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MASTERARBEIT

CHINA BIOGAS POTENTIAL AND ITS ESTIMATED CONTRIBUTION TO CLIMATE CHANGE MITIGATION

von
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ZUSAMMENFASSUNG

China steht an der Spitze der Weltrangliste was den Verbrauch von Kohle als auch Stickstoff-Düngemittel betrifft. Das Land ist größter Produzent fester Abfälle wie auch von CO_2 und CH_4 Emissionen. Zugleich muss es mit einem der schnellsten Urbanisierungen aller Zeiten zu Rande kommen.

Um ein ausreichendes Energieangebot wie auch eine nachhaltige Sozial-, Wirtschafts- und Umweltentwicklung zu sichern, versucht China schon seit Längerem , diese Probleme in den Griff zu bekommen und sogar zu verringern.

Die Technologie der anaeroben Vergärung könnte einen großen, positiven Einfluss auf alle erwähnten Probleme nehmen und einen nicht unbeträchtlichen Beitrag auf dem Sektor der Erneuerbaren Energie leisten.

Eine Analyse von folgenden Biomasseressourcen wurde durchgeführt, um das theoretische Biogas-Potential einzuschätzen: Siedlungsabfälle (Hausabfall, Klärschlamm) und Agrarabfälle (Pflanzenrückstände und Tierdung). Diese Studie errechnet nur das Biogas-Potential der schon genannten Ressourcen, welche in mittleren und großen Biogasanlagen genutzt werden. Deponiegas, dezentralisierte Abwasseranlagen und kleine Hausanlagen werden nicht berücksichtigt.

Ein derzeitiges, theoretisches, Potential von 290 Milliarden m^3 pro Jahr wurde geschätzt, welches 6.9% der gesamten Energienachfrage decken könnte. Dieses Potential könnte bis zum Jahr 2030 auf 439.4 Milliarden m^3 steigen Energiepflanzen von Grenzertragsflächen mitgerechnet. Daher könnten Biogasanlagen mit einer Kapazität von 71.4 GW installiert werden und einen riesigen Beitrag zu den politischen Zielen der Erneuerbaren Energie leisten.

Der Gärrückstand, ein Nebenprodukt des Prozesses, kann als ein nachhaltiges Düngemittel verwendet werden. Bei der Behandlung der gesamten Rohstoffe, könnten beinahe 30% des anorganischen Düngemittels ersetzt werden und somit Chinas gesamte Nachfrage für Bio-Düngemittel decken.

Bei Behandlung der gesamten Rohstoffe im anaeroben Prozess könnten 4.75 Milliarden Tonnen CO_2 Äquivalente reduziert werden. Im Jahr 2030 würde diese Zahl sogar auf 7 Milliarden ansteigen.

Die enormen Mengen an derzeitigem und zukünftigem Biomassematerial zeigen nicht nur deutlich auf, dass diese Ressourcen bei weitem noch nicht ausgeschöpft sind, sondern, dass auch die politischen Ziele, welche die Entwicklung nachhaltiger Biogasenergie weiter vorantreiben (6.6% im Jahr 2010 und 10% im Jahr 2020), leicht erreichbar sind und sogar noch viel höher gesteckt werden könnten.

Stichwörter:

Stickstoffdünger, Anaerobe Vergärung, Erneuerbare Energie, Energiepflanzen, Grenzertragsflächen, Gärrückstand, CO_2 Äquivalente

ABSTRACT

China comes first on the world list as to coal and nitrogen-fertilizer consumption, solid waste production and CO_2 and CH_4 emissions. At the same time the country has to cope with one of the most rapid periods of urbanization in history. China is currently making many efforts to reduce and even to cope with these problems in order to ensure its energy supply and a sustainable social, economic and environmental development.

Anaerobic digestion technology could greatly impact on all the above-mentioned problems and positively contribute to the renewable energy sector.

An assessment of biomass resources was performed to evaluate the theoretical biogas potential from: household wastes (household waste, municipal sewage sludge) and agricultural wastes (crop residues, animal manure). This study calculates only the biogas potential of feedstock, which is used in middle- and large- scale biogas plants. Landfill gas, decentralized wastewater treatment systems and small household digesters are not included.

A theoretical current annual biogas potential of 290 billion m^3 was estimated, which could account for 6.9% of the total energy demand. Furthermore, the annual potential could increase to 439.4 billion m^3 by 2030 by including the feedstock energy crops from marginal land. Biogas plants with an initial capacity potential of 71.4 GW could, therefore, be installed and contribute more to the renewable energy targets as so far planned.

Digestate, a by-product of the process, is a sustainable green fertilizer. By treating the whole assessed feedstock, the digestate generated would replace nearly 30% of inorganic fertilizer and exceed China’s current demand for bio-fertilizer.

By using the anaerobic digestion process as the main treatment option for the selected feedstock, the current total reduction potential of CO_2 equivalents is 4.75 billion tons. By 2030 even 7 billion tons of CO_2 equivalents could be saved.

The current and future forecasts of the biomass availability highlights that the resources are far from being fully exploited, but they also show that the policy targets to develop sustainable biogas energy (6.6% by 2010 and 10% by 2020) could be easily reached and could be much more ambitious.

Keywords:

Nitrogen-Fertilizer, Anaerobic Digestion, Renewable Energy, Energy Crops, Marginal Land, Digestate, CO_2 equivalents

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ABBREVIATIONS

AD	Anaerobic Digestion
BMW	Biodegradable Municipal Waste
CER	Certified Emission Reduction
CDM	Clean Development Mechanism
CHP	Combined Heat and Power
CH_4	Carbon Dioxide
FYP	Five Year - Plan
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GW	Gigawatt
ha	hectare
IEA	International Energy Agency
IPCC	Intergovernmental Penal on Climate Change
km^2	square kilometres
MLSBP	Medium- and Large-Scale Biogas Plants
MOA	The Ministry of Agriculture
MSW	Municipal Solid Waste
MW	Megawatt

N	Nitrogen
NDRC	National Development and Reform Commission
NEA	National Energy Administration
Nm^3	normal cubic metre
NOx	Nitrogen Oxide
N_2O	Nitrous Oxide
PJ	Petajoule
PRC	People’s Republic of China
RMB	Renminbi
Tce	Tonnes of coal equivalents
TS	Total Solid
TW	Terawatt
UNFCCC	United Nations Framework Convention on Climate Change
VS	Volatile Solids

1 INTRODUCTION

At present, over 1.3 billion people live in the People's Republic of China (PRC), which is approximately 20% of the world population, with a growth rate nearly of 0.5%. (Index Mundi, 2011)

China´s economy is also growing rapidly; it is the second largest producer of electricity after the United States. Its energy demand is also the highest in the world (The World Bank, 2010). As indicated by the National Energy Administration (NEA), its primary energy consumption overtopped 3.07 billion tons of standard coal equivalent in 2009, i.e. an increase of 30% since 2005. (EMCA, 2011)

The PRC, therefore, ranks first in the list of the world's highest emitting countries. (EIA, 2009) However, with its low-carbon development strategy, the government of China has set an ambitious target for non-fossil energy consumption, which should increase to 15% by 2020. This would contribute to a reduction in the carbon dioxide emissions per gross domestic product (GDP) of 40% to 45% by 2020 in comparison with the year 2005. (EMCA, 2011)

In order to achieve these goals, the primary energy consumption should not exceed 4.2 billion tons coal equivalents within the period of China's 12th Five-Year Plan (FYP) (2011-2015). (EMCA, 2011)

In the last decades, renewable energy such as biomass, solar and wind energy as well as hydroelectricity has become a very important factor for energy supply and for making the climate change less severe. (Tang et al., 2010)

Bioenergy uses bio- organic materials, i.e. biomass for energy generation. Therefore, it includes materials of vegetable and animal origin as well as their waste products. However, before using them as renewable energy source, they have to be treated. Transportation, mechanical treatment and deposit must be done in such a way as to be able to coordinate the biomass produced with the energy demand. (FNR, 2005)

The following bio-energy technologies find application in China: biogas, syn-gases from straw and stalk gasification, electricity from biomass power generation, and various solid and liquid bio-fuels, such as bio-ethanol. (Wu et al., 2009)

This study deals with the technology of anaerobic digestion focusing on the main feedstock of China which is suitable for biogas generation, such as agricultural waste, i.e. crop residues and animal manure, household waste, i.e. the native organic fraction of household waste and municipal sewage sludge, and as well as energy crops from marginal land.

This thesis is divided into six parts, which are listed below:

Part 1 includes a literature review, which introduces the term of biogas in general as well as the technology of anaerobic digestion and its advantages.

It deals also with the development of the biogas sector in China and analyses the problems encountered. Furthermore, it shows the development of renewable energies and current policies concerning biogas energy, including the 12th FYP.

As a last point it gives an insight into China's Greenhouse gas (GHG) emissions and their national policy drivers to reduce them.

Part 2 assesses, based on present data, the amount, distribution, availability and the status- quo of the biogas energy potential of the PRC´s abundant biomass resources.

Part 3 assesses, based on present arisings, the energy potential in 2030.

Part 4 gives insight into how much of China's total energy demand could be met by the estimated biogas energy potential and could thus replace primary energy sources. In addition, present and future policies are seen in the light of biogas potential in order to demonstrate the current standing and resource utilization of biomass. Furthermore, discussions have been led whether China's policy targets are ambitious enough. The central point of discussion also concerns the potential of improvement and whether further investments should be made or not.

Part 5 deals with the German biogas sector and compares it with that of China.

Part 6 deals with the contribution of biogas energy to climate change mitigation. Calculations of saved amounts of GHG emissions are made using the total available biomass feedstock for biogas generation.

This study can be seen as a guideline for the responsible authorities for promoting and disseminating biogas technology in China but above all for raising awareness of the diverse uses of biomass.

2 LITERATURE REVIEW

2.1 Biogas and Anaerobic Digestion

Biogas is a gas produced during the biological breakdown of organic matter in the absence of oxygen, anaerobic digestion (AD), which can be used to provide energy. This technology has been used for more than 100 years under controlled environment. The biogas route map below illustrates that different type of feedstock can be used in a digester, for instance, animal manure, household organic waste, industrial food waste, sewage sludge, agriculture and forest residue, dedicated energy crops and many more. Biogas, produce the same manner, can also be gained from landfills, commonly known as 'Landfill Gas'. (Berglund, 2006)

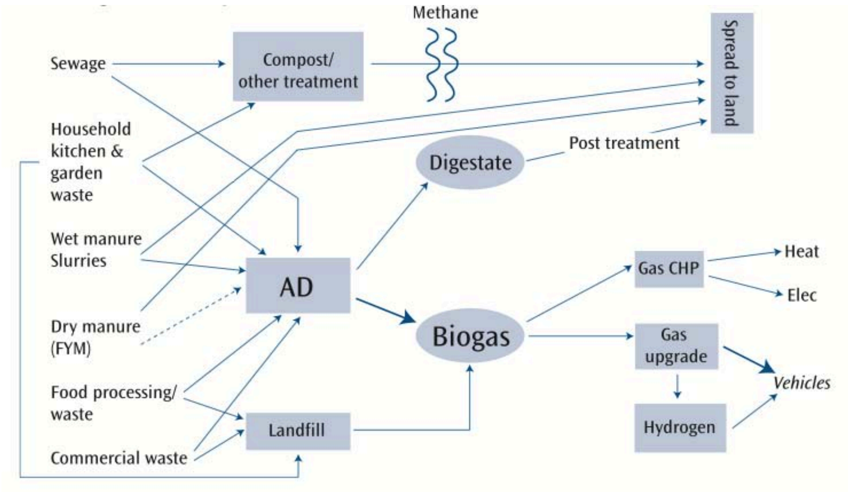

Figure 1 Biogas Route Map

(NSCA, 2006, p.6)

The raw biogas, generated in a controlled environment, is composed by methane (50-80%), carbon dioxide (20-50%) and trace elements like nitrogen and hydrogen sulphide. Besides being affected by the nature of different feedstock the composition of the gases is also influenced by a process design and the level of technology. (Berglund, 2006) By treating different kinds of materials at the same time, 'co-digestion', not only a higher content of methane but also a larger amount of treated feedstock can be achieved. Furthermore, a dilution or counteraction of inhibitors can be increased, resulting in operational advantages and improved overall process economics. (Feng et al., 2009)

This process produces not only a highly valuable gas but also a nutrient-rich digested mixture of liquids and solids as an end- product, which can be used as an organic fertilizer.

Besides the highly valuable gas, the nutrient-rich digested mixture of liquids and solids is also generated as an end product out of this process, which can be used as an organic fertilizer.

Biogas can be used e.g. in small-scale domestic units or can be converted into power & heat in engines, gas turbines or fuel cells. However, as to the last mentioned use, this gas must almost reach the quality of natural gas by undergoing an upgrading process.

The technology of AD offers an efficient and environmental-friendly solution in many sectors such as organic waste management, transportation, renewable energy development, climate change mitigation, biodiversity and many more. (Berglund, 2006)

2.2 Biogas Development in China

In former days, China’s biogas industry mainly focused on small rural household biogas digesters using livestock and poultry manure as a feedstock.

Since 1950 over 35 million household scale anaerobic digesters with an annual biogas output of about 12 million cubic meters (m^3) have been installed and this number should be increased to 80 million units by 2020.

On the basis of national renewable energy legislation, the aims to be achieved are changing from the environmental benefits of digestion to gaining energy out of this technology. In recent years, the country has put a focus on building medium- and large-scale biogas plants (MLSBP), located around large cities, which use diversified feedstock for biogas production. (GIZ, 2011a)

Figure 2 gives a clear picture of the rapid gain in importance of the biogas energy sector in the last few years.

