JINGJING HUANG

Characterization of decentralized biogas technology in China and evaluation of the transferability to other regions in Africa and Latin America

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Vorgelegt von

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Foreword

It is necessary worldwide to place the energy supply on a regenerative basis in order to achieve climate protection targets. In this context, the provision of energy through biogas, which is produced by the anaerobic decomposition of organic materials, is becoming increasingly important. Domestic biogenic waste and agricultural residues as well as renewable raw materials cultivated specifically for this purpose can be used as substrates.

In Germany and other industrialized countries biogas technology is generally practiced in large-scale plants in the waste management sector. Also and in the agricultural sector the throughput rates are several 100 to over 10,000 Mg/a. In contrast to this biogas plants at household level with a throughput rate of around 10 Mg/a offer major advantages in economically developing countries and in emerging economies with predominantly decentralized small-scale farming structures. Here, toilet waste, kitchen waste, and manure from own animal husbandry are usually used as substrates. In addition to the residual material treatment, which also enables hygienization of the waste, a fertilizer is produced at the same time, which can be reused in the own garden or on the own agricultural land. Furthermore, biogas is produced, which can be used directly for cooking, lighting or heating. Particularly in regions with a lack of infrastructure (e.g. with regard to electrical energy supply) and a shortage of fuels, this biogas production makes it possible to create an energy self-sufficient household.

In China, decentralized household biogas plants have developed strongly since the 1970s, especially in rural areas, so that about 42 million of these plants (fixed-dome reactors with a volume of 6 - 10 m³) are currently installed there. Based on the many years of positive experience with this decentralized biogas technology in China, it is obvious to implement it in other emerging countries as well.

This is where Ms. Jingjing Huang's dissertation comes in by systematically evaluating the transferability of household biogas plants, as used in China, to other regions using selected countries as examples, deriving potential for improvement, and making a regional potential assessment.

The scientific findings obtained by Dr.-Ing. Jingjing Huang show that the technology and operation of household biogas plants installed on a large scale in China, especially in rural areas, can be transferred to other countries. At the same time, the investigations show that the existing boundary conditions in the individual countries mean that the potential for these plants can be assessed very differently. Especially with regard to the expansion of decentralized biogas technology in developing countries, the presented dissertation provides a valuable basis for evaluation.

This is an important scientific research work for science and practice for international experts. I wish the dissertation a wide distribution.

Stuttgart, June 2022 Prof. Dr.-Ing. Martin Kranert

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My family is the most important part of my life. None of this would have been possible without their moral and financial support during my doctoral studies. Whether it is my husband and daughter by my side, or my parents far away in China, they have always supported me. I am deeply grateful to my friends who encouraged and supported me when I was in trouble and needed help.

I would like to thank every IGNIS project partners, as well as all the collaborating institutions and individuals who helped me and provided data for my thesis so that I have complete a large amount of data collection, field visits and questionnaire surveys.

My sincere thanks to DAAD for the financial support I received during my doctoral studies.

Although there is still a long way to go for further studies, I will keep going. I am very grateful every people for the accompanying and support along the way.

Stuttgart, September 2022 Jingjing Huang

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Abbreviations

AATPI	Appropriate Agricultural Technology Promotion Initiative
ABiogás	Brazilian Biogas Association
ABPP	Africa Biogas Partnership Program
AD	Anaerobic digestion
AEMFI	Association of Ethiopian Microfinance Institutions
BES	Biogas Extension Service
BiogaST	Biogas support for Tanzania
BIOMA	Biogas Institute of Ministry of Agriculture
BMBF	German Federal Ministry of Education and Research
BOD	Biochemical oxygen demand
CAMARTEC	Centre for Agricultural Mechanization and Rural Technology
CCP	Chinese Communist Party
CCCCP	Central Committee of the Communist Party of China
CERs	certified emission reductions
COD	chemical oxygen demand
CRI	Crop-to-residues index
CSA	Central statistical Agency of Ethiopia
CSTR	Continuous Stirred Tank Reactor
DGIS	Directorate General for International Cooperation
DIT	Dar es Salaam Institute of Technology
EIA	Environmental impact assessment
ELCT	Evangelical Lutheran Church in Tanzania
EREDPC	Ethiopian Rural Energy Development and Promotion Center
FECC	Foreign Economic Cooperation Center
FM	Fresh Matter
GCTI	German Climate Technology Initiative
GDP	Gross domestic product
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GNI	Gross National Income
HDI	human development index
HEP	health extension program
Hivos	Humanist Institute for Cooperation

LPG	Liquefied Petroleum Gas
MFIs	Microfinance Institutions
MOA	Ministry of Agriculture of the People's Republic of China
MPN	most probable number
MSW	municipal solid waste
NGO	Non-governmental organization
NIA	National Implementing Agency
NPCSC	Standing Committee of the National People's Congress
PE	polyethylen
PHC	Population and Housing Census
PPP	purchasing power parity
PRC	People's Republic of China
PROINFA	Programa de Incentivo às Fontes Alternativeas de Energia Elétrica
RTPC	Regional Technical and Promotions Centres
SEP	Special Energy Program
SIDO	Small Industries Development Organization
SNV	Netherlands Development Organisation
SS	suspended solids
TDBP	Tanzania Domestic Biogas Program
TFC	Total Final Consumption
TPES	Total Primary Energy Supply
TS	Total Solid
UASB	Up-flow Anaerobic Sludge Blanket
UNDP	United Nations Development Programme
UMSS	Universidad Mayor de San Simon
VERs	verified emission reductions
VS	Volatile Solids

Units

a	year
atm	atmospheric pressure
cm	centimeter
d	day
h	hour

ha	hectare
kg	kilogram
kPa	kilopascal
km	kilometer
km^2	square kilometer
Ktoe	kilo tons of oil equivalent
kWh	kilowatt-hour
l	liter
m	meter
m^2	square meter
m^3	Cubic Meter
mg	milligram
Mg	Mega gram
MJ	megajoule
mm	millimeter
Mtce	Million tons of coal equivalent
Mtoc	Million tons of oil equivalent
MWh	megawatt-hour
TWh	Terawatt-hour

Abstract

Due to the limited resources of fossil and nuclear energy sources as well as considerable environmental damage causing by using of fossil energy, it is necessary to change the primary energy sources to reach a sustainable energy supply in terms of environmental and climate protection. Biogas can be a valuable contribution in the transition to renewable energies. The share of energy generated from biogas in Germany is currently 11.9% of the total renewable energy sources in 2019. Worldwide, the use of biogas is also expected to 4% of renewable energy in 2017.

Biogas is a combustible mixture of gases with the main component methane (60% - 70%) and carbon dioxide (30% - 40%), which is produced in anaerobic digesters through the fermentation process of biological breakdown of organic matter such as biological waste, sewage sludge, manure, straw or other organic substances. With approximately 9,700 biogas plants in 2020, Germany is the European leader in terms of energy production from biogas in large-scale plants. In comparison, household biogas plants have been operated in rural areas of several developing and emerging countries for many years. Household biogas plants usually uses animal manure, toilet waste and kitchen waste from household as input material. The biogas is directly used for cooking, lighting or heating, additionally the digestate could be used as fertilizer back to yard or garden.

The popularization and scientific research of biogas in China began around 1970. After more than four decades of development, by the end of 2015, around 42 million household biogas plants had been counted in the form of fixed-dome type digester with volume of 6-10 m^3, throughout the country. Trained technicians and members of the household carry out the construction of the reactors. These biogas plants are particularly simple to operate and maintain. Frequent input and output within the biogas digester are required in order to maintain the biogas production. According to the specific local conditions, many ecological models have been developed in different areas of China. "Pig-biogas-fruit" model is one of the typical countryside biogas models. In this system, the garden as the basic unit, the constructing pigpen together with the biogas digester forms a kind of circular economy. This model was considered as assumption for following economical, ecological and social assessment.

Chinese government has always attached great importance and provided strong support for rural biogas development for many years, and the capital investment has been increasing year by year. A relatively complete and efficient work net has been developed, which covers the adoption of marketing biogas application, technical support and maintenance outlets all together. More than 1,900 counties and towns have established more than 8,000 rural energy offices and they have 40,000 full-time staff members, who are responsible for the administration of biogas in rural areas.

The experience in China shows that biogas technology has not only economic benefits, but also an impact on aspects of energy, environment, agricultural production, socio-economic development, health and sanitation. It can provide a solution to the treatment of human and animal feces, eradication of parasites and pathogens to improve the rural sanitation. According to the results of relevant tests, most biogas slurries reach the Chinese sanitary standard for the non-hazardous treatment of night soil. The porosity, organic substances and pH value of the soil have increased after biogas slurry application as a fertilizer. With the replacement of energy sources of coal, electricity or oil products, the use of biogas contributes to the reduction of greenhouse gas (CO_2 equivalent). Furthermore, the working cost is substantially cut down in activities such as collecting firewood or raising crops. The share of the experience of Chinese household biogas technology will represent an important contribution to promotion the biogas technology and realize the sustainable energy supply.

The aim of this dissertation is to obtain an overview of the household biogas system in China and evaluation of the transferability to other comparable regions. For this purpose, it is particularly important to answer the following research questions:

- What are the important conditions and parameters of household biogas digester systems?
- What are the practical benefits of household biogas systems?
- Which regions are suitable for promotion of household biogas systems?
- How to evaluate the transferability of the household biogas systems to other regions systematically?
- Where are the weaknesses and strengths points of these regions? What is the potential for improvement compared to the status quo?
- How much potential for household biogas digesters are there in these regions to which the transferability will be proved?

Characterization of the household biogas digester system provide a basis information foundation, which describes the framework conditions for the construction, operation and management of household biogas digesters in China. Furthermore, based on the framework conditions, a method to analyze the transferability including potential opportunities and risks for household biogas development have to be developed. In addition, the potential of household biogas plants and their ecological and economical assessments will be quantitative forecasted using scenarios.

The transferability study is based on 7 criteria, which are itemized into a total of 18 sub-criteria. In this dissertation, cost–benefit analysis is used to construct an objective, scientific and comprehensive transferability study of household biogas digester in different regions. The suitable climate condition, demand of clean energy supply and accessibility of material as the most important criteria are taken into account. Besides, the financial, technical, social, and political conditions are also considered. Criteria are scored according to a 0 - 1 scale, with 1 indicating the highest degree of target fulfillment. China, Tanzania, Ethiopia, Bolivia, and Brazil were chosen for processing the identical transferability analysis. It is proved that this transferability analysis can provide reliably and valuable results aiming to various decision-making processes.

The results of transferability study showed that China achieves the highest utility value in comparison with other countries regards to household biogas plant technology and many years of experience. Because of a relatively long history of biogas and supportive international cooperation, Tanzania and Ethiopia achieve a middle score. In contrast, due to insufficient technical and material availability, Bolivia has less suitable conditions for the promotion of household biogas digesters. Household biogas plants are not an interesting solution for Brazil. With sufficient hydroelectricity, Brazil has adequate energy supply with renewable energy in urban and rural areas. In addition, relatively centralized livestock farming in Brazil is a trend for medium- or large-scale biogas plants.

The slow population growth in China and the rapid urbanization in the meantime leads to a decrease of potential household biogas digesters. It is expected that China's appropriate households for the biogas development will be reduced from 67.24 million households by 2020 to only 19.85 million by 2050. Due to the population growth and social-economic increase, the potentials of biogas digester will continue to increase for the next 40 years in Ethiopia and Tanzania. In Bolivia, potential of household biogas digesters with ca. 0.03 million has no significant change till 2050. In Brazil, the proportion of suitable households for the development of household biogas remains extremely low and represents the decreasing tendency.

With an adequate approach as in China, the economic benefits of a biogas plant can be calculated for Tanzania, Ethiopia, Bolivia and Brazil. The investment costs for biogas digesters depend intensively on the price of construction materials. The revenue is a result of the savings of conventional energies and the increasing of agricultural yields. Based on the concept of biogas uses and energy mix for cooking, the saving costs of biogas as an alternative energy were calculated. A typical 8 m^3 biogas plant in China require an investment of € 912 and annual maintenance cost of € 162. With annual biogas production of 340 m^3, of which 263 m^3 for cooking and 77 m^3 are used for lighting, generates a total annual revenue of € 591. This shows the payback period for the investment is around 3 years. In Ethiopia and Tanzania, with lower investment costs and relatively lower benefits of the household biogas digesters, it needs 2 years and 3 years till the recovery of investment, respectively. Farmers in Bolivia have more income by using biogas; although the highest investment costs, the payback period is 7 years. The household biogas digester in Brazil has a payback period of 4 years.

Most countries in Latin America and Africa, especially those with limited access to renewable energy, have outstanding potential for promotion and application of household biogas technology. Requirements of promotion and application of household biogas technology include government support, adequate feeding materials, available finances and technologies. However, despite of the willing and potential, there can be still numerous problems and challenges in the sustainable promotion. Due to the high initial investment cost, it is necessary to increase finance subsidize from government. Regarding to inadequate technology support, besides international cooperation and exchange, improved project management with regular inspection by the decentralized biogas office can ensure the normally working of biogas digester. The regions with centralized breeding should consider medium- or large high tech biogas plants. And the areas, where are rich in solar, wind, hydro and geothermal resources, should make full use of those resources with the inclusion of biogas technology and due to local conditions develop that renewable energy. In this way, it can construct a feasible model in the rural areas of Africa and Latin America featuring stable energy supply, minimized environmental pollution and sustainable resources management, which will also increase employment opportunities as well as household incomes, and ultimately improve the living standards of the rural population.

Zusammenfassung

Fossile und nukleare Energiereserven sind begrenzt und deren Nutzung ist mit erheblichen Umweltbeeinträchtigungen verbunden. Im Gegensatz dazu leisten erneuerbare Energiequellen einen wichtigen Betrag, um eine nachhaltige Energieversorgung im Hinblick auf den Umwelt- und Klimaschutz zu erreichen. Als regenerativer Energieträger spielt Biogas eine zunehmende Rolle. Der Anteil an aus Biogas erzeugter Energie war im Jahr 2019 in Deutschland knapp 12% der gesamten regenerativen Energieerzeugung. Weltweit liegt der Anteil von Biogas bei ca. 4% der erzeugten regenerativen Energie.

Biogas ist ein brennbares Gasgemisch aus Methan (60% - 70%) und Kohlenstoffdioxid (30% - 40%), das unter anaeroben Bedingungen durch den biologischen Abbau von organischen Stoffen wie Bioabfällen, Klärschlamm, Gülle oder anderer nachwachsender Biomasse sowie organischen Rest- und Abfallstoffen entsteht. Deutschland ist mit ca. 9 700 Biogasanlagen im Jahr 2020 im europaweiten Vergleich führend was die Energieproduktion aus Biogas in großtechnischen Anlagen betrifft. Im Vergleich dazu werden in ländlichen Regionen in Entwicklungs- und Schwellenländern schon seit vielen Jahren Haushalts-Biogasanlagen betrieben. Als Inputmaterial werden üblicherweise Gülle, Toilettenabfälle und Küchenabfälle aus dem eigenen Haushalt verwendet. Das Biogas wird direkt zum Kochen, Beleuchten oder Heizen verwendet. Der aus dem Prozess entstehende Gärrest wird direkt als Dünger im eigenen Garten oder auf landwirtschaftlichen Flächen verwendet.

In den 1970-er Jahren wurde in China begonnen die Biogas-Technologie wissenschaftlich zu untersuchen und dadurch wurde das Thema zunehmend populärer. Bis Ende 2015 waren landesweit rund 42 Millionen Haushalts-Biogasanlagen in Form eines Festkuppelreaktors mit einem Volumen von 6 – 10 m³ installiert. Der Bau von Haushalts-Biogasanlagen erfolgt durch ausgebildete Techniker und die Haushaltsmitglieder. Ein Vorteil dieser Haushalts-Biogasanlagen ist, dass sie relativ einfach im Betrieb und der Wartung sind. Entsprechend den spezifischen lokalen Bedingungen wurden unterschiedliche Modelle für die verschiedenen Gebieten Chinas entwickelt. Das Modell "Schweine-Biogas-Frucht" ist eines der typischen ländlichen Biogasmodelle. In diesem Modell werden der Garten, zusammen mit dem Schweinestall und der Biogasanlage als Grundbestandteile des Systems betrachtet, um so eine Kreislaufwirtschaft zu bilden. Dieses Modell wurde in dieser Arbeit als Basis für die Erarbeitung der ökonomischen, ökologischen und sozialen Bewertung festgelegt.

Die chinesische Regierung hat der Entwicklung von Biogastechnologien in ländlichen Gebieten seit vielen Jahren große Bedeutung beigemessen und diese Technologien stark gefördert, die Kapitalinvestitionen sind von Jahr zu Jahr gestiegen. Es wurde ein Arbeitsnetzwerk entwickelt, das die Vermarktung von

Biogasanwendungen, technischem Support und Wartungsmöglichkeiten zusammenfasst. In über 1 900 Landkreisen und Städten wurden mehr als 8 000 ländliche Energiebüros eingerichtet mit rund 40 000 Vollzeitmitarbeitern, die für die Verwaltung von Biogas in ländlichen Gebieten verantwortlich sind.

Die Ergebnisse aus China zeigen, dass die Haushalt-Biogastechnologie nicht nur wirtschaftliche Vorteile, sondern auch positive Auswirkungen im Hinblick auf Energieversorgung, Umwelt, landwirtschaftliche Produktion, sozioökonomische Entwicklung, Gesundheit und Abwasserentsorgung hat. Sie kann eine Lösung für die Behandlung von menschlichen und tierischen Exkrementen sein, durch die Hygienisierung der Exkremente können Parasiten und Krankheitserreger reduziert oder sogar eliminiert werden und die Biogaserzeugung kann somit zur Verbesserung der ländlichen Sanitärsituation beitragen. Nach den Ergebnissen einschlägiger Tests erreichen die meisten Gärreste den chinesischen Hygienestandard für die ungefährliche Behandlung von menschlichen Fäkalien. Die Nutzung der Gärreste als Dünger verbessert die Porosität, den Gehalt an organischer Substanz und den pH-Wert des Bodens. Beim Ersatz von fossilen Energiequellen wie Kohle, Strom und Öl trägt die Verwendung von Biogas zur Reduzierung der Treibhausgase (CO_2-Äquivalente) bei. Darüber hinaus werden die Arbeitskosten bei Tätigkeiten wie dem Sammeln von Brennholz oder dem Anbau von Pflanzen erheblich gesenkt. Die Entwicklungen und Erfahrungen in China mit den Haushalts-Biogasanlagen leisten einen wichtigen Beitrag zur Förderung der Biogastechnologie und somit zur Realisierung einer nachhaltigen Energieversorgung in ländlichen Regionen in anderen Entwicklungs- und Schwellenländern.

Ziel dieser Dissertation ist es, das Haushalts-Biogasanlagen-Modell in China und die unterschiedlichen Anwendungen in den verschiedenen Regionen in China zu beschreiben und zu bewerten und dessen Übertragbarkeit auf vergleichbare Regionen anderer Länder zu bewerten. Im Vordergrund steht die Beantwortung von folgenden Forschungsfragen:

- Was sind die relevanten Bedingungen und Parameter der Haushalts-Biogasanlagen?
- Was sind die praktischen Vorteile von Haushaltsbiogasanlagen?
- Welche Regionen sind für die Förderung von Haushalts-Biogasanlagen geeignet? Wie kann die Übertragbarkeit des Haushaltsbiogassystems auf andere Regionen systematisch bewertet werden?
- Wo liegen die Schwachstellen und Stärken? Wie ist das Verbesserungspotential?
- Wie hoch ist das regionale Potenzial für Haushalts-Biogasanlagen?

Die Charakterisierung von Haushalts-Biogasanlagen liefert eine grundlegende Informationsbasis, welche die Rahmenbedingungen für die Planung, die Konstruktion, den Betrieb und die Instandhaltung von Haushalts-Biogasanlagen in China identifiziert und spezifiziert. Darüber hinaus wird auf der Grundlage der

Rahmenbedingungen eine Methode zur Analyse der Übertragbarkeit einschließlich möglicher Chancen und Risiken für die Entwicklung von Haushalts-Biogasanlagen entwickelt. Das Potenzial von Haushaltsbiogasanlagen und deren ökologische und ökonomische Bewertung wird ebenfalls quantitativ anhand von Szenarien abgeleitet.

Die Bewertung der Übertragbarkeit erfolgt anhand von 7 Kriterien, die in insgesamt 18 Unterkriterien aufgeschlüsselt sind. In dieser Dissertation wird die Nutzwert-Analyse verwendet, um eine objektive, wissenschaftliche und umfassende Übertragbarkeitsstudie von Haushalts-Biogasanlagen in verschiedenen Regionen zu erstellen. Als wichtigste Kriterien werden das vorherrschende Klima, die Nachfrage nach sauberer Energieversorgung und die Zugänglichkeit des Materials berücksichtigt. Daneben werden auch die finanziellen, technischen, sozialen und politischen Bedingungen berücksichtigt. Die Kriterien werden auf einer Skala von 0 bis 1 bewertet, wobei 1 den höchsten Zielerfüllungsgrad beinhaltet. Für die Bearbeitung der Übertragbarkeitsstudie wurden China, Tansania, Äthiopien, Bolivien und Brasilien ausgewählt. Die Ergebnisse zeigen, dass diese Übertragbarkeitsstudie zuverlässige und wertvolle Ergebnisse für verschiedene Entscheidungsprozesse liefern kann.

China erreicht im Vergleich mit anderen Ländern im Hinblick auf die Technologie von Haushalts-Biogasanlage und seinen langjährigen Erfahrungen den höchsten Nutzwert. Aufgrund ebenfalls langjähriger Erfahrungen mit der Biogastechnologie und durch unterstützende internationale Zusammenarbeit erreicht Tansania und Äthiopien einen mittleren Nutzwert. Unzureichende technische Faktoren und eine geringe Materialverfügbarkeit führten dazu, dass Bolivien zu den Ländern mit den schlechteren Bedingungen für die Förderung von Haushalts-Biogasanlagen zählt. Im Gegensatz dazu stellen Haushaltsbiogasanlagen für Brasilien keine interessante Lösung dar, da Brasilien, mit ausreichend Hydroenergie, mit regenerativen Energien schon gut versorgt ist und eine relativ zentralisierte Viehzucht besitzt.

Das prognostizierte langsame Bevölkerungswachstum in China und die zunehmende Verstädterung in führen zu einem Rückgang potenzieller Haushalt-Biogasanlagen (von 67,24 Millionen Haushalten im Jahr 2020 auf 19,85 Millionen im Jahr 2050). Für Äthiopien und Tansania wird das Potenzial von Haushalt-Biogasanlagen aufgrund der relativ langsamen Entwicklung der Wirtschaft und der starken Abhängigkeit vom Agrarsektor in den nächsten 40 Jahren weiter steigen. In Bolivien hat das Potenzial an Haushalts-Biogasanlagen mit ca. 0,03 Millionen bis 2050 keine signifikante Veränderung. In Brasilien bleibt der Anteil der für die Entwicklung von Haushalts-Biogasanlagen geeigneten Haushalte niedrig und besitzt eine abnehmende Tendenz.

Mit einer adäquaten Vorgehensweise wie in China können die wirtschaftlichen Vorteile von Haushalt-Biogasanlagen für Tansania, Äthiopien, Bolivien und Brasilien berechnet werden. Die Investitionskosten für die Biogasanlagen hängen stark vom Baustoffpreis ab. Die Einnahmen resultieren aus den Einsparungen konventioneller Energien und der Steigerung der landwirtschaftlichen Erträge. Eine typische 8-m^3-Biogasanlage in China erfordert eine Investition von 912 €. Bei einer jährlichen Biogasproduktion von 340 m^3, wovon 263 m^3 zum Kochen und 77 m^3 für die Beleuchtung benutzt werden, wird ein jährlicher Gesamtumsatz von 591 € erzielt. Dies zeigt, dass die Amortisationszeit für die Investition etwa 3 Jahre beträgt. In Äthiopien und Tansania, mit geringeren Investitionskosten und relativ geringeren Umsatz der Haushalts-Biogasanlage dauert es 2 Jahre bzw. 3 Jahre, bis sich die Investition amortisiert. Landwirte in Bolivien haben mehr Einkommen durch die Nutzung von Biogas, obwohl hier die Investitionskosten im Ländervergleich am höchsten sind, die Amortisationszeit beträgt hier 7 Jahre. Eine Haushalts-Biogasanlage in Brasilien hat eine Amortisationszeit von 4 Jahren.

Die meisten Länder Lateinamerikas und Afrikas, besonders, die in begrenztem Umfang auf regenerative Energien zurückgreifen können, haben ein enormes Potenzial für die Förderung der Haushalts-Biogastechnologie. Die Anforderungen an die Förderung und Anwendung von Biogastechnologien umfassen Unterstützung durch die Regierung, adäquate Rohstoffe, verfügbare Finanzmittel und Technologien. Trotz der Bereitschaft und des Potenzials kann es bei der Förderung noch zahlreiche Probleme und Herausforderungen geben. Aufgrund der hohen Investitionskosten ist es notwendig, die Finanzierungszuschüsse der Regierung zu erhöhen. Im Hinblick auf die unzureichende Technologieförderung kann neben der internationalen Zusammenarbeit und dem Knowhow-Austausch auch ein verbessertes Projektmanagement mit regelmäßiger Überprüfung durch dezentrale Biogasbüros den normalen Betrieb von Biogasanlagen sicherstellen. Für die Regionen mit zentralisierter Viehzucht sollten mittelgroße oder große Hightech-Biogasanlagen in Betracht gezogen werden. Die Gebiete, die reich an Sonnen-, Wind-, Wasser- und geothermischen Ressourcen sind, sollten diese Ressourcen auch unter Einbeziehung der Biogastechnologie nutzen und diese erneuerbaren Energien entwickeln. Auf diese Weise kann ein praktikables Modell in Afrika und Lateinamerika dargestellt werden, welches eine stabile Energieversorgung, eine verringerte Umweltbelastung und ein nachhaltiges Ressourcenmanagement umfasst, das auch die Beschäftigungsmöglichkeiten sowie die Haushaltseinkommen erhöht und letztlich den Lebensstandard der Landbevölkerung verbessert.

1 Introduction and Objectives

1.1 Introduction

Nowadays, global energy consumption presents an accelerated increase not only due to the massive population growth but also to the industrialization worldwide. The reserves of fossil fuels are limited and expected to be consumed in few decades (F.Manzano-Agugliaro, 2013). In many developing countries, especially in rural areas, there is in fact no electricity or gas available for basic needs. Yet, the use of conventional energy is associated to negative environmental impacts, e.g. excessive carbon dioxide emissions that lead to global climate warming (also known as greenhouse effect) (Tasneem Abbasi, 2012). On the other hand, solid waste such as municipal organic waste, green waste, and animal manure are not treated in many areas, but directly deposited. The latter situation often causes hygienic problems and environmental damage (Epstein, 2015). To achieve sustainable energy supply and to help with the environment protection, a challenge of transforming the energy supply structure shall be met. The use of renewable energy sources such as wind, solar, hydro and biomass are mandatory for these reasons.

Biogas is playing an increasingly important role as a renewable energy source. The share of energy generated from biogas in Germany is currently 11.9% of the total renewable energy sources in 2019 (BMWi, 2020a). Worldwide, the use of biogas is also expected to 4% of renewable energy in 2017 (IRENA, 2019).

Biogas is produced by fermentation process of biomass under anaerobic conditions. Biomass and organic residuals such as sewage sludge, manure or organic wastes can be utilized as input materials for the biogas plants. The products from this process are biogas and digestate. Biogas can be further used as bio-fuel to generate power and heat, or injected as biomethane into the grid after upgrading, while the digestate could be used as valuable fertilizer and soil conditioner.

With approximately 9,700 biogas plants in 2020, Germany is the European leader in terms of energy production from biogas in large-scale plants (Statista, 2021c). In comparison, household biogas plants have been operated in rural areas of several developing and emerging countries for many years. Household biogas plant, as known as small biogas digester for only one or two families, usually uses animal manure, toilet waste and kitchen waste from household as input material, and the biogas is directly used for cooking, lighting or heating. The digestate could be possibly used as fertilizer back to yard or garden.

