550	0.24	4.1	0%	18%	68%	0%	13%	1%	0%	0%	0%	6	19	33
Oceania	500	0.24	3.5	16%	1%	0%	0%	76%	8%	0%	0%	0%	31	32	33
Latin America	400	0.13	2.9	0%	1%	1%	0%	36%	62%	0%	0%	0%	0	1	2
Africa	275	0.13	1.9	0%	0%	1%	0%	83%	5%	0%	6%	4%	1	1	1
Middle East	275	0.13	1.9	0%	1%	2%	0%	80%	2%	0%	17%	0%	1	2	2
Asia	350	0.13	2.8	4%	38%	0%	0%	20%	29%	2%	7%	0%	7	16	27
Indian Subcontinent	275	0.13	2.6	0%	1%	0%	0%	27%	19%	1%	51%	0%	5	5	6

a Average dairy cow mass for each region.

b Average VS production for per head per day for the average dairy cow.

Emission Factors (EF) for a climate region, k, are calculated as follows:

$$EF_k = B_o \times VS \times 365 \times \sum_{j=1}^{\text{all manure systems}} MS\%_j \times MCF_{jk}$$

TABLE B-4
MANURE MANAGEMENT EMISSION FACTOR DERIVATION FOR NON-DAIRY CATTLE

Climate				Manure Management System MCFs									Emission Factors kg CH_4 / hd / yr		
				Lagoon	Liquid / Slurry	Solid Storage	Drylot	Pasture / Range	Daily Spread	Digester	Burned for Fuel	Other			
Cool				90%	10%	1%	1%	1%	0.1%	10%	10%	1%			
Temperate				90%	35%	1.5%	1.5%	1.5%	0.5%	10%	10%	1%			
Warm				90%	65%	2%	5%	2%	1%	10%	10%	1%			
Region	Non-dairy Cattle Characteristics			Manure Management System Usage (MS%)											
	Mass[a] (kg)	B_o (m^3CH_4 /kg VS)	VS[b] (kg/hd/day)										Cool	Temperate	Warm
North America	357	0.17	2.4	0%	1%	0%	14%	84%	0%	0%	0%	1%	1	2	3
Western Europe	405	0.17	2.7	0%	50%	0%	2%	38%	0%	0%	2%	8%	6	20	38
Eastern Europe	391	0.17	2.7	0%	28%	0%	0%	26%	0%	0%	0%	46%	4	13	23
Oceania	330	0.17	3.0	3%	0%	0%	6%	91%	0%	0%	0%	0%	5	6	7
Latin America	305	0.10	2.5	0%	0%	0%	0%	99%	0%	0%	0%	1%	1	1	1
Africa	173	0.10	1.5	0%	0%	0%	1%	95%	1%	0%	3%	0%	0	1	1
Middle East	173	0.10	1.5	0%	0%	0%	1%	79%	2%	0%	17%	2%	1	1	1
Asia	319	0.10	2.3	0%	0%	0%	46%	50%	2%	0%	2%	0%	1	1	2
Indian Subcontinent	110	0.10	1.4	0%	1%	0%	4%	22%	20%	1%	53%	0%	2	2	2

a Average non-dairy cow mass for each region.

b Average VS production for per head per day for the average non-dairy animal.

Emission Factors (EF) for a climate region, k, are calculated as follows:

$$EF_k = B_o \times VS \times 365 \times \sum_{j=1}^{\text{all manure systems}} MS\%_j \times MCF_{jk}$$

TABLE B-5
MANURE MANAGEMENT EMISSION FACTOR DERIVATION FOR BUFFALO

Climate				Manure Management System MCFs						
				Liquid/ Slurry	Drylot	Pasture/ Range	Daily Spread	Digester	Burned for Fuel	Other
Cool				10.0%	1.0%	1.0%	0.1%	10.0%	10.0%	1.0%
Temperate				35.0%	1.5%	1.5%	0.5%	10.0%	10.0%	1.0%
Warm				65.0%	5.0%	2.0%	1.0%	10.0%	10.0%	1.0%

Region	Buffalo Characteristics			Manure Management System Usage (MS%)							Emission Factors kg CH_4 / hd / yr		
	Mass[a] kg	B_o m^3CH_4 /kg VS	VS[b] kg/hd/day	Liquid/ Slurry	Drylot	Pasture/ Range	Daily Spread	Digester	Burned for Fuel	Other	Cool	Temperate	Warm
North America	(not applicable)												
Western Europe	380	0.10	3.9	20%	79%	0%	0%	0%	0%	0%	3	8	17
Eastern Europe	380	0.10	3.9	24%	0%	29%	0%	0%	0%	47%	3	9	16
Oceania	(not applicable)												
Latin America	380	0.10	3.9	0%	0%	99%	0%	0%	0%	1%	1	1	2
Africa	(not applicable)												
Middle East	380	0.10	3.9	0%	0%	20%	19%	0%	42%	19%	4	5	5
Asia	380	0.10	3.9	0%	41%	50%	4%	0%	5%	0%	1	2	3
Indian Subcontinent	295	0.10	3.1	0%	4%	19%	21%	1%	55%	0%	4	5	5

a Average buffalo mass for each region.

b Average VS production for per head per day for the average buffalo.