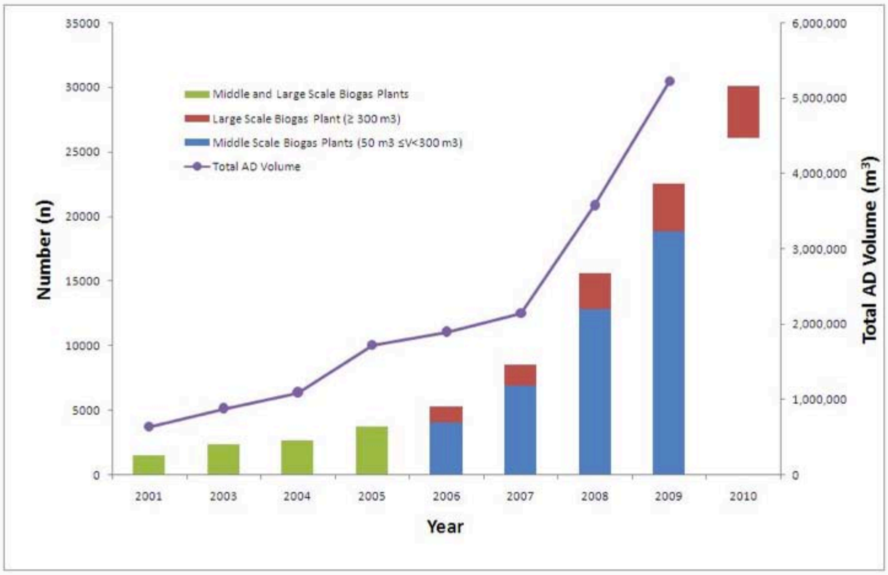

Figure 2 Middle- and Large-Scale Biogas Plants Developed in China, Number of Plants and Fermenter Volume 2001-2010

(GIZ, 2011a)

Until 2009 about 34,000 small-scale biogas plants and 22,900 medium- and large-scale biogas plants (Fermenter > 50 m^3), with 3,717 large scale installations (Fermenter > 300 m^3) were built. A biogas-driven power generation with a capacity of 42 MW electricity was established. (GIZ, 2011a)

2.2.1 Current Biogas Plant Performance

The last decade rapid developments is due to the large investment of about 24.2 billion Renminbi (RMB), i.e. 3.8 billion U.S. dollars, made by the government during the period from 2003 to 2010. The financial support of the local governments and of course plant owners for the construction of biogas plants should also be mentioned. (Li et al., 2011) However, the Chinese biogas sector faces some major problems.

Their standard cannot compete with international performance as insufficient specific biogas is available, i.e. not enough is produced and thus, there is no process of controlling and monitoring. Furthermore, the PRC does not have relevant know-how regarding the design and operate the pre-treatment equipment. (MPRA, 2010)

So far, just three plants have been connected to the electrical supply network and only seven units of them are ‘Clean Development Mechanism’ (CDM)-Projects whereby only two can generate some CDM carbon credits based on certified emission reduction (CER). China has enhanced the building of plants by financially supporting them, yet the running of the plants as well as the use of gas and digested, have not been taken into account. (GIZ, 2011a)

2.3 Policy Targets concerning Renewable Energies with special Focus on Biogas Energy

Since a further increase in population, urbanization, industrialization and residential energy consumption is predicted the country has to cope with enormous challenges that are treated by large-scale policy programmes and renewable energy development. (The World Bank, 2010 and NDRC, 2007a)

Besides the coal reserves, on which China mainly relies, the country provides a rich array of renewable energy due to its expansive territory and diverse landscape. (Martinot et al., 2007)

In the “Medium and Long Term Development Plan for Renewable Energy in China” the National Development and Reform Commission (NDRC) states that by 2010, China is willing to achieve 10% of the total primary energy consumption from renewable sources, which has been successfully achieved. By 2020, this share will even be increased to 15%. (NDRC, 2007a)

China will have more than 360 Gigawatts (GW) of renewable energy by 2020, provided all the aims concerning renewable power are achieved. (Martinot et al., 2007)

Table 1 shows the set targets for energy production from different kind of renewable sources.

Furthermore table 2 summarises specific and ambitious policy targets concerning the development of the biogas sector in China. The goals for the year 2010 were already successfully achieved.

Table 1 Renewable Energy Capacity Targets

Type	2010 Target	2020 Target
Energy from Renewable Sources	**10%**	**15%**
Hydropower **Small Hydropower**	190 GW 50 GW	300 GW 55 GW
Wind power	10 GW (5 GW)	100 GW (30 GW)
Solar PV	0.3 GW	20 GW (1.8 GW)
Solar water heating capacity	150 million m^3	300 million m^3
Biomass power (agriculture/forestry)	5.5 GW	30 GW
Biogas	**19 billion m^3** **(MLBG 4 billion m^3)**	**44 billion m^3**
Bioethanol	3 million tonnes	10 million tonnes
Biodiesel	0.2 million tonnes	2 million tonnes

(NDRC, 2007b and The China Greentech Initiative, 2009)

Table 2 Targets of Biogas Energy Generation

Type of Biogas Plant	2010 Target	2015 Target	2020 Target	Policy
Large-scale Biogas Plants, Production from agricultural and industrial	0.8 GW		3 GW	NDRC, Medium and Long-Term Development Plan for Renewable Energy in China
			10,000 large-scale on livestock farms and	(The Ministry of Agriculture) MOA, National Rural

feedstock	4,000-4,700 units		6,000 industrial organic sewage treatment plants (with 14billion m^3 biogas/a)*	Biogas Construction Plan, China, 2003 and 2007
Small-scale Biogas Plants	11 million m^3 40 million rural households	60 million rural household	18 million m^3 80 million rural households	NDRC, Medium and Long-Term Development Plan for Renewable Energy in China
Straw Biogas Plants	100 units	500 units	1,000 units	MOA, Development Plan on Agricultural Biomass Industry, 2007–2015 and PRC, Renewable Energy Law
Biogas generated from municipal wastewater & septic sludge treatment	100 million m^3			NDRC, Medium and Long-Term Development Plan for Renewable Energy in China

*Note: * 3 connected to grid*

As indicated in Table 1, China relies and invests mainly on renewable energy, such as water and wind.

In 2009 China topped the world list of water- power and was ranked 5 of the world list of wind power in 2009. (EIA, 2011)

Investment in biomass power falls far behind these other two resources.

2.3.1 The 12th Five - Year Plan (2011-2015)

China´s current Five-Year Plan foresees a growth of the biogas sector.

The Five-Year Plans of the Peoples Republic of China are a series of economic and social development initiatives, drafted by the Communist Party of China. In the 11th FYP (2006-2010) China, for the first time, set some goals concerning the sustainable development of an environment and energy policy. The 12th FYP (2011-2015) puts even more emphasis on sustainability, such as ‘Green Development’, and ‘Low Carbon Development’. For the first time, market mechanisms such as the planned Emissions Trading Scheme are used and this should lead China to more successful results. At present, groups of professionals are working on the detailed implementation concepts, which will be released in autumn 2011. (GIZ, 2011b)

2.3.1.1 Objectives of the Biogas Sector Development until 2020 and later

China´s current Five-Year Plan foresees a growth of the biogas sector.

The following paragraph lists the aims concerning development in the biogas sector:

1. Diversification of bio-energy based on local circumstances with great emphasis on large-scale plants, which utilize biogas for electricity and heat supply.

2. In 2020 the total amount of all kinds of bio-energy utilization will be over 40 million tons of coal equivalents, and 50 million units of household digesters should be developed. The installed capacity of biogas power generation will be 2 GW, and 12 billion kWh will be produced.

3. The target of the 5-FYP is to build 10,000 small and 1,500 middle and large scale biogas plants (MLBGPs, >300m^3 digester volume per year in 31 provinces and 2000 counties till 2015. From current 2% of the breeding farms 20-30% shall be equipped with biogas plants. Feedstock will be manure, straw and other bio-waste. (MOA, 2011)

4. Biogas and especially bio-methane to be from increasing importance for the rural renewable energy supply and nutrient cycles. The use to households through compressed bio-methane (CBM) in local gas grids will be supported

and, biogas upgrading shall be applied for projects between 50 and > 2000 m^3 biome than per day. (MOA, 2011)

5. Problems of low productivity and low lifetime of Biogas plant shall be solved. Biogas plants shall mostly follow international state of the art technology with high performance based on a sustainable business concept. (MOA, 2011)

6. 55 fermentation plants with a total capacity of 10,000 tons/day for restaurant and kitchen waste from households are to be built in 33 cities. This should be a good starting point for separate collection of the biogenic fraction of household waste in the future. (MOA, 2011)

7. Improving gas grid constructions and supply of public service systems. Thus, the large-scale biogas project and large-scale biomass gasification project could provide gas to additional 3 million households in 2015. By 2015, 200 “Green Energy Demo Counties” and 10,000 “New Energy Demo villages” (an average of about 300 households) will be built. The government will subsidize infrastructure constructions, including gas grid, gas storage and purification. (NDRC, 2011)

To sum up one may say that the 12th FYP does not consider the development of biogas at first sight but considering the impact of the anticipated measures, there are great opportunities for the industrial scale biogas sector and its development, which is supposed to boost during this period. (NDRC, 2011)

2.4 Greenhouse Gas Emissions and Climate Change

The PRC, with its huge area and number of inhabitants, and its enormous geographical, cultural and social diversity, faces massive ecological problems. The impact of climate change is already present and visible in a changing environment and overstrained ecological systems resulting in extreme weather conditions such as major storms, flooding, heat and drought. Melting glaciers, shortage of drinking and irrigation water, reduced biodiversity, destroyed landscapes, soil degradation, loss of arable land, desertification and land contamination are some of the severe effects of these changes. (UNFCCC, 2007)

According to the International Energy Agency (IEA, 2009a), in 2009, China´s energy sector emitted 7.5 billion tonnes of carbon dioxide (CO_2) equivalents and since 2007 China has been leading in global CO_2 emissions worldwide. China has already overtaken the United States in its output of carbon dioxide emissions.

Besides the enormous release of CO_2 emissions, China is also at top of the list of emission of anthropogenic methane (CH_4). (EPA, 2007) Methane has a much higher greenhouse gas potential than carbon dioxide. This gas is naturally produced by agriculture (manure management), coal mines, landfills, natural gas and oil systems. (IPCC, s.a. and EPA, 2011)

In order to comply with the non-binding agreement of the UN Climate Change Conference in Copenhagen (2009), an increase in the global temperature of not more than 2°C should be avoided, i.e. the temperature should not exceed the degree that it was when industrialization began. Therefore, a massive reduction in GHG emission is obviously required. (UNFCCC, 2009)

2.4.1 National Policy Drivers for Greenhouse Gas Emission Reduction

China has set itself ambitious ecological policy targets by contributing to the main goal of reducing CO_2 emissions.

Concerning the agreement on the low-carbon development, China aims at increasing the amount of non-fossil energy of 15% by 2020 and within the period from 2005 to 2020 a reduction of CO_2 emissions of 40% to 45% per unit of GDP is foreseen. (NDRC, 2007a) The GHG emissions would, thus, also be reduced. Yet, China's economic and technological growth and its further dependence on coal should be taken into account.

According to the NEA, China´s primary energy consumption must not exceed 4.2 billion tonnes in the period of the 12th Five-Year Plan (2011-2015) in order to achieve these goals. (EMCA, 2011)

3 METHODOLOGY

3.1 Introduction

The aim of this paper is to give an extensive and detailed presentation of all selected kinds of feedstock for the generation of biogas, which is the result of thorough research and discussions with various experts.

As already mentioned in the previous chapter, this study assesses the current and the future feedstock such as household waste and municipal sewage sludge, agricultural waste including crop residues, animal manure and energy crops from marginal land for biogas energy.

It also estimates to what extent biogas could meet China's energy demand and how much GHG can be saved.

The study is divided into four main parts, such as

- ✓ Current Feedstock Levels, Distribution and Biogas Energy Potential
- ✓ Future Feedstock Levels and Biogas Energy Potential
- ✓ The Contribution of Biogas to the total Energy Demand; Potential versus Production, including Policy Targets
- ✓ GHG Savings – The Contribution of Biogas to Climate Change Mitigation

The chapter 'Methodology' is divided equally.

The first two parts explain all the different processes used for estimating the current and future amount of feedstock. The data collection was done using published international papers and Chinese governmental reports. The data was scanted and different for each feedstock identified. Therefore an individual method of feedstock estimation as well as biogas potential calculation had to be chosen for each kind of feedstock.

Besides collecting and selecting of data, basic statistical analyses were made. Microsoft Excel has been used to perform the calculations and draw graphics.

3.2 Current Feedstock Levels, Distribution and Biogas Potential

3.2.1 Household Waste

Information Source:

The Sino-German RRU-BMW Project (Resource recovery and utilization of bioorganic municipal waste) conducted from 2005 to 2009 (Raninger et al., 2006, Raninger et al., 2009) collected data on the estimated potential of organic household waste in China as well as the quantity, quality and composition of Municipal Solid Waste (MSW). Furthermore, the participation of the population in waste separation, especially organic waste, has been conducted.This project was carried out in four communities in Shenyang and was taken as a basis for this paper in making assumptions of the current amount of the biodegradable fraction within household waste.

Table 3 Data on Household Waste

Data	***Source***
Total Urban MSW: 360 million tons	*Raninger, 2011*
Organic Fraction within MSW: 80%	*Raninger et al., 2006*
Biogas Potential: 100 m^3/t FM	
Total Solid (TS) content: 35%	
Volatile Solid (VS) content: 80%	*Steffen et al., 1998*
Waste in Cities	
Urban Population China: 621,860,000	*NBSC, 2010a*
Generation of MSW: 0.9kg/c/d	*Raninger et al., 2006*
MSW Generation: 200 million tons	
Waste in Counties	
Population in Countries: 626,223,092	
Generation of MSW: 0.7kg/c/d	*Raninger, 2011*
MSW Generation : 160 million tons	

Assumptions:

The current collected amount of Biodegradable Municipal Waste (BMW) is mainly landfilled at present. It could, however, become a highly valuable resource for biogas production.