Developing stable clean energy and reducing pollution to the environment are common problems for developing countries and emerging countries to face. For the developing countries with great agricultural development potential, household biogas plant as anaerobic treatment of livestock manure and agricultural waste is a reasonable option to improve the domestic energy supply and to reduce the damage to the ecological environment. Many developing countries has already long history of utilization of biogas technology. By the end of 2020, over 900,000 biogas digesters have been installed in 24 countries in Asia, Africa and Latin America supported by Netherlands Development Organisation (SNV) (SNV, 2021). As a country with early development of biogas technology, the Indian "floating" type biogas digester is widely used in South Asia. In India, there are 4.55 million of household biogas digester in 2017 (BMWi, 2020b). Around 2,300 biogas plants gave been installed in Thailand till 2013 (Aggarangsi, et al., 2013).

The evolution of biogas technology in China extends over a period of more than 40 years. By the year 2019, China had about 33.81 million biogas plants, this is the highest number of biogas plants worldwide, especially household biogas plants. The amount of biogas production is currently about 11.22 billion m³ per year (Yearbookchina, 2020). According to the long-term plans, there will be an increase of four million new consumers every year. The experiences in China show that the use of household biogas digesters not only can supply clean energy for household use, but also provide ecological and social benefits.

The application and promotion of household biogas digesters could significantly improve the living and environmental conditions also in many low-income regions of Africa and Latin America. In the same way, this would significantly contribute to the reduction of migratory pressures on the fast-growing cities and megacities as well as the greenhouse gas effect in general. Latin America and Africa with plenty of available materials and suitable climate conditions are ideal for biogas development. Since 1970, the household biogas technology was introduced in Latin America and Africa, where more than 10,000 biogas plants were set up, but only few of them are still working. The causes for the failure or failures of existing biogas plants have several reasons: lack of motivation of the user, material errors and technical defects, insufficiently training of users, reduced animal holdings and water problems.

1.2 Objective and tasks

Results from research and other investigations are now supporting the basic information and advancement in household biogas technologies. However, the literature did not provide a systemic detail characterization of the decentral biogas technology, which can be summarized in a model of biogas digester for promotion of this technology, and for assessment of the risks and opportunities of biogas development. This model should consider all the criteria within the whole biogas system, from design, construction, operation up to governance. Besides, there is unfortunately no method for verifying the transferability of biogas technology that can be comfortable conducted by decision-making by government or self-checking by farmer. So far, the research focus was on the extermination of biogas potential, but has not related their economical, ecological, and social benefits of each household biogas digester, which can be as the most important motivation for potential biogas user.

Based on the above-mentioned items, the requested further studies and transferability analysis appears to be a continuation of previous work to identify the research points:

- What are the important conditions and parameters of household biogas digester systems?
- What are the practical benefits of household biogas systems?
- Which regions are suitable for promotion of household biogas systems?
- How to evaluate the transferability of the household biogas systems to other regions systematically?
- Where are the weaknesses and strengths points of these regions? What is the potential for improvement compared to the status quo?
- How much potential for household biogas digesters are there in these regions to which the transferability will be proved?

The share of the experience of Chinese household biogas technology will represent an important contribution to promotion the biogas technology and realize the sustainable energy supply. The aim of this dissertation is to obtain an overview of the household biogas system in China and evaluation of the transferability to other comparable regions.

Characterization of the household biogas digester system provide a basis information foundation, which describes the framework conditions for the construction, operation and management of household biogas digesters in China. Furthermore, based on the framework conditions, a method to analyze the transferability including potential opportunities and risks for household biogas development have to be developed. In addition, the potential of household biogas plants and their ecological and economical assessments will be quantitative forecasted. This transferability analysis helps the decision-making to popularization of the advanced technology on more regions.

Four countries are chosen as examples to conduct the transferability analysis. Tanzania is one of the least developed countries in the world, and the economy is dominated by agriculture. Agriculture accounts for 85% of the country's exports and half of its gross domestic product (GDP) (CIA Tanzania, 2019). The plentiful availability of raw materials guaranties the input materials for biogas plant. Ethiopia with the second highest population in Africa, owns the worst energy supply system (International Energy Agency, 2019f). The application of biogas systems may be a promising solution for the energy system in Ethiopia. Brazil as the biggest and also the most developed country in Latin America (The World Bank, 2019d), the possibility of application of the household biogas plant is high encouraging. Bolivia with extremely difficult climate and geography conditions (World Bank Group, 2019a), the review of the transferability of the household biogas technology will be a valuable example for other comparable regions.

The procedure of this dissertation can be divided into following stages:

- Data research for legal and political background and governance of household biogas plants in China.
- Data research and laboratory tests to identify the framework conditions and criteria for construction, operation and management of household biogas digesters.
- Analysis of the economic, environmental and social advantages of household biogas projects in China.
- Elaboration of criteria for transferability analysis.
- Develop the method for transferability analysis of household biogas technology and perform the transferability analysis in five selected countries.
- Calculation of theoretical biogas potential in five selected countries.
- Identification of barriers and suggestions.

1.3 Structure of dissertation

The thematic focus as well as the used methodic in each chapter are summarized as following:

Chapter one starts with the background information about the research topic including the problem statement, the current research questions and open points, aims and the objectives of conducting the dissertation.

Chapter two introduces the state of research and technology of biogas. Through literature research the general information about biogas and biogas technology is present.

Chapter three describes the decentralized biogas technology in China. The main objective of this chapter is the characterization of decentralized biogas technology in China, which consists of the determination of legal regulations and laws in sector of biogas, history of biogas development, structure and operation of household biogas digester as well as the utilization of digestate in China. In this chapter, a large amount of historical data and actual situation is obtained through literature evaluation and interview surveys with responsible persons such as biogas users, relevant government staffs or researchers from universities.

Chapter four represents the results obtained from onsite investigation of household biogas digesters in different regions in China. In this chapter, the investigation on the rural household biogas digesters including site visits, sample survey, laboratory tests as well as interview survey are conducted. Considerations of climate, geographic and socio- economic conditions, biogas digesters in south, north and west area of China have been investigated. Questionnaire surveys have been used in face-to-face conversations with users of biogas to approach and study their experiences. Observation on-site joined the data collection and field sampling in order to accurately record research process and results.

Chapter five gives a review of selected countries in Latin America and Africa. Literature research is used for collection of basic data including climate conditions, energy supply and consumption, potential biomass for biogas plant, waste management etc., which are relevant for promotion of biogas digester. The main sources of data come from public sector information, collected in previous years. Besides, because of the difficulty to obtain official data in Africa and Latin America, some data in these continents are based on network information.

Chapter six introduces the development of a method of transferability studies, including the determination of relevant criteria and its weighting. Besides, the method to assessment of impact of economic and ecological aspect are determined. Cost–utility analysis based on relevance criteria were developed to construct an objective, scientific and comprehensive transferability study. Sensitivity analysis of weightings is an important part of transferability study. Furthermore, the methodic using for calculation of invest cost, revenues and payback period of household biogas digester is introduced for economic assessment. The amount of reduction of CO_2 emission and forest deforestation will be counted as ecological aspect.

Chapter seven represents and discusses the results of transferability studies. These include the results of cost-utilize analysis and sensibility analysis in five countries, the potential of biogas digester as well as the economic and ecological benefits. In addition, the comparison of results from different regions is done for discovering the advantages and disadvantages of the regions on transferability of household biogas digester. Moreover, in this chapter the identification of barriers according to the results of the applicability study is described, additionally it is providing suggestions.

Finally, chapter eight summarizes the general conclusions of household biogas technology and its transferability in other regions. Meanwhile, outlook for the transferability of the knowledge and the further research forces is presented.

2 States of research and technology

Biogas was used many centuries ago in different parts of the world. Biogas was used for heating bath water in Assyria as long ago as the 10th century B.C. and that anaerobic digestion (AD) of solid waste may well have been applied in ancient China (He, 2010). As early as 1630, Vam Helmeuy discovered that anaerobic fermentation of biomass can produce a combustible gas. In 1776, the Italian physicist Alessandro Volta discovered a combustible gas from swamps and believed that, this gas production was related to the decomposition of organic matter (IOANA IONEL, 2010). In 1806, Herry ensured that this gas was methane. In 1868, methane formation process done by microbiology was first proposed by Becbamp (Ferry, 1993).

2.1 Biogas characterization

Biogas is a combustible gas, which is generated by a variety of organic substances through microbial fermentation under anaerobic conditions (Deng, 2007). Biogas is very common in the daily life of human beings, such as the gas bubble from the surface of standing water, sewage or septic tanks. Biogas fermentation is a common process of circulation of substances in nature. After the regular pattern of biogas being generated under nature condition is sufficiently aware, people consciously simulates the artificial conditions in order to produce and use of biogas.

As biogas is a mixture of gases, its composition not only depends on the category and content of fermentation materials, but also varies with the fermentation condition and process. Nevertheless, the main components in biogas are methane (CH_4) in around 50% - 75% (volume), followed by carbon dioxide (CO_2) in around 25% - 45% (volume). In addition, there are 2% - 10% water vapor (H_2O), 0% - 5% nitrogen (N_2), 0% - 2% hydrogen sulfide (H_2S) and less than 1% corresponds to hydrogen (H_2), carbon monoxide (CO) and ammonia (NH_3) (Kranert, et al., 2012). Biogas is a colorless gas, but it has slightly a similar smell to rotten egg as a consequence of the presence of hydrogen sulfide. Explosion limit of standard biogas in the air is 6% - 22% (BG RCI & BGHM, 2021). As reaching this concentration, fire or tiny sparks will lead to explosion or combustion. In closed conditions, the mixture of biogas and air would burn quickly after sparked, and it also would expand and produce a great driving force. Therefore, biogas cannot be used for cooking, lighting, or fuel without proper controls. Table 2-1 shows the basic properties of biogas.

Biogas not only can be burnt directly for cooking, lighting, heating and gas welding but also can be used as a fuel for internal combustion engines and production of methanol, formaldehyde, carbon tetrachloride and other chemical raw materials as well. Through the fermentation process, digestate (and residues) contains affluent nutrients, which can be used as fertilizer for soil improvement and also as feed for livestock or fishes (JING, et al., 2016).

Table 2-1 Basic properties of biogas

Parameter	Value
Lower heating value[1]	14.4 – 27 MJ/m³
Density[1]	1.2 kg/m³
Explosion limit in the air[2]	6 – 22 %
Critical temperature[3]	-37° C
Critical pressure[3]	56.6 atm
Ignition temperature[1]	700°C

[1] (MUEEF, 2009) [2] (BG RCI & BGHM, 2021) [3] (Kishore, 2009)

2.2 Anaerobic digestion process

The process of biogas production is a complex biochemical process in which organic matter comes into the formation of both methane and carbon dioxide under the anaerobic conditions (FNR, 2016). This process uses the help of the catabolism of different bacteria that perform different functions. The process is called “anaerobic digestion" (AD). This complex transformation can be divided into four stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis (Kranert, 2017).

Hydrolysis

In this stage, high molecular complex compounds and not dissolved compounds (such as cellulose, protein, fat, etc.) can be hydrolyzed by enzymatic conversion into small molecules, that are soluble monosaccharaides, amino acids, glycerol and fatty acids. Those soluble materials of small molecules can enter within the microbial cells and further be decomposed.

Acidogenesis

The soluble substances continue its decomposition under the action of the acid-producing bacteria into some smaller molecular substances, such as acetic acid, propionic acid, butyric acid, as well as into simple organic substances like alcohol, aldehyde, ketone, etc.

Acetogenesis

The fatty acid (> C3-Chain) is in this stage converted into acetic or formic acid. In both stages, acidogenesis and acetogenesis, inorganic substances such as hydrogen, ammonia and carbon dioxide hydrogen and carbon are released.

Methanogenesis

In this stage, methanogenic bacteria decompose the simple organics chains (acetic acid, etc.) coming from the second stage into methane and carbon dioxide. Moreover a part of carbon dioxide is reduced to methane with the help of the existing hydrogen. About 70% of the methane produced is achieved thanks to the acetic acid and the other 30% comes from the reduction of carbon dioxide (Wandrey, et al., 1983)

Four stages of biogas fermentation must be conducted under strict conditions in order to reach the maximum production of biogas with good quality (Kranert, 2017).

1. Strict anaerobic environment

   The core microorganisms of biogas fermentation - methanogens are anaerobic bacterium, which grow merely in strictly anaerobic environment. These bacteria are particularly sensitive to oxygen, because the oxygen in the air would inhibit its life activity, causing even its death. Therefore, the construction of biogas digesters must be tightly closed, watertight and airtight. It is not only a requirement for biogas collection but also for the storage of raw materials. This isolated condition also ensures a normal gas production in the digesters, because of the requirements of microorganisms to grow and reproduce.

2. Suitable nutrient of raw materials

   The raw material is the basis for the survival of biogas microorganism and nutrients for their life activities especially production of biogas. Cells consist of approx. 50% carbon, 20% oxygen, 10% nitrogen, 10% hydrogen and 2% phosphorus, furthermore sulfur, calcium, potassium etc.. All these elements should be present in suitable proportions in the reaction environment. The ratio C:N plays a especially important roll. Nitrogen is the decisive part of the microbial cytoplasmic body, and carbon not only constitutes the microbial cytoplasm but also provides the energy of life activities.

   Examples of raw materials with affluent content of nitrogen are usually dung of human, livestock and poultry. After fully being processed by the digestive system of humans and animals, these materials generally contain fine particles and a large number of low-molecular-weight compounds with high moisture. As a result, these materials can be easily decomposed in an anaerobic way producing gas quickly with the need of no pretreatment.

Crops residues such as straw or blighted shell are usually considered as the raw materials rich in carbon. These raw materials are rich in cellulose, pectin and some substrates difficult to degrade like lignin and plant wax. Beside this, high dry matter content, loose texture and small proportion of such raw materials easily float into the digester forming a layer of floating shell that must be pretreated before its fermentation.

The best fermentation feedstock is carbon-nitrogen ratio in the range of 25:1 - 35:1. If there is an excessive amount of carbon and a lack in nitrogen then the microbial metabolism will slow down and as a consequence the speed of gas production will be also lower. Conversely, high nitrogen content in the materials would converted to ammonia, which can counteract excessive acid formation in the reactor, which can be highly toxic at high concentrations. For the N:P ratio, the suitable value is around 5:1 (Kranert, 2017).

3. High quality and quantity of bacteria

   The microorganisms are the internal factors of the artificial preparation biogas and all other external conditions are serviced for it. Therefore, the digesters need to have abundant bacteria. In new digesters, an important point is to add an inoculum with a large number of microorganisms. The purpose is to ensure a quick start-up of the fermentation and process and also a quick breeding of microorganisms to guarantee the gas production.

   The microorganisms for biogas digesters usually come from nature and can be found with organic subtracts and under anaerobic conditions. Household biogas digesters generally contain 10% -30% of inoculum of the total feedstock amount, which can be usually collected in old biogas digesters.

4. Suitable fermentation temperature

   Temperature is the most important external factor in biogas fermentation. The decomposition rate of material under anaerobic conditions is faster with the right temperature and also the production of methane is higher. Meanwhile, a suitable temperature leads to a microbial proliferation be strong and with high vitality.

In the temperature range of 10°C - 60°C, the digester can produce gas normally. Below 10°C or above 60°C, it will inhibit microbial survival and gas production. In the mentioned temperature range, the higher the temperature the more microbial activity, thus the gas production is higher. Though thermophile digestion systems are considered to be less stable and also because the energy input is higher, more energy is removed by the organic matter. The increased temperatures facilitate faster reaction rates and, hence, higher gas yields. Operation at temperatures higher than 50°C facilitates hygienisation of the end products.

Usually different fermentation temperature zones have been classified into three ranges: 45°C - 60°C for thermophile (optimum app. 55°C), 25°C - 45°C for mesophile (optimum app. 35°C), 10°C - 25°C for room temperature (Kranert, 2017). Rural household biogas digesters generally rely on the natural temperature fermentation without heat equipment and work in the range of room temperature (10°C - 25°C). Within this range, the higher temperature achieved would lead to the greater gas production. This is the reason why more gas is produced in summer than in winter. Likewise, rural household biogas must take precautionary measures in winter to guarantee stable gas production.

5. Suitable pH value

The growth and breeding of microorganisms in fermentation require a neutral or slightly alkaline pH-value in the material feedstock. However, gas production will be affected with excessive acid or alkaline materials. It is definitive that the gas can be produced when pH is 6 to 8 and the highest output would come with 6.5 - 7.5 pH value. But when the pH value is lower than 6 or higher than 9, biogas will not be generated any longer.

Because of the activities of acid-producing bacteria in the rural household biogas digesters at the beginning of the fermentation process, large amounts of organic acids are produced leading to the decrease in pH. As the fermentation process continues, the ammonia coming from ammonification neutralizes a part of the organic acids. Moreover, the activity of methanogenic bacteria cause a lot of volatile acids that are transformed then into methane (CH_4) and carbon dioxide (CO_2), then pH value rises gradually to normal. Thus, in the normal fermentation process, changes in pH in the digesters can be adjusted naturally, which fall from high to low and then increase again until the pH reaches a constant natural balance at the end of the process (named as suitable pH value). There is no need of artificial adjustment.

6. Limited heavy metal and other inhibitors

   Heavy metals are present in every fermentation substrate and are required by microorganisms in low concentrations for cell growth. However, excessive concentration of heavy metal is toxic and inhibit the biogas process. There are other substances that can be harmful for fermentation and are also undesirable in the digestate, e.g. antibiotics or aromatic compounds such as phenols. (Kranert, 2017)

7. Appropriate concentrations

   The regular production of biogas usually requires a suitable concentration of fermentation materials, consisting in a suitable concentration of dry matter in the range of ca. 5% to 30%. Although there is no precise definition of the boundary between “wet” and “solid” fermentation, the fermentation with up to a dry matter content in the fermenter of approx. 10 % belongs to “wet fermentation”, since the fermenter contents are generally still pumpable at this water content. If the dry matter content in the fermenter rises to values of over 15%, the material is usually difficultly pumpable, and the process is referred to as “dry fermentation”. (Kranert, 2017)

   For rural biogas digesters, the household biogas digesters without any stirring devices, dry fermentation can cause the problem of difficult mass transfer, uneven distribution of temperature, inoculum, etc. Therefore, the water content of fermentation material should be around 90% to 96% (Lv, 2012).

2.2.1 Biogas plants

Anaerobic digesters can be designed and engineered to operate using a number of different process configurations (FNR, 2016):

- Batch or continuous fermentation

  Most of the biogas plants are operated continuously, in which needs usually several times feeding of substrate and output of digestate every day. Advantageously, the stabile and continuous gas production makes sense for the further steps, so that the gas cleaning plant or power unit can also work continuously. By batch fermentation, the gas production is completed for each feeding substrate und the biogas plant must be emptied before the next feeding. Through coordination of several fermenters also a continuous gas production is effectively possible.

- Temperature: mesophilic or thermophilic

  Temperature is the most importance indicator by fermentation process, which influences directly the gas production, gas quality, retention time and hygiene effect. Normally, the biogas plants are operated by mesophilic condition (~ 35°C) or thermophilic condition (~ 55°C).

- Solids content: dry anaerobic digester or wet anaerobic digester

  Biogas technology concentrated mostly on traditional wet fermentation, especially by agriculture waste. By wet fermentation has the substrate excellent flowing characteristics with high water content (more than 85%), so that the substrate can be mixed and stirred in der fermenter. Dry anaerobic digester is designed to fermentation the materials with 25% - 40% solid content, which can be stacked like garden waste or green waste. The primary styles of dry digesters are continuous vertical plug flow and batch tunnel horizontal digesters. By vertical plug flow digester, the materials are fed into the top of the digester and flows downward by gravity during digester. Compare with the wet fermentation, the dry fermentation requires less energy for heating water and stirring, which leads to cheaper operation. And another advantage is more gas production per unit feedstock.

- Complexity: single stage or multistage

  In single stage digester, the whole process of anaerobic fermentation occurs within a single, sealed reactor. Advantages are the easy operation and lower invest and operation cost. But the pH value of the reactor decreased through the production of acid by acidogenic bacteria, which results the decline of methane production, while methanogenic bacteria require very strict pH range to work. Therefore, in order to better control of the reaction within the reactor and make sure the best pH range for acidogenic bacteria and methanogenic bacteria, multistage digester are currently popularized. Normally, hydrolysis, acetogenesis, and acidogenesis occur in the first reactor, and then the organic material will be heated (either mesophilic or thermophilic) prior to being pumped into the methanogenic reactor.

- Decentral and central biogas digester

  A decentralized biogas digester is usually small size since feedstock are in the small quantities and dispersed. This is suitable for small farm without consideration of storage and transport and for the region far away from energy sources (islands, farm and rural area) (Wang, 2014). Decentralized biogas plants are usually low-tech plants. Therefore, the household biogas plants in China belongs to decentralized biogas digesters. The biogas produced by the decentralized biogas digester can be used directly (as fuels or generate electricity), it can be also transport for central utilization (generation of electricity or upgrade to methane gas) (Han, et al., 2015).

A centralized biogas digester usually refers to large-scale biogas plant, which has concentrated, stable and large quantities of feedstock. Therefore, a long-term contract of feedstock supply, transport and storage are decisive issues of a centralized biogas plant. Besides, centralized biogas plants are high-tech biogas plants with the advantage of pretreatment of material, adjusted processes and trained operators (Wang, 2014). The biogas from centralized biogas plants are generally used in concentrated ways: power generation or purification. Through physical/chemical upgrading processes, the contaminants present in biogas such as CO_2, H_2S, H_2O, N_2, O_2, siloxanes, and halocarbons can be removed, which leads to CH_4 purities of 88–98% and removal efficiencies of higher than 99% for H_2S, halocarbons, and siloxanes. (Rodero, et al., 2018)

- Large, Medium and small biogas plant

  According to the daily biogas production and volume of digester, biogas plant can be classified into 4 scales (see Table 2-2) (NY/T 677-2011, 2011):

Table 2-2 Classification of biogas plant according to the size (NY/T 677-2011, 2011)

	Biogas production (Q) [m³/d]	Volume of digester (V) [m³]
Extra large scale	$Q \geq 5000$	$V \geq 2500$
Large scale	$5000 > Q \geq 500$	$1500 > V \geq 500$
Medium scale	$500 > Q \geq 150$	$5000 > V \geq 300$
Small scale	$150 > Q \geq 5$	$300 > V \geq 20$

- Household biogas digester

  The household biogas digester is usually a small biogas digester, which is built for household purpose (Rajendran, et al., 1996). Depending on geographic location, substrate availability and climatic conditions, the design of the digester can be varied. The main types of household biogas digester are fix dome digester, floating drum digester and tubular digester (Vögeli, et al., 2014)

2.2.2 Biogas yields of important input material for household biogas plant

The raw material is the material basis for producing biogas. The volume of the digester should be determined according to the amount of raw material before constructing. The fermentation feedstock in rural area mainly include various crop residues, fallen leaves, weeds, manure, human excrement, organic garbage, organic household waste, waste water from the township enterprises and factories, a variety of residues from agricultural and sideline production.

Agricultural waste is the main rural raw material for biogas fermentation, except human and animal excrement. Annual estimates of straws in China are calculated based on crop yield and the crop-to-residues index (CRI), defined as the ratio of the dry weight of residues produced to the total weight of crops produced. CRI for each type of crops varies with differences in regional, inter-annual, field management and harvesting way. The corresponding CRI are listed in Table 2-3.

Table 2-3 Crop-to-residues ratio for different crops (Lal, 2004)

Crop	CRI
Corn	1.0
Rice	1.5
Wheat	1.5
Barley	1.5
Oil-bearing crops	1.4
Beans	1.0
Cotton	1.5
Tubers	0.25
Sugarcane	0.25
Oats	1.0
Soybeans	1.0
Potato	0.25
Coffee	1.4
Cassava	0.58
Sorghum	1.5

The ratio of C and N of raw materials refers to the proportion of the total carbon and nitrogen amount in fermentation raw materials. Biogas microorganisms have certain requirements on carbon nitrogen ratio of raw material, generally being 25:1 to 30:1 appropriate (Kranert, et al., 2012). It is worth noting that not all the elements of carbon and nitrogen can be used by the biogas microorganisms. For example, lignin also is a carbon source, but this kind of carbon can hardly be used by biogas fermentation microorganisms. Generally, the soluble carbon and nitrogen are easy to be broken down and utilized. The ratio of carbon and nitrogen of several kinds of common fermentation raw materials are shown in the Table 2-4.

The amount of human and animal excretion and its content and ingredients are mainly determined by the size, metabolism state and type of nutrients as well as other various factors, such as seasonal changes, management and feeding levels (Wang, et al., 2006). Therefore, there are some deviations between the estimated amount and the actual amount of livestock manure.

Table 2-4 Carbon and nitrogen ratio of raw material for biogas fermentation (Zhu, et al., 2009)

	Material	C (Mass-%)	N (Mass-%)	C:N
Manure	Fresh pig excrement	7.8	0.60	13:1
	Fresh cow excrement	7.3	0.29	25:1
	Fresh sheep excrement	16	0.55	29:1
	Fresh horse excrement	10	0.42	24:1
	Fresh chicken excrement	35.7	3.7	10:1
	Fresh people manure	2.5	0.85	3:1
	Fresh people urine	0.4	0.93	0.5:1
Straw	Dry wheat straw	46	0.53	87:1
	Dry rice straw	42	0.63	67:1
	Rice hull	40	0.60	66:1
	Dry maize straw	40	0.75	53:1
	Fallen leaves	41	1.00	41:1
	Beanstalk	41	1.30	32:1
	Wild grass	14	0.54	27:1
	Peanut vine	11	0.59	19:1
	Rapeseed stem	38.4	2.09	18:1
	Potato stem	36.8	2.13	17:1

Biogas yield of fermentation raw material, also known as the raw material biogas production potential, refers to the total biogas yield of unit weight or volume of the raw materials by anaerobic fermentation under appropriate conditions, which indicate a capacity of gas production of raw material. The gas yield of raw material is an important basis of the design of digester volume. A variety of raw materials have the different properties of the gas production due to the different components. Being affected by the fermentation conditions and process, facilities type, management techniques and many other factors, there are differences in the potential of gas production, the speed of the biogas production or quality of the gas. The measured values usually tend to be lower than the indoor small test values and theoretical calculations. As the result of generating a certain amount of biogas, the used materials actually are much more than theoretical calculations of materials. The following Table 2-5 lists the dry matter content and biogas yield of the main fermentation raw materials.

Table 2-5 Biogas yield of several raw materials (Kranert, et al., 2012)

Material	Amount	Total solid (TS)	Volatile solid (VS)	Biogas yield	Biogas yield	Methane Content
	[kg/d]	[%]	[%]	[m^3/kg VS]	[m^3/t Fresh matter (FM)]	[%]
Pig urine	4	7	75	0.59	31	62
Pig excrement	2.5	20	78	0.36	56	62
Cow urine	30	8	78	0.35	22	60
Cow excrement	25	25	72	0.38	68	60
Sheep excrement	2	30	80	0.45	108	55
Horse excrement	12	25	75	0.55	103	60
Chicken urine	0.2	20	72	0.55	80	59
Chicken excrement	0.1	60	70	0.35	147	60
Human urine	1.5	5	60	0.3	9	60
Human feces	0.5	28	72	0.3	60	55
Dry wheat straw	-	40	93.6	0.5	187.7	52
Dry maize straw	-	29	96	0.58	160	52
Fallen leaves	-	85	82	0.4	400	50
Wild grass	-	35	91	0.46	143	55
Peanut vine	-	40	94	0.52	196.8	55
Rapeseed stem	-	14	80	0.67	75.4	56

2.2.3 Utilization of digestate

Digestate is the fermentation residue after fermentation in the digester with human and livestock manure, crop stalks and other plant waste (Guo, et al., 2005). In the fermentation process of raw materials in the digester, 40% to 50% of dry matter has been decomposed, in which most carbon were transformed into biogas and used as energy. The nutrient elements like nitrogen, phosphorus, potassium and others remain in the fermentation residue to become a fresh and stable organic fertilizer with complete nutrients, which is the best fertilizer for pollution-free agricultural products and green food. Ding etc. (Ding, et al., 2016) has analyzed nutrition of biogas digestate in three biogas projects with different raw materials (cow dung, pig manure and chicken manure) in Beijing, the nutrients content showed in Table 2-6.

