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Residential Consumption of Bioenergy in China

A Literature Study

Statistics Norway
Statistisk sentralbyrå

Preface

This document is a product of a Partnership Agreement between the State Statistical Bureau of China (SSB) and Statistics Norway (SN).

The project aims at:

- *Building capacity in the field of natural resource accounting*
- *Enhancing the capacity to prepare environmental statistics*
- *Developing analytical tools for linking natural resource use to economic activity and environmental impacts*
- *More comprehensive and widespread publications and improved methods of presentation*

During a four year period (1997-2001) SSB and SN will co-operate on an institution-to-institution basis for transfer of knowledge and sharing of experiences. The project is financed by the Norwegian Agency for Development Aid (NORAD). The National Environmental Protection Agency in China (NEPA) has the overall responsibility.

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1. Introduction

"*Biofuels* are, as the name implies, renewable energy sources from living things. They are to be distinguished from *fossil fuels* which are also of biological origin, but which are non-renewable." (Merril and Gage 1978)

Bioenergy is biomass used as fuel for heating and cooking, also called biomass energy and biofuel. The most common bioenergy sources are:

- Crop residues
- Firewood and other phytomass
- Dung (dried animal excreta)
- Biogas
- Others

More detailed explanation of the different sources is presented later in this report.

It has been estimated that China derived one third of its energy needs from biomass in the 1980s (Smil 1981 and Hall and de Groot 1987). Bioenergy is mostly used in the rural areas, and has accounted for the majority of the energy supply to rural households. Since the late 1970s to 1989 the rural household consumption of bioenergy increased by 20 percent, while the growth in consumption of commercial energy increased by 80 percent. This fuel switching was probably caused by easier access to coal and more efficient biomass stoves (LBL 1992).

In the beginning of 1993 about 850 million (72%) of China's 1.19 billion inhabitants were living in rural areas. Studies of the energy consumption in rural areas in 1979 found that the average daily effective energy requirement was between 16.2 MJ (Wu and Chen 1982) and 18.7 MJ (Deng and Zhou 1981) per family[1]. The aim of this paper is to estimate the amount of the different biomass sources used as fuel and compare our results with other related studies. The purpose of the study is to illustrate the importance of biofuels in rural areas of China.

This paper is a literature study and focuses on 1993, while further research by Statistics Norway (SN) and State Statistical Bureau of China (SSB) will use 1995 as the base year. Most of our references are from the 1980s, and the reliability of our results would therefore be better for a 1993 estimation than for a 1995 estimation.

2. Summary

Table 1 illustrates that the results from this and other studies are within the same range. Our figures are probably a little over-estimated since we have not subtracted the amount of biomass energy consumed in the production sectors (this is not concerning the amount of animal dung). The fraction of bioenergy used in other sectors than households is about 1-7 percent of the total biomass energy consumption (FNI 1997, Haugland and Roland 1990 and Smil 1988).

From our study we find the daily biomass energy consumption per capita to be 26 MJ for rural areas and 19 MJ for all of China. FNI (1997) found the consumption for all of China, for the same year (1993), to be 13 MJ/capita/day which is within the same magnitude.

[1] Just fuel, not including food.

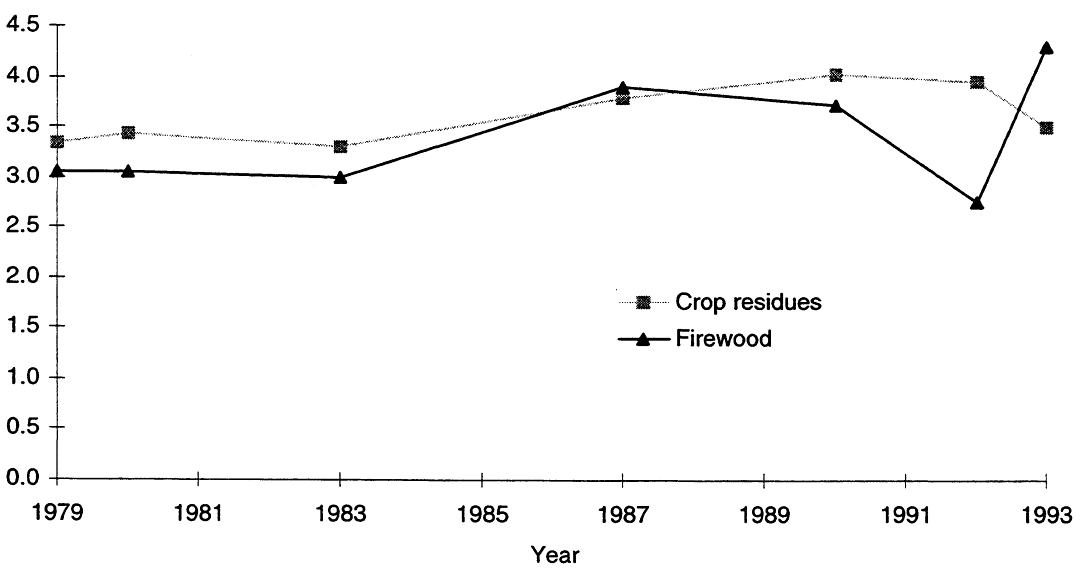
Table 1. Residential consumption of biomass energy, results from this and similar studies