On the basis of the European Union Landfill Directive of 1999**,** landfilling of bio-organic wastes is going to be prohibited in Europe (65% reduction until 2016) (The Council of the European Union, 1999). Since 2005 only waste material consisting of up to 5% bio- organic matter (3% total organic carbon) has been disposed of in Germany and Austria. (BMJ, 1991) It is, therefore, expected that earlier or later China will not allow the landfilling of organic waste either. This study assumes that all the generated organic waste can be collected in order to gain biogas energy out of it rather than being lost in landfills. It has to be mentioned that due to various reasons Landfill gas collection does not be effective at landfills in China, which excluded this way to generate reasonable amounts of Landfill-bio-gas, it works somehow in industrialised countries. (Raninger, 2010)

This study assumes that all the generated organic waste is collected separately from the waste stream and can therefore be used for producing biogas energy out of it rather than being lost in landfills.

3.2.2 Municipal Sewage Sludge

Data used to estimate the current production and the total biogas potential of sewage sludge are summarized in the following table.

Table 4 Data on Municipal Sewage Sludge

Data	Source
Population in cities and counties: 1,248,083,092	
22% of the total amount are treated: 80,000 t/d, Total: 133 million t/a	*Li, 2011*
Biogas potential: 0.027m^3/d/c	*Lindeburg, 2011*
TS content: 20%	*Raninger, 2011*

3.2.3 Crop Residues

Information Sources:

In order to obtain the current available amount of crop residues, China's main eight kinds of crops were chosen and the amount of arising has been taken from the 'China Statistical Yearbook 2010' (NBSC, 2010b) (see Table 5). Numbers of arising and energy potential of agricultural by-products such as rice hull, corncob and bagasse has been taken from the 2nd Volume of the 'Study of Potential and Constraint of the Biomass Sector in China' conducted by the Europe-China Clean Energy Centre (ECCEC, 2011). Information, about the current distribution has also been taken from ECCEC, as well as from the study by *Zhong et al.* (2003).

Data Recalculation:

All the results achieved from the current situation as well as from energy potentials are based on a recalculation of original data. On the basis of indices for straw: crop conversions and the energy content within the crop residues taken from different studies, calculations were made estimating the biogas potential.

Table 5 Data on Crop Residues

Biogas Potential: 300m^3/t FM	*Raninger, 2011*

Current Situation, Biogas Potential:

Table 6 Productivity of Crop Straw in 2009

Crops	Yield of Crops (10^4 t) *(1)*	Index of straw:crop *(2)*	Yield of residues (10^4 t)	Proportion (%)	Biogas potential (10^9 m^3)
Rice	19510.3	0.623	12155	16.3	36.5
Wheat	11511.5	1.366	15725	21.1	47
Maize	16397.4	2	32795	44.1	98
Beans	1930.3	1.5	2895.5	3.9	8.7
Tubers	2995.5	0.5	1497.8	2	4.5
Oil bearing crops	3154.3	2	6308.6	8.5	19
Cotton	637.7	3	1913.1	2.6	5.7
Sugarcane	11558.7	0.1*	1155.9	1.6	3.5
Total	67695.7	--	74445.9	100	222.9

*Note: * Sugar crops, ** Legume, ***Peanuts*

(1) NBSC, 2010b, (2) Wang, 1994, (3) Luo, 2011

Current Utilization and Availability of Energy Usage

Figure 3 shows the current utilization of crop residues. However, according to *Shi* (2011), approximately 60% of the total crops of straw could be used for energy generation.

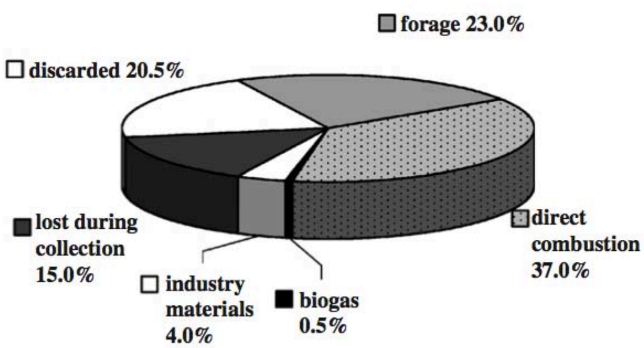

Figure 3 Current Utilization Situation of Crop Residues in Rural China

(Liu et al., 2007, p. 1408)

3.2.4 Animal Manure

Information Sources:

In order to estimate the amount of animal manure generated in one year, this study focuses on China´s three main kinds of animals kept and bred on farms, such as pigs, cows and poultry.

Data on the current number of animals were used on the basis of the ‘China Rural Statistical Yearbook 2010’.

Information about the distribution of large and medium-sized farms was taken from the *ECCEC* (2011).

Data Recalculation:

In order to estimate the biogas potential, the conversion table from the interim report from the Asia Development Bank (ADB, 2009) was used. It provides data about the generated amount of manure (kg/d/c), the chemical oxygen demand (COD) (kg/d/c) as well as its converting factor to biogas used in China. The conversion is as follows: 1kg COD = 0.23 m^3 biogas. Data on the collectable amount of manure used from *Shi*'s study (2011) are considered and included in the calculations.

Table 7 Average Production of Animal Manure and Biogas in 2009

Animals	Population on hand (10^4) (1)	COD (kg/d/c) (2)	Biogas potential (10^9 m^3 /a)
Pig, total	46996	0.6	23.7
Cow, total	10726	5	45
Poultry, total	533000	0.02*	8.9
Total	590722	--	77.6

*Note: * Layer chicken*

(1) NBSC, 2010c, (2) ADB, 2009

Current Utilization and Availability for Energy Usage

According to *Cui et al.* approximately 35-40% remains untreated, 50% is returned to the field directly, 5% are composted, and only 3% is going to methane fermentation. (Cui, 2005)

Beside the 3%, which is already in use, a utilization factor of 43% is taken for the calculations, assuming the huge untreated amount can be fully made use of.

3.3 Future Feedstock Levels and Biogas Potential

The year 2030 was chosen to show the further increase in amount and biogas energy potential of each feedstock in the future.

3.3.1 Household Waste

Assumptions:

In order to predict the future potential of China´s household waste for biogas production, the following assumptions are made.

As a result of the rapid urbanization, 1 billion people will live in urban areas by 2030. (McKinsey&Company, 2008) Therefore, only 50% of the counties` population are still remaining in the counties, which results in 313,111,546 people.

There are contradictory predictions in various studies as to the amount of organic waste produced by people in the future.

According to a study analysing the situation in the US, the organic fraction in the MSW will diminish, as people will use more ready-made package foods and microwave ovens. (Daskalopoulos et al., 1998) The World Bank estimates that even if a larger amount of packaging waste, paper products and plastics and a smaller amount of coal ash for heating compared to gas will be used in households, the amount of the organics will still be more than 50% of the waste stream by 2030. (The World Bank, 2005) The changes in lifestyle and growth in wealth predicted for the future will entail an increase in money spent for food. (Ru et al., 2010) Materials suitable for recycling are recovered by cheap labour and have a market value in China also this trend most likely will remain (Raninger, 2009). Therefore this study assumes that the organic fraction of MSW will remain nearly the same.

3.3.2 Municipal Sewage Sludge

Assumptions:

In order to estimate the amount generated only the rapid urbanization, i.e. the population will rise to 1 billion people by 2030, is considered in these calculations. (McKinsey&Company, 2008)

3.3.3 Crop Residues

Assumptions:

The following graph shows a clear continuous rise in the production of total crops in the last 10 years. Therefore, a further increase in the future can also be assumed.

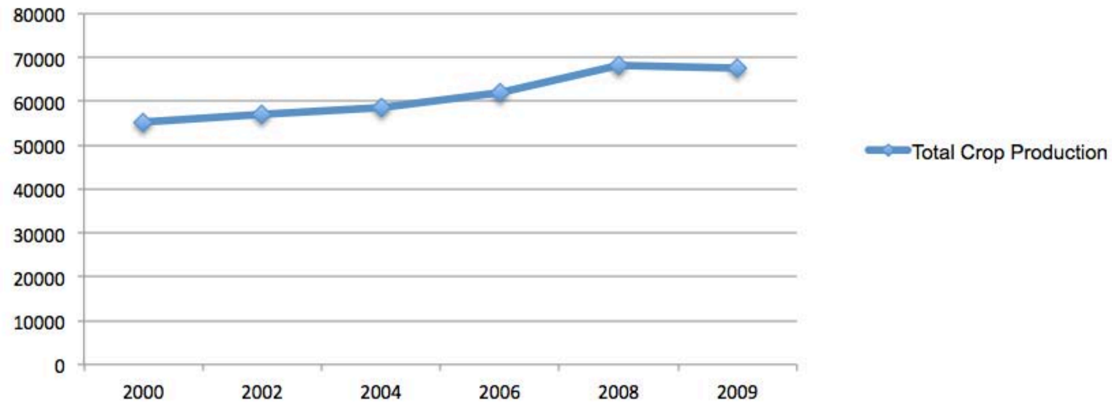

Figure 4 Total Production of Eight Different Kinds of Crops from 2000 to 2009 in Rural China
(unit: 10^4 tonnes)
Source: see Appendix, 7.1

Due to the regional and climatic situation, the increase of crops will be limited. But according to many studies, one of the most influential factors for future development of farmland is national land use planning. (Hu, 2010a)

There will be also a rise in the population in the future and changes will take place concerning land use, which would entail a continuous decrease in the entire farmland area as well as in the farmland area for each person.

The Government of China sees to it that there will be no shortage of food by making sure that arable areas are never less than 1.8 billion Chinese mu, i.e. 120 million ha. By 2020, arable land should still be about 1.805 or 1.818 Chinese mu. (Hu, 2010a)

It can also be predicted that mechanized farming as well as the use of chemical fertilizers will increase whereas manual work in the fields is going to decline. This would result in a decrease in 'collection loss' and direct returns to the fields. (Liu et al., 2007) Therefore, more feedstock will be available for energy production and the organic fertilizer, which is a highly valuable product gained out of the biogas process, could further be used in the field in order to ensure sustainable agriculture.

Liu et al. (2007) calculated the crop residues increase rate since the 1970s whereby the average rate has been about 1.2% in the last twenty years. This seems to be a constant index and is also used for prediction until 2030.

3.3.4 Animal Manure

Assumptions:

On the basis of the 'China Rural Statistical Yearbook' from 2000 until 2010, calculations on the situation of three different kinds of livestock such as pigs, cows and poultry during the last 10 years are made in order to predict the increase of animal manure. The numbers have been added together in order to calculate the increase in percentage over these years.

The following figure shows the continuous increase in livestock for the last 10 years. It is assumed that the average rate of 12% between the years 2000 and 2009 will stay the same.

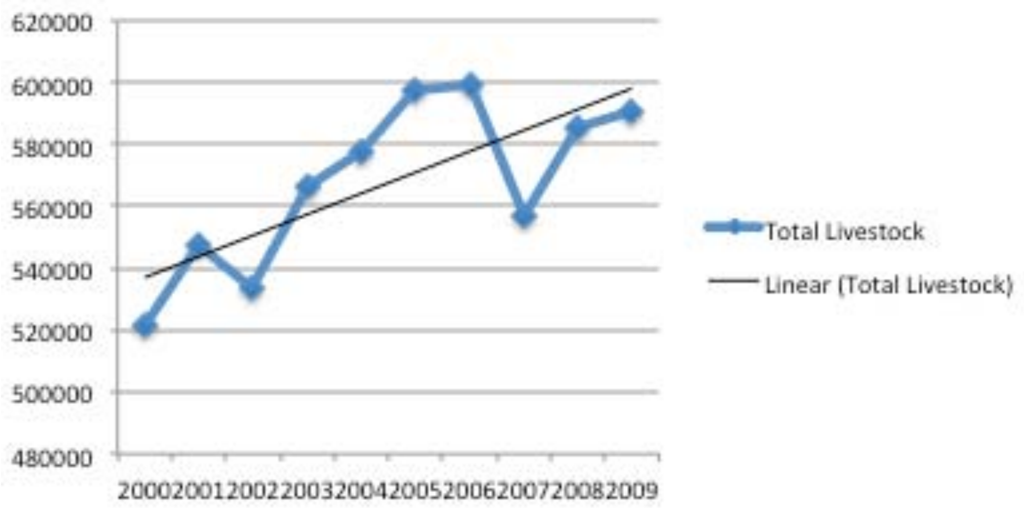

Figure 5 Total Arising of Livestock from 2000 to 2009
(unit: 10^4)
Source: see Appendix, 7.2

3.3.5 Energy Crops from Marginal Land

Information Source:

This part of the study is mainly based on one of the latest studies of “China´s Biomass Resources” published in 2011 and conducted by *Shi Yuanchun*.

Assumptions and Data Recalculation:

Evaluation of biogas potential is performed in the following steps:

Step 1: Marginal land appropriate for growing energy plants was analysed. The crucial results were the size, composition and distribution of marginal land in China.

Step 2: Exploration of energy plants that are suitable for biogas production was made and what amount and species of plants can be grown per ha were taken account of in the calculations in order to gain data about how many tonnes of plants are available for the entire generation of energy.

Step 3: The Biogas potential of the amount of different kinds of plants has been estimated.

<u>Definition of ‘Marginal Land’</u>

In order to estimate the available size of marginal land, one must first define what is meant by marginal land. However, no reliable source concerning the definition of marginal land has been found as data vary very much, and researches choose different kinds of species for their evaluation.

‘Marginal land’ has been used in this study as ‘the land which has poor natural conditions, has not been used for agriculture currently but has production potential and development value to produce a certain amount of biomass. Such land is not fit for farmland temporarily, but can grow some kinds of plants with high adaptability’. (Hu, 2010a)

The marginal land, which is used for growing energy plants, consists of woodland (shrub land and sparse forest land), grassland and land without vegetation including shoal/bottomland, saline and alkaline land as well as plain land. (Zhuang et al., 2010)

Size and Composition of Marginal Land Suitable for Energy Plants

The estimated figure concerning the size and composition of marginal land is based on factors such as land use data, terrain data (like elevation and slope), meteorological data (including precipitation data and air temperature data) and soil characteristics.