Table 2-6 Nutrients of digestate as fertilizer (Ding, et al., 2016)

Average nutrient content [mg/L]	N_{total}	P_{total}	K_{total}
Liquid digestate	1,500 – 5,706	34 - 121	1,300 – 2,054
Solid digestate	15,609 – 31,000	5,173 – 23,951	7,000 – 10,000

2.3 Status of scientific research

Through more than 40 years of research and practice in terms of promotion and application of decentral biogas technology in Africa and Latin America, the technique is far developed. Some international organizations, such as the Netherlands Development Organisation (SNV) and China Biogas Institute of Ministry of Agriculture (BIOMA) played an important role (Cyimana, et al., 2013). Currently, some organizations have established and started a series of the national and international biogas programs to facilitate the biogas development in Latin-American and in Africa. The "Biogas for better life" project has the goal: until 2020 there will be 2 million biogas plants installed in Africa. "IGNIS" - project committed for the waste management in Addis Ababa, Ethiopia, in which the biogas development is also an important task (Rymkiewicz, 2014). Besides, there are lots of publications on this subject.

The research project "Biogas support for Tanzania (BiogaST)" by the organization "Ingenieure ohne Grenzen" released a master thesis with the topic "Potential and realization possibilities of small biogas plant in Kagera in Tansania", which has calculated the biogas potential according to the energy demands and material sources (Becker, 2008). The total theoretical biogas potential in the Kagera region amounts to around 48 million m^3 per year.

In the project „Tanzania Domestic Biogas Program", which is conducted by SNV, a technical potential for domestic biogas is determined by a quantitative technical analysis of the availability of substrate and process water, the ambient temperature, the availability of construction materials, enough land (space) for plant installation etc. The approximation suggests a 10-year potential of 165,000 installations for the country (Ng'wandu, et al., 2009).

According to the report on the transferability study of a national program for domestic biogas in Ethiopia by SNV, with less than 2% of Ethiopia's rural population having access to the national electricity grid and 85% of the population is living and working in rural areas – the lack of modern energy is one of the biggest problems in Ethiopia. With the Ethiopia's livestock data and an interpretation of data regarding the availability of process water, the potential for household biogas in 4 research regions (Amhara, Oromia, SNNPRS and Tigray) is between 1.1 and 3.5 million (Getachew, et al., 2006).

In the study „The Possibilities for Biogas in Bolivia: Symbioses Between Generators of Organic Residues, Biogas Producers and Biogas Users" by Gabriela Aue, the theoretical biogas potential in La Paz and El Alto in Bolivia were quantified: approximately 33 Mio. m^3 of biogas can be produced from 270,000 Mg available waste per year (Aue, 2010).

Gusmao has evaluated the composition and quantify the production of biogas in 13 anaerobic reactors used for the treatment of swine dungs, in the different regions of Santa Catarina in Brazil. It shows the potential of the biogas production is around 490 million m^3/year from about 7.2 million swine (Gusmão, 2008).

ENEA Consulting has published a report „Domestic biogas development in developing countries“, which provides a short methodological guide for domestic biogas project holders with relevant information on the key factors in the early stages of setting up projects in developing countries. The report gives not only the general presentation of domestic biogas, its environmental, social and economic benefits and also the important aspects to consider the local risks and opportunities for domestic biogas development (Rakotojaona, 2013).

It was determined by the report “Biogas as a sustainable energy source for developing countries: Opportunities and challenges“, 1,068 million dry metric Mg animal waste and human excreta are available for anaerobic digester in Asia, South America, Caribben and Africa. 1,689 million Mg CO_2 equivalent Greenhouse gas (GHG) emission can be mitigated annually through the utilization of animal waste and human excreta for biogas production (Proper management, biogas as a substitute for fuelwood and kerosene, and subsequent utilization of biogas slurry as an organic fertilizer). (Surendra, et al., 2014).

In the aspect of selection of criteria of biogas digester system, there are several studies supported the purpose. The report of “Biogas Guide” describes the basics of the construction and operation of biogas plants and the legal, administrative, and economic framework of biogas plant operation and economic analysis by Fachagentur Nachwachsende Rohstoff e.V (FNR) (FNR, 2016). Adriana Perez Garcia did the techno-economic feasibility study of a small-scale biogas plant for treating market waste with the criteria of lifespan, technical knowledge and skills, physical structure and invest cost (Garcia, 2014). In addition, Jaqueline Daniel-Gromke from DBFZ Germany identify the economically and ecologically feasible operating models of biogas plant. Various plant concepts and operating models were evaluated with criteria of costs and GHG balances (Daniel-Gromke, et al., 2020).

3 Background for biogas technology in China

3.1 General introduction of China

3.1.1 Geography and climate

China, officially the People's Republic of China (PRC), is a country located in East Asia (see Figure 3-1). Covering approximately 9.6 million square kilometers, China is the 3rd largest country in the world behind Russia and Canada.

Figure 3-1 China card (Worldometer, 2020)

China has a vast territory, widely span latitude, different altitudes and diversity of terrains and mountains; the variations in temperature and precipitation cause varied atmospheric conditions. Continental monsoon climate is the main characteristic of Chinese weather. China's northern-most point lies in the cold-temperate zone; its southern-most point, Hainan Island, has a tropical climate. From September to April, a cold and dry winter is present in China. The average temperature is about -3°C (China Meteorological Administration, 2016). On the other hand, from April to September a warm and humid summer wind blows from the eastern and Southern Ocean, this summer is characterized by a high temperature and rain in China. The average temperature from April to September in most of the area may exceed 20°C, and some southern regions have even more than 30°C (China Meteorological Administration, 2016).

Precipitation in most parts of China is caused by the impact of a maritime soft and wet airflow; nevertheless, rainfall is unevenly distributed in the different regions at different times. Precipitation is gradually reduced from the southeast to the northwest, but the annual average amount varies highly, for instance, south-east coast could rise to 1,200 mm or more, but in the northwest inland could be less than 200 mm. Most of the regions in the country perform the same condition: rainy in summer but rainless winter (China Meteorological Administration, 2016).

3.1.2 Population and economy

China is the most populated country in the world, by the end of 2018 the population in Chinese mainland was 1,395 billion inhabitants (see Figure 3-2), having the 19.7% of the world's population and the 33% of Asia's. The average annual infant birth rate was 1.09% and the mortality was 0.71%, while the natural growth rate was 0.38%. The national average life expectancy was 76 years (National Bureau of Statistics of China, 2018).

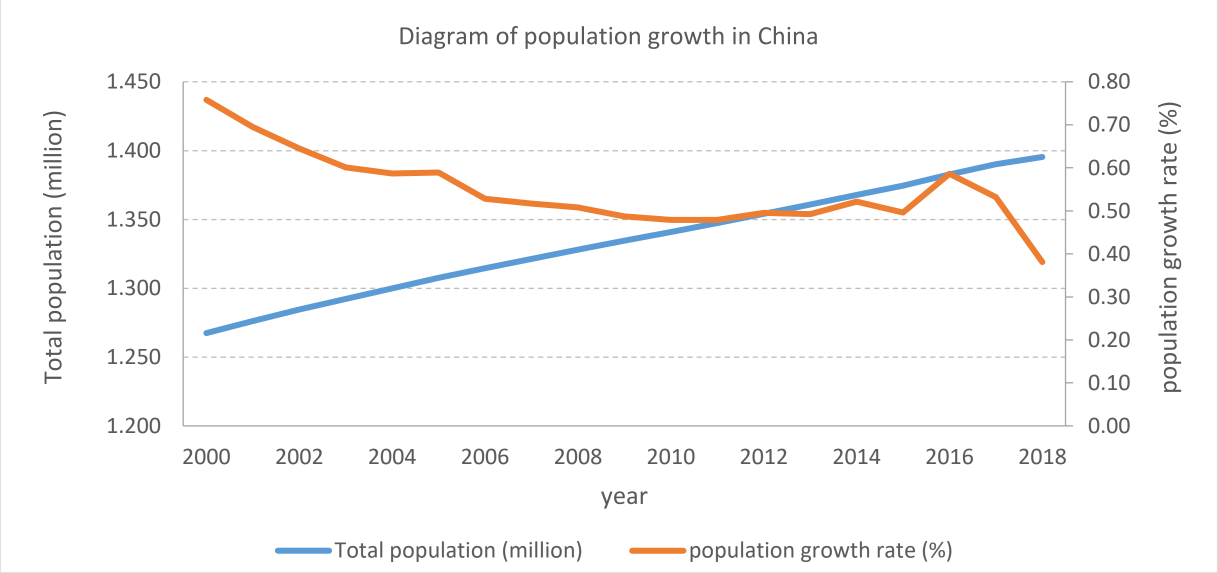

Figure 3-2 Population and natural population growth rate in China (National Bureau of Statistics of China, 2018)

According to the 2018 statistics, in China nearly 57.35% of people live in rural areas (National Bureau of Statistics of China, 2018). The others are urban populations. While China is the most populated country in the world, its national population density is 143 inhabitants per km^2, two times higher than the average worldwide level (58 inhabitants per km^2) (The World Bank, 2018). The overall population density in China shows major regional variations, for example in the western and northern part of the country have a few million people, while the vast majority of China's population lives in the fertile plains of the southeast with about 94% of the total population (despite of the fact that this area represents 43% of the total territory). As an example, in Jiangsu province, its population density was 717 inhabitants per km^2 and even over 2,000 inhabitants per km^2 in Shanghai or Hong Kong, but only 7 inhabitants per km^2 in Qinhai province, where located in west of China.

As of 2018, China has the world's largest economy in terms of nominal GDP, totaling approximately US$ 25.36 trillion, of which agriculture, industry and service industries contributed 7.9%, 40.5%, and 51.6% respectively to its total GDP. It is the world's fastest-growing major economy, with growth rates averaging 6.9%. China's per capita GDP was US$ 18,200 in 2018 (CIA China, 2019). With a human development index (HDI) score of 0.758 in 2018, China ranks 85th among 189 countries in the world (UNDP, 2019). China`s gross national income (GNI) was US$ 9,620 (€ 8,238) per capita in 2018 (The World Bank, 2020).

3.1.3 Energy supply and consumption in China

China has abundant coal resources. By the end of 2017, China had 249 billion Mg of coal reserves (National Bureau of Statistics of China, 2017). These amounts have allowed China ranks four around the world in terms of total coal reserves (BP, 2018). As the major source of energy in China, coal is a predominantly element in energy structure which is hardly to get passed in the short term.

According to statistics of 2016, it has been evident that China’s Gross domestic product (GDP) -with 14.74% of world’s total GDP- consumed 20.80% of world’s total energy consumption. This condition means that China has relatively low energy efficiency. The total primary energy supply and consumption by source in China from 2000 to 2018 are listed in Table 3-1 and Table 3-2, and their graphical representation in year 2018 are in Figure 3-3 and Figure 3-4 respectively. In 2018, coal represented 36% of the structure of China’s primary energy consumption, 25% higher than the average level in the world (International Energy Agency, 2020). In 2016, China imported 381 million Mg of crude oil, standing a dependence on foreign regions of nearly 65% (The state council of China, 2017). Along with the improvement of China's per capita income levels, China's oil consumption will continue increasing dramatically, therefore the import crude oil will also be in great amounts in order to meet the domestic demand.

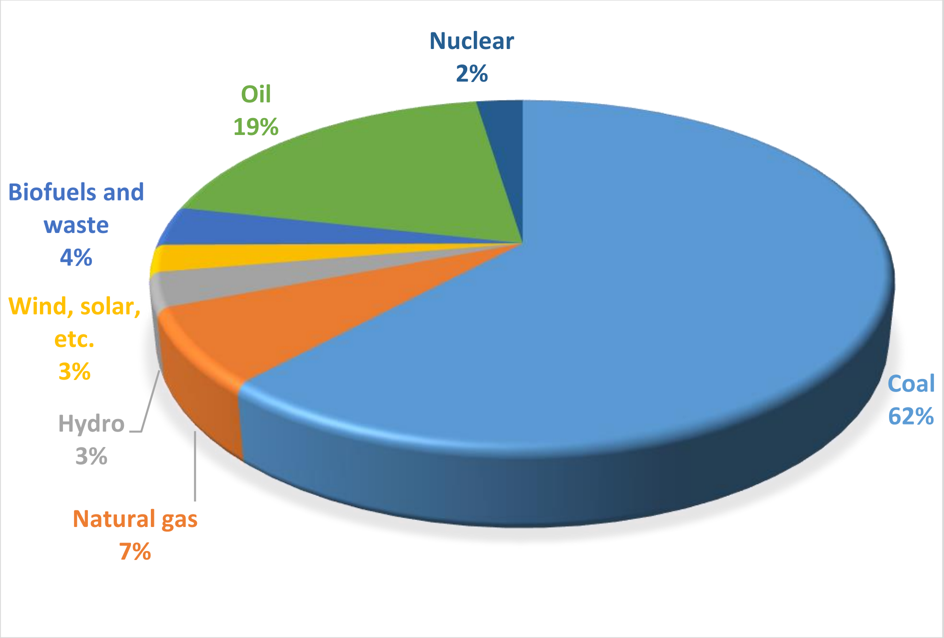

Figure 3-3 Total primary energy supply in China in 2018 (International Energy Agency, 2020)

Table 3-1 Total Primary Energy Supply (TPES) by source in China from 2000 to 2018 (International Energy Agency, 2017b)

[Unit: Ktoe]	2000	2005	2010	2015	2018
Coal	664,720	1,203,693	1,790,421	1,996,620	1,979,524
Natural gas	20,756	38,790	89,382	158,588	230,359
Nuclear	19,124	34,137	61,168	95,827	103,113
Hydro	2,646	5,282	15,887	49,576	81,120
Geothermal solar	198,171	168,394	133,301	113,656	116,691
Biofuels and waste	220,810	317,821	427,956	533,732	609,959
Oil	4,361	13,833	19,250	44,501	76,865
Sum	1,130,588	1,781,950	2,537,365	2,992,500	3,197,631

Table 3-2 Total Final Consumption (TFC) by source in China from 2000 to 2018 (International Energy Agency, 2020)

[Unit: ktoe]	2000	2005	2010	2015	2018
Coal	274,465	538,337	711,851	752,922	634,976
Crude oil	2,259	3,617	3,239	3,423	536
Oil products	178,110	270,041	365,790	477,009	534,864
Natural gas	12,377	29,099	73,301	105,244	153,259
Solar and geo	2,497	5,001	11,881	29,637	34,269
Biofuels and waste	196,852	166,122	120,524	90,282	79,591
Electricity	89,130	171,506	296,711	419,287	516,837
Heat	25,501	43,391	61,715	83,295	103,332
Sum	781,191	1,227,114	1,645,012	1,961,099	2,057,664

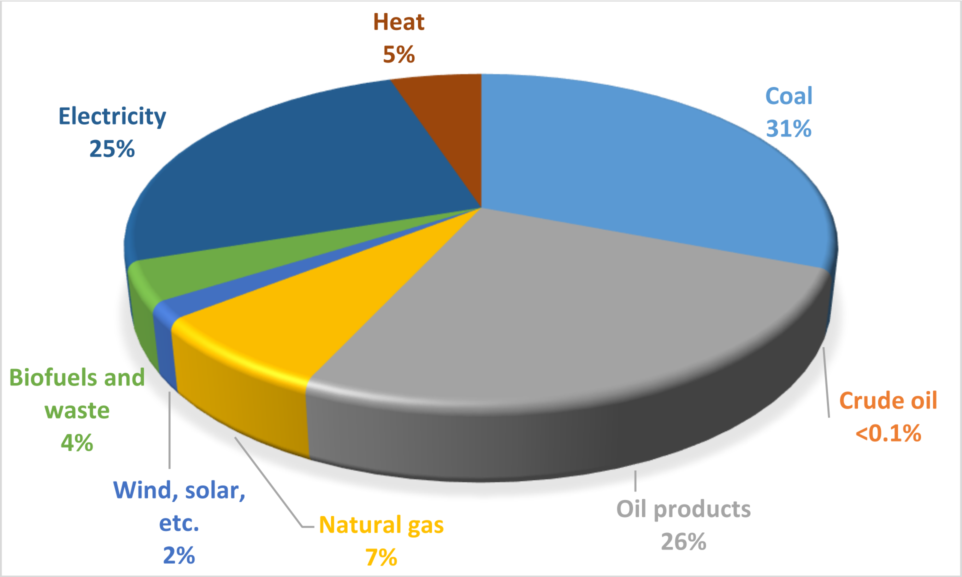

Figure 3-4 Total final consumption (TFC) of energy by source in China in 2018 (International Energy Agency, 2020)

In 2013, the average rural household energy consumption in China reached 1.12 tons coal equivalent (tce) per household, representing an annual energy consumption of 0.38 tce per capita. China's rural behavior regarding energy consumption structure has been based on biomass fuels such as biogas, animal dung, fuelwood and straw, these supplies up to 61% of the demand. The development and utilization of renewable energy has been focused mainly on the daily-life energy requirements being dominant biogas used for heating and cooking (44% respectively) (National Academy of Development and Strategy, 2016).

China's total energy consumption should be controlled at around 4.5 billion Mg of standard coal in 2020 and up to 5-5.5 billion Mg by 2050. The proportion of coal amid primary energy should decline gradually, and try to reduce to 40% by 2050, even 35%. Renewable energies are expected to contribute to the reduction of 200 million Mg of standard coal, 400 million Mg and 800 million Mg by years 2020, 2030 and 2050 respectively (Information Office of the State Council, 2012). The strategic position of the renewable energies has gradually risen from a supplementary energy to an alternative energy; and trying to become even one of the leading energy sources.

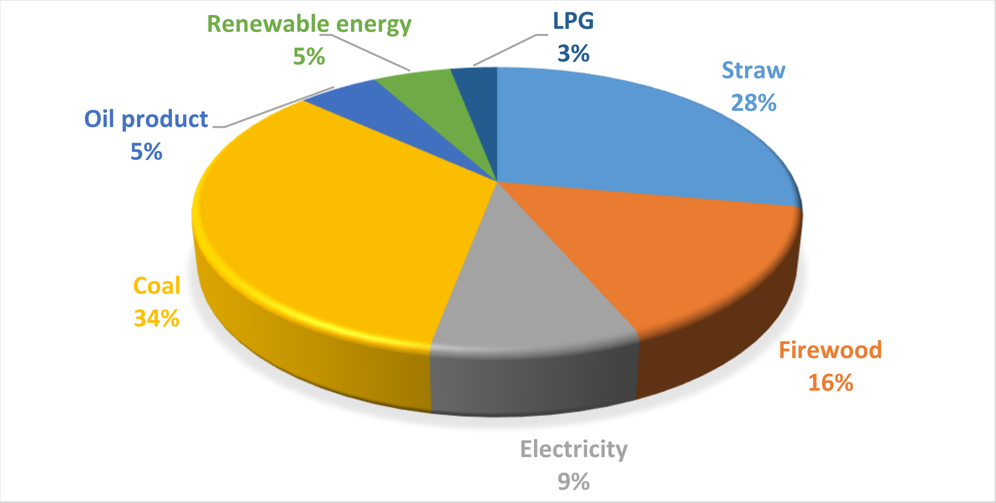

Figure 3-5 Energy consumption by source in rural areas in China in 2014 (Cong, et al., 2017)

In recent years, due to the rapid development of the rural economy, energy consumption patterns have changed significantly. In 2014, the total energy consumption of life in rural areas has reached 430 million standard coal (Cong, et al., 2017). As shown in Figure 3-5, China's rural behavior regarding energy consumption structure has been based on traditional fuels such as straw and fuelwood, these two fuels supply 27.8% and 15.7% of the demand, respectively. The proportion of coal consumption in rural areas is only 33.8% of the total energy consumption; electricity and kerosene requirements represent about 9.4% and 5.2% (Cong, et al., 2017). Consumption of renewable energies such as biogas, wind, or solar perform a small portion (ca. 5%) but showing an upward trend. The development and utilization of renewable energy has been focused mainly on the daily-life energy requirements being dominant biogas used for cooking and lighting (Cong, et al., 2017).

3.1.4 Agriculture in China

The crops considered include maize, rice, wheat, beans, tubers, cotton, oil-bearing crops (peanut, sesame), and sugar crops (sugar cane, sugar-beet). China as the biggest agriculture land in the world (5.3 million km^2) (The World Bank, 2017a), employing about 203 million farmers in 2018, equivalents to 26.1% of total employed people (National Bureau of Statistics of China, 2018). The production number of crops shows the rising tendency in the last years (see Table 3-3). The crops yield and the production of agriculture residues in 2010 and 2018 are listed in Table 3-3. It is estimated that the total yield of crop residues in China in 2010 was about 768 million Mg, and in 2018 was 908 million Mg.

Table 3-3 Crops production and crop residues in China in 2010 and 2018

	Yield 2010[1] [Million Mg]	Yield 2018[1] [Million Mg]	CRI[2]	Crop Residue 2010 [Million Mg]	Crop Residue 2018 [Million Mg]
Corn	177.43	257.17	1.0	177.43	257.17
Rice	195.76	212.13	1.5	293.64	318.19
Wheat	115.18	131.44	1.5	172.77	197.16
Cotton	5.77	6.10	1.5	8.66	9.15
Beans	15.17	21.01	1.0	15.17	21.01
Oil-bearing-crops	31.57	34.33	1.4	44.19	48.07
Sugar crops	110.79	108.10	0.25	27.70	27.02
Tubers	28.43	28.65	0.25	7.11	7.16
Cassava	4.57	4.93	0,58	2.65	2.86
Sorghum	2.46	2.91	1,50	3.69	4.37
Soybeans	15.08	15.97	1	15.08	15.97
Sum	702.20	822.75		768.08	908.15

[1] (National Bureau of Statistics of China, 2019)

[2] (Lal, 2004)

Table 3-4 presents the livestock production in China from 2010, 2015 and 2018. With the rapid development of the livestock, the total amount of contaminated waste from livestock and poultry breeding has exceeded the industrial solid waste and has become the main source of rural pollution.

Livestock manure and straw produce biogas digestate through anaerobic fermentation. Use of digestate as fertilizer is the most widely used mode, including its utilization to the field as untreated manure, dried manure and organic fertilizer after fermentation. Utilization of the untreated animal waste directly to the field is the most wildly selected approach by farmers, accounting for more than 87% of the total livestock waste by household backyard farming and 50% of centralized farming. However, either usage of the untreated manure or dried manure is easily to cause secondary pollution problems. The energy utilization is mainly achieved by biogas plant (15% of the manure by centralized farming).

Table 3-4 Livestock production in China from 2010, 2015 and 2018 (National Bureau of Statistics of China, 2019)

[Unit: Million]	2010	2015	2018
Cow	98.20	90.56	89.15
Pig	467.65	458.03	428.17
Goats	141.95	145.08	135.75
Sheep	145.35	166.67	161.39
Horses	5.30	3.98	3.47
Chicken	5,302.72	4,683.05	5,372.56
Duck	796.57	675.18	692.69
Turkey	0.13	0.11	0.08
Poultry sum	6,434.06	5,657.18	6,384.53

In China, livestock farming is gradually making a transition from the household backyard farming to the professional centralized farming. For example, the proportion of pork supplied from backyard farming decreased from 89% to 76% in 2005 - 2010 and professional centralized farming increased from 11% to 24%. Over the same period, the proportion of chicken supply from backyard farming also reduced from 90% to 72%. Separation of crops and livestock production has become a common trend, which maybe aggravate pollution of the environment by livestock excrement (Ministry of ecology and environment of people´s republic of China, 2019).

3.1.5 Waste management in China

In 2018, 228.02 million Mg of municipal solid waste has been generated in urban China (National Bureau of Statistics of China, 2019). In China, the urban household waste collection is currently based on mixed-collection.

The main characteristic of municipal solid waste is the high moisture content 55.0% ± 5.5% (Yang, et al., 2018). Food waste, which has a high organic composition, is estimated with a share of 58.0% ± 9.8% of total municipal solid waste.

Still 196.74 million Mg of municipal solid waste (96.62%) are subject to treatment with sanitary landfill (58.28%), incineration (36.23%). The 661 cities of the country count with 663 sanitary landfills and the total treatment capacity reaches 373,498 Mg per day. At the end of 2018, 331 urban waste incineration power plants had been finished with a capacity of 364,595 Mg per day (as Table 3-5).

Table 3-5 Treatment plant of municipal solid waste in China in 2018
(National Bureau of Statistics of China, 2019)

	Amount of treatment plant	Potential Capacity [Mg/day]	Treatment amount [million Mg/a]
Sanitary landfill	663	373,498	117
Incineration	331	364,595	102
Others	97	28,102	7
Sum	1,091	766,195	226

At the end of 2015, China had a total of 20,515 towns, 11,315 townships, and 2.64 million natural villages. China's current annual domestic waste in rural areas has reached 210 million Mg. The per capita domestic waste generation rate is 0.79 kg/d in towns, 0.52 kg/d in townships, and 0.50 kg/d in villages (Nelles, et al., 2017).

The average household waste treatment rates in towns and townships are 86.03% and 70.37%, respectively (Tang, et al., 2018). The household waste treatment rate in towns is higher than that in townships. The remainder waste is dumped in the rural areas. Nevertheless, the average harmless sanitary treatment rates of towns and townships nationwide were 46.94% and 17.03%, both of which did not exceed 50%, and the harmless sanitary treatment rate of townships was very low (Tang, et al., 2018). The food waste by farmers is mainly used for feeding poultry (72.56%). There are also 16.72% of household, which mix the food waste in domestic waste around big cities (Zhang, et al., 2016).

The total amount of waste production (productive waste per capita) in the rural areas is 2.03 kg. Production waste is divided into industrial waste, agricultural waste, straw and grass among others, which has been quantified in 44.11% of agriculture waste and 33.36% of straw and grass waste. 83.44% of the production waste is collected, 46.31% is directly re-used and 26.29% of is composted by high-temperature composting (Yao, et al., 2009).

3.2 Decentralized biogas technology in China

3.2.1 History of biogas development in China

The biogas application in China has followed a long path with more than a century of history. These 100 years of biogas technology development in China can be divided generally into five periods: the 1920s to1930s, the 1970s, 1980s, and the 1990s and after then to the present.

The application of biogas plants has begun truly in the late 1920s. A man called Luo Guorui built China's first concrete biogas digesters in Chao Mei region of Guangdong and set up a "China Guo Rui” gas office (then known "biogas" as "gas") with the purpose to promote biogas technology and to build biogas digesters and biogas lamps. In the 1930s, this type of digesters was constructed in many other places of China (He, 2010).

The period from 1973 to 1983 was the second phase of the development of biogas. The Chinese government was eager to solve the problem of serious shortage of living fuel, so that strongly promoted of biogas in the whole country and became a high record in 1976 with 2.57 million new biogas plants. The result of overanxious for quick results, the lack of ripe technology base and support, as well as mismanagement and other reasons, caused a followed substantially dropped stage of biogas plants, and the number of biogas users felt down from more than 7 million in 1976 to 4 million in 1982 (He, 2010).

The third stage encompasses the eight years between 1984 and 1991, when the government focused on the research of biogas technology and repaired the previous mistakes, which resulted in a slowdown of biogas plants development. The number of new digesters only increased to 82.7 thousand (cumulatively) during this period, with an average annual increasing of 10,000 biogas plants.

The fourth stage is from 1992 to 1998. Owing to the important results of the research and also to the demonstration work done in the second phase confirming the efficiency of the digesters technology, a “pig-biogas-fruit” model in southern and the "four in one" model in north, the comprehensive benefits of biogas construction became increasingly evident and the trend of biogas development rebounded to the point that about 500.000 new biogas plants were built every year.