Reference	Year	Biomass energy consumption (MJ)				
		Total*	Crop residues	Animal dung	Firewood	Biogas
LBL (1992)	1979	$6.6*10^{12}$	$3.3*10^{12}$	$1.9*10^{11}$	$3.0*10^{12}$	-
Woodward (1980)	1980	$2.2\text{-}2.5*10^{12}$	$0.9\text{-}1.0*10^{12}$	-	$1.3\text{-}1.5*10^{12}$	-
FNI (1997)	1980	$6.5*10^{12}$	$3,4*10^{12}$	-	$3,0*10^{12}$	-
Smil (1988)	1983	$6.3*10^{12}$	$3.3*10^{12}$	$1.2*10^{11}$	$3.0*10^{12}$	$1.8*10^{10}$
Haugland and Roland (1990)	1984	$6.5*10^{12}$	-	-	-	-
LBL (1992)	1987	$7.8*10^{12}$	$3.8*10^{12}$	$9.5*10^{10}$	$3.9*10^{12}$	-
FNI (1997)	1990	$7.7*10^{12}$	$3.9*10^{12}$	-	$3.9*10^{12}$	-
He, Zhang and Ye (1996)	1990	$7.8*10^{12}$	$4.2*10^{12}$	-	$3.6*10^{12}$	$2.4*10^{10}$
FNI (1997)	1992	$6.7*10^{12}$	$4.0*10^{12}$	-	$2.8*10^{12}$	-
United Nations[2]	1993	-	-	-	-	$2.4*10^{10}$
Statistics Norway	1993	$8.1*10^{12}$	$3.5*10^{12x}$	$2.7*10^{11x}$	$4.3*10^{12x}$	-*

x: Total consumption both for households and production.
*: Not calculated

Figure 1 suggests a trend in estimated annual residential consumption of crop residues and firewood. It seems that we have overestimated the consumption of firewood (see also Table 1). This may have been caused by overestimation of the total annual residential energy requirement or bigger families than we presumed.

Figure 1. Consumption of crop residues and firewood. (10^{12} MJ)