The following table illustrates the percentages of marginal land, ‘wasted marginal land’, which is still uncultivated land and cultivated land, called ‘current marginal land’.

Table 8 Marginal Land Resources Suitable for Producing Biomass Feedstock

Type		Area (in ha)	Percentage
Wasted marginal land	Total	8 491	51.9%
	Suitable for farmland	2 787	17%
	Suitable for forest	5 704	34.9%
Current marginal land	Total	7 883	48.1%
	Marginal farmland	2 000	12.2%
	Marginal forest	5 883	35.9%

(unit: 10^4 ha)
(Modified according to Shi, 2011, p. 20)

Biogas Potential:

In order to compare the overall outputs, the yield per hectare is a better measurement, due to different climate conditions. Table 8 shows the distribution, the unit output of major biomass plants as well as their biogas energy potential.

Table 9 Potential Energ Output of Biomass Plants of China's Marginal Land

Type of marginal land	Area/ 10^4 hectares (1)	Suitable energy plants and area percentage (1)	Energy Output (tce/t.ha) (1)	Energy Potential (10^4 tce) (1)		Unit output (t/hectares FM) (1)	Biogas energy potential (10^9 m^3 VS)
Suitable for farmland	2 787	Sweet sorghum, 35%; Sweet potato, 15% (north);	2-3	22 140		60-80 (stalks) 15-20	205 25
Current marginal land	2 000	Cassava, 35% (south) Sorghum, 15% (south)	4-6			20-30 60-80 (stalks)	53 63
Barren mountain	5 004	Energy 60%	3.3	9 908		6.5	59
		Oil plant forest 20%	1.8	1 801		4.0 (seedlings)	12
		Energy crop 20%	3-5	4 003		6.5	20
Desert	700	Xerophyte shrub	2.6	1 820		4.0*	8.4
Firewood forest	175	Firewood forest	4.2	735		4.0**	2.1
Oil plant forest	343	Oil plant forest	1.8	617		4.0 (seedlings)	4.1
Shrub wood	5 365	Shrub wood	2.6	13 950		4.0	64
Total	16 374	--		54 974		--	515.6

*Notes: *oil plant forest, **shrub wood*
Source: (1) Shi, 2011

The following data were used to calculate the biogas potential.

Table 10 Data on Energy Crops from Marginal Land

Data	Source
Biogas potential: 300m^3/t VS	*Braun et al., 2010*
Reference Plant: Miscanthus TS content: 30% (m/m FM) VS content: 67% (m/m DM)	*Jewell et al., 2003*

3.4 Biogas’ Contribution to the Total Energy Demand; Potential versus Production, including Policy Targets

This part covers the potential contribution to the total energy demand in 2010 as well as in the next 20 years of the current and of the future arising in feedstock, calculated in the first two parts of the study. Moreover, a comparison is made between the biogas energy targets as specified in China’s Renewable Energy policy targets for the next 10 years and the current energy potential of the feedstock which is already used in China, such as municipal sewage sludge and agricultural biomass waste.

Table 11 Data on Biogas Energy Potential

Data	Source
$1m^3$ of Methane: 9.97 kWh	*FNR, 2011a*
$1\ m^3$ of Biogas: 1.8 kWh electricity	

3.5 GHG Savings – Biogas’ Contribution to Climate Change Mitigation

By taking a first look at the current amount of GHG emission in China per year, this section covers the estimation of the saved amounts of CO_2 equivalents by using the total available biomass feedstock for biogas generation.

Assumptions and Calculations:

There are three ways to avoid GHG emissions by generating biogas out of an AD process. Additionally, CO_2 emissions can also be saved, if a certain amount of crop residues is no longer burnt on open fields.

Table 11 shows a summary of the results from Part 1 of the study. These data as well as the figures from Table 12 have been used to estimate the saved amounts of emissions in CO_2 equivalents.

Table 12 Amount, Energy Potential and Methane Content of the Different Kinds of Feedstock and Amount of Crop Residues

Type of Feedstock	Available Amount (10^6 tons/a)	TS content (%)	Biogas potential (10^9 m^3/a)	CH_4 content, assuming 60% of biogas (10^9 m^3/a)
CURRENT LEVELS				
Household Waste	291	35	29.1	
Municipal Wastewater Sludge	133	20	12.3	
Crop Residues (Straw)	581	40	215	
Animal Manure	658	4	33.4	
Total	1663	--	290	174
	37% of total			
Crop Residues	215			
FUTURE LEVELS				
Household Waste	327	35	33	
Municipal Wastewater Sludge	141	20	13	
Crop Residues (Straw)	588	40	218	
Animal Manure	737	4	37.4	
Energy crops (40%)	680	30	138	
Total	2473	--	439.4	264
	37% of total			
Crop Residues	218			

Table 13 Global Warming Potential$_{100}$ of Gases

Gas	Value (in kg CO_2 equivalents)	Source
CO_2	1	IPCC, s.a.
CH_4	23	
N_2O	296	
NH_4NO_3 as N	7.2	Williams et al., 2006

3.5.1 Gaining Electricity out of a Renewable Energy Source; Replacing Coal

This section estimates the amount of GHG emissions, which can be avoided by replacing coal by energy gained from the anaerobic digestion process producing the same amount of power.

As a first step, the amount of electricity produced out of the total amount of biogas energy potential of the total feedstock is calculated below.

This calculation assumes that the heat of the CHP process is not used. Therefore, the calculation, which is stated below slightly underestimates the amounts of saved CO_2 emissions.

- **Methane (m^3) x Calorific Value of Methane (MJ/Nm^3) x Efficiency of CHP**

Furthermore, calculations are made as to the sum of emissions that are released by generating the same amount of power by using coal as energy source. As a last step these two numbers are compared.

Table 14 Data on GHG Savings - Calculation No. 1

Data	Source
CV of CH_4: 36MJ/Nm^3	FNR, 2011a
CHP Efficiency (only electricity): 35%	FNR, 2005
Emission intensity of conventional coal: 1.186 CO_2 /MWh	Wang et al., 2009

3.5.2 Choosing Anaerobic Digestion instead of Landfilling as a Waste Treatment Option

In this section, only two kinds of feedstock, namely household and agricultural biomass waste, are looked at. Energy crops are planted with the purpose of generating energy from them. Therefore, landfill is no option for this resource.

First, emissions generated by landfilling as well as during the anaerobic digestion process are calculated and in a second step are compared. The additional amount of emissions, which are generated by landfilling, can be avoided by choosing the more environmental friendly option of anaerobic digestion.

This calculation assumes that not all the landfill sites are controlled. Rather than collecting methane and using it as a renewable energy source, the gas is venting into the atmosphere. Furthermore, it has to be mentioned that methane emissions of landfill sites will take longer to emit into the atmosphere than during an AD process, even Chinese easy decayable bioorganic waste fraction converts very fast into leachate and some biogas. (Raninger, 2010)

For these calculations the following equations have been used:

- **Emissions of Landfill = 2.46 t CO_2 equivalent/t of waste**
(The World Bank, 2005)

- **Emissions of Anaerobic Digestion = Methane (m^3) (CO_2/ CH_4)* x (kg CO_2/Nm3 CO_2)** x GWP of CO_2**

Explanations of Formulas:

* This formula stands for the amount of CO_2 received, when CH_4 is burnt. It depends on the units of methane. Because of the stoichiometric ratio for combustion, which is stated below, the ratio between Nm^3 (normal cubic metre) of methane and carbon dioxide is one.

** As gas yields are calculated in m^3 and tons of CO_2 are to be calculated, this figure must be converted. This is, thus, indicated as: '(kg CO_2 /Nm^3 CO_2)'. Thereafter, it has to be further multiplied by the density of each gas.

Stoichiometric ratio for combustion:

$CH_4 + 2\ O_2 ==> CO_2 + 2\ H_2O$

Table 15 Data on GHG Savings - Calculation No. 2

Data	Source
Density of CO_2 : 1.977kg/m^3	O'Leary, 2000

3.5.3 Replacing Inorganic Fertilizer

In 2009 China's consumption of nitrogen (N) fertilizer resulted in a total of 36.9 million tons, being 35% of the total world´s use. (FAO STAT, 2011) and the per capita consumption is about 3 time of the world's population average.

In order to ensure the same amount of plant yield, only 25-30% of organic fertilizer can be added to the inorganic fertilizer (11 million tons). (Roelcke, 2011), but the plant availability of the total nitrogen in AD slurry (mainly Ammonia) is 60%. (Wendland, 2011) The total N content in the total feedstock even overtops this demand (see Table 14), which exceed China's demand. .

Assumptions:

The calculation concerning the emissions saved by replacing the inorganic fertilizer – by using the end- product of the AD technology i.e. the digested - by an organic fertilizer is rather simple**.**

The process of generating inorganic fertilizer, mainly Ammonium Nitrate, is quite energy consuming. The nitrogen (N) of the e.g. food waste, if landfilled, would then be completely lost and useless. This is not true of the crop residues as the alternative can be left on the ground so that they still supply N for the next cultivation. But as farmers mainly burn it on the open fields, it can be assumed to be lost.

The emissions, which are generated while the fertilizer is produced are so-called embedded emissions i.e. 'indirect emissions' of the inorganic fertilizer.

These are measured by the amount of active compounds they contain (kg of N).

From each kg of N contained in the fertilizer, it takes 5,0395 kg CO_2 equivalents.

In this study it is assumed that the bio-fertilizer from AD is absorbed as well by the crops as the inorganic fertilizer and that there are no N losses on the organic fertilizer.

Calculations:

In order to achieve the same amount of plant yield when using inorganic fertilizers, the specific quantity of organic fertilizer, which can be added to the inorganic fertilizer is calculated.

The generated amount of emissions, by producing the same amount of inorganic fertilizer can therefore be saved.

For these calculations the following equation is used:

- **N/Feedstock (t) x GWP of NH_4NO_3**

The following table lists the data, which are used for the calculations.

Table 16 Total Solid (TS) and Typical Values of Nitrogen (N) Content of the Feedstock

Feedstock	TS content in %	N content in %	N content in 10^6 t	N content in 10^6 t	Source
			Current Levels	Future Levels	
Food Waste	35	4.14	4.2	4.7	Dong et al., 2011
Crop Residues	40	2.79	6.5	6.6	
Animal Manure	4	1.36*	0.36	0.4	
Energy crops	30	1.2**	--	2.4	
Urban Sludge	20	11kgN/t	0.3	0.31	Defra, 2010
Total	--	--	11.36	14.41	--

*Notes: *Pig Manure, **Sugar beet*

3.5.4 Using Crop Residues as Feedstock rather than Burning Them on Fields

Assumptions:

According to *Liu et al*., (2007), 37% of crop residues are burnt directly on open fields. By instead treating this amount in a clean, sustainable way in an AD plant, huge amounts of GHG can be avoided.

Calculations:

This chapter covers the calculation of the amounts of GHG emissions, which are generated by burning straw on open fields and which at the same time is the amount saved by using straw as a feedstock for an AD plant.

The amount of GHG gases generated by burning straw is calculated using the methodology published by the Intergovernmental Panel on Climate Change (IPCC) in '2006 IPCC Guidelines for National Greenhouse Gas Inventories'. The formula used by IPCC was slightly changed for the purpose of this paper. It should also be mentioned that indirect green house gases like carbon monoxide (CO) and nitrogen oxide (NOx) were neglected. Therefore the result is slightly underestimated as CO as well as NOx have a negative impact on the climate and lead to atmospheric and surface effects. (ITS, 2005)

Estimation of GHG emissions from fire:

- $\mathbf{L_{fire} = B \times C_f \times G_{ef} \times 10^{-3}}$

Where:

L_{fire} = Amount of greenhouse gas emissions from fire, tonnes of each GHG e.g., CH_4, nitrous oxide (N_2O), etc.

B = Biomass available for combustion, tonnes

C_f = Combustion factor, dimensionless, for maize residues: 0.80

G_{ef} = Emission factor, g/kg dry matter burnt, for

CO_2 : 1515

CH_4 : 2.7

N_2O : 0.07

Therefore, the results for each GHG are as followed:

Current Levels:

CO_2 → $215 \times 10^6 \times 0.80 \times 1515 \times 10^3 = 261 \times 10^6$ tons

CH_4 → $215 \times 10^6 \times 0.80 \times 2.7 \times 10^3$ = 464,000 tons

N_2O → $215 \times 10^6 \times 0.80 \times 0.07 \times 10^3$ = 12,040 tons

Future Levels:

CO_2 → $218 \times 10^6 \times 0.80 \times 1515 \times 10^3 = 264 \times 10^6$ tons

CH_4 → $218 \times 10^6 \times 0.80 \times 2.7 \times 10^3$ = 471,000 tons

N_2O → $218 \times 10^6 \times 0.80 \times 0.07 \times 10^3$ = 12,208 tons

By converting the GHG into tonnes of CO_2 equivalents and adding them up, the amount of tonnes of CO_2 equivalents can be calculated.

4 RESULTS

4.1 Current Feedstock Levels and Biogas Potential

This chapter summarizes the results of the study on current arising and biogas energy potential of the main kinds of feedstock, which are suitable for biogas production, such as household and agricultural waste. It also includes energy crops from marginal land, which China is just starting to utilize. The chapter also identifies the regional distribution in available biomass resources.

4.1.1 Household Waste

The part entitled “household waste” of this study focuses on the resource of organic household waste which is over 80% of the biodegradable fraction within municipal solid waste (MSW) generated from households in China. (Liu, 2011a) In addition it also includes the feedstock of municipal wastewater sludge generated from domestic as well as from industrial sources.