The recent stage from 1999 till now, industrial biogas technology has quickly and widely developed, including pretreatment, high-tech biogas plant, purify of biogas as well as comprehensive utilization of digestate. Household biogas digesters have been standardized and the technical service system has been perfected. Furthermore, biogas technology is widely combined with agriculture planting, so that fruit tree, vegetable and tea planting become the base for utilization of digestate, and many successful experiences and practices in the circular economy has been accumulated (NDRC, 2017).

After summed up the effective ecological biogas model of north "Four in One", Southern "Pig - Biogas - Fruit" and Northwest "five supporting" in 1999, the ministry of agriculture ruled the “energy and environment program” and “project for ecological homes to enrich people " and also ensured annual subvention support for small-scale rural biogas plants with 100 million yuan by the years 2001 and 2002. Moreover, it sponsored with 200 million yuan the rural infrastructure in 2002 and with other 10 million supported rural infrastructure in the later year. Since then, the development of Chinese biogas plants has faced a new stage. In 2003, 2.1 million new biogas digesters were built, and the total amount of digesters was 12.89 million, getting then more than double in comparison to 1996 with 6.02 million. Meanwhile, the total biogas production of 4.58 billion cubic meters confirmed that the biogas construction has entered in a new stage with rapid development.

Since 2003, the number of China's rural biogas plants have been constantly expanding, the investment structure is continually optimizing, and the service system is gradually improving. In terms of scale, it has become in a diversified development pattern of rural household biogas, joint household biogas plants and the centralized biogas plant for farming community. Also, the sources of fermentation materials have been developed expanding from single animal manure to mixtures of manure and straw. Regarding utilization, rural biogas plants support nowadays not only the gas for lighting and cooking but also the compost as fertilizer, and even heating purposes and electricity.

At the same time, China's large and medium-sized biogas projects also have grown rapidly. In 1936, Ningbo Branch of the China Guorui natural gas office built 125.17 m^3 of biogas digesters in Hongfa Buddhist Temple in Zhejiang, which use manure, kitchen waste and grass as fermentation material and use biogas for cooking and lighting (Baidu, 2011). An industrial biogas plant of 2,000 m^3 was finished in 1964 in Nanyang’s alcohol factory in Henan province. Alcohol waste was degraded to produce biogas. In the 1980s, two more large-scale industrial digesters were built with an individual volume of 5,000 m^3. So far, the factory has 12,000 m^3 biogas plants and 30,000 m^3 gas tank as well as over 40,000 m^3 biogas yielded per day and supplied gas for 215 living area and 12,751 residents in the City (Baidu, 2011). Due to the demonstration of large-scale biogas projects in Nanyang’s alcohol factory, beginning in the 1980s; many other large and medium-sized digesters were constructed in wineries, sugar mills, food processing factories and animal husbandry. There were 110,975 biogas projects of various types supported by central and local government investment among 458 biogas projects using straw as the main raw material and 110,517 biogas projects using livestock manure as the main raw material, which include 103,898 small and medium-sized biogas projects, 6,737 large-scale biogas projects, 34 super large-scale biogas projects and 306 industrial waste biogas projects. The total capacity of the country's rural biogas projects reached 18.93 million cubic meters, the annual biogas production was 2.23 billion cubic meters, and the number of gas supply households reached 2.10 million (NDRC, 2017).

3.2.2 Policy and strategy

3.2.2.1 Establishment of policies and regulations

Since 2003, China has promulgated and implemented a series of policies and statutes to encourage and regulate the biogas development, promulgated the "Renewable Energy Law" (NPCSC, 2013), revised "Energy Conservation Law" and ancillary released implementing rules, such as “Catalog for the Guidance of the Industrial Development of Renewable Energy”, "Interim measures for the management of special fund of renewable energy development", "Interim Measures for management of subsidies of straw energy utilization" and "Implementation of programs to accelerate the construction of renewable energy applications in rural areas” as well as introduced “Long-term development planning of renewable energy”, “Construction planning of national rural biogas project” and “Industry development plan for agricultural biomass” (Li, 2010).

Especially, releasing the "Long-term development planning of renewable energy" has been proved that biogas is counted as the most important biomass energy to develop in China (Wang, 2005).

"Central Committee of the Communist Party of China (CCCCP) and State Council Opinions on Agricultural and Rural Affairs, promulgated by Central Comm. of the Chinese Communist Party (CCP) and State Council (zhongfa [2003] No. 3)" states that: "construction of small and medium-sized infrastructure in rural area should be well developed, which has directly effect to increase farmers' income and improve rural living conditions". “National agricultural investment in infrastructure and financial support for agriculture funds, should be continue focused on 'six small' projects, including water-saving irrigation, drinking water, rural roads, rural biogas, rural hydropower and pasture fence. The scale of investment should be expanded to enrich construction content. " (MOA, 2003)

"The views of the State Council of the Central Committee of the Communist Party of China on the promotion of policies to increase farmers income certain (zhongfa [2004] No. 1)" (State Council of the People's Republic of China, 2003) states that: “biogas in rural areas play an active role on improving the living conditions of farmers, leading farmers to employment and increasing farmers' income. It should further increase the amount of investment; enrich construction content and expand the scope of the biogas projects. "

"Several Opinions by the CCCCP and the State Council regarding the Active Development of a Modernized Agricultural Sector and the Sound Construction of a Socialist New Countryside (zhongfa [2006] No. 1)” (State Council of the People's Republic of China, 2006): To accelerate the pace of rural energy construction, biogas must be active promoted in the appropriate areas. The investment for construction of rural biogas and also the construction of large and medium-sized biogas plants should be increased, especially on the permit area. Construction of biogas digesters propels the reformation of livestock pens, lavatories and kitchen forward.

“National Sustainable Agriculture Development Plan (2015-2030)” (MOA, 2015): By 2020 and 2030, the comprehensive utilization rate of aquaculture wastes will exceed 75% and 90%, respectively, and the large-scale farms will achieve ecological consumption or discharge by the way of resource utilization of livestock manure. By forbidden to burn straw in the open air and promote the full utilization of straw, until 2030, the crop straw in the main agricultural production areas will be fully utilized.

"13th Five-Year Plan for Renewable Energy Development planning” (State Council of the People's Republic of China, 2017): according to the conditions of biomass resources, orderly develop biomass of agricultural and forestry direct-fired power generation and biogas power generation. By 2020, power generation capacity reached 7 million kilowatts, and biogas power generation reached 500,000 kilowatts, while the total installed capacity of biomass power generation will reach 15 million kilowatts, and the annual power generation will exceed 90 billion kilowatt hours. In areas where is less-developed and farmers have free-range breeding habits, as well as densely populated small and medium-sized farms, household biogas or small and medium-sized biogas projects should be developed in accordance with local conditions. The biogas produced is used to meet the demand of clean gas for farmers' households and farms. It is planned to invest 3.33 billion yuan to install 1.11 million household biogas digesters for rural households.

Many relevant laws and regulations make clear stipulation about the development of rural energy focused on biogas, as followed:

Agriculture Law of the People's Republic of China (December 2002) (NPCSC, 2012), Article 54 provides:" The governments at all levels should develop the division of agricultural resources and the plan of agricultural environmental protection and the plan of rural renewable energy development. "

Water and Soil Conservation Law of the People’s Republic of China (January 2010) (NPCSC, 2010), Article 39 provides that: " The state encourages and supports the adoption of the following measures helpful for water and soil conservation in mountainous areas, hilly areas, windy-sandy areas and other areas prone to water and soil loss: Developing biogas-powered and fuelwood-saving ranges, utilizing solar energy, wind energy and water energy, and using coal, electric power and gas in place of fuelwood".

Renewable Energy Law of the People's Republic of China (January 2006) (NPCSC, 2013), the provisions of Article 18: "The state encourages and supports the development and utilization of renewable energy in rural areas. Departments of energy together with relevant departments of local governments at or above the county level, in accordance with the local economic and social development, ecological protection and health needs of the comprehensive management of the actual situation, draw up the plan of renewable energy development and the plan of application of biogas-, solar-, wind- and hydro- as well as other technology. The governments above the county level should provide financial support for the use of renewable energy projects in rural areas. "

Medium and Long-Term Development Plan for Renewable Energy in China (September 2007) (MOHURD, 2008) pointed out: we should promote household biogas technology, especially in combination with agricultural production in rural areas; develop large-scale biogas projects for livestock farms and industrial wastewater with centralized gas supply system in small and medium-sized towns.

Energy Conservation Law of the People's Republic of China (October 2007) (NPCSC, 2007), Article 4 provides: "The state encourages the development and utilization of new energy and renewable energy"; Article 11: "The State Council and the provinces, autonomous regions, municipalities directly under the Central People's Government shall arrange energy conservation funds in infrastructure, technological innovation funding for the rational development and utilization of energy as well as the development of new energy and renewable energy. "

Agricultural Biomass Energy Industry Development Plan (2007-2015) (May 2007) (MOA, 2007a) index: the energy utilization of agricultural waste, vigorously develop rural biogas is the main theme of the development of agricultural biomass industry.

3.2.2.2 Gradually formed standard system

Through strengthening basic research, ongoing technological innovation and organizing the development and revising the standards in a timely manner, a Chinese biogas standard system has been gradually established to improve the biogas technology, biogas products, biogas equipment and engineering technology. In accordance with the standard range or standard approval authority, the Chinese standards can be divided into national standards, industry standards, local standards and enterprise standard. Also 45 Biogas standards have been formulated by the Ministry of Agriculture (Li, 2009). Some paragraphs of national standards and industry standards are listed in annex Table A-2.

In recent years, the numbers of large and medium-sized biogas plants increased quickly around the country. In order to standardize the biogas project outside of the rural household biogas digesters, ensure the construction and safe operation of large biogas plants, provide practical science of behavior norms for designers, builders and managers; the Ministry of Agriculture released an industry standard about a biogas scale project classification in April 2003, which was updated in 2011. Also, lots of biogas engineering industry standards were released since 2006 in annex Table A-3.

3.2.2.3 Gradually completed management system

In accordance with the principle of "Monitoring and investment by government, development with multi stakeholder, diverse mode of operation" and "specialized services, propertied management ", as shown in Figure 3-6, biogas management and service system has gradually established relying on provincial-, county-, and rural level service in China (Office of the Ministry of Agriculture, 2007). The Government investment has put a focus on supporting equipment of inlet and outlet, equipment of detection, tools for maintenance and so on to strengthen the basic construction conditions for the institutions of biogas quality inspection, monitoring, research and training.

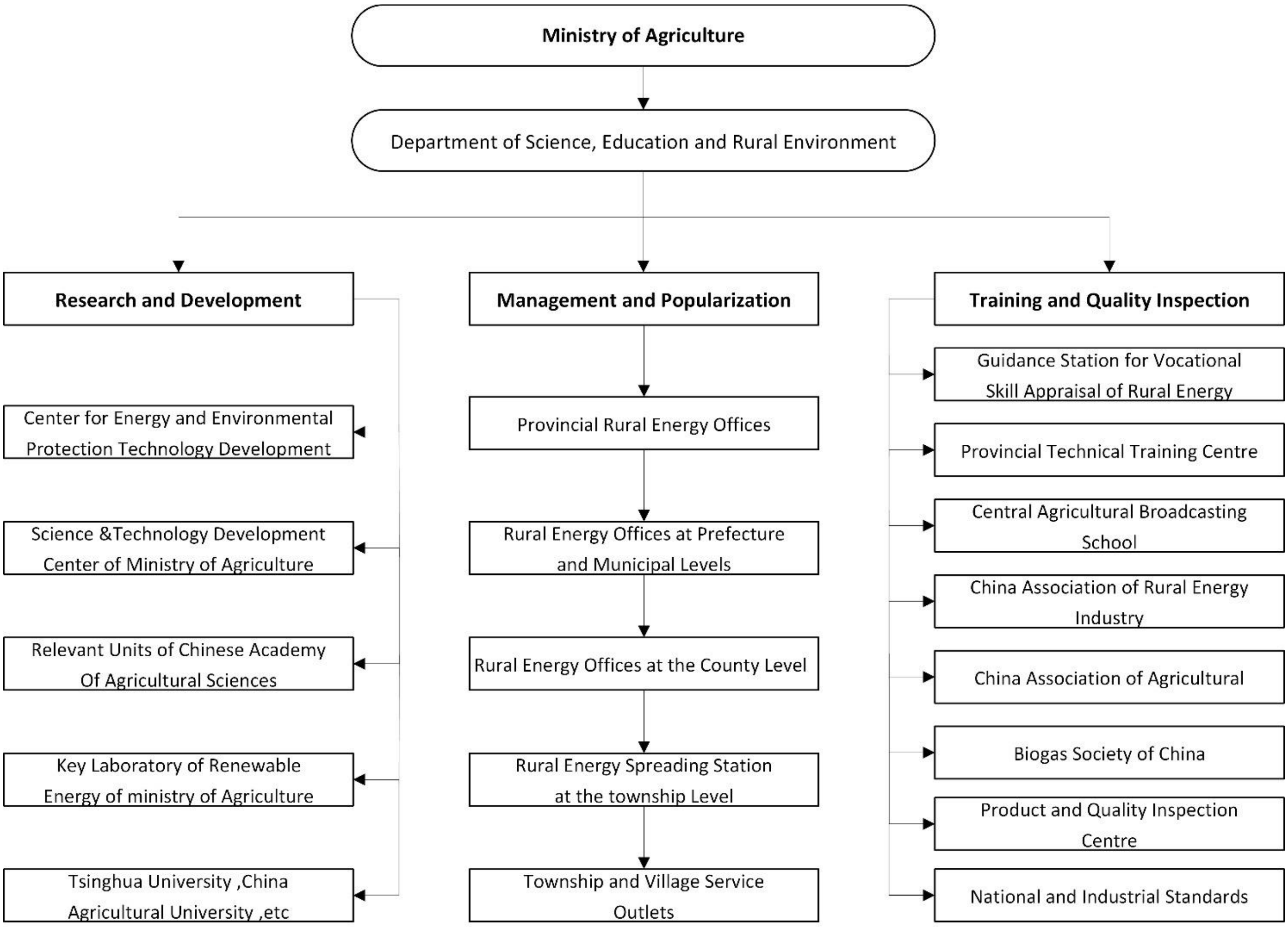

Figure 3-6 Management System of rural biogas program in China (Hao, 2010)

Service stations at all levels should carry out service work, including (Office of the Ministry of Agriculture, 2007):

1. extensively propaganda the biogas construction policy and the benefits of using biogas, set up demonstration of households' biogas plant;
2. establish a user profile to understand the usage condition of customer;
3. regularly inspections of biogas plants;
4. provide the training of security and efficient usage of biogas plant for the farmers;
5. on-site repair services, removal of fault in the process of using;
6. service of inlet and outlet and fully refueling of the biogas plant;
7. provide the training for the farmers to carry out the comprehensive utilization of digestate, to develop the circular agriculture.

I. Rural service points

Every biogas service point in rural level should have the ability to serve 300 - 500 household biogas plants. In principle, it should have „six instruments“, namely a service office, a pool for storage and pre-fermentation of raw material, an equipment for inlet and outlet process, an equipment of detection, a set tool of maintenance, the number of biogas fittings. It should have at least 1 to 2 service technicians, who focus on providing construction of biogas digester, inlet and outlet service, replacement of accessories, training program:

1. Construction of digester. The services for farmers include selection of digester type, design and site selection, arranging line and beginning digging, casting digester body, laying pipeline, installation of biogas appliances.
2. Inlet and outlet service. According to the farmers demand, the services of delivery of raw materials and the daily outlet and utilization of digestate would be carried out.
3. Replacement fittings. Biogas digester within the jurisdiction should be consequence inspected for fault diagnosed and repair, and also for timely update and replace the biogas fittings.
4. Training program. The knowledge about safety operation, daily maintenance and efficient use of biogas plant, should be publicized and trained to the biogas user.
5. Comprehensive utilization. According to the agriculture of farmer, the farmer should comprehensive utilize the digestate to develop an ecological agriculture.

II. county-level service station

Commissioned by the administrative department, county-level service station has obligation and responsibility of managing rural service points to carry out the services such as technical training, regular inspection, emergency response, fittings supply, overhaul services and pilot demonstration:

1. Technical training. Technical seminars and training of biogas construction, maintenance, management, utilization and other aspects are organized for biogas construction workers, worker of rural service points and biogas management members.
2. Regular inspection. It is responsible to carry out the advice and guidance of biogas technology; to regular check the quality of service on rural-level service point; to rectify the improper fault repair methods and techniques; and to guide the farmers for safe use of gas.
3. Emergency response. It provides the services like organizing technical persons, to solve the technical problems cannot be solved by rural service points; takes appropriate plans for handling of serious incidents of accidental leakage of methane gas and contingency of human and animal biogas poisoning; and handles complaints of rural service points.

4. Fittings' supply. The biogas appliances, vulnerable fittings, and tools for the follow-up services should be centralized purchased and supplied to the rural service points according of the demands.
5. Overhaul services. The large multi-functional equipment for inlet and outlet should be unified purchased, and it provides services to the user for overhaul of digesters or fully refueling of material of biogas plants by way of lease or contract.
6. Pilot demonstration. New biogas technology, new processes, new products and new materials should be developed, which are suitable for local situation and makes applications and tastings, then report the demonstration effect.

Currently, China has formed a relatively complete system of management, promotion, research, development, training and quality control. From central level to rural level, the agriculture departments at all the provinces and municipalities and more than 90% of the county have management and promotion agencies of rural energy. At the end of 2015, there are 110,700 rural biogas service points with the coverage rate of 74.3% (NDRC, 2017). Till 2009, around 267,000 farmer-technicians obtain national vocational qualification certificate “biogas production workers”, which is issued by the Ministry of Agriculture (Energy and Environmental Development Research Center, 2018). There are more than 2,000 biogas companies nationwide, with more than 30,000 employees and an annual value of production of about 8 billion yuan (Xia, 2013).

3.2.2.4 Significantly increased capital input

In 2003, the state promulgated the "rural biogas construction bond project management approaches (Trial)", which pointed out the central government subsidize the construction of rural biogas project by government bonds. It greatly stimulated the construction of China's rural household biogas plants. At present, the central government's standard subsidy for rural household biogas project is € 180 per household for the northeast and the western region of China and € 150 per household for the central region. Similarly, it finances € 120 per household for the eastern region, respectively. In 2003-2009, the cumulative investment of the central government for the construction of biogas plants reached 1.96 billion euros, from which the investment for rural household biogas plants was 1.56 billion euros for 14,534,000 household biogas plants that represents for 41.4% of total biogas plants. The investment of construction of biogas plants in the year 2008 reached about 6 billion euros. In 2010, the central government invested 0.52 billion euros to subsidize construction of biogas in rural areas, 3.2 million new biogas plants were completed, of which the numbers of large and medium-sized biogas projects were over 1,000 (Wang, 2012). According to the National “13th Five-Year Plan” for Rural Biogas Development, the invest for rural biogas projects will reach 6 milliard euros, of which 420 million euros for household biogas plant (NDRC, 2017).

Beginning in 2007, the nation invested in biogas service points in the western, midlands and eastern regions, which were subsidized according to the standards of € 5,600, € 4,300 and € 3,100 for each service point from the central government and not less than € 620, € 1,800 and € 3,100 from local authority respectively in those three mentioned regions.

3.2.2.5 Widely conducted international cooperation

China has been actively expanding bilateral and multilateral, and vigorously promotes multi-level and all-round open technical cooperation in the biogas field. With the United Nations Development Program (UNDP), the Asian Development Bank, World Bank, EU, ASEAN and the Netherlands, the United States, Germany and other international organizations and countries has been carried out fruitful cooperation (Hao, 2010).

- China-Netherland's cooperation project of Promoting West China Comprehensive Development and Utilization of rural Renewable Energies (2003-2007) has been implemented in 14 villages of Gansu, Sichuan, Hubei and Hunan Provinces with 5.3 million euros of Netherlands government.

- In 2003 and 2010, China implemented rural energy ecological construction and loan of large and medium sized biogas projects in eight provinces with the Asian Development Bank, which provided loans in total by USD 99,201,000.

- In 2009, China associated with the World Bank provided USD 100 million for the project of China new Rural Eco-homestead in Guangxi, Yunnan, Anhui and Chongqing.

- In January 2013, China and Germany jointly signed the "2013-2014 China-Germany Biogas Cooperation Action Plan". The aim of this cooperation is to establish a Sino-German biogas working group, set up a Sino-German biogas Research & Development center, jointly host exhibitions and forums, and organize entrepreneurs to visits and exchanges (Newenergy, 2013)

- In September 2014, the Biogas Institute of Ministry of Agriculture (BIOMA) has been certified as "FAO Reference Center for Biogas Research and Training". As one of the FAO reference centers, BIOMA participate in relevant areas of activities to assist FAO with extensive industry resources integration and provide professional technical and scientific advice to support more research and training activities in biogas field (BIOMA, 2014).

- In March 2015, the Sino-German Agricultural Center was established, which was implemented by Foreign Economic Cooperation Center (FECC) and Gesellschaft für Internationale Zusammenarbeit (GIZ). Sino-German

Biogas Technology Cooperation and Demonstration project are one of the bilateral cooperation projects under the framework of the Sino-German Agricultural Center (FECC, 2015).

In addition, China also actively carries out international cooperation and assistance projects. From 1979 to 2019, China has been successfully held 130 training courses of international biogas / renewable energy technology for more than 3000 biogas technical and managerial personnel from 120 countries. Meanwhile, Chinese government often has sent many biogas experts to African countries to promote China's biogas technology, such as, went to Lesotho, Benin, Ethiopia, Tunisia, Rwanda, Guinea-Bissau and other countries. They implemented biogas projects and bilateral cooperation, which are organized by the United Nations and assisted by the Chinese government, including the rural household biogas projects, large and medium sized biogas projects, biogas power generation, urban domestic sewage treatment, the establishment of national biogas laboratory, surveys of biogas resources and the planning of national development strategy of biogas, as well as training courses for management and technical personnel. The government and farmers of Thailand, Cambodia, Laos and other ASEAN countries are grateful for Chinese government's works for its demonstration of biogas technology and training groups of local technical personnel (BIOMA, 2020).

3.2.3 Types of household biogas plants

Currently, the types of biogas digester can be divided into (NY/T 1220.1-2006, 2006):

I. Classified by the mode of gas storage: ① hydraulic biogas digesters; ② airbags biogas digesters; ③ floating drum biogas digesters. However, in practical situations, taking into account layout of rural courtyard and convenient management, hydraulic digesters with its simple structure, easy construction and lower cost, are commonly used as household biogas digester in Chinese rural areas, it can be said that these types represent more than 85% of total rural biogas digesters.

II. Classified by geometry of the structure of biogas digester: ① cylindrical; ② spherical; ③ flat ball; ④ rectangle; ⑤ arched; ⑥ altar-shaped; ⑦ ellipsoid; ⑧ square, etc.. Cylindrical digesters are the most common form, followed by spherical and flat spherical.

III. Classified by the laying position of biogas digester: ① Upground; ② underground; ③ semi-underground. Most farmers are using underground style.

IV. Classified by the construction material of digesters: ① brick, stone materials; ② concrete materials; ③ reinforced concrete materials (mainly for large, medium-sized digesters); ④ new material called polymer materials, such as polyethylene plastic, red mud plastic, fiberglass, etc.; ⑤ metalmaterials.

V. Classified by the fermentation process: ① thermophile fermentation (at 45°C to 60°C); ② mesophile fermentation (25°C to 45°C); ③ room temperature (10°C to 25°C); ④ Continuous fermented; ⑤ semi-continuous fermentation; ⑥ Batch fermentation; ⑦ two-step fermentation; ⑧ single-step fermentation.

VI. Classified by the water fabric, wall structure on the internal digester: ① Bottom discharge hydraulic digesters; ② top return hydraulic digesters; ③ strong cycle digesters; ④ meandering distributed feedstock hydraulic digesters; ⑤ filter bed hydraulic digesters.

As mentioned in 2.2.1, there are three typical household biogas digesters:

1. Fix-Dome-Digester

Fix-dome-digester, which is developed in China and the most common model until today in China, is a closed dome shape digester with an immovable, rigid gasholder, a feedstock inlet, and a gas storage room and an outlet pip (see Figure 3-7).

- The fermentation room: it is the primary room of the digester. Its function is the fermentation of materials.
- The gas storage room: it is the space that above the part of fermentation liquid level within the fermentation room, and its main function is to store gas.
- The feedstock inlet pipe: feedstock inlet point is built on the ground of the livestock house or the toilet outfall, being connected with the digester by an underground inlet pipe. The function is a collection of human and animal feces, and sewage into the digester.
- The overflow tank: the overflow tank is on the right side of fermentation room. The function is the discharge of biogas slurry and maintains pressure in order. Its volume is 1/2 of the gas yield of the biogas digester for 24 hours.
- The outlet pip: it is a place between the fermentation room and overflow room, and biogas slurry discharge through this outlet pip from the bottom of fermentation room to overflow room.
- Gas pipe: it is located at the top center of pool arch. Its function is the transportation of biogas from the gas storage room to the connected gas pipeline, either for cooking or lighting.

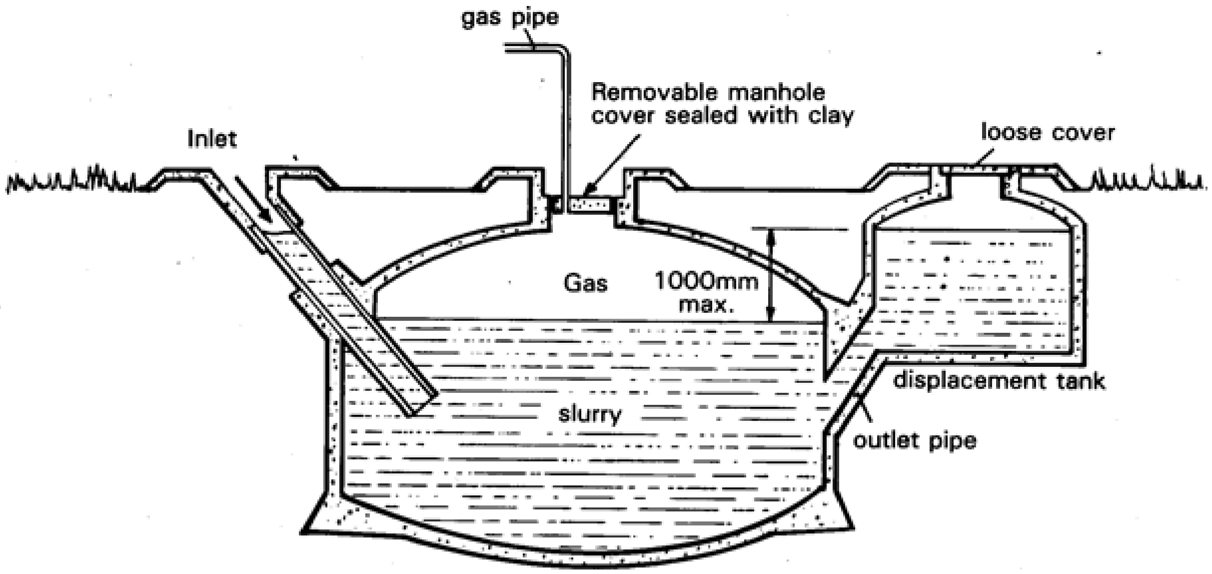

Figure 3-7 Scheme of Fix-dome-digester (Fraenkel, 1986)

According to the principle of communicating vessels, fermentation tank of biogas plants is placed in a same closed container with gas storage. The biogas will be collected by displaced of water as taking advantage of biogas characteristics of water-insoluble; these biogas plants are called hydraulic digesters. When gas was produced from biogas digester, biogas rose from the fermentation room to the room of gas storage. Here the pressure of biogas increases gradually. The biogas slurry on the bottom of the fermentation room goes through the outlet pipe by pressure to the overflow tank. The liquid surface level between the overflow tank and the fermentation room results in a water pressure, namely biogas pressure. When the biogas operator use biogas, it continuous the flow out under water pressure through the gas pipeline, then the gas pressure in gas storage room continuously falls. The biogas slurry pressures back into the fermentation room in order to maintain the balance of the digester pressure and external pressures. Gas is constantly produced and used, so that the liquid levels lift constantly in the fermentation room and overflow tank to maintain a balanced pressure state. commercial biogas digesters are derived from traditional fix-dome-digester. Materials such as fiberglass cloth and unsaturated polyester resin are typically used for the constructions of commercial biogas digesters. The shape of fiberglass reinforced digesters is usually produced according to the mold manufacturing; however, they are generally spherical or flat spherical. Digesters can be divided into upper and lower hemispheres, which can be assembled with gaskets and screws, and then coated with resin to ensure tightness. Because of high strength, stable and reliable performance of the material of fiberglass, the fiberglass reinforced biogas digesters have some advantages such as light weight, easy transportation and installation, and convenient operation and management.