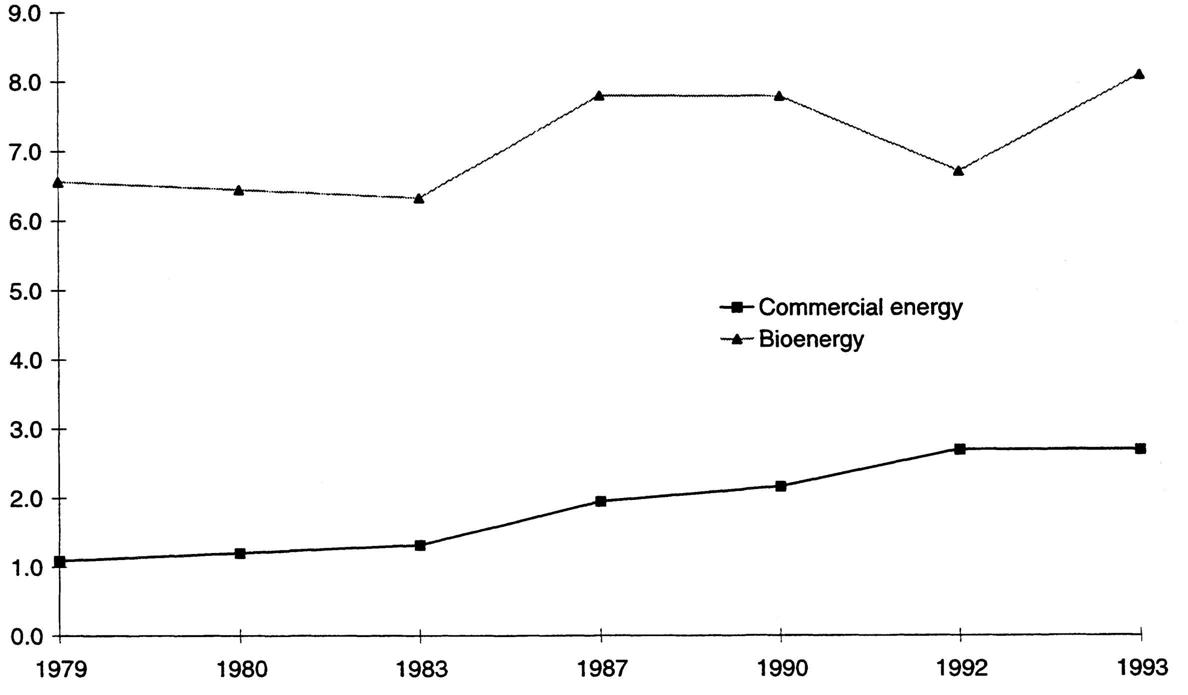


Sources: FNI (1997), He, Zhang and Ye (1996), LBL (1992), Smil (1988) and Statistics Norway.

[2] United Nations internet site: www.un.org.

Bioenergy is by far the most important energy source, but the trend (see Figure 2) indicates that the situation is changing.

Figure 2. Annual residential energy consumption in rural areas. (10^{12} MJ)



Sources: FNI (1997), He, Zhang and Ye (1996), LBL (1992), SSB (1989, 1995 and 1997), Smil (1988) and World Bank (1985) and own estimations.

3. Definitions

Biogas	A mixture of several gases, of which methane is the major component. It is generated from fermentation of manure, human wastes, gras and straw.
Crop residues	Cereal straws, maize stover and stalks and vines of tubers, leguminous and oil crops, and cotton.
Crop residue ratio	Amount of crop residues/harvested yield.
Digester	Container used to produce biogas.
Effective energy	The amount of energy utilised.
Fuelwood/firewood	Trees and shrubs which are collected, dried and burned.
Phytomass	Forest biomass like roots, stumps, needles, leaves, grasses, dried pieces of sod, etc. that are collected and used as firewood.
1 tonne standard fuel	29,307.6 MJ (Smil 1988 and UN 1987)
1 tonne standard fuel	1 tonne coal equivalent (tce)

4. Estimating the bioenergy use in rural areas in 1993

4.1. Total use of bioenergy

Direct information about the consumption is not available, and an indirect approach has to be used. We started off finding the approximate amount of total energy consumed by rural households (see Table 2). It has been observed that a rural family on average requires 16.2-18.7 MJ/day of effective energy (Wu and Chen 1982 and Deng and Zhou 1981). However, the size of an average rural family is not clear. Smil (1988) states five persons, while SSB now uses a figure between three and four. Since the studies done by Wu and Chen (1982) and Deng and Zhou (1981) were carried out in the 1980s we believe that Smil's (1988) figure is better for this estimation. Our estimates of total bioenergy use is underestimated if the household size is smaller than five persons. The requirements found in the studies are effective energy. We use an energy efficiency factor of 10 percent, which is the same as Smil (1988) and Hall and de Groot (1987)[3] uses. Energy efficient stoves for burning biomass are widespread (LBL 1992), and the output of the biomass may therefore be higher than 10 percent. NAS (1980) stated that an improved stove could extract 20 percent or more of the biomass energy. The energy output of biogas is much higher, about 60 percent, but biogas is treated separately in this paper to ease the calculations. Using these presumptions we end up with an average total energy requirement in rural areas of 32.4-37.4 MJ/day/capita. In the following calculations we use the average figure 35 MJ/day/capita.

Table 2. Total residential energy need in rural areas. 1993

Number of people	*	Average daily energy requirements per person	=	Total energy demand in rural areas
850 million		35 MJ/day/capita[4]		$1.1 * 10^{13}$ MJ

Sources: Smil (1988), Wu and Chen (1982), Deng and Zhou (1981) and SSB (1997).