China is the largest producer of MSW in the world and it is predicted that by 2030 the country will generate twice the amount that the United States produces. (The World Bank, 2005) The huge amount of organic fraction within MSW can be used for biogas production and thus solve problems not only of energy supply but also with a health and environmental impact. (ECCEC, 2011) The waste generated in China is due mainly to the growth of urban population and increased wealth.

It can be said that because of economic activity, the population in the city produces twice or three times more waste than the population in the countryside, no matter what their income is. (The World Bank, 2005)

Present Solid Waste Management

In 2010 there were about 360 million tonnes of MSW generated in 654 cities of China. Approximately 200 millions of them are generated in major cities. The remaining 160 million tons of MSW are produced in counties. (Raninger, 2011)

Nowadays 72% of the total generated MSW in cities is collected, from which nearly 80% is to be landfilled. 18% is burnt and 2% is composted. (Li, 2011) 80% of the landfilled waste is put in poorly developed dumping sites. Leachate and landfill gas emissions may thus end up as local and global ecological catastrophes. (Raninger, 2011)

Approximately 3% of methane emissions caused by humane beings can be traced back to landfills. (EC, 2010) Incineration and composting are not very successful either as there is little technical and biological knowledge, a low standard of equipment, hardly any emissions and a low calorific value of 3500kJ/kg for fresh matter of MSW as the bioorganic waste consists of a lot of water. Coal is, therefore, often used as a co-incinerator. (Raninger, 2011)

Achievements

In its 12th FYP, China is fighting these problems with a proposed continuous reduction of pollution from waste disposal. ‘Resources conservation‘, ´Renewable energy‘ and ‘Environmental protection‘ have become an issue in state policies.

In the larger cities of China, the government has also started to educate people in waste reduction and source segregation. For example, 600 demo-communities in Beijing are provided with colour-coded waste bags and waste bins where ‘recyclables’, ‘kitchen waste’ and ‘other waste’ can be collected separately (BMAC and OCSCCC, 2010) and 100 communities in Shanghai have started to separate dry and wet waste. By the end of this year there will even be 1009 ecologically aware communities and by 2015 they will have their own property management. (Liu, 2011b)

Current Levels and Biogas Potential

China's population which are living in major cities produces approximately 163 million tons and the population in counties 128 million tons of biodegradable waste per year. In total, 29.1 billion m^3 of biogas could be gained in biogas plants from this amount.

4.1.1.1 Municipal Sewage Sludge

Sewage contains a mixture of contaminants such as pathogens, toxic chemicals, heavy metals, debris, nutrients, nitrates and phosphates. Removing these contaminants is the main reason to treat wastewater. In addition, biogas can also be gained. The wastewater is generated from domestic as well as from industrial sources. (Gray, 2010)

Present Wastewater Management

At present, China runs 2,630 treatment plants. Nevertheless, 60% of the generated amount of wastewater sludge is being landfilled; the rest is burnt or composted. It is also used as construction material, for example in brick production. (Raninger, 2011)

Current Levels and Biogas Potential

In total, 146 million tons of sewage sludge is produced per year, which results in an amount of 12.3 billion m^3 biogas.

4.1.2 Agricultural Waste

Agricultural residues are another valuable biomass feedstock for biogas energy conversion. This part of the study is focuses on crop residues as well as on animal manure, which are the main resources occurring in the agricultural sector.

4.1.2.1 Crop Residues

Crop residues, such as straw stalks, and husks, are defined as ‘vegetative organic materials’, which remain on the field after harvesting. This term includes field residues i.e. crop straw as well as process residues i.e. by-products.

In addition to coal, oil and natural gas, straw, which is available on a large scale in China, can be seen as the fourth biggest energy resource as it contains 40% of carbon in its fibre. (ECCEC, 2011) It can be seen as a highly valuable resource not only because energy can be generated from it but also because it maintains soil fertility, prevents soil erosion and produces sustainable crops. Moreover, besides being used as feed for livestock it is also of great use for cooking and heating in rural households. (Xie, 2011)

<u>Distribution</u>

50% of the straw resources is distributed in 10% of the country. The highest amount of nearly 180 million tonnes, which is approximately a quarter of the total straw amount, is produced in the north of China, whereas Tibet has the lowest amount with 0.1%. (ECCEC, 2011)

The North Eastern as well as the Southern provinces of China are the regions where most of the crop straw is produced, such as in Heilongjiang, Hebei, Henan, Shandong, Jiangsu, and Sichuan. However, there are different types of straw, i.e. maize in Heilongjiang, maize and wheat in Hebei, rice and wheat in Jiangsu, rice and sugar cane in Guangdong, and maize and cotton in Sinkiang. (Zhong et al., 2003)

<u>Current Levels</u>

The predicted amount of straw was about 744 million tonnes and the total energy output was 480 billion m^3. The three major food crops of maize, wheat, and rice are the main source of crop residues, with an amount up to 328 million tonnes, 157 million tonnes, and 122 million tonnes respectively, accounting for even more than 80%.

Further potential raw materials for biogas energy generation are agricultural by-products such as rice hull, corncob and bagasse. In 2006 the output of rice hull, corncob and bagasse was 36.5, 72.7 and 24.9 million tonnes respectively, from which 23, 55 and 2.6 billion m^3 biogas could be generated. (ECCEC, 2011)

Biogas Potential

Nearly 447 million tons, which are 60% of the useable amount, of the whole generated amount can be put into biogas energy generation. Including the by-products, it comes to a total amount of 215 billion m^3.

4.1.2.2 Animal Manure

Animal manure is a very suitable feedstock for the technology of anaerobic digestion and it is widely used throughout in China.

If this resource were used for gaining energy, there would be no urban and rural environmental problems, such as pollution of air, water and soil; in particular pollution of drinking water and ecological agriculture could be avoided. (ADB, 2009)

In China there are two methods of feeding domestic livestock. Families and small-sized farms practise the traditional method, namely ‘natural feeding’ and breed mainly sheep, horses and ducks. The manure from this type of farming is difficult to collect as it is distributed on grass and ponds or through household biogas digesters. Farms with some pigs and cows can also have such 8-12m3 passive digesters or the dung is used as fertilizer directly.

On the other hand, there is the centralized feeding in medium- (breeding belts around the cities) and large-sized farms for cattle, pigs and poultry. (ADB, 2009) The manure of these animals is easier to collect as they are held in a confined area. (Li et al., 2001) Therefore, this section estimates the amount and energy potential of animals arising in centralized feeding farms.

Distribution

Due to the different climatic situation in the various regions of China, the amount of livestock also varies from province to province. Large and medium-sized farms in the provinces of Henan, Guangdong, Shandong, Hebei, Liaoning, Hunan, Fujian, Jiangsu, and Zhejiang produced the highest amount of manure in 2006, namely up to 63.6% of the whole country. (ECCEC, 2011)

Current Levels

In 2006 in China 519 million pigs, which is 49% of world production, with a 3.5% annual increase were raised. The total generated and collectable amount of manure accounts up to 3 billion tons in 2009, 3.5 billion tons forecasted for 2015 with a COD three times higher than the industry emissions. (ADB, 2009)

Biogas Potential

The biogas yield of the available amount for biogas generation adds up to approximately 33.4 billion m^3.

4.1.3 The Total Current Biogas Energy Potential

The total biogas potential, including household and agricultural biomass waste sum up to 290 billion m^3.

4.2 Feedstock Arising and Biogas Potential until the Year 2030

Due to the predicted increase in urbanization, the highest increase in the occurrence of waste will be in cities. It will reach 263 million tons of organic fraction in major cities and 64 million tons of biodegradable fraction in counties. Resulting in 327 million tons in total, i.e. 33 billion m^3.

The resource of wastewater sewage sludge will also undergo an enormous increase of about 6%, resulting in a biogas potential of 13 billion m^3.

As the increase in crops is limited by factors like land use changes as well as by the regional and climatic situation, this fact will not change a lot in the future; only 1.2% is assumed. Therefore, a biogas yield of 218 billion m^3 is predicted.

On account of the rapid economic development and the increased living standards, the demand for meat as well as for dairy products is rising. This has led to a steady grow in the numbers of commercial livestock farms from about 2.4 million in 2002 to about 4.3 million in 2006, with an improved quality and increased productivity. (ADB, 2009)

Assuming the average rate of 12% during the period from 2000 and 2009 will stay the same, a biogas yield of approximately 37.4 billion m^3 would be the result by the year 2030.

Therefore, due to an increase in urbanization and change in people's lifestyle, the highest rise will concern the resources of household waste as well as animal manure.

4.2.1 Energy Crops from Marginal Land

A fifth kind of feedstock, the energy crops from marginal land, is also included in the forecast calculations of biogas potential for the year 2030. Using energy crops for energy production is a relatively new field, especially for the biogas generation. This study assumes a utilization factor of 40% of the total energy crops amount for 2030.

Bio-energy produced from energy plants will play an increasingly important role in future energy supply and as China has fairly limited cultivated land resources, bio-energy development will mainly rely on the exploitation of marginal land. This section focuses on the assessment of marginal land resources and biogas potential of energy crops in China. (Zhuang et al., 2010)

While China has focused on the mixed fermentation of straw and livestock manure for a long time, the country has just started to do some research on the highly promising field of energy crops from marginal land. (Hu, 2010a) In addition to the energy production economic development in remote and depressed rural area can be improved too. Research studies also prove that besides greenhouse gas emission abatement, significant eco-environmental benefits can be achieved. By planting bio-energy plants on marginal lands, the eco-function of soil/water conservation and wind erosion protection can be improved. (Li et al., 2009)

Land Utilization

China´s total surface area is approximately 9.600 million square kilometres (km^2). (TCG, 2011)

In contrast to other countries, China has a large population but limited arable land. (Hu, 2010a)

The following figure shows the proportion of land and how it is used.

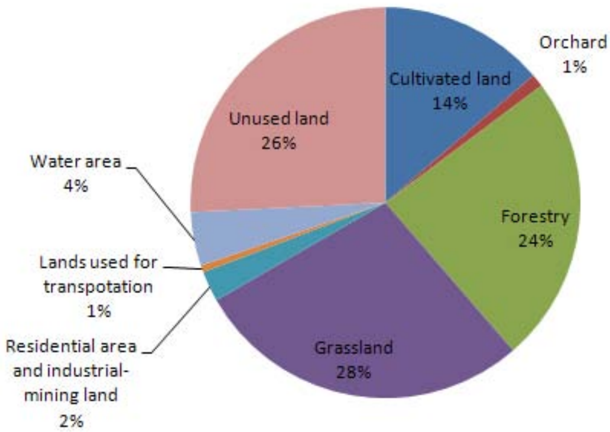

Figure 6 Classification of Land Utilisation in China

Note: The data base on the investigated land area of 9.507 million km^2 of China. (Hu, 2010a)

As bio-energy industries should not compete for land with the production of food, feed and fiber, the plantation of energy crops will be restricted to marginal land. (Tang et al., 2010)

Size and Composition of Marginal Land Suitable for Energy Plants

Shi (2011) estimates that around 163.74 million ha of China´s total marginal land might be suitable for growing energy crops. 84.91 million ha, which account for 51.9% of the total area, are still not used. 70.8% of the total marginal land is well suited for forestry, 29.2% for agriculture. (Shi, 2011)

Distribution

Marginal land resources can be found in two main areas of China:

1. Southwest China as well as Yunnan, Guizhou, Sichuan Province and Chongging City. The area of marginal land in this region is about 38.7 million ha, accounting for 39.1% of the territory of China. In this area, the cultivation of energy plants is supported by sufficient water and sunshine.

2. Inner Mongolia and Northeast China, with a good quality of soil and low slopes. (Zhuang et al., 2010*)*

Energy Plants

Energy plants are defined as any plant containing biomass, which serves as energy source. China disposes of a great biodiversity. (Guo et al., 2011)

The main energy plants suitable for growth in China are energy corn**,** sweet sorghum**,** cassava**,** sweet potato, sugarcane**,** sugar beet, jerusalem artichoke, *Pennisetum clandestinum*, and *Panicum virgatum***.** (Hu, 2010a)

The characteristics of the terrain (like elevation and slope) and soil as well as meteorological factors (including precipitation data and air temperature data) should be considered when choosing the type of plant to be cultivated.

Biogas Potential:

The total energy potential of energy crops planted on the total available area of 163.74 million hectares come to nearly 345 billion m^3 biogas. As this study assumes a utilization factor of 40%, 138 billion m^3 will be used by the year 2030.

4.2.2 Total Future Biogas Energy Potential

Figure 5 summarizes the current biogas potential and shows as well the expected changes up to the year 2030. Any kind of feedstock will increase in the future. The ranking will remain the same, i.e. crop residues are on the top of the list followed by the new but highly valued feedstock of energy crops and animal manure. Household waste represents the smallest amount and, therefore, also in energy potential. Nevertheless it is more likely to be used than for example the energy crops.

In summary it may be said, the future biogas potential will increase to 439.4 billion m^3 by 2030 with a total increase of 52%, respectively.