2. Floating drum biogas digester

The biogas digester is constructed separately with the floating drum of gas storage, and biogas, being produced by the digester, is stored on the floating drum. The Fermentation room is separated with the gas storage room, the cover of which is sealed generally by the water (see Figure 3-8). Biogas is delivered through the gas pipeline to the floating drum, which is produced by digester. As the production of biogas is increasing, the floating drum rises continually. Biogas is forced out through the floating drum by its gravity when the biogas is used. The processes of biogas are generated and used to keep a stationary pressure, which is determined by the weight of the floating drum.

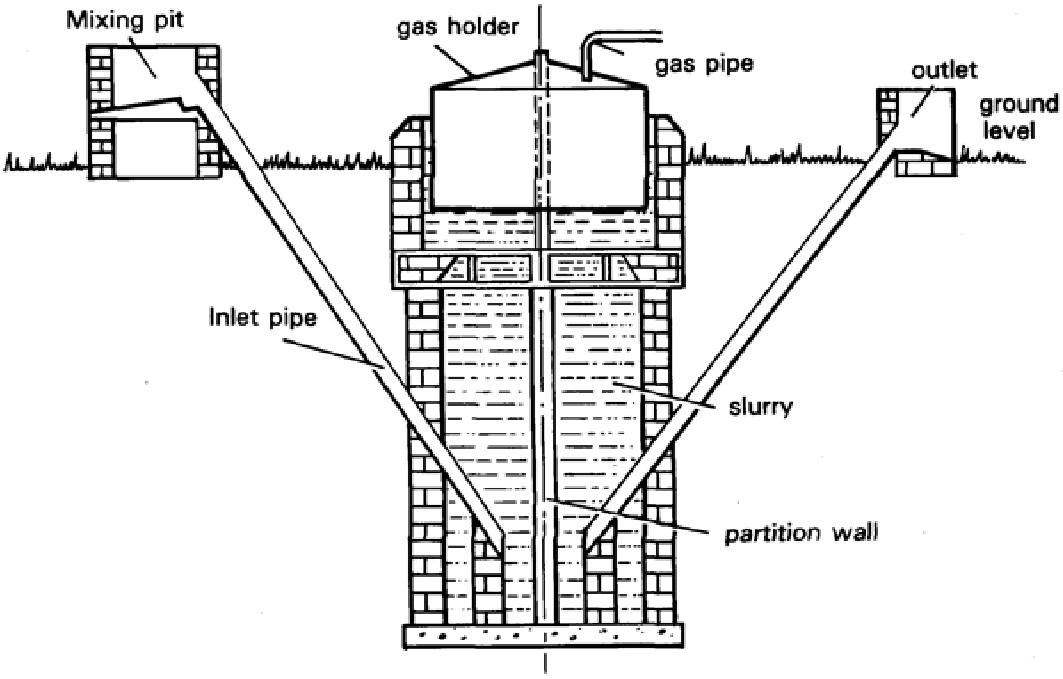

Figure 3-8 Scheme of Floating drum biogas digester (Fraenkel, 1986)

3. Tubular digester

Tubular digesters are usually built by plastic, which has an oblate spherical shape. The parts of the digester body are pressed with the help of plastics engineering and a compression molding machine, and then welded on another using plastic welding (see Figure 3-9). The strength achieved with plastics engineering is fully able to withstand the running hydraulic load of household digesters dealing with the maximum pressure. Plastic digesters have large fermentation area and reasonable structure which ensure a stable gas production. The advantages and disadvantages of these three types of biogas digester are summarized in Table 3-6.

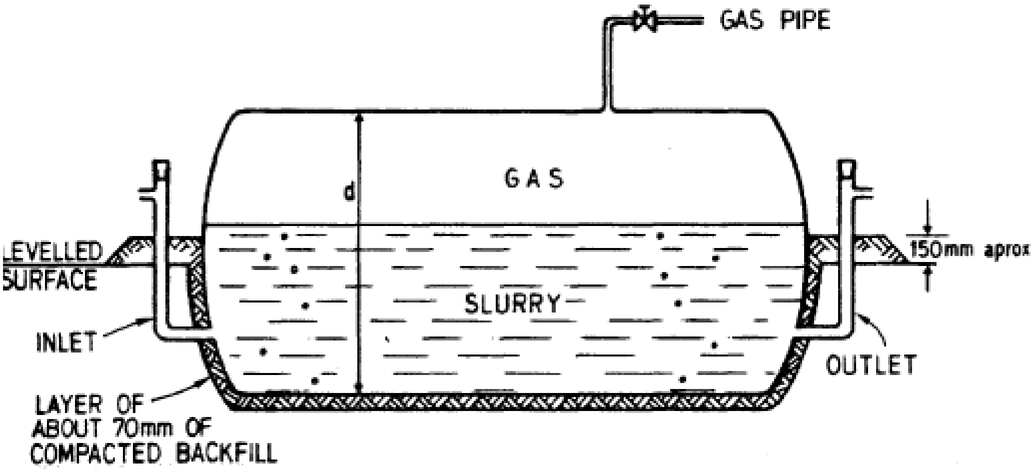

Figure 3-9 Scheme of tubular biogas digester (Marchaim, 1992)

Table 3-6 Advantages and disadvantages of fix-dome-digester, floating drum digester, Fiberglas reinforced and tubular digester (Cheng, et al., 2014)

	Advantages	Disadvantages
Fix-Dome-Digester	• Long life span • Low space requires because of underground construction • Local construction provides opportunities for skilled local employment • Easy operation • Low maintenance	• Requires high technical skills to ensure a gas-tight construction • Fluctuating gas pressure depending on volume of stored gas • Difficult to repair in case of leakage
Floating drum digester	• Easy operation • Low maintenance • Visible stored gas volume • Constant gas pressure • Relatively easy construction	• High material costs for steel drum • Short lifespan because of steel drum corrosion • High maintenance because of regular painting of drum
Tubular-Digester	• Low invest cost • Easy of transportation • Easy to construction • Uncomplicated maintenance • Less subject to climatic variations for fixed dome type	• Requires of large space • Relatively short lifespan • High susceptibility to damage • Low gas pressure • High impact on environment, less environmental-friendly

3.2.4 Structure of biogas plants

Household biogas systems consist of digesters, transmission and distribution system and gas appliance. Digesters make up by the digester body, inlet pipe, displacement room, outlet pipe and the active digester covers. Transmission and distribution systems include gas pipe, various couplings (elbow, two-way, three-way adjustable tube), switch, and pressure gauge and so on. Gas appliances are mainly gas stoves, gas lamps, water heaters, but some users also use the desulfurization and flow meter.

Several parts of the work must be done for building a digester, such as site selection and layout, preparation, excavation, digester body construction and quality examination.

1. Site selection (NY/T 1220.1-2006, 2006)

First is necessary to choose the place with solid soil and low level of groundwater, also a sunny and leeward area, at least keeping away 10 to 15 meters from the shallow wells to prevent contamination of well water. Second, it is essential to try to avoid the roots of bamboo and trees. If it is the case, they must be cut off and paint with diesel or lime the incision to stop its growing and for preventing the damage on the digesters. And third, it is the building of biogas digester under the pigsty and toilet. The latter one is to make sure the distance between the pool and gas point, controlling it within 25 meters. This measure is to stabilize the gas transportation and to save costs of the gas pipe.

2. Preparation of construction material

Materials used for the digester construction include red brick, cement, sand (particle size of 0.15 to 0.5 mm) and gravel (particle size of 0.5 to 3 cm and the clay content being less than 2%). Whether the selection and use of the materials for the digester construction are appropriate, it is directly reflected on the quality, costs and lifespan of the digester. In order to avoid the waste of materials or to run out of them, the estimation of a reasonable amount of construction materials should be carried out. Generally, to build a 8 cubic meters of digester using a combination brick and concrete, the actual requirements of material are: about one Mg of cement, two cubic meters of sand, one cubic meter of gravel, more than 600 blocks of red brick and 20 kg of reinforce (diameter in 6 mm). In addition, common tools for the construction of household biogas digester should be available, such as tape, rope, brush and wood block.

3. Positioning and excavation (NY/T 1220.3-2006, 2006)

Position is the key factor that ensures the quality of the digester, so it should be in accordance with the drawing design. It is important to choose the right center of the pole and the reference line for the elevation. The center pole and reference line for the elevation must be securely fixed on site to be then conveniently checked and corrected in case of deviations. Excavation of the digester pit should be based on the layout. When there is groundwater present, a headrace channel should be built with a catch pit as drainage measures to discharge the water away from the construction site.

4. Construction of digester body (NY/T 1220.3-2006, 2006)

It includes the construction of the bottom, the walls, vaults and sealing layer of the digester. It also must be constructed strictly according to national standards and operating procedures. Currently, the digester construction technology can be contributed into mold cast-in-place, brick and concrete, precast slab and fiberglass digesters.

5. Management after construction (NY/T 1220.4-2006, 2006)

Once the digester is constructed, the backfill must be hierarchically, symmetrically and uniformly compacted between the masonry of the digester wall and the old pit trying to conserve a humidity of 20% -25%. Backfill must be compacted when the concrete reaches 70% of the design strength to avoid excessive local loads. In addition, digesters must keep dampness to avoid drying-induced leakage. The most commonly used method is to cover the top of the digester with a layer of earth to maintain a wet state.

6. Quality control after construction (NY/T 1220.5-2006, 2006)

To ensure the quality of the construction and a normal production of biogas once the digester has been finished, the quality must be strictly checked when the structural layer and sealing layer of the digester´s body reached more than 70% of the design strength. The first step is the visual inspection. It is needed to go into the digester and to look closely, even block by block, around the wall, the bottom, the cover; and carefully check the input and output tube of the biogas digester taking especial attention on the switch point. This point is important because is where exists commonly liquid or gas leakage caused by cracks, trachoma or small pores. Even so, a leakage check should be done. To do this the operator opens the cover and fills with water the lower rim of the pool cover, then draws water line when the wall absorbed enough water, and the water level should be stabilized. After 24 hours watertight can be indicated if the water level does not drop or the decline in less than 3%, which is within the allowed range. The digester wall should be checked when water is renewed and if the old water declines more than 3% this is a sing of possible cracks. Likewise, gas leak inspection is another important step. Water is filled to the position 70 to 80 cm away from the actively cover, and the gas pipe is connected to the biogas pressure meter after closed cover and sealed it. Water should be continually added from the inlet or outlet pipe. As the water rises, the volume of the gas storage room decreases causing the increase of pressure, and then it is stopped adding water until the pressure is 10 kPa (1000 mm water column). Meanwhile, water level is marked in the overflow room and the pressure should be checked after 24 hours. The pressure should not decline more than 3%, otherwise the leak site must be ascertained and repaired.

3.2.5 Operating methods of biogas plants

3.2.5.1 Pretreatment of raw materials

In China, crop straw, livestock manure and human feces are used as the raw materials for household biogas plant. Feeding animal with household food waste has been common in China, especially in small farms in rural areas (Wand, et al., 2016). According to Article 43 of the Animal Husbandry Law of the People's Republic of China (NPCSC, 2006) of July 1, 2006, “an entity engaged in the breeding of livestock and poultry shall not commit the following acts: to use slops from restaurants or dining rooms without high-temperature processing to feed the livestock; to raise livestock and poultry at dumping grounds or feed them with the substances dumped at such grounds”. However, there is still some farmers, that raising livestock with food waste.

Crop straw has high carbon content with a ratio of carbon and nitrogen more than 30:1. Straw is comprised by some compounds such as lignin, cellulose, hemicellulose, and pectin and waxy. Lignin is a substance which is difficult to decompose by microorganisms as well as the cellulose. Thus, rate of decomposition of agricultural waste by fermentation is only about 50% in common, but as soluble materials are more easily decomposed, more than 90% of soluble organic matter generally can be removed. Straw is not easy to destroy by biogas microorganisms due to a layer of wax on its surface and cause a large number of floating crusts of straw (if straw directly get into the digester). Therefore, pretreatment of straw is necessary. Animal feces are the raw material of nitrogen-enriched with C/N ratio less than 25:1. Meanwhile, because the particles of the feces are relatively smaller and also contain a lot of low molecular weight compounds, the speed to decompose and produce of biogas is quickly, and they do not have to be pretreated (NY/T 1220.4-2006, 2006).

Pretreatment methods are the following:

1. Chopped or coarsely crushed

   The straw is cut into about 60mm of length with a guillotine or coarsely crushed with a grinder. So that it not only can damage the wax layer of stalk surface, but also accelerate decomposition and utilization of the raw material through increasing the contact surface of fermentation raw material with bacteria. The short and small pieces of materials are convenient for inlet and outlet process and fertilization. Gas production can generally be increased about 20% after chopped and coarsely crushed straw (Li, 2012).

2. Rotting process

   The rotting process is that ret stalks under the aerobic condition, which is propitious to help anaerobic fermentation of stalks in biogas digester. Contact surface between the fiber of stalk and bacteria is enlarged when the fiber becomes loose after rotting process. Therefore, it finally facilitates the decomposition of fiber and the process of biogas fermentation simultaneously. The wax layer of stalk surface is destroyed by rotting to availably prevent scum and agglomeration in the digester. Rotting of external digester is a common method for rotting processing, which lime or plant ash (1% -2% of the dry weight of component) is put hierarchically for the destruction of the waxy layer of stalk surface and neutralize the organic acid from rotting processing. Then fresh water or digestate is splashed into the layers of straw depending upon moisture index of stalk and the stockyard is covered with plastic film to keep the dampness. The stalks are rotted for about 2 to 3 days in summer but 5 to 7 days in winter. Rotting temperature, a significant factor, should always pay attention to. When it is heating and getting hot, should immediately flip straw and add more water. Straw can be put into the digester to ferment when most of the straw color becomes brown (Zhang, 2008).

3. Inoculum

   Inoculum, a substance which is rich in biogas microbial, is supplied to the digester in order to increase the starting speed of biogas fermentation and improve the yield of biogas. In general feedstock of biogas fermentation, biogas microorganisms reproduce by themself out of its less content, which is not conducive to produce gas as soon as possible. Therefore, 30% of inoculum containing a large number of biogas microorganisms is added when the new fermentation starts or the old digester needs fully refuel, to accelerate progress of biogas fermentation and it occurs properly. Inoculum of methanogenic bacteria is widely distributed and relatively easy to obtain, such as from swamps, sludge of ponds or ditch, the old cesspit of base fertilizer, sediment of digester bottom and so can be used as the inoculum (Zhang, 2008).

4. Dry matter content

   Dry matter content refers to the total dry matter content in the biogas fermentation feedstock, denoted by TS% and also represented with a total volatile solid (VS%). Generally, dry matter content of the raw material should be adjusted to 4% - 10% by pretreatment of the raw material. Suitable dry matter content differs with temperature, generally which is approximately 6% in summer and between 8% -10% in winter (Lv, 2012).

5. Ratio of dung to grass

   Ratio of dung to grass refers to the weight ratio of feces and straw which are mixed as the fermentation feedstock in the digester. In order to keep the carbon and nitrogen ratio of fermentation feedstock in a reasonable range at 20:1 to 35:1, the amount of feces and straw should be adjusted by different carbon and nitrogen ratio of each fermentation material. The ratio of feces to grass amongst raw material should be more than 2:1 appropriately, but not less than 1:1 in common. The Table 3-7 shows the actual requirement of different raw material per cubic meter biogas digester (Zheng, et al., 2009).

Table 3-7 Material requirement per cubic meter digester (Zheng, et al., 2009)

Raw material	Period	TS%	Inoculum%	Material weight ratio
Fresh cow manure : water	Summer	6	10	267 : 533
			30	233 : 467
	Spring and autumn	10	10	444 : 356
			30	389 : 311
People manure : Straw : Water	Summer	6	10	48 : 48 : 704
			30	42 : 42 : 616
	Spring and autumn	10	10	80 : 80 : 640
			30	70 : 70 : 560
People manure : Fresh pig manure : Straw : Water	Summer	6	10	41 : 41 : 41 : 677
			30	36 : 36 : 36 : 593
	Spring and autumn	10	10	68 : 68 : 68 : 596
			30	59 : 59 : 59 : 522
People manure : Fresh chicken manure : Straw : Water	Summer	6	10	19 : 19 : 49 : 714
			30	16 : 16 : 42 : 625
	Spring and autumn	10	10	31 : 31 : 81 : 657
			30	27 : 27 : 71 : 575
Fresh pig manure : People manure : Fresh cow manure : Water	Summer	6	10	58 : 29 : 187 : 526
			30	51 : 26 : 164 : 460
	Spring and autumn	10	10	97 : 49 : 311 : 343
			30	85 : 43 : 273 : 300

3.2.5.2 The daily management of household biogas digester

I. Regular replenishment of raw materials for fermentation

Fresh feedstock must be replenished into digesters to keep gas production steadily. The following feeding modes of rural household biogas digesters are described (Lv, 2012):

- Continuous feeding. Fresh fermentation feedstock is added into the digester and digestate is discharged every day. This method is widely adopted because of its advantage of continuous biogas production in the long-term and the stable daily yield of biogas.
- Semi-continuous feeding. Massive raw materials of fermentation are added into the digester before starting, and then raw materials are only supplied and digestate is discharged when the biogas production is declined.
- Batch feeding. Fermentation materials are fed only before the starting but basically neither feeding nor discharging in the operational phase. This method causes uneven biogas production; it is shown that biogas production continually rises in its initial period of running and maintains a period of high biogas production, followed by a steady fall from the peak until it stops.

Therefore, in order to ensure gas production normally, farmer’s digesters should be fed as continuously as possible with the same amount of feedstock and discharge.

II. Observing the changes of the fermentation materials, measurement and adjustment the pH value

Generally, acidification does not occur during the period of fermentation process and the materials in the fermentation room are neutral (pH 6.8-7.5). It should measure the pH value of fermentation materials with a pH paper when biogas yield is likely to decrease. The unfavorable condition for biogas bacterial activity likely causes the reduction of gas yield rate when pH is out of 6.5 to 8. Methods available include using a pH paper test and also measurement with an electronic pH tester. The easiest way of identification is to observe it with the eyes: the fermentation material in the digester shows the color of pale-blue when the fermentation materials are acid; conversely, alkaline materials illustrate a white film raised on the surface (Lv, 2012).

Acid digester can be adjusted as follows (Zheng, et al., 2009):

a. Removing some thick fermentation materials and adding the same amount of inoculum, fresh biogas slurry or the fermentation materials from the other digester, which produces biogas properly, to adjust the pH value.
b. Using a mixture of plant ash or ammonia and other alkaline substances to neutralize excessive acidity.
c. Generally, lime water should be added; it must be stirred uniformly, when it is mixed with fermentation raw materials, to avoid the strong base area.

Without feeding of fresh materials for a long time, the pH value of fermentation materials is likely more than 8 out of organic matter consumed excessively. Fresh human and animal feces and fresh water should be supplied in time. The particular measure is to use 2 - 3 cm long green weed, sliced previously, mixed with pig or cow manure and retted outside for 2 to 3 days, and then put into the digester and stirred in order to adjust the pH value back to neutral.

III. Adjusting the volume of fermentation materials in the fermentation room of digester.

As the digester need frequently input and output processes, the volume of gas in the storage room may become alternate larger or smaller. With the gas storage room becoming smaller, the pressure gets larger; when the pressure reaches 10 kPa or more, or the pointer of the pressure meter shows a span, it will lead to damage the pressure meter and the digester body or could cause the drum up of the digester cover. In this case, part of the feed solution should be properly extracted to increase the gas storage room, and the pressure will come down. The pointer of pressure meter shows always lower pressure when the gas storage room is too large, it is likely to cause biogas escape; therefore, raw fermentation materials or water should be supplied (Li, 2012).

IV. Stirring frequently.

The main purpose of stirring is to increase the contact surface of fermentation materials and microorganisms, and to homogenously distribute of the fermentation materials, so that it has more opportunity of intimate contact between fermentation materials and microorganisms, and then to speed up the fermentation rate and to increase gas production. Continuous feeding digester have fresh material every day, through stirring the stratification and crusts state of the surface of fermentation materials can be broken, to avoid the blind corner of material flow, and to prevent sediment of digestate and keeps inner temperature of digesters consistently (MOA, 2008).

Simple stirring methods in rural areas are mainly in the following three:

(1) Mechanical stirring: Each rural biogas service point is equipped with a variety of mechanical stirrers for different types of digesters, which facilitates the biogas user easily allowing the mechanic stirrer to mix the fermentation materials.

(2) Reflux stirring: the digestate is extracted from the discharge room, and then fed from the inlet pipe again, to produce a strong liquid refluxed in order to achieve the purpose of stirring and straining the reflux.

(3) The easiest way of stirring: vibration stirring in the digester with a bamboo pole from the inlet pipe or outlet pipes should be carried out for more than 10 times every day.

V. Intensive inspection

a. Annual leak detection on transmission and distribution systems.

b. After half a year of using the switch, some butter or oil should be coated on the switch for sealing and lubrication; if the switch has been worn and torn, it should be replaced.
c. Regular excluding of the condensate water from the condensate.
d. Regular checks of pipes and fittings. It should be reconnected, when it gets loose; aging pipe sections should be replaced.
e. The desulfurizer should be changed after six months or so.
f. Periodically check of the biogas appliances if they are sealed, damaged, aging or blocked. Regular cleaning of biogas lamp, biogas stoves. (Zhang, 2008)

3.2.5.3 Winter management on the digesters

Temperature is the key to affect the speed of biogas fermentation. In winter, as temperature drops, the rate of gas production will be more and more slowly or even stop completely (Su, et al., 2010). In order to ensure normal gas production in the winter, the following insulation measures should be taken before winter:

1. Before winter (usually in late September to early October), large refueling should be carried out timely, so all fermentation residues on the bottom of the digester can be pumped out.
2. Before refueling, raw fermentation materials should be ready, prepared and retted. They should have 10% of dry matter concentration and be rich in nitrogen-rich materials, like fresh manure and fresh cow dung; if less, should add dry straw or grass. After extracting the residual, the digester should be immediately fed with raw materials and heated water at 30°C.
3. A new digester, completely constructed in winter, should not be started because generally will lead to a crack.
4. Check the water within the pipe, to remove timely the stagnant water in gas pipelines.
5. Early establishment of the winter insulation mode of digesters. The biogas digesters generally have the following winter insulation mode:
    a. Digesters built under the pen of livestock: pen of livestock such as pigsty or sheep’s pen with a general construction area of 16 - 20 square meters should be built above the biogas digester and all fecal roads should be interlinked with digester’s inlet pipe, so pig manure will be able to flow automatically into the digester, which is conducive to manure management. Compared to other digesters, the temperature can be increased by 2°C to 8°C (Su, et al., 2010).
    b. Anti-cold ditch: it can be done by digging a 60cm wide ring ditch around the digester and then be filled it with straw, dry soil, or fuelwood to achieve the purpose of anti-cold. Ring ditch can be also used for insulation from the heat that comes from the fermentation of rotting feces or grass (Su, et al., 2010).

c. Heap material insulation: in winter, crop residues such as wheat, straw or feces like dung of cattle, horses, donkeys and sheep could be used to heap or ret above the principal part of the digester and the inlet or outlet parts which directly contact with the outside; likewise, the rotting materials must be humidified and covered with a film to benefit from either insulation of the digester or strengthening the rotting, which is conducive in the creation of the conditions for next year's timely feeding.
d. Plastic film cover: generally before frozen period (December), a layer of plastic film with 1.2 to 1.5 times of the area of digester body, is covered above the digester to prevent cold air from entering, and also a small arched shed could be built at the top of the pool body in order to absorb the solar radiation for heating (Sui, et al., 2009).
e. Built a simple greenhouse or solar panels, so solar radiation could be exploited for thermal insulation. A greenhouse could be built above the digester and plant some crops or vegetables in it. Igniting the gas lamps in the greenhouse also is a common method to rise the temperature.

As winter comes, it is important to pay attention to the following topics in the daily management, in order to ensure the normal operation of the digesters (Sui, et al., 2009):

1. Cold materials could not be directly put into the digester in winter, but it could be covered with plastic film or even put in a mix with hot water for a few days before putting into the digester.
2. As people put materials in and out under the condition of temperature being below 10°C, it should try not to get rid of the plastic film. The input and output process should be conducted in the afternoon, and the plastic film should be covered again in time.
3. The temperature of the feedstock should be higher than 15°C. With refueling, some warm water can be properly added to raise temperature of the digester.
4. Always fully stirring. It can promote microbial activity and metabolism to accelerate the rate of gas production.
5. The temperature of digesters surrounding should be maintained at above 15°C but at best higher than 30°C.
6. Feedstock should not be carried out when the temperature of fermentation material is below 5°C nor PH-value is less than 6.3 nor is biogas no longer produced from the digester.
7. As a result of a possible frozen block of the pipeline, suddenly the gas production may not occur in the digester in winter. In that case, the pipes must be checked carefully, and the frozen block must be melted with hot water or a hot towel.

3.2.5.4 Safe running of biogas digesters

1. Safe fermentation

Biogas bacteria, in the digester, are likely to stop breeding and even death in serious cases due to poison when contact with hazardous substances, which eventually cause the stop of gas production. Therefore, hazardous substances must not be put into digester, such as a variety of highly toxic pesticides, especially organic fungicides, antibiotics, anthelmintic, heavy metal compounds, industrial wastewater containing toxic substances and the salts, only just sterilized manure, crops stem with sprayed pesticide, calcium carbide, laundry detergent and laundry water. If biogas bacteria occur poisoning phenomenon, it should be fed the new material instead of the half of old fermentation materials which had been taken out from the digester, to make the gas production properly (Zheng, et al., 2009).

2. Safe management

① Inlet and outlet ports of the digester should be covered to prevent people or livestock falling into the pool. ② All of the digesters must install a pressure meter and check frequently the changes in its water column. As an active process of producing biogas, it leads to over pressure the inner digester, so biogas should be used or deflated immediately to prevent the accident in case of a big swelling of the gas storage tank; or should rush to open the digester cover. If the digester cover has been burst open, it is necessary to put out the fireworks nearby immediately, in order to avoid a fire. ③ Waterproof facilities should be set on the input or output port to prevent rainwater into the tanks. (Lv, 2012)

3. Safe biogas usage

As being flammable and explosive, the following points regarding biogas usage are important (Zhang, 2008):

① biogas appliances, like the lamp and biogas stove, must keep away from flammable materials, such as fuelwood, clothing, mosquito nets, wooden furniture and other flammable items. The biogas lamp should be set further away from the roof, which may cause a fire due to roasting. ② Fire test on the gas pipeline is forbidden, and fireworks are strictly prohibited beside the biogas digester. To examine the status of biogas production, the biogas stoves make an ignition with a distance of more than 5 meters away from the digester, but do not ignite in the gas pipe because it may cause an explosion for backfire. ③ A fire is likely to happen due to leaking gas from the pipelines, switches and other accessories. Thus, leaks always must be checked and immediately replace or repair them while the leak occurs, in order to avoid the fire. Furthermore, the biogas user should turn off the switch while not using the gas and maintain the rooms like the kitchen or the bathroom well ventilated to keep the air fresh for more and frequent gas utilization. When a stink like rotten eggs has been emitted in the room, the doors, windows should quickly be opened and fans turned on to exhaust the biogas, but even more important is to avoid using an open flame at that time, which is likely to cause a fire.