After calculating an estimate for the total energy demand in rural areas, we subtract the amount of commercial fuels (electricity, coal and oil products). In 1992 the total consumption of commercial energy by rural households was $2.7*10^{12}$ MJ (FNI 1997), while the total residential consumption was $4.6*10^{12}$ MJ (SSB 1995). Meaning that while 72 percent of the Chinese population lived in rural areas they only consumed 59 percent of the annual residential commercial energy consumption. The development of the annual residential energy consumption and the population in rural areas are described in Table 3. If we presume that the pattern of consumption was the same in 1993 as in 1992, we find that the total consumption in 1993 was $2.7*10^{12}$ MJ. The estimation of total residential consumption of commercial energy in rural areas in 1993 is illustrated in Table 4.

Table 3. Development of population and energy consumption

	1980	1987	1990	1992
Total population (mill.)	987	1 093	1 114	1 171
Total population in rural areas (mill.)	796	816	841	848
Proportion of the population in rural areas	81%	75%	74%	72%
Total residential consumption of commercial energy (10^{12} MJ)	2.8	4.2	4.6	4.6
Residential consumption of commercial energy in rural areas (10^{12} MJ)	1.2	1.9	2.2	2.7
Proportion of residential consumption of commercial energy in rural areas	43%	46%	47%	59%

Sources: FNI (1997) LBL (1992) and SSB (1989, 1995, 1996).

[3] Hall and de Groot's (1987) efficiency factor concerns dung only.

[4] This figure is an average of the studies done by Wu and Chen (1982) and Deng and Zhou (1981).

When the terms "household energy consumption" and "residential energy consumption" are referred to in this report they do not include production of agricultural products.

Table 4. Estimated annual consumption of commercial energy by residents in rural areas. 1993

Average annual residential energy	*	Proportion consumed in rural areas	=	Consumption in rural areas
157 310 000 tce * 29 308 MJ/tce		59%		$2.7 * 10^{12}$ MJ

Sources: FNI (1997) and SSB (1997).

The gap between how much energy that is required and the amount bought, must be filled with some other sort of energy, presumed to be biomass energy. The amounts of different biofuels are now calculated.

Table 5. Estimation of the total bioenergy use in rural areas. 1993

	Total energy consumed	$1.09 * 10^{13}$ MJ
-	Total consumption of commercial energy	$2.72 * 10^{12}$ MJ
=	Total residential consumption of bioenergy	$8.14 * 10^{12}$ MJ

Source: SSB (1997)

From Table 5 we see that if our calculations are reasonable, almost 75 percent of the energy consumed by households in rural areas is bioenergy.

In the following chapters we will show how much each biofuel contribute and which is the most important.

4.2. Crop residues

Crop residues are stalks, stems, cobs, husks, straw, etc. that are left from the harvest when the yield[5] is removed. The residues may be used as fodder for the livestock, building materials, etc. or burnt in stoves to produce heat and for cooking.

We start by calculating the amount of crop residues. This is then the upper limit of what is available for heating, cooking, etc. The calculations are done by using a bottom-up approach. Data on the amount of agricultural output are used to estimate the total output of crop residues. To find the amount of crop residues produced we use the ratio between yield and residues.

Table 6. Amount of crop residues. Million tonnes. 1993

Crop	Crop harvested	*	Crop residue ratios	=	Total crop residue output
Rice	177.5		1.0		177.5
Wheat	106.4		1.3		138.3
Maize	102.7		1.2		123.2
Other grains	19.5		1.3		25.4
Tubers	31.8		0.2		6.4
Oilcrop	18.0		0.6		10.8
Sugar cane	64.2		0.2		12.8
Cotton	3.7		2.0		7.4
Beetroots	12.0		0.2		2.4
Total					504.3

Sources: Smil (1988) and SSB (1997).

[5] Meaning the grains, tubers, etc.

It is now crucial to have a good estimate on how much of the $504.3*10^6$ tonnes that are burned. There are several suggestions on what the ratio is, Shangguan (1980) used a rural energy survey conducted nation-wide in 1979 and found that 51 percent was left for combustion, Wu and Chen (1982) used a ratio of 60 percent, while Shi (1982) stated that the ratio was 75 percent. Smil (1988) found that about 50 percent of total crop residue was used for fuels. His approach was to calculate the amount of residues used for other purposes than heating and cooking. To do this he used the number of livestock, their fodder requirement, and ratio grazed, the fraction of crop residues returned to the soil directly and the amount used for other purposes than heating and cooking. We used Smil's (1988) and Shangguan's (1980) estimate, and were now able to calculate the amount of energy which crop residues accounts for (see Table 7). If this estimate is right, we find that 43 percent of all biomass energy is crop residues.