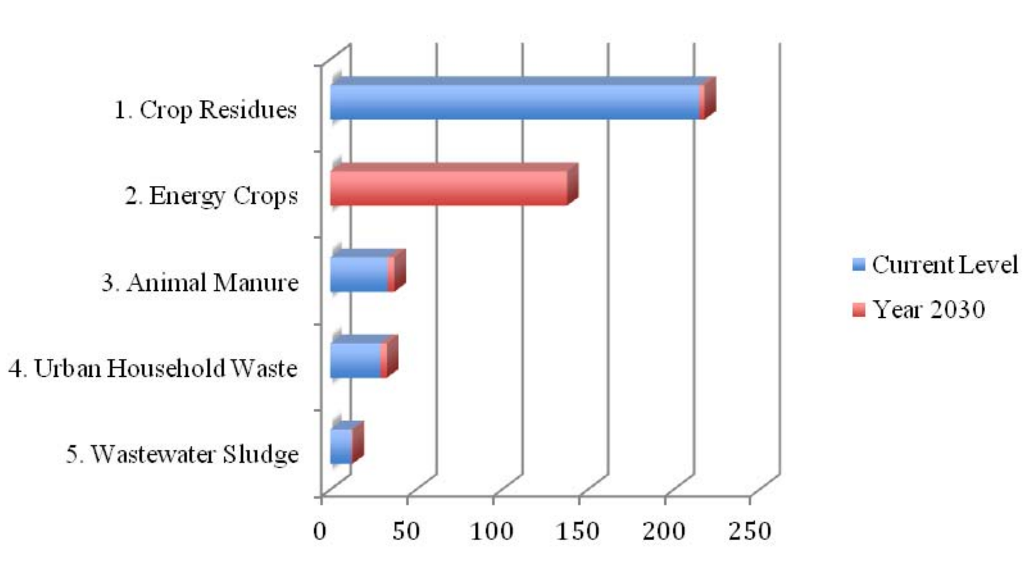

Figure 7 Current Situation of Municipal, Agricultural Biomass Waste and Energy Crops and the Increment until 2030 (in billion m^3 biogas)

4.3 Contribution of Biogas Energy to China's Energy Demand

In total, the current biogas potential totals 290 billion m^3. Assuming an average methane content of 60 %, this would result to an amount of methane of 174 billion m^3/a. Assuming all the available biomass feedstock is used as an energy source a total biogas energy potential of about 6,246 PJ/a could contribute to 6.9% to the overall energy demand. The following figure represents the respective contribution of each feedstock.

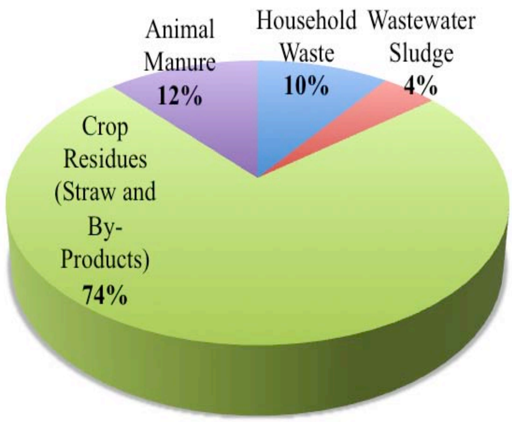

Figure 8 Contribution of the Current Potential of Biogas Energy to Total Energy Demand

Energy Potential

This part deals with the energy potential generated out of the total estimated biogas potential of 290 billion m^3 biogas, which can be used for electricity and/or heating purposes.

<ins>Electricity Production:</ins>

With a conversion factor of a Combined Heat and Power (CHP) plant of 35%, an available energy potential of around 607 TWh/a can be calculated. With 8500 full load hours per year, this would correspond to an installed power capacity of 71.4 GW. In addition, through co-combustion, the wastewater sewage sludge can be used in existing coal-fired power plants.

Heat Generation:

With a average conversion efficiency for the exclusive provision of heat of 96%, the potential availability of heat results in 5,996 PJ/a. Otherwise by gaining heat through a CHP plant with a conversion efficiency of 58%, heat of 3,623 PJ/a could be generated.

Due to the predicted strong increase in total energy consumption in China over 5%, which is approximately 9,463 PJ of the enormous energy demand in 2030 (189,000 PJ) could be met by biogas energy utilization.

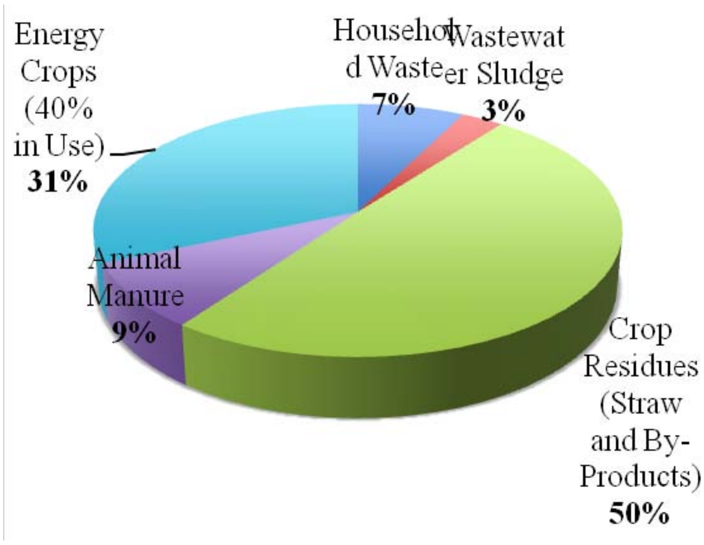

Figure 9 Contribution of the Future Potential of Biogas Energy to Total Energy Demand

4.3.1 Potential versus Production; including Policy Targets

Given the amount of biomass waste available, the use of biogas is still relatively low although China has made efforts to support the production of biogas by setting appropriate goals until 2020. The current performance of biogas-plants and grid – connection restrictions will not allow to reach even these goals.

Policy Targets:

Part 1 of this study estimates a current potential of up to 290 billion m^3 of municipal sewage sludge and agricultural waste, the two kinds of feedstock, which are already mainly in use in China.

However, according to the renewable energy targets achieved by the NDRC in 2010, only 6.6% of the available feedstock was used for energy supply on the market. The use of feedstock will increase to 10% until 2020.

Production:

The PRC already invested large sums in the construction of biogas plants in the last years, especially in those treating agricultural waste. The numbers of small, medium and large sized plants treating agricultural waste feedstock rose rapidly from 26,586 in 2007 to 39,510 in 2008 and to 56,534 in 2009, which results to a total biogas yield of 764.92 million m^3 out of agricultural biomass waste. (GIZ, 2011a) However, this is less than 1% of the total agricultural resources of about 248.4 billion m^3.

As animal manure has a biogas potential of 33.4 billion m^3 resulting in 60 GWh electricity, it would not have been a problem to contribute about 14% to the demand for electricity in households of China (440 GWh) (NBSC, 2011) by transforming the amount of animal manure from industrial livestock farms into biogas.

Another example of a lost opportunity in terms of biomass resources in China is the sewage sludge.

Less than 1%, which is 100 million m^3, of the total amount of municipal wastewater sludge (12.3 billion m^3) was used in biogas energy systems in 2010.

4.4 China Compared with Germany, the European Leader in Biogas Production

The main reason for the rapid increase in production as well as the usage of biogas energy in Germany, is the implementation of the renewable energy policy (‘Erneuerbare Energien Gesetz’, ‘EEG’) in 2000. This policy is the basis for connecting renewable sources of electricity generation with the grid and guarantees the producers the lowest selling prices.

The ‚EEG 2012’, which will be implemented in January, 2012, will change Germany’s biogas sector in so far as small sized plants will be built in addition to large sized ones. Besides that, a tariff of 25 Cent per kWh electricity produced has been promised as well as the support of direct marketing.

Plants have been mainly built in the regions of Bavaria and Baden-Wuerttemberg, Niedersachsen and Nordrhein-Westfalen. (Ökobit-Die Biogasexperten, 2011)

The previously used raw material are mainly manure from chicken, pig and cow and often co-digested with energy crops like corn and grass, harvest residues as well as and industrial and municipal organic waste.

According to the FNR, in 2005 Germany had a total biogas potential of 22 to 25 billion m^3, including also landfill sites. The following figure shows how the different kinds of feedstock contribute to the total biogas potential.

By using the whole substrate mix, a total energy potential of 360 to 520 PJ/a could be gained, which would contribute between 3.9 to 5.6% to Germany's energy consumption of 9,288PJ in 1999. (FNR, 2005)

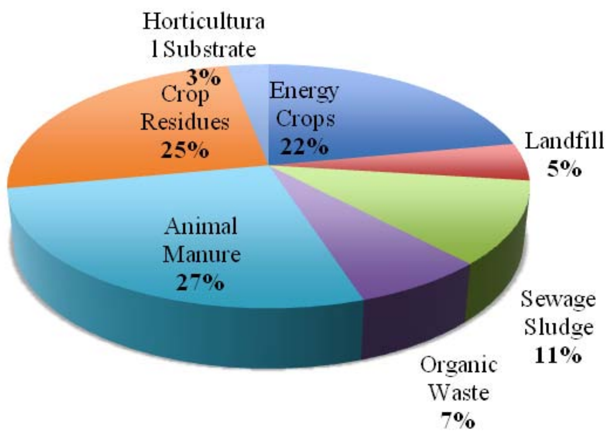

Figure 10 Germany's Total Biogas Potential

(FNR, 2005)

Germany 's biogas potential shows a similar contribution of each feedstock to the total energy demand. The main provider of feedstock is the agricultural sector in both countries.

Even though Germany's biogas potential is small compared to that of China as it consists of smaller areas (e.g. only an area of 2 million hectares which is suitable for growing energy crops was estimated) and having fewer inhabitants, over 5,900 anaerobic digestion plants have already been installed in Germany with an established power generation capacity of 2,300 MW electricity, which is a 20 fold increase compared to 2001. In 2010 12.8 billion kWh, which corresponds to 2.1% of the country's energy demand, and 12.6% of the energy supply of renewable energies. (FNR, 2011c)

Since the beginning of this year, 52 bio-methane plants have been connected to the natural gas grid and many more projects are under construction and in planning. (FNR, 2011d)

4.5 GHG Emissions and Savings

Besides gaining energy out of the technology of anaerobic digestion, biogas also makes an enormous contribution to the mitigation of climate change. This fact is also of great importance as China ranks first in the list of the world most-emitting countries in CO_2 as well as in CH_4 emissions (EIA, 2009) due to the fast development of energy-intensive industries, agriculture (manure management), coal mines, landfills, natural gas and oil systems. (EPA, 2011)

According to the 'United Nations Framework Convention on Climate Change' (UNFCCC) - secretariat (1994), over 74% of total GHG emissions is generated by China´s energy sector, which made up to 7.5 billion tonnes of CO_2 equivalents in 2009 (IEA, 2009b), followed by 15% emitted from the agricultural, 7% from the industrial and 4% from the waste sector (UNFCCC – secretariat, 1994), resulting in nearly 10 billion tonnes of GHG emissions in 2009.

Therefore, replacing fossil fuel sources by energy generated from clean, renewable resources turns out to be a big opportunity to contribute to climate change mitigation. In addition, avoiding CO_2 emissions also reduces airborne pollutants, such as toxic heavy metals, ozone-forming chemicals, and sulphur dioxide, which are responsible for acid rain (Li et al., 2009).

4.5.1 Contribution of Biogas to Climate Change Mitigation

This part of the study aims at estimating the amount of saved tonnes of carbon equivalent of CO_2 emissions due to the production of biogas energy and organic fertilizer gained from the feedstock of household and agricultural biomass waste as well as of energy crops from marginal land whose potential was carefully estimated in Part 1 of this study. In addition, it shows which role biogas technology could play in order to achieve the ambitious targets of the national policies concerning reductions in GHG emissions.

All assumptions made as well as all formulas and data used in order to calculate the amount of avoided GHG emissions are listed in the part ‘Methodology’.

Calculations and Results:

There are three ways to avoid GHG emissions by generating biogas from an AD process.

First, energy is produced out of a renewable resource.

Secondly, by assuming the waste is otherwise going to landfill and thirdly, the second highly valuable end- product of the process of anaerobic digestion, namely the produced digestate replaces inorganic fertilizer, whose production requires a huge amount of energy.

Additionally, CO_2 emissions can also be saved if a certain amount of crop residues are no longer burnt on open fields.

4.5.1.1 Gaining Electricity out of a Renewable Energy Source; Replacing Coal

In total, 2.2×10^{12} MJ electricity can be gained from the waste, which amounts to 611 million MWh.

According to *Wang et al.,* (2009) the emission intensity of conventional coal results in 1.186 CO_2/MWh.

Therefore, the amount of emissions of CO_2 equivalents, which can be avoided by replacing China´s number one energy source i.e. coal with clean and renewable biogas energy amounts to 725 million tons.

4.5.1.2 Choosing Anaerobic Digestion Instead of Landfilling as a Waste Treatment Option

Emissions generated by the two waste treatment options are compared and the saved amount of GHG emissions was calculated; this amount to 3.76 billion tons of CO2 equivalents.

4.5.1.3 Replacing Inorganic Fertilizer

By replacing inorganic fertilizer by using the end- product of the AD process, the digested, 81,200 tons of CO_2 equivalents can be avoided.

4.5.1.4 Using Crop Residues as Feedstock Rather than Burning Them on Fields

Instead of burning a huge amount of straw and agricultural by-products on the field, this high valuable feedstock is going to be treated in an AD plant. Therefore, emissions of approximately 261 million tons of CO_2 equivalents, which are generated during the burning process, can be saved.

4.5.1.5 Result

Therefore, the total reduction potential of CO_2 equivalents is 4.75 billion tons and it will rise to nearly 7 billion tons until the year 2030.

5 CONCLUSION AND RECOMMENDATIONS

China is the world's leader in energy demand, coal consumption, municipal solid waste production, CO_2 and CH_4 emissions and N-fertilizer consumption and has, at the same time to cope with a constantly and rapidly increasing urbanization. In order to tackle the above-mentioned problems and to reduce greenhouse gases but above all to become more energy self sufficient, the government has put special emphasis on expanding the renewable energy sector through targeted policies and huge investments in the last years. In this context, biogas energy plays a big role, which is gained from the feedstock of household and agricultural biomass waste and energy crops from marginal land.

The following table summarises all the findings regarding China's and Germany's biogas potential on the basis of the energy demand as well as policy targets of these countries.