4. Safe overhaul

Digester is a container, which is sealed and lacks oxygen as well. The main ingredients of biogas are methane, carbon dioxide and some toxic and harmful gases, such as hydrogen sulfide or carbon monoxide. When the concentration of methane in the air reaches to 30%, the blood in a person's lungs cannot get enough oxygen after methane is being inhaled, which might cause to this person asphyxia and poisoning as paralysis of the nervous system; but the concentration of methane at which deadly risk becomes significant is much more than the 70% in the air. The carbon dioxide is also an asphyxiating gas. Asphyxia results from asthma, dizziness and headache if the carbon dioxide concentration is raised to 3% -5% by oxygen displacement. Furthermore, people would feel difficulty in breathing as an oxygen deficiency while the concentration of carbon dioxide is up to 6%; even loss of consciousness, respiratory collapse, and death when the concentration reach 10%. Casual inspection and maintenance in the digester are prohibited in order to avoid accidents, because the oxygen is deficient in the digester and there are highly toxic gases like hydrogen sulfide, phosphide and hydrogen in it. The following points should be noted to overhaul the digester: ① animal testing must be done before people come down into the digester. For protection against unforeseen risk, the activity cover must be opened before overhauling the digester; all the raw materials must be taken out as well as promoting air circulation by ventilation. Frogs, rabbits, chickens and other small animals are put into the pool for about 20 minutes. People can come down into the digester if the result of the test is normal; otherwise, the blast and testing must continue to be strengthened until the animal activities become normal. ② do well the protection job. In order to avoid accidents, assistants must be outside the digester taking care about the worker who is working inside; the worker must fasten seat belts. The worker must rest outside the digester immediately when he feels uncomfortable symptoms like dizziness or nausea. ③ to avoid a fire by ignition of the digester, it is prohibited to open flame and lit cigarettes into the digester; for lighting must use a flashlight or lamp (Li, 2012).

3.2.5.5 Fault diagnosis and disposal

Common failures are mainly manifested in four aspects of the digester´s body, fermentation process, gas transmission pipeline and biogas equipment (Zheng, et al., 2009).

1. Common faults and disposal of digesters

Common failures of digesters are mainly leakage of water and air. The leakage of digesters must be detected and noted on the mark, to repair the exact site of the leak according to the specific situation. The common reasons of digester leakage are:

a. Holes or cracks in the concrete on digester walls because of substandard concrete, uneven agitating or a not enough rammed digester body.
b. The plumpness of mortar of the junction between the digester cover and the wall; the bond of junction is not strong.
c. The biogas digester was vibrated strongly after the completion of the digester, caused by bad maintenance, so the seams of the cement mortars drop down.
d. Not feeding timely the water or fermentation materials after totally refueling, so the biogas digester was exposed and frosted, leading the existence of cracks.
e. The cement mortar of the junction between gas pipe and digester cover is not durable, which can cause the leak.

2. Common faults and disposal in fermentation process

The common faults in fermentation mainly include abnormal gas production and poisoning of the methanogen bacteria. The reasons of abnormal gas production are (Zhang, 2008):

a. Fermentation materials were directly put into the digester without pretreatment, which is a phenomenon that usually happens. Such materials are not easy to be degraded, so the fermentation process is slowly and likely to cause dross crust.
b. Supply of too cold water or temperature is too low. Biogas fermentation can be carried out in the range of 8°C to 60°C, but less gas will be produced when the temperature of fermentation materials is below 12°C. When too cold water is added or when fermentation materials are fed in cold season, with the lower temperature in digester, some problems may happen and methanogen bacteria multiply slowly and less, causing abnormality for a long-term in the digester gas production.
c. The fermentation materials are more or less excessive. The fermentation materials in the fermentation process should be maintained in a certain dry substance concentration in the range of 6% to 10% to ensure gas production promptly. Acid produced bacteria in the fermentation process multiply quickly, but the methanogen bacteria propagate slowly, which is the reason that causes the rate of digestion and decomposition of raw materials to exceed the rate of gas production. Therefore, it is easy to cause a substantial accumulation of organic acids, and fermentation is blocked when the fermentation of raw materials and the dry substance concentration is much more than normal value. Conversely, biogas yield would reduce if the dry substance concentration of the fermentation materials is too low and the organic content decreases.

d. The ratio of carbon and nitrogen of fermentation feedstock is inappropriate. In actual applications, the normal fermentation requires a certain ratio of carbon and nitrogen (C: N) of raw material from 10:1 to 30:1, but 25:1 is more appropriate.
e. The nutrition of fermentation feedstock has been depleted before putting into the digester. Sometimes farmers start the digester with the manure which they heap for a long time, but the process of natural fermentation have occurred in the long-term stacking, resulting in not producing gas for nutrition depleted.
f. Fermentation feedstock contains ingredients of feed additives and antibiotic drugs or is sprayed with pesticides. In modern farming, the farmers use plenty of feed additives and antibiotic drugs to control of diseases and promote the growth for livestock and poultry. The ingredients of residual feces contain some substances, that is bactericidal and strongly inhibit the growth and reproduction of methanogen bacteria, leading to impossible production of gas. With the same result, some biogas users apply the straws which had been sprayed with pesticide, causing the poisoning of the methanogen bacterial and stopping propagation.
g. Harmful substances are put into the digester, such as a variety of heavy metal compounds, containing toxic substances of industrial wastewater, salts, spicy vegetables like stalk of onions and garlic, calcium carbide, washing powder and laundry water. Biogas bacteria will be poisoned if they come into contact with those harmful substances. In this case, the biogas bacteria stop the propagation and even die, which cause to not be produced from the digester.
h. Plenty of alkaline substances have been put into the digester. With the starting of the digester, biogas users often have to put alkaline substances such as plant ash and lime supernatant to adjust the pH of the fermentation materials, for the purpose of producing gas earlier. When the alkaline substance is put in excessive amounts, it will cause the fermentation materials to be alkaline, inhibiting the growth of biogas bacteria and not producing biogas.
i. The inoculum put into the digester, was not enough. The lack of inoculum is also one of reasons that cause the digester to produce gas slowly.

The reasons and solutions for stopping production gas for non-working of biogas bacteria are (Lv, 2012):

a. Materials inside biogas digester being acidic. Some new materials correspond with 1/3 to 1/2 of the old material taken out of the digester; they should be added and stirred well after mixing with an appropriate amount of pellucid lime.
b. Materials inside biogas digester being alkaline. A portion of the old material is removed from the digester instead of some acidic raw materials, such as grass and leaves, to adjust the pH value and reaching it about 7.

c. Poisoning for drug. Equal amounts of harmless new material should be fed instead of 1/2 old material which has been removed from the digester, and some of inoculums and water should be supplied into the digester to provide a suitable pH value.

3. Common Faults and disposal of gas transmission pipeline

Common failures of gas transmission pipeline are mainly air leakage, block and stagnant water (Zheng, et al., 2009).

a. some situations of biogas leakage and disposal of air leakage from gas transmission pipeline:

   First, air leakage does not occur in the gas transmission pipeline, it takes place in the fermentation room; this represent that the air pressure does not rise but decline fast over one standard atmospheric pressure, even after raising artificially the pressure of the inner digester. Then, the inner wall of digester should be repainted 2 to 4 times before brushing it with sealant.

   Second, bubbles emerge in a water sealed ring, which indicate that the leakage happened on the sealing cover. The digester cover should be re-sealed well and the water sealed ring fully filled with water as well, to ensure that the water sealed ring always has water.

   Third, when the smell of rotten eggs or sulfur is smelled from the room where is installed the biogas appliance, the leakage has occurred in the gas pipeline or switch and also in the purifier. In this case, soapy water should be applied to find the leak position and replace the damaged parts.

   Fourth, when the odor of rotten eggs can be smelled only in cooking or lighting it illustrates that the desulfurizer has a failure; the desulfurizer should be replaced at this time.

b. Reasons and disposal measures of pipeline block:

   When the gas switch was turned on, readings on the pressure meter suddenly dropped down and slowly rebounded to normal position after turning off the switch, which illustrates the possible faults of a partial obstruction on the gas transmission pipeline or some accessories, such as switches and connectors; the gas pipeline was crushed as well, causing an increase in the resistance and poor gas transmission. In this case, it should be checked first whether the airway was blocked, or any foreign matter accessed, and then clear the pipeline; second is to check the gas transmission pipeline, especially the hose, which is easily beaten around and flattened at the bend. Then, it should be recovered to reduce the loss of delivery pressure.

c. situation and disposal of stagnant water in the gas transmission pipe:

   Stagnant water of the gas pipeline is the reason of fluctuations in the gas pressure meter pointer. The disposal method is to turn off the master switch and pull out the pipeline to dredge the block and eliminate the stagnant water. Moreover, special attention must be paid to the place of low bending of the pipelines.

4. Common faults and disposal of biogas equipment

There are some common faults with the equipment of biogas stoves, biogas lamps, biogas water heater and biogas rice cooker.

a. The faults and causes in the process of gas stoves utilization (Lv, 2012):
    i. The flame of the gas stove does not roar. The first reason maybe is that the stove fire hole has been blocked, which require the cleaning of the clog; second, pressure is insufficient, which needs to be checked if the gas production is normal and the pipeline is blocked; third, the throttle of air inlet requires to be accommodated to the appropriate position; fourth, there are some defects on the design or the quality of the stove.
    ii. Although the barometer reading is higher, the combustion firepower rapidly diminishes for a short time and even extinguishes. First, the absence of frequent discharge leads to excessive fermentation materials, leaving only a small space for gas storage; second, there is more serious clogging in the gas pipeline, so biogas transport is not opportune; third, the pressure meter is broken and biogas yield is poor.
    iii. The barometer reading is higher, but the firepower of biogas stove is always weak. First, the content of combustible ingredient – methane - in biogas is lower; second, the stove throttle is opened or in an incorrect position, being smaller; third, the combustion plate of the stove burner has been blocked; fourth, pressure meter reading is not accurate, causing quality problems.
    iv. The pressure is high, but gas stoves cannot be ignited. First of all, due to the biogas stoves design, pressure should be kept at 800 Pa. When the biogas pressure is too high, it eventually results in no ignition. Second, the content of combustible components -methane - in the biogas is low. It could be caused by the following reasons: a. less inoculum; b. less content of methane in biogas, because the fermentation process has just started; c. the pH value is not between 6.5 and 7.5 for its normal gas production; d. fermentation material contains toxic or hazardous substances, which lead to abnormal gas production; e. the C:N ratio of fermentation materials is not in the range of 25:1 to 30:1. Third, the ignition equipment of the stove is defective, or the battery of the ignition equipment is not enough.

b. The faults, reasons and solutions in the process of gas lamp utilization:
    i. There are several reasons for open fire to exist on biogas lamp mantles: First, the air was brought in insufficiently when biogas combusted, and the air intake should be gradually increased by adjusting the gas lamp throttle. Second, biogas pressure is excessive, so the switch should be adjusted to reduce pressure. Third, he broken mantle should be replaced with a new mantle (Zhang, 2008).

   ii. A yarn mantle inside of a biogas lamp can break and fall off easily: a biogas lamp is a lighting appliance that utilizes mantles to light by irradiance from high-temperature combustion of the biogas. A yarn mantle is a lighting element of the biogas lamp that blends ramie, plant fibers and rayon, forming a shape and immersed in the alkaline solution of thorium nitrate to crank out finally. After mantles are burnt, artificial fibers are burned leaving a layer of white grid powder of thorium dioxide, which is very easy to be broken with any movement. Thus, the switch should not be opened completely at the first when people want to light the biogas lamp; it must be ignited and then turn on the switch slowly until gas lamps emit white light. With the ignition of the biogas lamp, people try not to touch the mantles to prevent the break and fall off the yarn mantle (MOA, 2008).
   iii. The glass mantle outside of biogas lamp is frangible: the biogas lamp glass mantle is made of a high temperature resistant glass and is used for windproof, pest control and protection of the mantles. Lighting the biogas lamp should be away from open fire and ignited with a small fire in the beginning. If the yarn mantle has holes, it must be promptly replaced to avoid rupture of the glass mantle for uneven heating (MOA, 2008).

c. The faults, reasons and solutions in the process of gas rice cooker utilization
   i. The reasons of failure to ignite: First, the biogas contains less methane and gas production is not quick; second, the battery power is low and should be replaced; third, the intake pipeline blocks and the pipeline should be cleared and the blockage should be removed; fourth, pressure is overmuch and the gas supply switch should be adjusted to control the pressure (Li, 2012).
   ii. The reasons of cooking rice scorch or still raw rice with biogas rice cooker: First, the rice cooker sensor or sensor switch is broken or does not work and should be replaced. Second, temperature detector is broken, and the surface of the temperature detector should be always clean. Third, inner pot is not set straight or was deformed. Fourth, the water is not enough for cooking and should be appropriate to increase the amount of water (MOA, 2008).

3.2.6 The utilization of digestate

3.2.6.1 The utilization of digestate as fertilizer in farming

Digestate is a high-quality organic fertilizer, which contains a large amount of organic matter and the nutrients required for plant´s growth. The contents of active substances are composed of trace auxin, hydrolase, group of vitamin B and vitamin C, humic acid and beneficial microorganisms, which play the role of sterilization for crops and prevent the occurrence of diseases and pests (Bioenergy Network, 2008). Thus, digestate is a good soil conditioner.

1. Digestate as a basal fertilizer: before planting crops, it should be directly sprinkled on field surface and then ploughed immediately to improve the quality of the field.
2. Biogas slurry as after fertilizer: Generally, there are two application ways which are root drench and sprayed foliar. The amount of spraying digestate on roots depends on the variety of vegetables, generally 2.2 - 3.7 kg per m^2 (He, 2017). Applying the digestate on foliar must be filtered with the gauze before using. Digestate should be diluted with the same amount of water and mainly sprayed to the surface of the leaf, generally 0.75 - 4.5 kg per m^2 (He, 2017). It can be fertilized during the whole period of growing season for leaf vegetables and also combined with the medicaments for disease prevention and pest control; but in the bud stage, flowering and fruit enlargement period for fruits-vegetables.
3. The be noted in the utilization of biogas Fertilizer (Bioenergy Network, 2008):
   a. Digestate cannot be immediately applied as fertilizer in the field after being taken out from the digester. As digestate has strong reducibility, it will battle with oxygen in the soil and it has an effect in the germination of the seed and growth of the root, which lead to yellow leaves and wilting of crops. Therefore, digestate should be at first stored in septic tanks for 5 to 7 days as composted and then used as fertilizer.
   b. Digestate cannot be used without dilution with water. If the biogas fertilizer does not dilute with water and is applied directly to the crops, especially for seedlings, burnt phenomenon is likely to occur. So it must be diluted before using digestate as an additional fertilizer, the quantity of water is the same as of digestate.
   c. Digestate cannot be fertilized directly on the soil surface. Applying it to the crops of dry land should adopt fertilizing in a hole or a ditch of the field, and then covered with earth. But fertilizing in paddy fields should distribute on the field surface and then ploughed into the underlying soil.
   d. Digestate should not be utilized excessively. The amount of utilization of digestate as fertilizer should be less than the use of ordinary pig manure in general. If enormous amounts of biogas fertilizers are applied blindly, it would occur a reduction in production yield due to crops overgrowth.
   e. Digestate cannot be mixed with plant ash, lime, and other alkaline fertilizer. It will result in the loss of efficiency of nitrogen fertilizer, for which plant ash and lime are a relatively strong alkaline.
   f. Furthermore, additional biogas fertilizer should not be applied on vegetables in general seven days before being on sale.

In 2015, the average rate of fertilizer application for fruit trees in China was high at 1,100 kg/ha, whereas for vegetable acres was 700 kg/ha, and for tea acres was only 450 kg/ha. The annual application of chemical fertilizers in fruit (vegetable, tea) gardens nationwide amounts to 29 million Mg, accounting for about 50% of the national total. Fruit (vegetable, tea) gardens have great potential for reducing fertilizer application (NDRC, 2017).

3.2.6.2 The utilization of digestate as feed

Digestate is rich in protein, variety of constant materials, free amino acids, vitamins, trace elements, phosphorus, calcium, potassium, copper, iron, zinc, magnesium and strong vitality cellulose, protease. Simultaneously, all of them are very soluble nutrients and it is easy to digest, absorb and satisfy the growth needs of livestock. Therefore, digestate is an ideal source of feed.

1. Breeding pigs with digestate: Digestate, as pig feed additive, has a significant role under the condition of the lower trophic level of feed, which has an advantage in the improvement of feed efficiency, shortening the breeding cycle, reducing production costs and increasing the rate of lean meat. The suitable concentration of digestate is between 1% and 1.5% of dry matter (MOA, 2008).
2. Note of application of digestate as feed (Guo, et al., 2005).
   a. Digestate, whose retention time is less than three months after starting a new plant or fully refueling, cannot be fed to pigs. Due to the reasons of too short fermentation time, the digestate has excessive biogas concentration, unstable pH value and some pathogenic microorganisms; it cannot be appropriate to feed pigs.
   b. It should not be fed to pigs when the dry matter content of digestate is larger than 1.5%. Taking supernatant after settlement or dilution with water can be used to adjust the concentration (Zhang, 2008).
   c. The poisonous biogas fertilizer cannot feed the pigs because of some conditions, such as dead rats, pigs and other dead animal or pesticides appeared in the discharging room or inlet pipe of the digester, as well as a lot of rain flow to the digester.
   d. The areas around the digester must be cleaned frequently and drains must be constructed to prevent sewage into the discharge room, which contaminates digestate.
   e. Diseases such as Bovine spongiform encephalopathy (BSE) caused by homologous contamination of feedstuffs occur from time to time. Since 2001, European has regulated in REGULATION (EC) No 999/2001: “The feeding to ruminants of protein derived from animals shall be prohibited”. Compared with European, the safety use of biomass fertilizer in China is still in its initial stage, and there is no regulatory document and management system for the safe use of biomass fertilizer

(Zhang, et al., 2011). Therefore, concentration of digestate in feeding material should be limited and the growth situation of the feeding animals should be attended.

3.3 Biogas Status in China

3.3.1 Raw materials of fermentation in China

At present, the fermentation raw materials for rural household biogas digesters are mainly crop residues, animal manure and human excrement. The estimation of these different kinds of raw material resources and analyzing their distribution provides basic data support for the calculation of the total capacity of Chinese household biogas digesters and their regional distribution.

Annual estimates of straws in China are calculated based on crop yield and the CRI, defined as the ratio of the dry weight of residues produced to the total weight of crops produced. CRI for each type of crops varies with differences in regional, inter-annual, field management and harvesting way. The production of agriculture residues in 2018 and corresponding CRIs are listed in Table 3-8. It is estimated that the total yield of crop residues in China in 2018 is about 908 million Mg (TS 85%) (National Bureau of Statistics of China, 2019). The three main principle straws are straws of maize, rice and wheat that accounted for 28.32%, 35.04% and 21.71%, respectively.

Table 3-8 Annual estimate of crop residues in China in 2018

Crop	Yield [million Mg][1]	CRI[2]	Crop residue [million Mg]	%
Maize	257.17	1	257.17	28.32%
Rice	212.13	1.5	318.19	35.04%
Wheat	131.44	1.5	197.16	21.71%
Cotton	34.33	1.4	48.07	1.01%
Beans	21.01	1	21.01	2.31%
Oil-bearing-crops	6.10	1.5	9.15	5.29%
Sugar canes	28.65	0.25	7.16	2.98%
Tubers	108.10	0.25	27.02	0.79%
Others			23.20	2.55%
Sum			908.15	100

[1] (National Bureau of Statistics of China, 2019)

[2] (NDRC, 2015)

Based on the total yield of straws and the consideration of sustainability (sustainable reaping rate, cost analysis, etc.), net availability of straws for bioenergy purpose is then estimated. Net available crop residue equals that the total crop residues yield minus the amount of crop residues returning to the fields for conservation purpose. Figure 3-10 shows a significant regional unbalance of net availability of straws in China. The majority of crop residues were concentrated in the middle-east of China. (Jiang, et al., 2012)

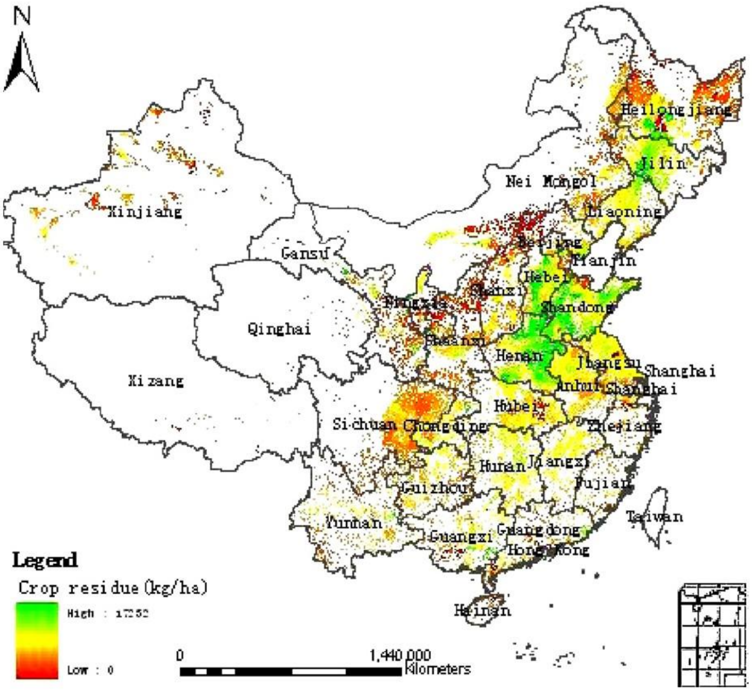

Figure 3-10 Spatial distributions of net crop residues in China in 2009 (100 m × 100 m) (Jiang, et al., 2012)

For a long time, crop residues have been the farmers' basic valuable resources for production and living; it can be used as fertilizer, feed, fuel, raw materials of paper industrial and so on. However, with the rapid development of the rural economy, traditional use patterns of crop residues are changing. The utilization of crop residues in China is illustrated in Figure 3-11, which shows that approximately 390 million Mg of crop residues were left in the field or burned directly in the field in China in 2016, accounting for 54.17%; but in recent years, the percentage of the straws burned directly in the fields has decreased dramatically in China. 23.61% of crop residues (170 million Mg) were used as animal fodders; only 13.89% of crop residues were used for bioenergy purpose; 20 million Mg of crop residues were used as industrial raw materials such as paper-industry, accounting for 2.78%; to produce of mushroom cultivation was about 40 million Mg, accounting for 5.56% (MOA, 2016). Residue resources play an increasingly significant role in sustainable development of agriculture and economy in rural areas, and the comprehensive utilization of crop residue resources is still a challenging task.

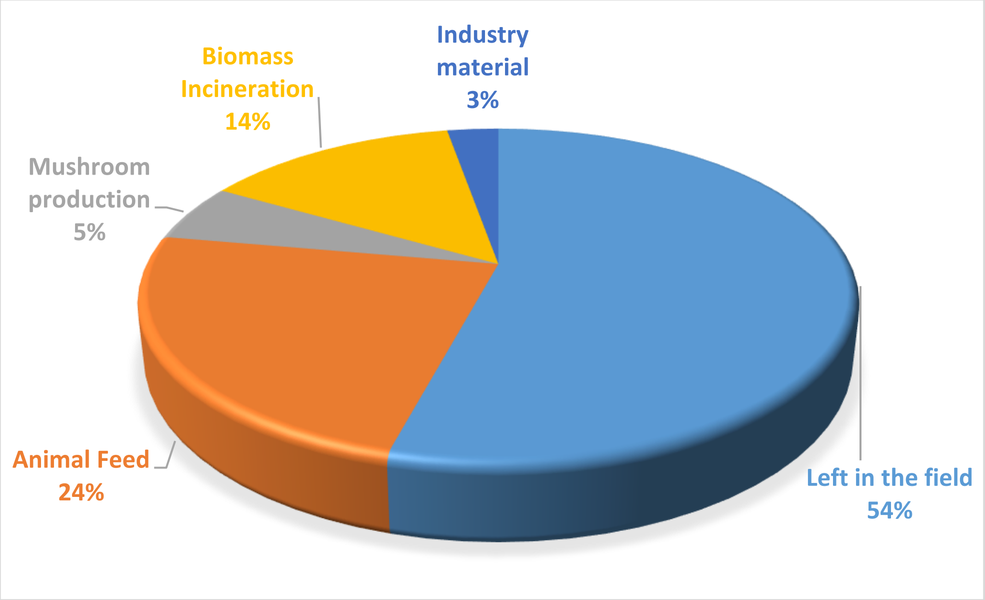

Figure 3-11 Utilization of crop residues in China (MOA, 2016)

Livestock manure resources are estimated generally based on the amount of individual manure and the number of livestock and poultry. The following Table 3-9 lists the daily individual amount of manure, feeding period and the number of some common livestock and poultry, as well as the total annual livestock manure.

Table 3-9 Daily amount, total amount of dung of livestock and poultry in China in 2016

		Daily manure[1] [kg/d]	TS[1] [%]	Available manure [kg] (with 20% TS)	Feeding period[1] [days]	Amount of animals[2] [million]	Amount of manure resource [million Mg / year]
Pig	urine	3.1	3.8	0.59	179	463.69	48.89
	excrement	2.4	18	2.16			179.28
Cow	urine	10.2	6.5	3.32	365	63.54	76.88
	excrement	21.3	20	21.30			493.99
Horse	manure	12	25	15.00	365	3.98	21.79
Sheep	urine	0.8	11.1	0.44	365	311.9	50.55
	excrement	2.2	32	3.52	365	311.9	400.73
Chicken	manure	0.1	47.7	0.24	59	5,312.24	74.75
Duck	manure	0.1	49	0.25	108	739.15	19.56
Sum							1,366.42

[1] (Bao, et al., 2018), [2] (FAOSTAT, 2019b)

The uneven contribution of livestock dungs in different regions of China was indicated that: mainly cattle livestock is concentrated in North China, due to the vast grassland located so cattle dung was also grouped there; meanwhile, majority of pig dung was contributed from South and Middle regions. There were a few poultry dung in North and West China; it mainly comes from Middle and East of China. Livestock manure is a recycling resource, which contains many nutrients for crop growth such as nitrogen, phosphorus, potassium and so on. Likewise, there are 75% of volatile organic compounds, in which the protein content is of 15.8% to 23.5%. The treated livestock manure can be used as fertilizer to improve the quality of soil, to increase the organic matter content and to promote crops production. Meanwhile, biological treatment can be easily accessed the high use-value of biogas due to livestock dung contains a high concentration of organic matter. The nutritional components several typical aquaculture wastes are listed in the Table 3-10.

Table 3-10 Animal excreta parameter and its nutritional components in China (Wang, et al., 2006)

	N Content [%]	P Content [%]	Amount of excrement [t/a]
Pig	0.238	0.074	2.37
Cow	0.351	0.082	20.08
Horse	0.378	0.077	4.38
Donkey	0.378	0.077	5.00
Sheep	1.014	0.216	0.73
Chicken	1.032	0.413	0.11
Duck	0.625	0.290	0.11
Rabbit	0.874	0.297	0.11

Currently, there are mainly three disposal methods of livestock manure: to use the manure as fertilizer, as energy and as feed.

The moderate dispersion farming is an important condition of the rural household biogas. At the present time, China's dispersed livestock farmers are 249.72 million households. In most of China's rural areas, almost all farmers are engaged in more or less the livestock and poultry breeding activities, except the following two types of farmers: one group of farmers is engaged in mainly non-agricultural production or working in cities; another kind of professional farmers are major in agriculture, but their main operating target is fishery and horticulture. These two types of farmers account for 26% of the country's total number of households. Therefore, from the aspect of the fermentation feedstock, the suitable households for the development of household biogas farmers are about 172 million, which remains at 74% of total households (MOA, 2007b).

3.3.2 Suitable climatic zone for biogas plant in China

Appropriate temperature (temperature of air and soil) is a necessary condition for the biogas digesters for their safely operation in winter. As rural household biogas digesters operated under normal temperature, the temperature should be maintained at more than 8°C. Low temperature and permafrost are major natural factors of restricting the development of China's rural biogas, which not only damage the life of digesters but also affect the gas production efficiency. For evaluation of natural suitability, permafrost, temperature of ground and air temperature are selected as the indicators and the index system of regional planning of natural suitability is established; specific indicators are listed in the Table 3-11.