Emission Factors (EF) for a climate region, k, are calculated as follows:

$$EF_k = B_o \times VS \times 365 \times \sum_{j=1}^{\text{all manure systems}} MS\%_j \times MCF_{jk}$$

TABLE B-6
MANURE MANAGEMENT EMISSION FACTOR DERIVATION FOR SWINE

Climate				Manure Management Systems MCFs								
				Lagoon	Liquid/ Slurry	Solid Storage	Drylot	Pit <1 month	Pit >1 month	Daily Spread	Digester	Other
Cool				90%	10%	1%	1%	5%	10%	0.1%	10%	1%
Temperate				90%	35%	1.5%	1.5%	18%	35%	0.5%	10%	1%
Warm				90%	65%	2%	5%	33%	65%	1%	10%	1%
Region	Swine Characteristics			Manure Management System Usage (MS%)								
	Mass[a] kg	B_o m^3CH_4 /kg VS	VS[b] kg/hd/day									
North America	82	0.45	0.5	24%	1%	2%	16%	10%	26%	0%	0%	19%
Western Europe	82	0.45	0.5	0%	0%	21%	2%	3%	73%	0%	0%	1%
Eastern Europe	82	0.45	0.5	8%	0%	39%	14%	19%	19%	0%	0%	1%
Oceania	82	0.45	0.5	54%	0%	3%	15%	0%	0%	0%	0%	28%
Latin America	28	0.29	0.3	0%	8%	10%	41%	0%	0%	2%	0%	40%
Africa	28	0.29	0.3	0%	6%	6%	87%	1%	0%	0%	0%	0%
Middle East	28	0.29	0.3	0%	14%	0%	69%	0%	17%	0%	0%	0%
Asia	28	0.29	0.3	0%	40%	0%	54%	0%	0%	0%	7%	0%
Indian Subcontinent	28	0.29	0.3	9%	22%	16%	30%	3%	0%	9%	8%	3%

a Average swine mass for each region.

b Average VS production for per head per day for the average swine.

Emission Factors (EF) for a climate region, k, are calculated as follows:

$$EF_k = B_o \times VS \times 365 \times \sum_{j=1}^{\text{all manure systems}} MS\%_j \times MCF_{jk}$$

EMISSION FACTORS
kg CH_4 / hd / yr

Region	Cool	Temperate	Warm
North America	10	14	18
Western Europe	3	10	19
Eastern Europe	4	7	11
Oceania	20	20	20
Latin America	0	1	2
Africa	0	1	2
Middle East	1	3	6
Asia	1	4	7
Indian Subcontinent	3	4	6

TABLE B-7
MANURE MANAGEMENT EMISSION FACTOR DERIVATION FOR OTHER LIVESTOCK

Animal		Animal Characteristics						Manure Management System MCFs[a]			Emission Factors[a] kg CH_4 / hd / yr		
		Mass (kg)	Digest (%)	Intake/d (kg Feed)	% Ash (Dry Basis)	VS/day (kg VS)	B_o (m^3/kg VS)	MCF Cool	MCF Temperate	MCF Warm	Cool	Temperate	Warm
Sheep	Developed Countries	43	60%	1.08	8.0	0.40	0.19	1%	1.5%	2%	0.19	0.28	0.37
	Developing Countries	28	50%	0.70	8.0	0.32	0.13	1%	1.5%	2%	0.10	0.16	0.21
Goats	Developed Countries	30	60%	0.76	8.0	0.28	0.17	1%	1.5%	2%	0.12	0.18	0.23
	Developing Countries	30	50%	0.76	8.0	0.35	0.13	1%	1.5%	2%	0.11	0.17	0.22
Camels	Developed Countries	217	50%	5.42	8.0	2.49	0.26	1%	1.5%	2%	1.59	2.38	3.17
	Developing Countries	217	50%	5.42	8.0	2.49	0.21	1%	1.5%	2%	1.28	1.92	2.56
Horses	Developed Countries	238	70%	5.96	4.0	1.72	0.33	1%	1.5%	2%	1.39	2.08	2.77
	Developing Countries	238	70%	5.96	4.0	1.72	0.26	1%	1.5%	2%	1.09	1.64	2.18
Mule/Asses	Developed Countries	130	70%	3.25	4.0	0.94	0.33	1%	1.5%	2%	0.76	1.14	1.51
	Developing Countries	130	70%	3.25	4.0	0.94	0.26	1%	1.5%	2%	0.60	0.90	1.19
Poultry[b]	Developed Countries	1.1	NR[c]	NR	NR	0.10	0.32	1%	1.5%	2%	0.078	0.117	0.157
	Developing Countries	NR	NR	NR	NR	0.02	0.24	1%	1.5%	2%	0.012	0.018	0.023

a The range of estimates reflects cool to warm climates. Cool climates have an average annual temperature below 15°C; temperate climates have an average annual temperature between 15°C and 25°C; and warm climates have an average annual temperature above 25°C.

b Poultry include chickens, ducks, and turkeys.

c Not reported.