Table 7. Amount of energy which crop residues accounts for. 1993

Total crop residue output	*	Ratio burnt	*	Energy content	=	Energy
504.3 mill. tonnes		0.5		14 000 MJ/tonne		$3.5 * 10^{12}$ MJ

Source: Smil (1988).

4.3. Animal dung

Animal dung is used as fertiliser, but some is also collected, dried and burned to produce heat. Estimating the amount of this kind of bioenergy implies some of the same difficulties as for estimating the use of crop residues. In this case the difficulty lies in estimating the collection rate of the dung and the fraction used as fuel. Wu and Chen (1982) and Smil (1988) calculated that the total production of dung in 1980 and 1983 was 103 and 150 million dry tonnes, respectively. Our estimate for 1993 is 280 mill. tonnes dry weight.

Table 8. Amount of animal dung used as fuel. 1993

Livestock	Heads (1000)	Output (kg/head)	Solid output (1000 tonnes)	Collection rate	Amount of dry output collected (1000 tonnes)
Cattle and buffalo	113,157	800	90,526	30 %	27,158
Horses	9,959	900	8,963	30 %	2,689
Donkeys	0,886	800	8,709	30 %	2,613
Mules	5,498	800	4,398	30 %	1,320
Camels	373	800	298	30 %	90
Slaughtered fattened hogs	378,240	200	75,648	90 %	68,083
Hogs	393,000	200	78,600	90 %	70,740
Sheep	105,700	80	8,456	25 %	2,114
Goats	111,620	80	8,930	25 %	2,232
Total					177,038

Sources: Smil (1988), SSB (1997) and Wu and Chen (1982).

The collection rate and the ratio burned might have changed since 1980, but so far we have not been able to find more recent calculated estimates.

Table 9. Total energy content of the animal dung. 1993

Total amount of dry dung	*	Energy content	*	Ratio burned	=	Energy
$1.8*10^8$ tonne		15 500 MJ/tonne		0.1		$2.7 * 10^{11}$ MJ

Source: Smil (1988).

If our estimation is correct, animal dung is only contributing 3.4 percent of the total bioenergy consumption by rural households and is therefore not a very significant bioenergy source (see Table 9).

4.4. Firewood and other phytomass[6]

The difference between estimated consumption and the amount of crop residues and dung burned is presumed to represent the amount of firewood and other phytomass used for combustion. It is found that this biomass accounts for 53 percent of the residential bioenergy consumption (see Table 10).

Table 10. Amount of firewood supplied. 1993

	Total amount of bioenergy consumed	$8.1 * 10^{12}$ MJ
-	Amount of crop residues consumed	$3.5 * 10^{12}$ MJ
-	Amount of dung used as fuel	$2.7 * 10^{11}$ MJ
=	Amount of firewood consumed	$4.3 * 10^{12}$ MJ

Source: Own estimations.

4.5. Biogas

We have so far not regarded possible substitution between some of the bioenergy sources described above and the production of biogas, this will not be done in this paper either. An attempt, however, to reveal the amount of biogas produced from digested animal excreta, human wastes and crop residues has been made.

The Chinese have experimented with biogas since the 1950s, but it was not until the 1970s that the method of utilising this gas became widespread, mostly in Sichuan. The use of biogas has reduced the demand for firewood and coal in Sichuan, easing the pressure on the forest. The anaerobic fermentation of the manure does not only produce biogas, it also decomposes the manure into a better fertiliser (high in ammonia and phosphorus), called sludge[7]. The fermentation of manure in addition reduces its contents of parasite eggs, after 30 days 90% of the eggs is dead (99% after 70 days), which in turn reduces the frequency of diseases. For further information about the fermentation process see appendix A.1. Another advantage of biogas is that it is burned with a significant higher efficiency, about 60 percent, compared to the other biofuels mentioned in this paper. Several hundreds of thousands of commune members were using biogas in the beginning of the 80s (van Buren 1981).