Table 3-11 The first-grade regions index system of regional planning of natural suitability for rural household biogas in China (Bi, et al., 2009)

	Criterion	Thickness of Frozen soil	Duration	Annual average temperature of ground	Average temperature of the coldest month of ground	Average minimum temperature of several years
naturally suitable regions	No frozen soil or instantaneously frozen soil	< 30cm	< 30 days	-	> 0°C	> -15°C
Conditional suitable regions	Seasonal frozen soil	30-300cm	30 – 200 days	> 0°C	< 0°C	-15 - 35°C
Non suitable regions	permafrost	> 300cm	> 200 days	< 0°C	-	< -35°C

As shown in Figure 3-12, according to the climate and geography conditions, China can be divided into 3 zones (NDRC, 2017):

Zone I: Naturally suitable regions for biogas plant installation. In the southern regions, the average temperature of the coldest month is > 0°C. In these regions, without many insulation measures, the biogas digesters can also operate normally in winter.

Zone II: Conditionally suitable regions for biogas plant installation. In northern China, the average temperature in the coldest month is less than -2°C. To ensure the safety of digesters in winter, insulation measures must be completed. Such areas can be seen as an unnatural rural household biogas suitable area, also known as conditionally suitable area.

Zone III: Unsuitable regions with extreme cold weather. In the northern part of China, the Qinghai-Tibet Plateau and northwest of the Altai Mountains such alpine region, the average temperature of the coldest month is generally less than -15°C to -20°C and the lowest temperature at -30°C to -35°C or less. Under bitterly cold climatic conditions, even if the biogas digester is covered with a fully enclosed green house, it cannot ensure that, the biogas digester will not be damaged in cold winter. This region basically belongs in the areas were non-suitable for development of rural household biogas. Although these range of regions are very large, the amounts of rural households are extremely limited, only 5% of the total number in China. However, in zone III there are only few biogas plants, which are out of function in winter for at least 4 months.

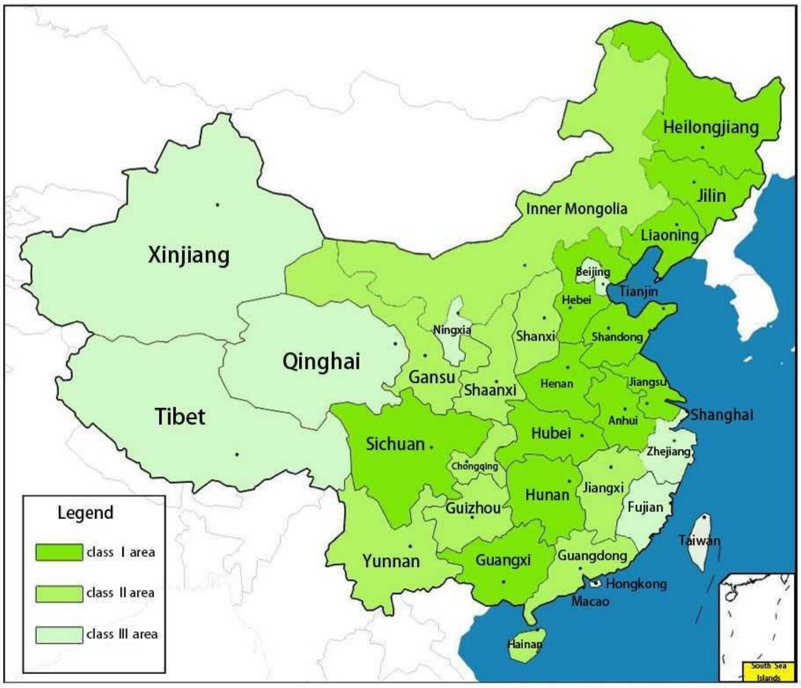

Figure 3-12 Zone Distribution for Biogas Technology in China (NDRC, 2017)

As the feedstock of digesters must be kept at more than 90% moisture content, therefore, the adequate water resource is a necessary condition for normal operation of digesters. In 2000, 98% of the people gained access to drinking water in urban area, meanwhile 70% of the people in rural area (WHO, 2019). However, Northwest of China with arid weather is a desertification concentrated area, which is caused by excessive felling. Some remote mountainous areas have neither the water supply system nor the natural water resources (groundwater or rainwater). These regions, which are characterized as arid with water shortage, also belong to the non-suitable areas of biogas development, accounting for 26% of the total households (WHO, 2019).

3.3.3 Suitable Socio-economic conditions for biogas plant in China

From the aspect of socio-economic conditions, the farmers who use non-suitable biogas are mainly included the following three categories: First, the areas, where are rich in coal, solar, wind and micro-hydro resources, should make full use of those resources and due to local conditions develop that renewable energy. Second, in the areas of grazing, especially nomadic, biogas feedstock cannot be supplied uninterruptedly and sufficiently. Third, from the aspect of the economic, in the economic developed area, the farmers already have utilized comprehensively clean commercial energy, it is not necessary to use biogas as fuel. In contrast, some poor farmers still have not the ability of construction of a biogas digester. Those mentioned three categories of farmers are about 17.8% of the distributed households in China. (MOA, 2007b)

3.3.4 Present status of household biogas development in China

China is the largest biogas consumer in the world. The popularization and scientific research of biogas in China was actually initiated around 1970. After more than 3 decades of development, by the end of 2015, there had been around 6,972 large biogas plants, 103,476 medium- and small biogas plants, and around 42 million household biogas digesters all over the country. In 2015, China's biogas project produced a total of 15.8 billion m^3 biogas and the digestate amount reached 71 million Mg. According to the National “13th Five-Year Plan” for Rural Biogas Development, China will focus on the development of large and medium-sized biogas plants. As shown in Table 3-12, total 10,122 large biogas plants should be in operation in 2020 in China. From 2015 to 2020, around 25,500 new medium- and small biogas plants should be built. And there will be 43.04 household biogas plants. The production of biogas can reach 20.7 billion m^3 and digestate 97.51 million Mg respectively. The number of existing rural household biogas digesters in China in 2019 reached 33.80 million (Yearbookchina, 2020).

Especially from 2000 to 2010, the number of China's rural household biogas digesters increase from 8.48 million to 38.50 million with an average annual growth rate of 15.41%. In recent years, with the development of the large-scale breeding industry, the acceleration of urbanization and the increasing diversification and convenience of living energy in rural area, farmers' demand for household biogas digesters is decreasing. Therefore, the number of biogas digesters has grown slowly (see Figure 3-13). Meanwhile, and the use rate of rural household biogas digester has also generally declined, and even exist many abandoned household biogas digesters.

Table 3-12 Status of biogas plant in 2015 and the plan in 2020 (NDRC, 2017)

	Status in 2015	Plan in 2020
Large biogas plant [pieces]	6,972	10,122
Medium- and small biogas plant [pieces]	103,476	128,976
Household biogas digester [million pieces]	41.93	43.04
Total biogas production [billion m^3]	15.8	20.7
Total digestate production [million Mg]	71	97.51

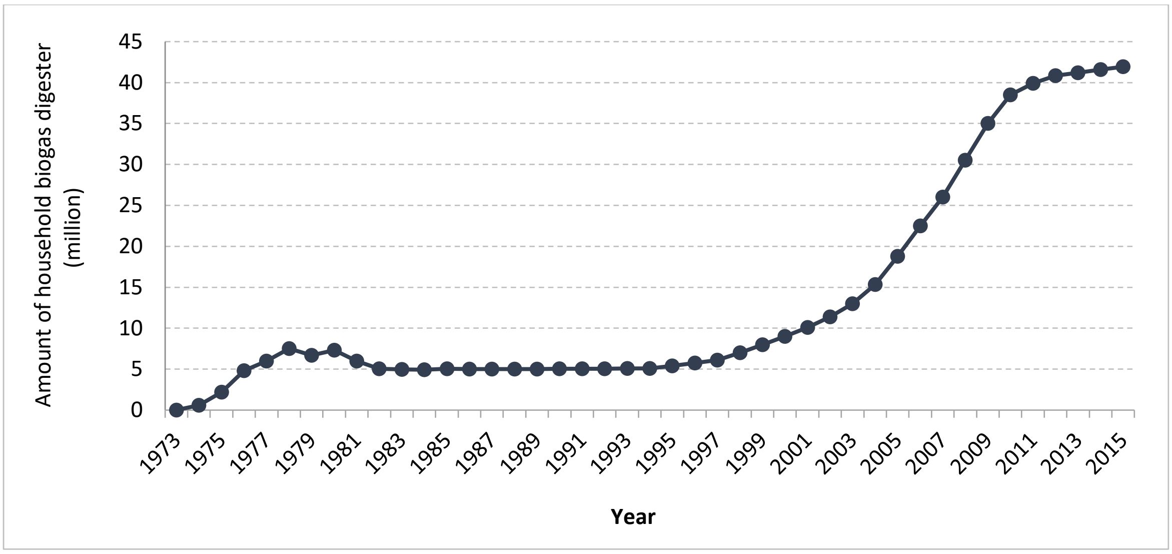

Figure 3-13 Household biogas digester in China from 1973 to 2015 (MOA, 2007b), (NDRC, 2017)

As a result, a regional map of China with the amount of biogas production has been drawn (see Figure 3-14). Obviously, more biogas is produced and utilized in south of China than in other regions of China, especially in Sichuan, Guangxi and Henan province, of which the annual biogas production reached 2,366 million m^3, 1,587 million m^3 and 1,366 million m^3 respectively in 2014 (National Bureau of Statistics of China, 2015). Because of the high altitude and extreme cold climate, biogas plants in the north and west of China are not very much promoted.

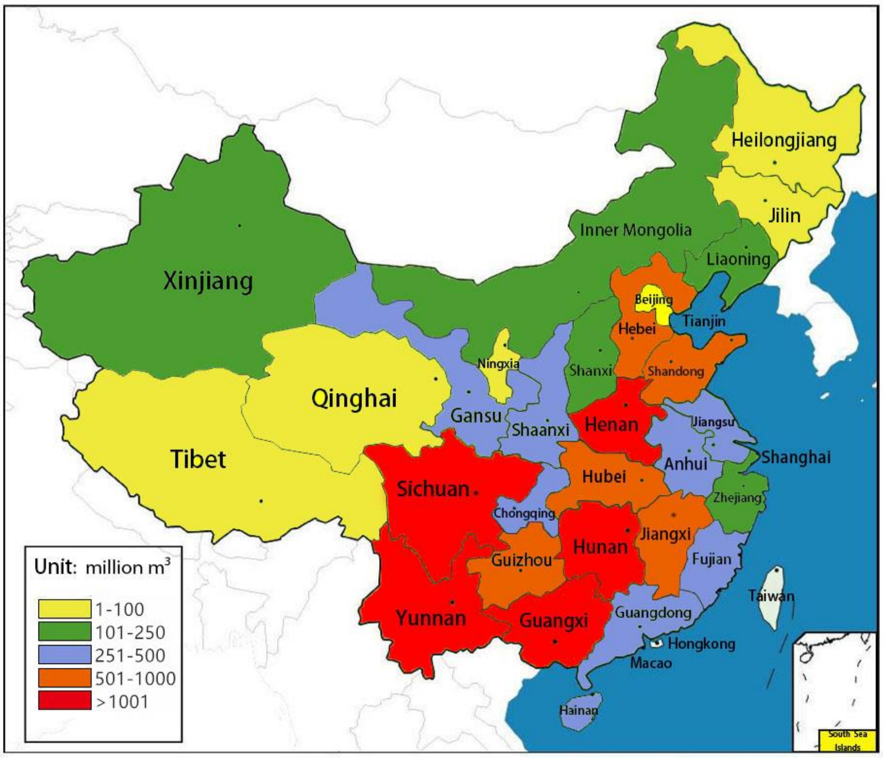

Figure 3-14 Distribution of total biogas production in China in 2014 (National Bureau of Statistics of China, 2015)

3.3.5 Present status of industrial biogas development in China

By the end of 2015, totally 110,975 industrial biogas plants of various types were built with the support of central and local investment, including 103,898 small and medium-sized biogas plants, 6,737 large biogas plants, 34 extra-large biogas plants, and 306 industrial waste biogas plants. There are 458 biogas plants with straw as the main feeding material, and 110,517 biogas plants with livestock manure as the main feeding material. The total capacity of industrial biogas plants nationwide reached 18.93 million m^3, with an annual production capacity of 2.23 billion m^3 of biogas (NDRC, 2017). Compared with the total biogas potential from agricultural waste (122.7 billion m^3 of biogas), the industrial biogas accounted for only 1.82%. Even together with household biogas plant, the total gas production reaches 15.8 billion m^3, which is equivalent to 12.88% of biogas potential (NDRC, 2017).

3.3.6 Ecological benefits of household biogas digester in China

3.3.6.1 Impact on the nature and forestry

In most developing countries, especially in rural areas, fuelwood remains as the main energy sources for households. The approach of "fuelwood to make fire" results not only in deforestation and waste of resources, but also in pollution of the environment. The use of biogas can significantly reduce the employment of fuelwood and protect forest resources. The substitution of fuelwood by biogas contributes the reduction of fuelwood shock and reduces the deforestation. Thus, the biodiversity, the remaining forests and reforestation are obtained. It helps protect forest and grass resources, promotes the development of afforestation, reduces soil erosion, and improves the agricultural ecological environment.

3.3.6.2 Impact on waste

The municipal waste, human and animal feces and crop straw are the main sources of waste in rural China. In the present, most part of the rural waste is burned in the open air or untreated and placed anywhere on the edge of a village, on ponds, on the banks of the rivers or deposited beside the road. Therefore, the pollution on environment is caused by waste in rural areas.

Through the use of biogas, the current environmental situation with the disordered disposal of municipal waste can be improved. As shown in Table 3-13, the rural biogas development influenced the treatment of human and animal excrement. In 2007, about 96% of the feces of non-biogas users and about 39% of the excrement of biogas users were discharged untreated directly to the fields. This means that the feces of non-biogas users are mainly used as untreated fertilizer. About 60% of the total excrement of biogas users is fed as input material into the biogas plant (Lu, et al., 2007).

Table 3-13 Treatment ratio of human and animal manure in 2007 (Lu, et al., 2007)

Treatment ratio of human and animal manure	Biogas-user	Non-biogas-user
Directly use as fertilizer	39.0%	96%
Deposit as waste	1.0%	1%
Rinsing with water	0.2%	3%
Feedstock for biogas plant	59.8%	/

The straw is a typical waste in rural areas. The burning of straw is a traditional method for straw treatment in rural areas of China. In this case the burned straws cause water pollution and air pollution.

By fertilization with the use of digestate, fertilizers and pesticides can be reduced. Thus, residues of pesticide and parasites can be also reduced in the soil. Hookworm larvae and ascaris eggs from the soil samples, which were collected from vegetable garden and courtyard of biogas users for 3 years, were each reduced by 60% - 85% and 50% - 76%. This means that the use of biogas in rural areas improves soil quality.

In rural China, the wastewater is generally unresolved and untreated conducted directly into rivers or on the field, which directly affects the quality of groundwater and drinking water. The concentrations of pollutants in wastewater from rural households are significantly reduced by the fermentation.

3.3.6.3 Reduction of Green House Gas

With the replacement of energy sources of coal, fuelwood, straw and animal dried manure, the use of biogas contributes to reduction of greenhouse gas (CO_2 equivalent) (Zhang, et al., 2005). Besides the deforestation, reduction of greenhouse gas is one of the most important ecological aspects of the utilization of biogas. With the parameter of GHG emission factor and the substituted among different fuels, the amount GHG emission that is being reduced can be calculated (see chapter 6.6.2).

3.3.6.4 Effects on the hygienic situation in the domestic and rural environment

The deposition of animal manure, municipal waste straw etc. in open areas leads to a deterioration of the hygienic situation in the rural areas of China. The household biogas plant is an effective approach to improve sanitary status in rural area. During the study period of 3 years by Lu et al. (Lu, et al., 2003), the insect’s density was compared in the house and surroundings of the biogas user and non-biogas-user. In the house with biogas digester fewer insects (flies and mosquitos) were found significantly (reduction rate of 64%). The studies have also shown that the 93% of insects in the pig farm of biogas users is reduced. High numbers of insects in the toilet were found in non-biogas-users, but no mosquitos were discovered around the toilet of biogas users (Lu, et al., 2003).

To compare the sanitary status between the biogas users and non-biogas-users, 1,619 households were investigated in the provinces of Jiangxi, Guizhou, Hebei and Shanxi in the study by Sun, et al. (Sun, et al., 2006). In the Table 3-14, the results are summarized for hygienic situation in the surrounding of the house. It should be noted that the sanitary situation in the kitchen and toilets are clearly improved by the construction of sanitary toilets and biogas plants under the pig pens. Furthermore, it is evident that the breeding places for mosquitoes and flies in the garden of biogas users are significantly reduced.

Table 3-14 Sanitary situation in the home environment in China (Sun, et al., 2006)

Criteria	Biogas-user [%]	Non-biogas-user [%]
Very satisfy with hygiene situation in the kitchen	26 - 44	2 - 14
Renovation of sanitary toilets	65 - 84	0 - 3
Very satisfy with hygiene situation in the toilet	25 - 36	1 - 8
Renovation of pig pens with biogas lamp	52 - 69	0
Garden without mosquitoes and flies	45 - 75	32 - 39

3.3.7 Social benefits

The assessment of human development involves the determination of the per capita income, growth of population, education status and health status. Determination of the indicators shows that human development (HDI) by the use of biogas in rural areas has significantly increased.

Natural population growth is used as an indicator for social evaluation. Through the use of biogas, the natural population growth has not changed significantly. In addition, there is almost no influence on the age structure of rural population. The budgets of biogas users and non-biogas users are almost the same.

The microorganisms in the feces may damage the human and animal health. Many pathogens of human and animal excrement can be killed through the thermophile fermentation process (Wagner, et al., 2008). Although the operating area of household biogas plant is mesophile, the digestate reached is also the hygiene requirement due to the extreme long retention time. According to survey of hygiene situation of 80 samples by Zheng et al., the pollution to the soil, vegetable, pond water quality and the fish productions from coliform, alive roundworm eggs, helmmthes is clearly decreased when the manure is fermented. The value of coliform reduced from 10^{-8} - 10^{-7} to 10^{-3} - 10^{-2}, and the mortality rate of roundworm eggs reaches 90% (Zheng, et al., 2003). In Table 3-15, survival and mortality of the most common harmful microorganisms in various temperature ranges are listed.

Table 3-15 Removal / destruction of harmful microorganisms in the fermentation process (Zhang, et al., 2001)

Harmful microorganisms	thermophile (53-55°C)		mesophilic (35-37°C)		psychrophilic (8-25°C)	
	days	mortality [%]	days	mortality [%]	days	mortality [%]
Schistosoma eggs	Some hours	100	7	100	7-22	100
Ascaris-eggs	2	100	36	98.8	100	53
Hookworm eggs	1	100	10	100	30	90
Salmonella typhi and Salmonella enteridis	1 - 2	100	7	100	44	100
Shigella dysenteriae	1	100	5	100	30	100

In rural areas, traditional fuels such as coal, fuelwood and straw are used for cooking and heating, which endanger human health because of the air pollutants and smoke formed during the combustion. Through the use of biogas in rural areas, many diseases caused by air pollutants and smoke are obviously decreased. These include, eye disease, lung disease, respiratory diseases and intestinal disorders. Therefore, the medical expenses will fall to a certain extent. In Table 3-16, the disease situation is represented with a comparison between the biogas users and non-users in southern China. It is shown that the health status of biogas users has improved slightly. (Sun, et al., 2006)

In rural areas of China, most farmers have the education level of primary and secondary education. With the application of biogas technology, the population is gaining more leisure time, which can also be used for further education. The daily working time for the operation and maintenance of the biogas plant with the situation of farmers without a biogas plant are compared. The traditional working time for fuelwood preparation, cooking and fertilization must be considered for this comparison.

Table 3-16 Compare of the disease situation of farmers (Sun, et al., 2006)

General diseases	Biogas-user	Non-biogas-user
Ascariasis [%] (roundworm infestation)	7.1 - 7.7	17.3 - 22.3
Ancylostomiasis [%] (Hookworm disease)	0.0 - 5.2	0.0 - 20.4
Schistosomiasis [%]	0.0 - 5.5	0.0 - 6.8
Oxyuriasis [%]	0.0 - 1.0	0.0 - 2.9
Bowel disease [%]	1.0 - 1.3	1.0 - 3.8

According to the hygiene requirements for the stable and the recovery of the substrate human and animal excrement must be fed into the biogas plant, which needs about 10 minutes per day which corresponds to approximately 64 hours per year (Yan, et al., 2006). A household biogas plant can produce about 15 Mg of digestate per year, the fertilization of the digestate requires about 120 hours per year. Compared to conventional fertilization; the working times of biogas users for managing the feedstock and use of the fertilizer has increased in a total of 136 hours a year. This practice shows that approximately 2.2 Mg of fuelwood per year is necessary for the satisfaction of 5-person household energy needs (without feeding and heating) (Yan, et al., 2006). This means working times of approximately 176 hours per year for the non-biogas-users. In addition, the biogas non-users need 1.5 hours every day for the ignition and refilling of fuels, which corresponds to 544 hours per year.

In Figure 3-15, the working time for preparing of cooking fuels of biogas users is compared with the non-biogas-users. Accordingly, the working time of biogas users is approximately 584 hours less than non-biogas-users.

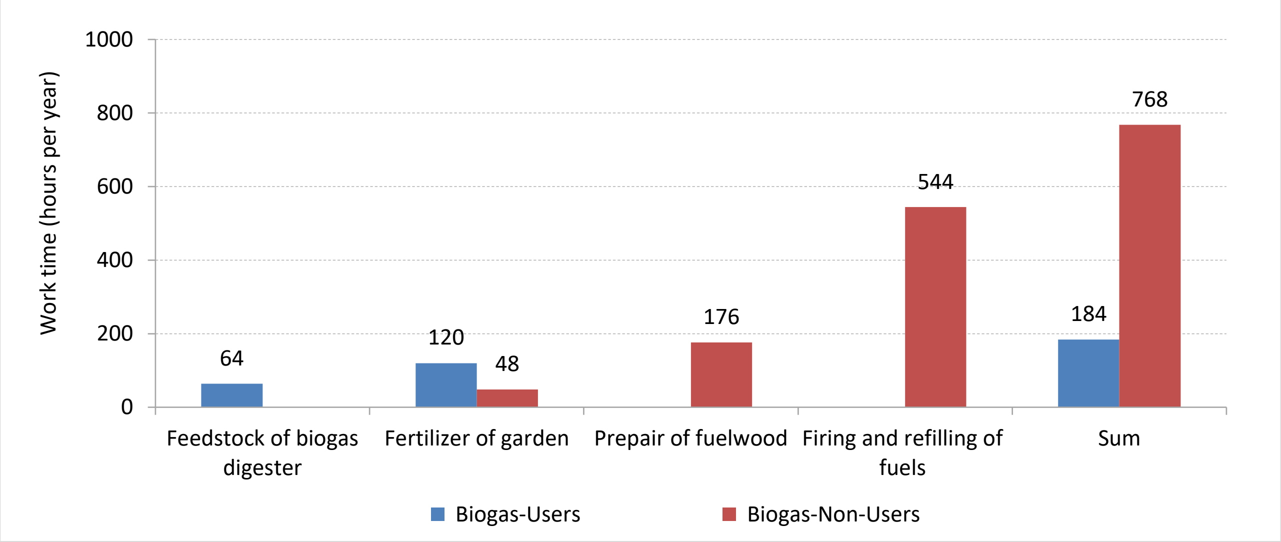

Figure 3-15 Comparing the daily work time between biogas users and non-biogas-uses in China (Yan, et al., 2006)

4 Onsite investigations in China, laboratories tests and results

4.1 Investigation concept and methods

Collection of basic data has an especially important significance for biogas transferability study. In this dissertation, a large amount of historical data and actual situation has been required for analysis. Therefore, the main sources of data come from public sector information collected in previous years, furthermore, site visits, sampling survey and laboratory experiments, interview survey and comparative evaluation studies in the selected regions in China were conducted.

Interviews survey is a method of data collection through face-to-face communication with experienced people of relevant agencies. To collect official data about policies and measures in this dissertation, interview surveys were conducted with the person responsible of biogas user, biogas technical person, relevant government departments, colleges and universities. According to the requirements of data collection, questions were orally raised by interviews in order to fulfill the objective facts on the replies.

This is a method to obtain information or conclusions through experimentation, which has standardized test methods and test equipment to obtain more accurate and thorough data. Experimental methods used in this dissertation consist in on-site experiments, laboratory experiments and computer simulations. On-site experiments have been conducted in real biogas digesters proper for investigation. Some process parameters must be measured on site because they can change if it is transported to another place. Due to the limitation of on-site measure equipment, space and conditions, on-site experiments could be performed just for limited parameters, such as pH value and temperature in this dissertation. Additional laboratory experiments were conducted in an artificial environment with rigorous controlled conditions. These additional experiments allowed to take into consideration more parameters and also because of the availability of more advanced technology.

Samples and surveys have been taken during 2009 - 2011 based on scientific principles and methods in order to scale up and to infer the missing data. Determination of sampling methods and sample size is the most important point in sample survey. In this dissertation, investigation on the rural household biogas digesters has been conducted. Considerations of climate, geographic and socio- economic conditions, and benchmarking of current experiences, biogas digesters in south, north and west area of China have been investigated. According to the different sizes and different possibilities of feedstock of the digesters, 6 - 8 digesters with the volume of 6 - 9 m^3 in each region were subject of analysis.

Figure 4-1 Investigation of biogas digesters in China (based on (Google Maps, 2021))

As shown in Figure 4-1, 15 biogas digesters were investigated in south of China, where the biogas technology best developed and popularized (7 biogas digesters in Lingli city (No.1 to No.7) and 8 in Hechi city (No.8 to No.15)); in contrast, 8 household biogas digesters in Hulunbeier City in north of China (No.16 to No.23) and 6 in Urumqi City in west of China (No. 24 to No.29) were visited.

Questionnaire surveys have been used in face-to-face conversations with users of biogas to approach and study their experiences (see annex A-1). Besides the questionnaire survey of basic information (Table A-1), field sampling was conducted in order to accurately record research process and results, so as to improve the reliability of the information and further results. Among them, the experiments on pH value, Temperature and odor intensity were done on site. Further results from experiments on CH_4 content and CO_2 content of biogas, nutrients content of digestate were from the token samples and laboratory analysis.

Due to territorial limitations, biogas and digestate are unable to bring back to Germany to be analyzed. Therefore, important parameters of household biogas digester that have been investigated in China were only measured in local laboratories. The biogas composition and their content were determinate in laboratory. Right after the digestate has been sampled, the selected parameters were measured in local research institutions and laboratories. Measured parameters and experimental methods are contacted according to the national standards, which are in Table 4-1 summarized. The concrete measurement method and requirements are shown in annex A-3.

Table 4-1 Measured parameters and experimental methods in China

Parameter of biogas	Method	Sources
CH_4 Content	Gas chromatography	NY/T 1700-2009
CO_2 Content	Gas chromatography	NY/T 1700-2009

Parameter of digestate	Method	Sources
Temperature	Thermometer	GB13195-91
pH	Glass Electrode Method	GB 6920-86
Total phosphorus	Ammonium molybdate spectrophotometric method	GB11893-89
Total nitrogen	Gas-phase molecular absorption spectrometry	HJ/T 199-2005
Suspended substance	Gravimetric method	GB11901-89
Colority	Platinum-cobalt colorimetry and Dilution method	GB 11903-89
Turbidity	Spectrophotometry and Visual turbidimetry	GB 13200-91
COD	Dichromate method	GB11914-89
BOD_5	Dilution and seeding method	HJ 505-2009
Odor	Triangle odor bag method	GB/T 14675-93
Fecal coliform	Manifold zymotechnics and filter membrane	HJ/T 347-2007
Ascaris eggs mortality	Visual method	GB/T 19524.2-2004

4.2 Investigation Results

4.2.1 Results of onsite investigation

In this investigation, all the 29 household biogas digesters in China are for single family with average 3-5 adults and 1-2 children. All of them have some livestock, which is necessary condition for biogas plant. All the biogas digesters are underground fixed-dome digester form. With the input material of animal manure, toilet waste and organic waste of kitchen, the biogas digester produces daily around 1 m³ biogas, which is enough for the household utilization. There was no odor by all the biogas digesters. Table 4-2 lists the results of the investigation of 4 household biogas digesters, that represents the typically household with different livestock in each region. For instance, the household in west of China holds cows and horse, in contrast, biogas digester in north of China uses pig manure as main feeding material. This is considered to build up of different size of biogas digester. The household no. 4 in south of China has the most family member in all investigated family, and holds 4 pigs and 10 chickens, that leads to operation of a relatively big biogas digester with 9m^3. The complete results of investigation are addressed in annex A-2.