Table 17 Chinese Biogas Energy Potential and Policy Targets in Relation to the Total Energy Demand and German Performance Figures, 2010-2050

		China					**Germany**
Year	**Final energy consumption**	**Renewable** Energy targets	**Biogas** Energy targets	**Biogas Potential**			**Biogas**
	PJ/a	% Energy consumption	Energy consumption	bn Nm^3	% Energy consumption	*Policy target % potential*	% Energy consumption
2010	91,000	10	19 bn Nm^3	290	6.9		Achieved 1.5
2020	131,000	15 – 16 [ooo]	44 bn Nm^3	365	10	<10**	Target 5.5
2030	189,000			440	5		
2050		26 [ooo] - 30					Potential up to 10*

[o] NDRC, Medium and Long Term Development Plan for Renewable Energy in China (Beijing, September 2007);

** Potential in 2020 = 2050 von 0.5 PJ (FNR, 2011)*

*** Target Biomass = 18.5% within Renewable Energy*

[o o] Target Biogas all (NDRC 2007)

[ooo] State Grid 2010

With regard to the specific aims of the present study the following conclusion and recommendations can be drawn:

- Due to its large and diverse areas and the huge population, the country has the availability of abundant biomass resources. This study estimates a current annual biogas potential of 290 billion m^3, which could cover 6.9% of the total energy demand. A biogas-driven power generation with a capacity of 71.4 GW electricity could be established. Furthermore, the resources will constantly grow and an amount of 439.4 billion m^3 by 2030.

- In order to use the energy resources in the most efficient way, the use for heating energy should be promoted in particular. The heating energy can contribute to the economic returns of an anaerobic digestion plant.

- The agricultural sector has the greatest potential, such as crop residues, followed by energy crops from marginal land and animal manure. Animal manure currently used as the main feedstock for biogas production should be co-digested with diversified feedstock especially with straw.

- As to the highly valuable feedstock of energy crops from marginal land, the country is, besides of a vivid bio-ethanol production to be blended with petrol (10% bio-ethanol in many provinces) still at the starting point of doing research in this very promising field. So far, there is neither an agreed definition of the term ‘marginal land’ nor have assessment standards been implemented concerning suitable land resources, energy crop varieties, feedstock availability and related energy potential. Therefore, research in this highly valuable resource should be supported.

- Concerning the future of the biogas potential, the ranking will still remain the same, i.e. crop residues are on the top of the list followed by energy crops and animal manure. Household waste represents a smaller amount and therefore also in energy potential. But it should be mentioned, due to the rapid urbanization, urban waste will increase the most, namely over 12% by 2030 and 2050. It is not only a great challenge for China to gain energy from this waste but also to cope with these huge amounts of waste in the cities in terms of environmental pollution. Therefore municipal solid waste management needs to be enhanced.

- Biomass resources offer a realistic chance to ensure energy security and sustainable social and economic development. However, the resources are still not used in a sustainable and efficient way and are instead wasted. High quantities (35-40%) of animal manure are untreated and huge amounts of crop residues are still burnt on open fields which lead to pollution (Liu et al., 2007). A more environmental-friendly management in this sector would also be required.

- Although the country is rich in biogas feedstock, the current and future forecasts concerning the availability of biomass not only mean that the resources are far from being fully exploited but they also show that the policy targets to develop sustainable biogas energy are not ambitious enough; 6.6% of it was used by 2010 and 10% will be used for 2020.

- Notwithstanding this, an enormous increase in both biogas production and utilization has been recognized during the last years. From 2007 to 2009, the numbers of plants has increased by 53%. However, only three of them have been connected to the electrical supply network so far and only seven units are so-called CDM-Projects whereby only two can generate some CDM carbon credits based on certified emission reduction (CER).

- In spite of the discernible trend of a further increase in biogas energy production in the future, the necessary know-how as well as technology concerning design, construction and performance of the plant as well as pre-treatment of the feedstock and maintaining of the whole process are often still missing. The limited capacity of technical service for project operation creates a bottleneck for the rapid development of biogas projects at present. It is, therefore, important not only to enhance the utilization of biogas feedstock and to extend energy supply but also to encourage the competent authorities to invest into maintenance and control of the process of existing plants. A further step would be promoting the industrialization of biogas energy development.

- Besides methane, which is used to generate energy from the biogas, the second product, the digestate is also of great potential. By treating the whole feedstock, the generated amount would exceed China's demand for bio-fertilizer. Therefore, not only money but also a huge amount of GHG emissions can be avoided by replacing inorganic fertilizer.

- The study estimates an amount of 4.75 billion tons CO_2 equivalents, which could be saved by using anaerobic digestion as the main treatment option and it could rise to nearly 7 billion tons until the year 2030. Energy could be produced at lower costs - provided low-priced carbon is sold on the world market - which would entail an increase in the bio-energy development. (Li et al., 2009)

China disposes of a remarkable potential for biogas, both at present and in the future. The biogas sector represents a promising option for using renewable energies, which could make further contributions to a sustainable energy supply as well as to mitigating greenhouse gases in the future.

The responsible authorities and decision-makers should be motivated to further promote the production and the use of biogas as well as maintain and control existing plants.

This study is meant to make a contribution to this development.

REFERENCES

ADB, Asian Development Bank (2009), PRC: Preparing the Integrated Renewable Biomass Energy Development Project – Final Report, Project Number: 40682 Beijing, China.

Berglund, M. (2006), Biogas Production from a Systems Analytical Perspective (PhD thesis), Lund University, Lund, Sweden.

BMAC, Beijing Municipal Administration Commission (2010), Lu Wa in action – Guideline for waste reduction and waste sorting in pictures, Beijing Press, Beijing, China, [in Chinese].

BMJ, Bundesministerium der Justiz (1991), Abfallablagerungsverordnung, available at: http://bundesrecht.juris.de/bundesrecht/abfablv/gesamt.pdf (accessed 09/06/2011), [in German].

Braun, R., Weiland, P. and Wellinger, A. (2010), Biogas from energy crop digestion, available at: http://www.ieabiogas.net/_download/energycrop_def_Low_Res.pdf (accessed 04/07/2011).

CREIA, Chinese Renewable Energy Industries Association (2011), 12th Five-Year Plan for Renewable Energy Development – Draft, Beijing, China.

Cui, Z. (2005), The Diversity and Applied Approaches of Biomass Resources in China, Biomass-Asia Workshop 2005, Powerpoint presentation, available at: http://www.biomass-asia-workshop.jp/biomassws/01workshop/en/program.html (accessed 04/08/2011).

Daskalopoulos, E., Badr, O. and Probert, S.D. (1998), Municipal solid waste: a prediction methodology for the generation rate and composition in the European Union countries and the United States of America, Resources, Conservation and Recycling 24, page: 155–166, Elsevier Ltd.

Defra, Department for Environment, Food and Rural Affairs (2010), Fertiliser Manual RB 209, 8th Edition, page 75, UK.

Dong B., Chen L., Zhang Y., Zhao L., Wan X., Gao X., Zhang X. and Luo J. (2011), Effect of pig manure addition on biogas production of combined two-phase anaerobic digestion, Vol. 2, Institute of Energy and Environmental Protection, Chinese Academy of Agricultural Engineering, Beijing, China.

EC, European Commission (2010), Biodegradable waste, available at: http://ec.europa.eu/environment/waste/compost/index.htm (accessed 09/06/2011).

ECCEC, Europe-China Clean Energy Centre (2011), Study of potential and constraint of the biomass sector in China, (unpublished report).
EIA, Energy Information Administration (2009), International Energy Outlook 2009, available at: http://www.eia.doe.gov/oiaf/ieo/pdf/0484(2009).pdf (accessed 24/05/2011).

EIA, Energy Information Administration (2009), *International Energy Outlook 2009*, available at: http://www.eia.doe.gov/oiaf/ieo/pdf/0484(2009).pdf (accessed 24/05/2011).

EIA, Energy Information Administration (2011), China, available at: http://www.eia.gov/countries/cab.cfm?fips=CH (accessed 04/08/2011).

EMCA, ESCO Commitee of China Energy Conservation Association (2011), China's primary energy consumption will be kept to between 4 to 4.2 billion tons of standard coal by 2015, available at: http://www.emca.cn/BG/en/newsinfo.aspx?cid=10&id=184 (accessed 25/05/2011).

EPA, United States Environmental Protection Act (2007), Global Mitigation of Non-CO2 Greenhouse Gases, available at: http://www.epa.gov/climatechange/economics/downloads/GlobalMitigationFullReport.pdf (accessed 25/05/2011).

EPA, United States Environmental Protection Act (2011), Methane, available at: http://www.epa.gov/methane/ (accessed 25/05/2011).

FAO STAT, Food and Agriculture Organizaiton of the United Nations (2011), statistical database, available at: http://faostat.fao.org/site/575/DesktopDefault.aspx?PageID=575#ancor (accessed 20/08/2011).

Feng, L. Raninger, B: Li, R., Li, Y. and Yang, G. (2009), Co-Digestion of Animal Manure and source separated Bioorganic Municipal Waste from Shenyang, China, Institute for Clean Energy and Environmental Engineering (ICEEE) & Liaoning Key Laboratory of Clean Energy & Environmental Engineering (LNKLCE), Shenyang Institute of Aeronautical Engineering, Hongkong University, China.

FNR, Fachagentur für nachwachsende Rohstoffe (2005) Handreichung – Biogasgewinnung und -nutzung, Gülzow, available at: http://www.big-east.eu/downloads/FNR_HR_Biogas.pdf (accessed 20/08/2001), [in German].

FNR, Fachagentur für nachwachsende Rohstoffe (2011a), Faustzahlen Biogas, available at: http://www.biogasportal.info/daten-und-fakten/faustzahlen/ (accessed on 20/08/2011), [in German].

FNR, Fachagentur für nachwachsende Rohstoffe (2011b), Einheimische Bioenergie: Was kann sie 2050 leisten?, available at: http://www.nachwachsenderohstoffe.de/uploads/media/Wuerfel_2011_gross.jpg (accessed 20/08/2011), [in German].

FNR, Fachagentur für nachwachsende Rohstoffe (2011c), *Biogasanlagen in Deutschland*, available at: http://www.biogasportal.info/daten-und-fakten/biogasanlagen/ (accessed 22(08/2011), [in German].

FNR, Fachagentur für nachwachsende Rohstoffe (2011d), *Biogaseinspeisung in das Erdgasnetz*, available at: http://www.biogasportal.info/daten-und-fakten/biogasanlagen/biomethan-anlagen/ (accessed 22/08/2011) [in German].

GIZ, Gesellschaft für Internationale Zusammenarbeit (2011a), China Biogas Sector – Historical Overview, available at: http://www.biogas-china.org/index.php?option=com_flexicontent&view=category&cid=18&Itemid=35&lang=en (accessed 20/08/2011).

GIZ, Gesellschaft für Internationale Zusammenarbeit (2011b), Klima- und Energieziele des 12. Fünfjahresplans - Chinas grüne Herausforderung an Europa?, Klimaschutzprogramm, Beijing, China, [in German].

Gray, J. (2010), Sustainable Sewage Design, available at: http://www.sustainablebuild.co.uk/sustainabledesignsewage.html (accessed 06/08/2011).

Guo, D.G., Zhang, X.Y., Shao, H.B., Bai, Z.K., Chu, L.Y., Shangguan, T.L., Kun,Y., Zhang, L.H., Xu, G. and Sun, J.N. (2011), Energy plants in the coastal zone of China: Category, distribution and development, Renewable and Sustainable Energy Reviews 15, page: 2014–2020, Elsevier Ltd.

Hu, L. (2010a), Potential and Regional Distribution of Marginal Land for Energy Crops Planting in China, Chengdu. Powerpoint presentation, December 2010.

Hu, Z. (2010b), Low Carbon Electricity : Integrated Resource Strategic Planning + Smart Grid, Seminar zum deutschen Energiekonzept und dem 12. 5-Jahresplans der VR China, Powerpoint presentation, 3 August 2010, Beijing, China.

IEA, International Energy Agency (2009a), Key World Energy Statistics, available at: http://www.iea.org/textbase/nppdf/free/2009/key_stats_2009.pdf (accessed 04/08/2011).

IEA, International Energy Agency (2009b), CO2 Emissions from Fuel Combustion Highlights, 2009 Edition, available at: www.iea.org/co2highlights/CO2highlights.pdf (accessed 04/08/2011).

Index Mundi (2011), China Population Growth rate, available at: http://www.indexmundi.com/china/population_growth_rate.html (accessed 20/08/2011).

IPCC, Intergovernmental Panel on Climate Change (2006), IPCC Guidelines for National Greenhouse Gas Inventories Vol. 4 – Agriculture, Forestry and Other Land Use, Chapter 2: Generic Methodologies applicable to multiple land-use categories, Equation 2.27 – Estimation of Greenhouse gas emissions from fire, available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html (accessed 22/08/2011).

IPCC, Intergovernmental Panel on Climate Change, s.a., Technical Summary, available at: http://www.ipcc.ch/ipccreports/tar/vol4/english/pdf/wg1ts.pdf (accessed 21/07/2011).

ITS, Institute of transportation studies (2005), Project 4: The Indirect Global Warming Potential of NOx Emission, available at: http://hydrogen.its.ucdavis.edu/research/track4/tr4pr4.html, (accessed 04/08/2011).

Jewell, W. J., Cummings, R. J. and Richards, B. K. (2003), Methane fermentation of energy crops: Maximum conversion kinetics and in situ biogas purification, Biomass and Bioenergy, Volume 5, Issues 3-4, page: 261-278, Elsevier Ltd.

Khaleey Times online, (2011), China's CO2 emissions rose over 10 pct in 2010, available at: http://www.khaleejtimes.com/DisplayArticle08.asp?xfile=data/environment/2011/June/environment_June13.xml&section=environment (accessed 04/08/2011).

Li, J., Zhuang, X., DeLaquil, P. and Larson, E.D. (2001), Biomass energy in China and its potential, Vol. 5, No. 4 in Energy for Sustainable Energy, page: 66-80, Elsevier Ltd.

Li, X., Huang, Y., Gong, J. and Zhang, X. (2009), A study of the development of bio-energy resources and the status of eco-society in China, Renewable and Sustainable Energy Reviews, page: 1-6, Elsevier Ltd.