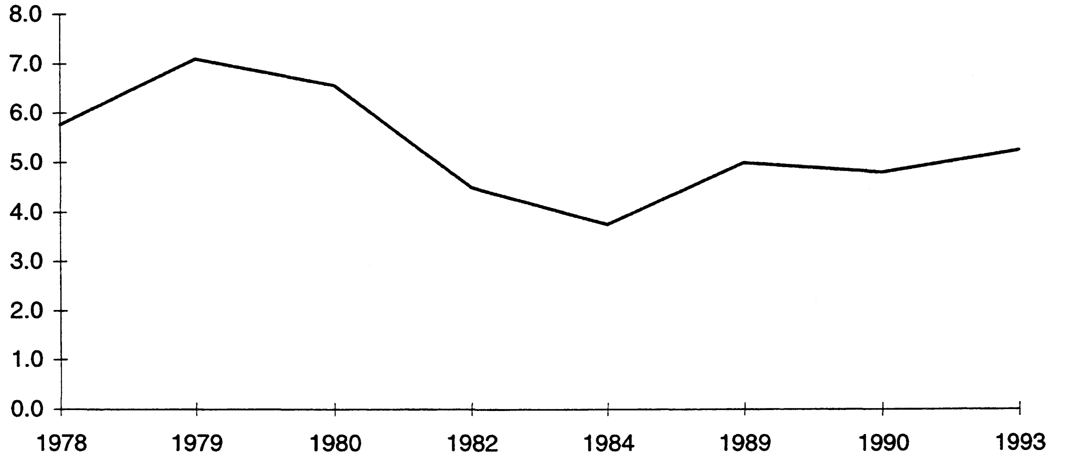
Biogas digesters that have been built in China are mostly small, meaning that they are only supposed to provide biogas to one or a few households. The average volume of the digesters is 8 m^3 (Smil 1988). To justify one of these digesters it requires four to five animals (Hall and de Groot 1987). By the end of 1993 there were about 5.25 million of these digesters belonging to rural households. United Nations[8] states that the annual production of biogas by rural households in China in 1993 was 1.2 billion m^3 ($2.4*10^{10}$ MJ[9]). The production in 1983 was $1.8*10^{10}$ MJ (Smil 1988). Biogas is insignificant compared with the consumption of the other three main sources of biomass energy, and accounts for only 0.3% of the total bioenergy consumption.

The number of digesters has more or less been constant the last ten years and the amount of biogas produced has therefore remained relatively stable. This might also be due to measurement failures.

[6] When only firewood or fuelwood is mentioned in the text, phytomass is included.
[7] The problem of leaching is, however, not reduced by using sludge as fertiliser.
[8] United Nations' internet site: www.un.org.
[9] 20 MJ/m^3 (UN 1991).

Keeping a digester productive is difficult, and is probably what cause a decline in the number of digesters from 1979 and up to now. Main challenges are keeping the digester air-tight and supplying it with the right mixture of manure, human wastes, straw, gras, water, etc.

Figure 3. Number of digesters in China. (Mill.)



Sources: He, Zhang and Ye (1996), Haugland and Roland (1990), Smil (1988) and UN[10]

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Appendix A

1. Technical information about the production of biogas

The fermentation process may be seen as two steps. First complex organic matter, such as carbohydrates and chain molecules is broken down into acetic acid, lactic acid, propanoic acid, butanoic acid, methanol, ethanol and buthanol, as well as CO_2, H_2, H_2S, and other non-organic materials, by bacteria. Then the simple organic compounds and CO_2 are either reduced or oxidised to methane by micro-organisms. (van Buren 1981)

$C_6H_{10}O_5 + H_2O$ - methane bacteria -> $3CH_4 + 3CO_2$ + heat

Individual reactions include:

1. Acid breakdown into methane
   $2C_3H_7COOH + H_2O \rightarrow 5CH_4 + 3CO_2$
2. Oxidation of ethanol by CO_2 to produce methane and acetic acid.
   $2CH_3CH_2OH + CO_2 \rightarrow 2CH_3COOH + CH_4$
3. Reduction with hydrogen of carbon dioxide to produce methane.
   $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

2. Parameters and coefficients

The parameters used in our calculations are **bold**.