Sources: Except for poultry, emission factors were developed from: feed intake values and feed digestibilities used to develop the enteric fermentation emission factors (see Appendix A); MCF, and B_o values reported in Woodbury and Hashimoto (1993). All manure is assumed to be managed in dry systems, which is consistent with the manure management system usage reported in Woodbury and Hashimoto (1993). Emission factors for poultry are based on Safley et al. (1992) and Woodbury and Hashimoto (1993).

Appendix C

Derivation of Tier 2 Enteric Fermentation Equations For Methane

This appendix summarises the derivation of the relationship between net energy (NE) and digestible energy (DE) that is used to estimate total feed-intake requirements for cattle. This derivation is drawn from Gibbs and Johnson (1993).

As described in the main text, the relationship among the energy values of feed consumed by cattle can be summarised as follows:

Digestible Energy	=	Gross Energy - Faecal Losses
Metabolisable Energy	=	Digestible Energy - Urinary and Combustible Gas Losses
Net Energy	=	Metabolisable Energy - Heat Increment

Net Energy	=	Gross Energy - Faecal Losses - Urinary and Combustible Gas Losses - Heat Increment

NRC (1984) presents the following quantitative relationships among these energy values:

$$ME = 0.82 \times DE \qquad (C.1)$$

$$NE_m = (1.37 \times ME) - (0.138 \times ME^2) + (0.0105 \times ME^3) - 1.12 \qquad (C.2)$$

$$NE_g = (1.42 \times ME) - (0.174 \times ME^2) + (0.0122 \times ME^3) - 1.65 \qquad (C.3)$$

where:

DE = digestible energy in Mcal/kg (dry matter basis);

ME = metabolisable energy in Mcal/kg (dry matter basis);

NE_m = net energy for maintenance in Mcal/kg (dry matter basis); and

NE_g = net energy for growth in Mcal/kg (dry matter basis).

Using these relationships, the ratio of NE_m and NE_g to ME or DE can be derived as follows:

$$NE/DE = 1.123 - (4.092 \times 10^{-3} \times DE\%) + (1.126 \times 10^{-5} \times (DE\%)^2) - 25.4/DE\% \qquad (C.4)$$

$$NE_g/DE = 1.164 - (5.160 \times 10^{-3} \times DE\%) + (1.308 \times 10^{-5} \times (DE\%)^2) - 37.4/DE\% \qquad (C.5)$$

where:

NE/DE = the ratio of net energy consumed for maintenance, lactation, work and pregnancy to digestible energy consumed;

NE_g/DE = the ratio of net energy consumed for growth to digestible energy consumed; and

DE% = digestible energy as percentage of gross energy, expressed in per cent (e.g., 65%).

Graph C-1 shows the relationships in graphical form. As shown in the graph, the ratio of NE to DE is non-linear, with an increasing slope with decreasing DE. These relationships imply that at lower values of DE, cattle are able to recover a decreasing portion of the energy to use for maintenance or growth.

For the purpose of estimating methane emissions from cattle, applying these relationships to cattle consuming relatively low-quality feeds (such as cattle in many tropical countries) may be inappropriate because the relationships were developed based on analyses of the higher-quality feeds typically found in the United States temperate agriculture system. Consequently, the experimental basis for extrapolating the non-linear relationships to low levels of DE is not very strong.

In examining other energy systems, it is seen that they also indicate that the rate of net energy retention declines at lower values of digestible energy. Unlike the NRC system, however, many imply a *linear* relationship between NE and DE. The UK energy system (ARC, 1980), which is typical of the energy systems used in Europe, has a slope for the linear NE_m:DE relationship that is similar to the slope of the non-linear NRC relationship in the range of 65-70 per cent digestibility. In the same way, the slope of the UK NE_g:DE relationship is similar to the slope of the non-linear NRC relationship in the range of 60-65 per cent digestibility.

To avoid possible biases in estimating feed-intake requirements in this study, the relationships were extrapolated linearly for DE values below 65 per cent using the average slopes of the NRC relationships between 60 and 70 per cent DE. The derived equations are as follows:

$$NE/DE = 0.298 + 0.00335 \times DE\% \quad (C.6)$$

$$NE_g/DE = -0.036 + 0.00535 \times DE\% \quad (C.7)$$

Graph C-2 shows the extrapolated linear relationships along with the non-linear estimates. As expected, the linear extrapolations fall *above* the original non-linear estimates.

The implication of making this adjustment to the NRC (1984) relationship for the global emissions estimate is relatively minor. Gibbs and Johnson (1993) report that using the non-linear relationship to estimate global emissions from cattle increases the 1990 emissions estimate by 1000 Gg, from 58,100 Gg to 59,100 Gg. Considering the wide range of factors that contribute to uncertainty in the estimates, including characterisation of animal populations, this adjustment has a minor influence on the estimates.