Li, X. and Yuan, H. (2011) China Biogas Industry in New Period - challenges and future development, Center for Resources and Environmental Research, Beijing University of Chemical Technology, Beijing, China, [in Chinese with English abstract].

Li, Y. (2011), Grundsituation der unschaedlichen Behandlung der Siedlungsabfaelle in China und die Entwicklungsschwerpunkte im 12. Fuenfjahrplan, GTZ und NDRC waste workshop – 12th Five-Year Plan, Powerpoint presentation, 25 May 2011, Beijing, China, [in German].

Lindeburg, M. (2011), Civil Engineering Reference Manual 65 of the PE Exam, 12th edition, Professional Publication Inc., USA.

Liu, H., Jiang, G.M., Zhuang, H.Y. and Wang, K.J. (2007), Distribution, utilization structure and potential of biomass resources in rural China: With special references of crop residues, Renewable and Sustainable Energy Reviews 2008 12, page: 1402–18, Elsevier Ltd.

Liu, J. (2011a), Chief Engineer, China Urban Construction Design & Research Institute, Personal conversation, 6th July 2011, Beijing, China.

Liu, J. (2011b), China Urban Construction Design & Research Institute (2011), Current situation and new progress of household waste in China, Sino-German Environmental Policy Programme Workshop on the 12th Five-Year Plan on Municipal Solid Waste Management, 25 May 2011, Beijing, China.

Luo, S. (2011), Ecoagriculture in China: A Systems Approach, Journal of Resources and Ecology, 2(1), page: 8-14, [in Chinese with English abstract].

Martinot, E. and Junfeng, L. (2007), Powering China´s Development – The Role of Renewable Energy, Worldwatch Report, Report number: 13: 978-1-878071-83-5, Washington.

McKinsey &Company (2008), Preparing for China´s urban billion, available at: http://www.mckinsey.com/mgi/publications/china_urban_summary_of_findings.asp (accessed 09/06/2011).

MOA, China Ministry of Agriculture, Science and Education, Biomass Department (2011), *Verbal information by Dir. Li Shaohua, to German Biogas Stakeholders in Germany.*

MPRA, Munich Personal RePEc Archive (2010), Rural biomass energy 2020: People's Republic of China, available at: (http://mpra.ub.uni-muenchen.de/24987/1/MPRA_paper_24987.pdf) (accessed 20/08/2011).

NBSC, National Bureau of Statistics of China (2003), China's rural yearbook 2003, 7-43 The increase or decrease of living animals at the end of the year, page: 189, China Statistical Press, Beijing, China, [in Chinese].

NBSC, National Bureau of Statistics of China (2005), China's rural yearbook 2005, 7-42 The increase or decrease of living animals at the end of the year, page 185, China Statistical Press, Beijing, China, [in Chinese].

NBSC, National Bureau of Statistics of China (2007), China's rural yearbook 2007, 7-42 The increase or decrease of living animals at the end of the year, page 185, China Statistical Press, Beijing, China, [in Chinese].

NBSC, National Bureau of Statistics of China (2008), Chinese Agricultural Yearbook 2008, China Statistics Press, Beijing, China, [in Chinese with English abstract].

NBSC, National Bureau of Statistics of China (2009), China's rural yearbook 2009, 7-42 The increase or decrease of living animals at the end of the year, page 181, China Statistical Press, Beijing, China, [in Chinese].

NBSC, National Bureau of Statistics of China (2010a), Total population by urban and rural population and birth rate, death rate, national growth rate, available at: http://www.stats.gov.cn/tjsj/ndsj/2010/indexeh.htm (accessed 09/06/2011).

NBSC, National Bureau of Statistics of China (2010b), China Statistical Yearbook 2010, Agriculture, 13-15 Output of Major Farm Products, China Statistics Press, Beijing, China, [in Chinese].

NBSC, National Bureau of Statistics of China (2010c), China's rural yearbook 2010, 7-42 The increase or decrease of living animals at the end of the year (page 193) China Statistical Press, Beijing, China, [in Chinese].

NBSC, National Bureau of Statistics of China (2010d), China Statistical Yearbook 2010, Agriculture, 13-15 Output of Major Farm Products, China Statistics Press, Beijing, China, [in Chinese].

NBSC, National Bureau of Statistics of China (2011), China Statistical Yearbook, Energy, 7-6 Electricity Balance Sheet, China Statistics Press, Beijing, China, [in Chinese].

NDRC, National Development and Reform Commission (2007a), Medium and Long Term Development Plan for Renewable Energy in China, available at: http://www.martinot.info/China_RE_Plan_to_2020_Sep-2007.pdf (accessed 25/05/2011).

NDRC, National Development and Reform Commission (2007b), China´s national climate change programme 2007, Beijing, China.

NDRC, National Development and Reform Commission (2011), China 12th FYP on (agricultural) Biogas Sector Development, in BioEnergy Expo Conference on Biogas Industrialization in China Conference, 19 May 2011, Qingdao, China.

NPC, The National People´s Congress of the People´s Republic of China (2011), China prepares to end GDP obsession, available at: http://www.npc.gov.cn/englishnpc/news/Focus/2011-03/07/content_1635453.htm, (accessed 04/08/2011).

NSCA, National Society for Clean Air and Environmental Protection (2006), Biogas as a road transport fuel, Biogas Route Map, available at:

http://www.environmental-protection.org.uk/assets/library/documents/biogas_as_transport_fuel_june06.pdf (accessed 20/08/2011).

OCSCCC, Office of Capital Spiritual Civilization Construction Commission (2010), Lu Wa in action – Guideline for waste reduction and waste sorting in pictures, Beijing Press, Beijing, China, [in Chinese].

Ökobit-Die Biogasexperten, (2011) EEG 2012: Vergütungssystem für Biogasanlagen weiter aufgefächert, available at: http://www.oekobit-biogas.com/biogas-im-eeg-2012-das-neue-verguetungssystem-fuer-biogas.html (accessed 04/12/2011) [in German].

O'Leary, D. (2000), Properties of Carbon Dioxide, available at: http://www.ucc.ie/academic/chem/dolchem/html/comp/co2.html (accessed 21/07/2011).

Raninger B., LI R., Bidlingmaier W., et al., (2006) *Bioorganic Municipal Waste Resource Recovery and Utilisation Project in Shenyang – RRU-BMW Summary Report'*. Proceedings of the 1st ICEEE Int. Conference on Bioorganic Municipal Waste and Landfill Management, pp. 1 – 120, Shenyang, P.R. China

Raninger B., Yang Guangzhong, R. Li, Feng Lei, (2009) '*The RRU-BMW Project - Four Years Pilot Tests on BMW Source Separation in Shenyang*, China', Biomass and Organic Waste as sustainable Resources, Proceedings of the Int. Conference ORBIT 2009, published in 'Biogas Engineering and Application', Vol.1, China Agriculture University Press, ISBN 978-7-5655-0190-6, pp 35-44, Beijing, China

Raninger B., Li R., Chen X., Xu H. (2010), *'Biomass Wastes-to-Energy in China, Biogas from Landfills or Anaerobic Digestion?'*, Depotech 2010, Montanuniversität Leoben, Abfallwirtschaft, Abfalltechnik, Deonietechnik und Altlasten, Hersg. Lorber, Adam, Aldrian,et.al, ISBN 987-3-200-02018-4, pp105–111.

Raninger, B. (2011), Biogas from landfill in China? ...implication on solid waste management, Biogas technology: Status and trends in Asia, Powerpoint presentation, 24 May 2011, Bangkok, Thailand.

Roelcke, M. (2011), Professor at Technische Universität Braunschweig, E-Mail Contact, 8th August 2011.

Ru, X., Lu, X. and Li, P. (2010), The China Society Yearbook, Vol. 4, Brill, Leiden, The Netherlands.

Shi, Y., (2011), China´s resources of biomass feedstock, China Engineering Sciences, 1009-1742, 02: page: 16-23, Beijing, China, [in Chinese with English abstract].

Steffen, R., Szolar, O. and Braun, R. (1998), Feedstocks for Anaerobic Digestion, available at: http://www.adnett.org/dl_feedstocks.pdf (accessed on 20/08/2011).

Tang, Y., Xie, J.S. and Geng, S. (2010), Marginal Land- based Biomass Energy Production in China, Journal of Integrative Plant Biology 2010, 52 (1), page: 112–121, Beijing, China.

TCG, Travel China Guide (2011), Country Description of China, available at: http://www.travelchinaguide.com/essential/country.htm (accessed 12/07/2011).

The China Greentech Initiative (2009), The China Greentech Report 2009, available at: http://www.greenexport.org/resources/pdf/CGTR2009-ExecutiveReviewEnglish.pdf (accessed 25/05/2011).

The Council of the European Union (1999), Council Directive 1999/31/EC of the European Parliament and of the Council of 26 April 1999 on the landfill of waste, available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1999:182:0001:0019:EN:PDF (accessed 09/06/2011).

The World Bank (2005), Waste Management in China: Issues and Recommendations, Urban Development Papers, Working Paper No. 9., s.l..

The World Bank (2010), Asia Sustainable and Alternative Energy Program ASTAE, Annual Status Report 18, Washington, D.C.

UNFCCC - secretariat, United Nations Framework Convention on Climate Change - secretariat (1994), Emissions summary for China, available at: http://unfccc.int/files/ghg_data/ghg_data_unfccc/ghg_profiles/application/pdf/chn_ghg_profile.pdf (accessed 06/08/2011).

UNFCCC, United Nations Framework Convention on Climate Change (2004), Project design document form (CDM PDD) – Version 2, available at: http://www.bcba.sba.com.ar/downloads/proyectos_argentinos/01_Extraccion_de_gas_de_relleno_sanitario_DOMINICO.pdf (accessed 21/07/2011).

UNFCCC, United Nations Framework Convention on Climate Change (2007), Climate change: Impacts, vulnerabilities and adaptation in developing countries, available at: http://unfccc.int/resource/docs/publications/impacts.pdf (accessed 25/05/2011).

UNFCCC, United Nations Framework Convention on Climate Change (2009), The United Nations Climate Change Conference in Copenhagen, available at: http://unfccc.int/meetings/cop_15/items/5257.php (accessed 24/05/2011).

Wang, Q.H. (1994), Investigation of rural straw utilization in China, Rural Eco-environment, 10(4), page: 67–71, s.l., [in Chinese with English abstract].

Wang, H. and Nakata, T. (2009), Analysis of the market penetration of clean coal technologies and its impacts on China's electricity sector, Energy Policy 37:338 page: 351,s.l..

Wendland M., Bayerische Landesanstalt für Landwirtscharft (LfL) (2011), *Verbal information about ongoing AD slurry application research*, Weihenstephan, Germany.

Williams, A.G., Audsley, E. and Sandars, D.L. (2006), Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra.

Wu, C.Z., Yin, X.L., Yuan, Z.H., Zhou, Z.Q. and Zhuang, X.S. (2009), The development of bioenergy technology in China, Energy 35, page: 4445–4450, Elsevier Ltd.

Xie, G., (2011), Professor at China Agricultural University, Personal conversation, 24th June 2011, Beijing, China.

Zhao, L., Wang G and Mang, H.P., (2006), Chinese Biomass Energy Potential - Concept for Sino-German Cooperation, Sustainable Development of the Bioenergy Sector, Inception Study, Part 1, Summary of Current Biomass Energy Situation, Beijing, China.

Zhong, H.P.,Yue, Y.Z. and Fan, J.W. (2003), Characteristics of crop straw resources in China and its utilization, Resources Science 2003, 25, page: 62–66, [in Chinese with English abstract].

Zhou, Y. (2005), Advance in the study of clean straw biomass as energy. Shaanxi Chemical Industry, 34(10), page: 595–597, [in Chinese with English abstract].

Zhuang, D., Jiang, D., Liu, L. and Huang, Y. (2010), Assessment of bioenergy potential on marginal land in China, Renewable and Sustainable Energy Reviews 15, page: 1050–1056, Elsevier Ltd.

APPENDICES

Appendix A Agriculture

A.1.1 Total Production of Crops

Table 18 Total Production of Eight Different Kinds of Crops, 2000-2009

Crop Production	2000	2002	2004	2006	2008	2009
Rice	18791	17453,9	17908,8	18171,8	19189,6	19510,3
Wheat	9964	9029	9195,2	10846,6	11246,4	11511,5
Maize	10600	12130,8	13028,7	15160,3	16591,4	16397,4
Tubers	3685,2	3665,9	3557,7	2701,3	2980,2	2995,5
Beans	2010	2241,2	2232,1	2003,7	2043,3	1930,3
Oil-bearing crops	2955	2897,2	3065,9	2640,3	2952,8	3154,3
Sugarcane	6828	9010,7	8984,9	9709,2	12415,2	11558,7
Cotton	442	491,6	632,4	753,3	749,2	637,7
Total	**55275,2**	**56920,3**	**58605,7**	**61986,5**	**68168,1**	**67695,7**

(unit: 10^6 tonnes)

Source: *NBSC, 2010c*

A.1.2 Total Arising of Livestock

Table 19 Total Arising of Livestock, 2000-2009

Animals	2000 (1)	2001 (1)	2002 (1)	2003 (2)	2004 (2)	2005 (3)	2006 (3)	2007 (4)	2008 (4)	2009 (5)
Pig	44681,5	45743	46291,5	46601,4	48189,1	50334,8	49440,7	43989,5	46291,3	46996
Cow	12866.3	12824,2	13084,8	13467,2	13781,8	14043,5	13944,2	10594,8	10576	10726,1
Poultry	464000	489000	474000	506000	516000	533000	536000	502000	528197,4	533000
Total	**521547,8**	**547567,2**	**533376,3**	**566068,6**	**577970,9**	**597378,3**	**599384,9**	**556584,3**	**585064,7**	**590720,5**

(unit: 10^4)

Sources: (1) NBSC 2003, (2) NBSC 2005, (3) NBSC 2007, (4) NBSC 2009, (5) NBSC 2010d