Table A1. Crop residues

Crop	Crop residue ratios	Reference
Cereals	**1.3**	Smil (1988)
	3.0	Kossila (1984)
Wheat	**1.3**	IPCC (1996)
	1.3	Smil (1988)
	1.3	Kossila (1984)
	1.3	Strehler and Stützle (1987)
Barley	1.2	IPCC (1996)
	1.3	Kossila (1984)
	1.2	Strehler and Stützle (1987)
Maize	1.0	IPCC (1996)
	1.2	Smil (1988)
	3.0*	Kossila (1984)
	1.0	Strehler and Stützle (1987)
Oats	1.3	IPCC (1996)
	1.3	Kossila (1984)
	1.3	Strehler and Stützle (1987)
Rye	1.6	IPCC (1996)
	2.0	Kossila (1984)
	1.6	Strehler and Stützle (1987)
Rice	1.4	IPCC (1996)
	1.0	Smil (1988)
	1.3	Kossila (1984)
	1.4	Strehler and Stützle (1987)
Millet	1.4	IPCC (1996)

Table A1. cont.

Crop	Crop residue ratios	Reference
	1.4	Strehler and Stützle (1987)
Sorghum	1.4	IPCC (1996)
	4.0	Kossila (1984)
	1.4	Strehler and Stützle (1987)
Buckwheat	3.0	Kossila (1984)
Pulse	4.0[11]	Kossila (1984)
Pea	1.5	IPCC (1996)
	1.5	Strehler and Stützle (1987)
Bean	2.1	IPCC (1996)
	2.1	Strehler and Stützle (1987)
Soya	2.1	IPCC (1996)
	2.1	Strehler and Stützle (1987)
Tubers and rootcrops	**0.2**	Smil (1988)
	0.2	Kossila (1984)
Potatoes	0.4	IPCC (1996)
	0.4	Strehler and Stützle (1987)
Peanut (straw)	1.0	IPCC (1996)
	1.0	Strehler and Stützle (1987)
Nuts (dry)	2.0	Kossila (1984)
Feedbeet	0.3	IPCC (1996)
	0.3	Strehler and Stützle (1987)
Sugarbeet	0.2	IPCC (1996)
Jerusalem artichoke	0.8	IPCC (1996)
	0.8	Strehler and Stützle (1987)
Oilcrop	**0.6**	Smil (1988)
	4.0	Kossila (1984)
Sugar cane (fresh)	**0.2**	Smil (1988)
	0.25	Kossila (1984)
	1.16**	Strehler and Stützle (1987)
Cotton	**2.0**	Smil (1988)
Vegetables, melons etc. (fresh)	0.25	Kossila (1984)
Fruits, berries (fresh)	0.4	Kossila (1984)

* Straw and cobs.
** Bagasse

[11] Dry

Table A2. Output of animal waste

Livestock	Solid waste (kg/head/year)	Reference
Cattle	**800**	Smil (1988)
	900	IPCC (1996)
	1080	Strehler and Stützle (1987)
Buffalo	**800**	Smil (1988)
	1060	IPCC (1996)
Horse	**900**	Smil (1988)
	650	IPCC (1996)
	1080	Strehler and Stützle (1987)
Donkey	**800**	Smil (1988)
	360	IPCC (1996)
Mule	**800**	Smil (1988)
	360	IPCC (1996)
Camel	**800**	Smil (1988)
	990	IPCC (1996)
Hog/pig	**200**	Smil (1988)
	130	IPCC (1996)
	100	Strehler and Stützle (1987)
Sheep	**80**	Smil (1988)
	130	IPCC (1996)
	100	Strehler and Stützle (1987)
Goat	**80**	Smil (1988)
	140	IPCC (1996)
Chicken	12	Strehler and Stützle (1987)

Table A3. Energy contents

Energy source	Energy content	Reference
Crop residues	**14 MJ/kg**	Smil(1988)
	15 MJ/kg	IPCC (1996)
	14.1 MJ/kg	LBL (1992)
	12 MJ/kg*	Strehler and Stützle (1987)
	6 MJ/kg**	Strehler and Stützle (1987)
Animal dung	**15.5 MJ/kg**	Smil (1988)
	13.6 MJ/kg	UN (1991)
	12 MJ/kg	IPCC (1996)
Firewood	16.5 MJ/kg	Smil (1988)
	15 MJ/kg	IPCC (1996)
	15.2 MJ/kg	UN (1991)
	16.7 MJ/kg	LBL (1992)
Biogas	**20 MJ/m^3**	UN (1991)
	20 MJ/m^3	Strehler and Stützle (1987)

* Cereals straw and oil plant straw.

** Legumes and stalks from root and tuber fruits.

Table A4. Energy requirements

Energy requirement (MJ/capita/day)	Reference
35	Smil (1988)
43	Woodward (1980)

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