Table 4-2 Results of onsite investigation in China

	Biogas digester No.16	Biogas digester No.26	Biogas digester No.4	Biogas digester No.10
Situation of Place	North of China	West of China	South of China	South of China
Investigation time	Aug. 2009	Sep. 2009	Sep. 2010	Feb. 2011
Situation of Family	3 adults, 1 child	3 adults, 1 child	5 adults, 1 child	3 adults, 1 child
Livestock	4 pigs	2 cows and 1 horse	4 pigs and 10 chickens	2 cows
Type of biogas digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester
Size	6 m^3	8 m^3	9 m^3	8 m^3
Year of construction	2000	2004	2004	2005
Input material	Pig manure, toilet and kitchen waste	Cow and horse manure, toilet and kitchen waste	Pig and chicken manure, toilet and kitchen waste	Cow manure, toilet and kitchen waste
Input amount / day	5 kg	6 kg	8 kg	5 kg
Input water/day	7 kg	9 kg	12 kg	11 kg
Output biogas /day	Biogas 0.6 - 0.8m^3	Biogas 0.8 - 1m^3	Biogas 0.8 - 1 m^3	Biogas 0.8 - 1 m^3
Output digestate /day	12 kg	15 kg	20 kg	16 kg
pH Value	7.09	7.50	7.84	7.81
Temperature	23.4°C	21.6°C	25.2°C	28.8°C
Odor	No	No	No	No

Figure 4-2 shows the outside of household biogas digester Lingli city in south of China. The household biogas digester locates around 20 meters far away from the household, so that the toilet waste can directly flow into the biogas digester (see Figure 4-5). The input of raw material is conducted every day and also the output of digestate, which will be storage at first in a tank for few days for further aerobic digestion (as shown in Figure 4-6).The produced biogas is stored in the top of the digester, which is sealed with water (see Figure 4-3). As shown in Figure 4-4, the Biogas is transfer to the household through the gas pipe and used for cooking and lighting (see Figure 4-8). Besides, there is a measurement for gas pressure (see Figure 4-7), in order to guarantee the safety use of biogas.

Figure 4-2 Household biogas digester in China - Outside look

Figure 4-3 Household biogas digester in China - Gas storage

Figure 4-4 Household biogas digester in China - Gas pipe

Figure 4-5 Household biogas digester in China - Inlet from toilet waste (right) and cow manure (left)

Figure 4-6 Household biogas digester in China - Outlet

Figure 4-7 Household biogas digester in China – measurement of gas pressure

Figure 4-8 Household biogas digester in China - appliance gas stove

4.2.2 Results of laboratory analyses

As mentioned in chapter 4.1, pH value and temperature has been determinate onsite immediately (see Figure 4-9), while the biogas has been sampled and the CH_4 and CO_2 content were tested in laboratories. The following Figure 4-10 to Figure 4-13 represents the results of the experiments of pH value, temperature, CH_4 content of biogas and CO_2 content of biogas.

No matter of the season times or location of biogas digester, the pH value in biogas digester remains between 7 and 8. Since the household biogas plant cannot guarantee a constant substrate composition of input material. Therefore, the frequent changes of substrates cause an increase of acidity in the fermentation process, consequently the methane-production is inhibited, and the pH value decreases (Becker, 2014).

In summer, whether in north or south of China, the inside of the biogas digester has the temperature of more than 20°C, which are suitable for biogas production. The inside temperature of the biogas digester in winter in south of China remains in more than 20°C, while it is only 10°C - 15°C in north of China, and in west of China even only 5°C - 12°C. Due to the big difference in outdoor temperature between the north and the south of China, the temperature of biogas digester represents also big difference. Most farmers, who were visited, have simple isolation measurement, such as straw mulch or insulating sheeting, to ensure that the temperature inside the biogas digester does not drop below zero or freeze in the winter.

The CH_4 content of biogas has barely a difference between regions and season times between 50% and 60%. In comparison with the biogas yields and methane contents of the input materials from KTBL as guide values, and considering the safety deviation of 10%, the results from on-site investigations are within the normal range (Becker, 2014). However, the gas production and methane concentration in household biogas digester is lower than that from industrial biogas plant, which causes by lower working´s temperature (room temperature) and unstable feeding substances. In contrast, industrial biogas plants have a stable working temperature in mesophile even thermophile range, a stable feeding material and a stirring device, which makes for a more even distribution and faster metabolism of the bacteria. The higher the temperature, the faster the metabolism of the bacteria can take place, which leads to the faster the conversion of the substrate to methane (FNR, 2021).

Figure 4-9 On-site pH value and temperature measurement

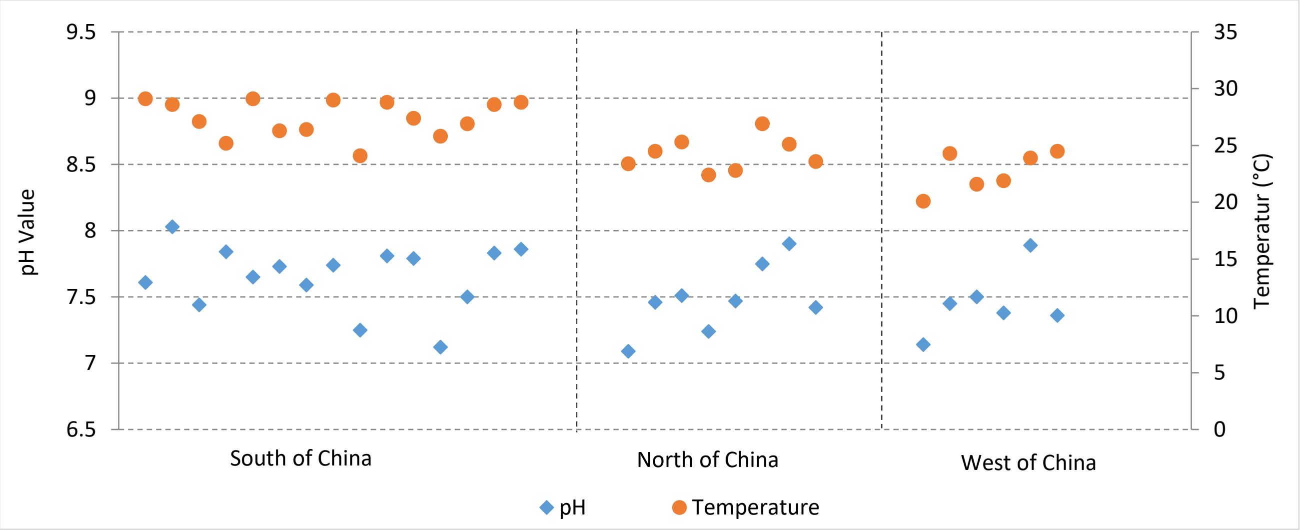

Figure 4-10 pH value and temperature of all investigated biogas digester in China in summer

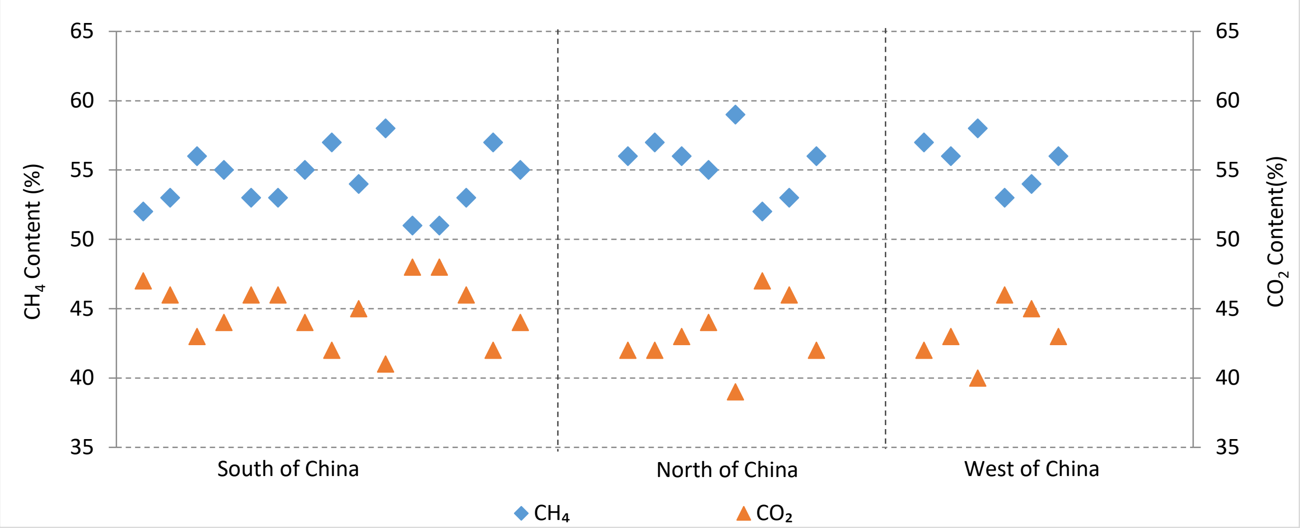

Figure 4-11 CH$_4$ and CO$_2$ content in biogas of all investigated biogas digester in China in summer

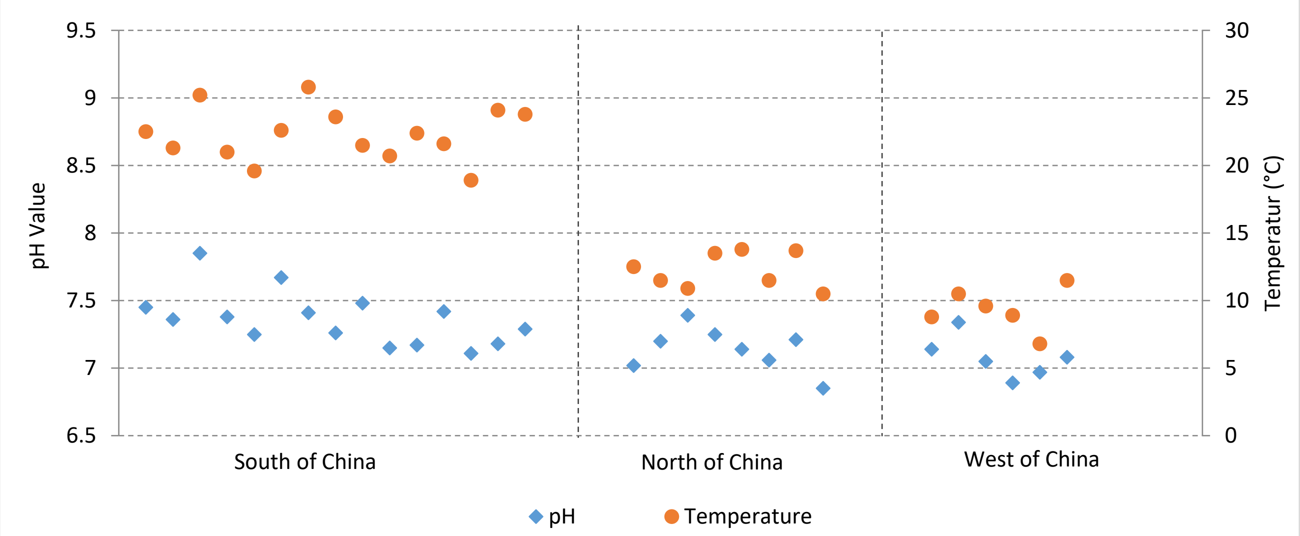

Figure 4-12 pH value and temperature of all investigated biogas digester in China in winter

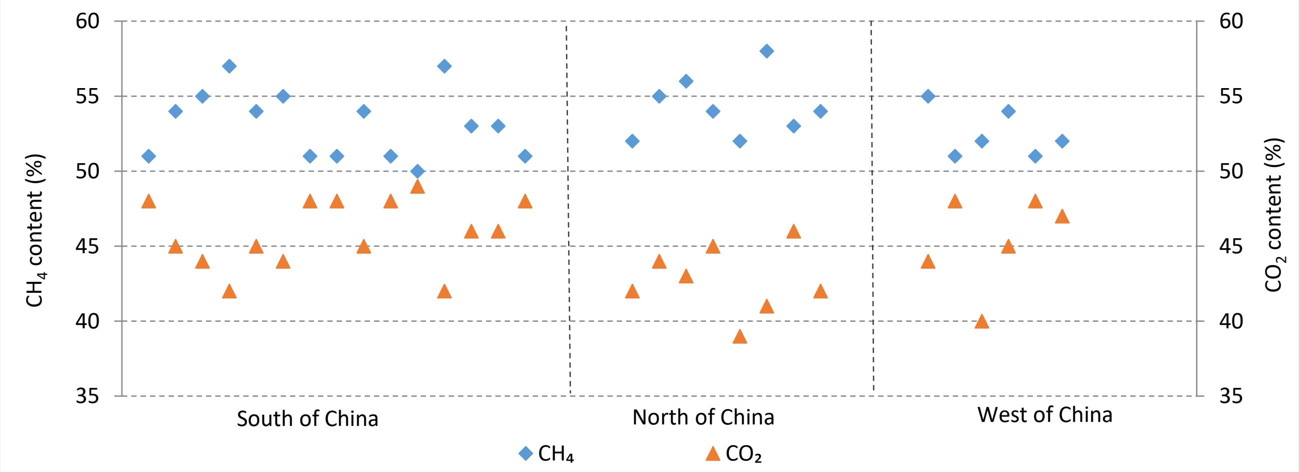

Figure 4-13 CH$_4$ and CO$_2$ content in biogas of all investigated biogas digester in China in winter

The experiment of digestate shows that digestate has rich nutrients, which contents ca. 0.25% Nitrogen and 0.15% phosphorus (see Table 4-3).

Table 4-3 The nutrients content in digestate of household biogas digesters in China

	Biogas digester Nr.16	Biogas digester Nr.26	Biogas digester Nr.4	Biogas digester Nr.10
Situation of Place	North of China	West of China	South of China	South of China
N content in digestate [mass-%]	0.21%	0.22%	0.17%	0.30%
P content in digestate [mass-%]	0.21%	0.13%	0.15%	0.11%

Table 4-4 shows the inspections results of the sanitary status of input and output materials. The results are the middle values for three parallel samples (see Table 4-4). Their color, odor intensive, pH value, suspended solids (SS), chemical oxygen demand (COD), Biochemical oxygen demand (BOD_5)-value, coliforms bacteria and number of ascaris eggs were determined. The result confirmed that, the hygienic status of animal manure of the output sample is much better than that of the input sample. Through the fermentation process, the unpleasant odors of animal excreta are substantially reduced. The removal rate of COD and BOD_5 can reach up to 85%. The most probable number (MPN) of coliforms per 100 ml input sample was 2.2 x 10^8, which decreased to 4.7 x 10^5 MPN per 100 ml output sample after the fermentation process. The number of ascaris eggs is reduced from 20,000 to 2 per 100 ml digestate, the effect is very significant.

Table 4-4 Character of input and output materials of household biogas plant in China

Item	Color	Odor	pH-Value	SS [mg/L]	COD [mg/L]	BOD_5 [mg/L]	Coliform bacteria [MPN/100ml]	Number of Ascaris-Eggs [number/100 ml]
Input sample	brown	stinks strong: 3~4	6.9	4,100	5,300	3,200	2.2 x 10^8	20,000
Output sample	light brown	little stinks strong: 0 - 1	7.8	560	670	310	4.7 x 10^5	2
Removal rate				86%	87%	90%	99.8%	99.9%

5 Selected countries in Latin-American and Africa

Four countries were chosen as examples to conduct the transferability analysis. Tanzania is one of the least developed countries in the world, and the economy is dominated by agriculture. Agriculture accounts for 85% of the country’s exports and half of its gross domestic product (GDP). The plentiful availability of raw materials guaranties the input materials for biogas plant. Ethiopia with the second highest population in Africa, owns the worst energy supply system. The application of biogas systems may be a promising solution for the energy system in Ethiopia. Brazil as the biggest and also the most developed country in Latin America, the possibility of application of the household biogas plant is high encouraging. Bolivia with extremely difficult climate and geography conditions, the review of the transferability of the household biogas technology will be a valuable example for other comparable regions.

5.1 Tanzania

5.1.1 General introduction

The United Republic of Tanzania is located in East Africa, with a surface area of 947,509 square kilometers. Tanzania is the world's 31st-largest country and the 13th largest in Africa (National Bureau of Statistics Tanzania, 2017). Tanzania has a tropical climate. The average temperature in Tanzania ranges between 20°C - 25°C. The hottest period extends between November and February (26°C - 33°C) while the coldest period occurs between May and August (5°C - 18°C) (National Bureau of Statistics Tanzania, 2017). The climate is tropical with general rainfall low and unreliable. According to the National Environment Statistics Report of Tanzania Mainland in 2017 by Tanzania national bureau of statistics, the range of annual rainfall from 2012 to 2016 is between 550 mm to 2,500 mm, with a minimum of 412 mm and a maximum of 2280 mm (National Bureau of Statistics Tanzania, 2017). Tanzania`s HDI was 0.528 in 2018, which corresponds to 159th out of 189 countries. The average annual HDI growth rate was 1.03% from 2010 to 2018 (UNDP, 2019). GNI per capita in Tanzania was reported at US$ 1,020 in 2018 (The World Bank, 2020).

When it was counted in 2018, the population of Tanzania had grown from 12.31 million persons in the 1967 Census to 56.31 million persons (National Bureau of Statistics Tanzania, 2013). The population growth rate declined to 2.98% in 2018, although there was a total of 12.45 million households in the country, with an average household size of 4.6 persons. Population distribution shows that, 66.22% of the populations live in rural areas while the annual rate of urbanization is 0.72%. (Statistia, 2021a)

Tanzania is one of the poorest economies in the world. Tanzania's GDP stands at 85th in the world, with a growth rate of approximately 6.95%, which was totaling US$ 141.6 billion in 2018. Its purchasing power parity (PPP) GDP at the same time was only ranked 203rd among countries compared to the world according to CIA statistic, corresponding to 2,590 US dollar per capita. The Tanzania economy depends heavily on agriculture, which accounts for more than 23.4% of GDP (CIA Tanzania, 2019). Based on The UNDP Human Development Report, Tanzania with HDI of 0.528 ranks 154 out of 189 countries (UNDP, 2019). In 2018, Tanzania's per capita GNI was US$ 1,020 (€ 874), and the average annual growth rate from 2010 to 2018 was 1.03% (The World Bank, 2020).

The current level of energy production and consumption in Tanzania signifies low level of the industry, commerce, and transportation. In 2018, the national power generation was consumed a total of 6.1 billion kWh (equivalent to 0.12 MWh / capita) (International Energy Agency, 2019a). The power generation reached 7.23 million MWh in 2018. Among them, 48.49% came from natural gas, while from hydroelectric plants, petroleum and solar plants and biomass, which respectively were 30.90%, 18.40% and 2.21% (International Energy Agency, 2019a). However, the demand for electricity is growing rapidly, although most of it was used in industry. The low access rate to electricity grid was estimated by only 33% of total population, including 65% in urban area and only 17% in rural areas (Mokveld, et al., 2018).

Summary of the primary energy supply in Tanzania is given in Figure 5-1. The total primary energy supply was 21.95 mega tons of oil equivalent (Mtoe) in 2018. Biomass is Tanzania's main source of energy and account for 82% of the country's total primary energy supply, which were mostly in the form of firewood or charcoal used for cooking and heating. Petroleum accounted for 12% of total primary energy supply, and natural gas represented only 2% of total primary energy supply (International Energy Agency, 2019d).

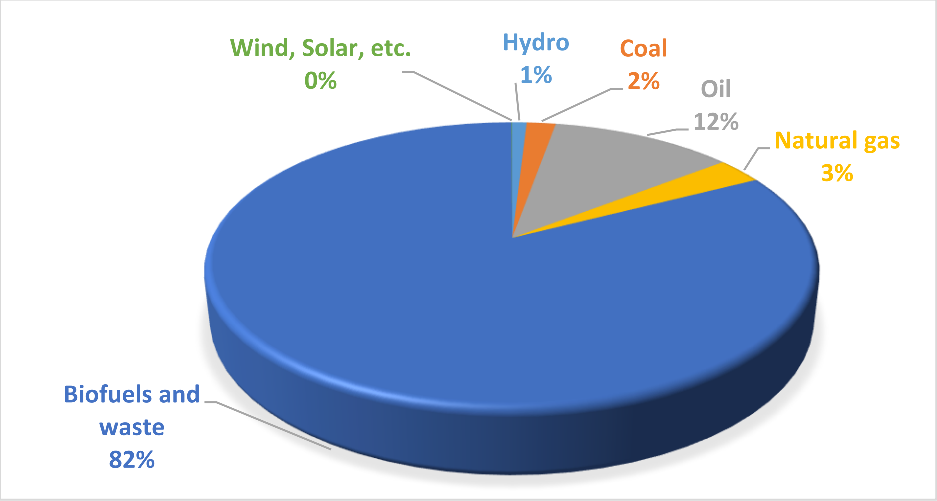

Figure 5-1 Total primary energy supply in Tanzania in 2018 (International Energy Agency, 2019d)

In Tanzania, the energy balance shows that mainly households use biomass especially charcoal and fuelwood as the main energy source for cooking purposes, which accounts for 75% of fuels used for cooking. Biomass is followed by Charcoal (12%), LPG (11%) etc. (Figure 5-2). It is worth mentioning that the renewable energy distributes almost the same as electricity in energy balance in Tanzania.

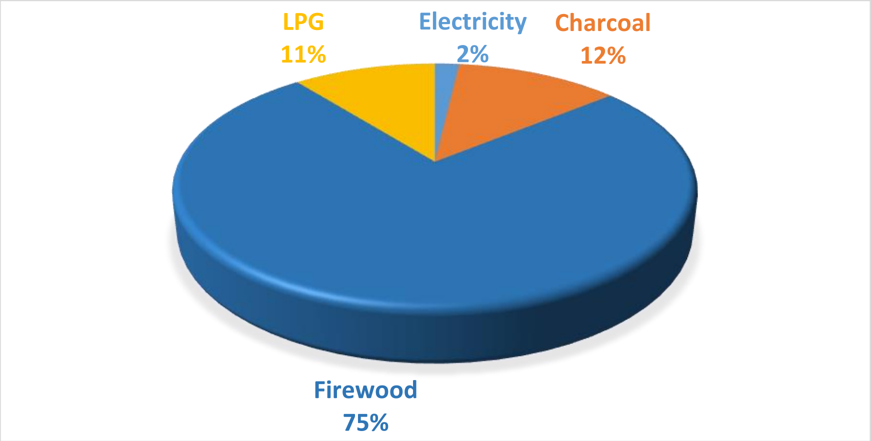

Figure 5-2 Fuels used for cooking in Tanzania (Mangula, et al., 2019)

The source of energy for lighting in Tanzania was also backwards compared to other counties in the world. Kerosene - Wick lamp was the most common source of lighting energy in Tanzania used by 40.6% of the households (50.7% in rural areas, 20.1% in urban areas). The second commonly most used source of energy for lighting was the electricity (18.9%), which accounted only 5.2% in rural area (Lighting Africa, Tanzania, 2018).

Livestock sector including poultry plays a significant role in the economy of agricultural households in Tanzania. Livestock Sector generated a considerable amount of cash income, which determined the economic and social status of families in many communities. According to the national sample census of agriculture 2007/08, around 4,431,674 households (about 52% of the national households) kept livestock, of which 4,341,920 households live in Tanzania mainland and 89,754 households in Zanzibar (NSCA Livestock Sector, 2012). The main types and number of livestock and poultry were cattle, goats, sheep, pigs, chicken, ducks etc. Table 5-1 summarizes the production data for different types of livestock in 2010, 2015 and 2018.

Approximately 99.6% of the livestock were kept by traditional (small) owners, while the large scale was accounted for 0.4% of the total livestock population excluding poultry. The contribution of Large-Scale Farms to the total livestock number was rather small. Therefore, the development of the livestock sector could contribute to reduce poverty level substantially (NSCA Livestock Sector, 2012).

Table 5-1 Livestock population in Tanzania from 2010, 2015 and 2018 (FAOSTAT, 2019b)

Livestock Amount	2010	2015	2018
Cow	19,245,648	26,713,644	27,427,658
Pig	495,000	509,262	521,716
Goats	13,600,000	18,026,051	18,385,463
Sheep	3,592,700	6,168,295	7,782,332
Chicken	33,500,000	36,578,000	37,963,000
Duck	1,330,000	1,350,000	1,359,000
Poultry total	34,830,000	37,928,000	39,323,000

Agriculture plays a considerable role in the Tanzania's economy. Approximately 65.5 percent of the population was employed by the agriculture sector (Deloitte, 2016). Among cereals, corn was the main subsistence crop, and was grown by more than 50 percent of Tanzanian farmers. Rice was the second most important staple and was grown mainly by small-scale farmers for domestic consumption (NSCA Crop Sector, 2012). The productions of mainly crops in Tanzania from 2010 and 2018 are given in Table 5-2. With the promotion of improved production by measured such as improved water management, with high-input mechanization, or the use of modern varieties, crop yields had increased. In 2018, the crop production reached 23.0 million Mg, and about 18.4 million Mg of main crop residue were produced in Tanzania.

Table 5-2 Crops production and crop residues in Tanzania in 2010 and 2018

	Yield 2010[1] [Mg]	Yield 2018[1] [Mg]	CRI[2]	Crop residue 2010 [Mg]	Crop residue 2018 [Mg]
Corn	4,733,070	6,273,151	1.0	4,733,070	6,273,151
Rice	2,650,120	3,414,815	1.5	3,975,180	5,122,223
Wheat	62,370	56,651	1.5	93,555	84,977
Barley	15,228	19,501	1.5	22,842	29,252
Sugarcane	2,800,825	3,117,812	0.25	700,206	779,453
Potatoes	1,472,560	1,080,144	0.25	368,140	270,036
Cassava	4,547,940	8,372,217	0.58	2,637,805	4,855,886
Sorghum	798,540	672,235	1.5	1,197,810	1,008,353
Sum	17,080,653	23,006,526		13,728,608	18,423,329

[1] (FAOSTAT, 2019a)

[2] (Lal, 2004)

Tanzania had the tradition to use pesticides for controlling insects, diseases and weeds on crops. This section analyses the use of these chemicals by smallholders on both annual and permanent crops in Tanzania. Insecticides were the most common pesticides used in the country accounting for 71% of the total planted area applied with pesticides (NSCA Crop Sector, 2012).

Tanzania has rich water resources, which are however distributed unevenly by seasons and space. Therefore, many Tanzanians have still problems of water shortage. Only 66.88% of the population had access to an improved water source, with stark difference between urban areas (about 84%) and rural areas (about 59%) (Deloitte, 2016).

Access to sanitation is also a serious problem to face in Tanzania. 90% of the population had some form of unimproved latrine. But only 10% of the population had access to an improved sanitation facility, for example flush toilet, even in urban area, only 20% of population, while only 7% in rural areas. This was particularly problematic to health in densely populated, unplanned settlements (CIA Tanzania, 2013).

Tanzania's per capita amount of municipal solid waste (MSW) was 0.36 kg per day. Tanzania could be generating 10.86 million Mg of MSW per year by 2016 (The World Bank, 2016). It was estimated that 39 % of the generated MSW was food waste (around 4.22 million Mg) (National Bureau of Statistics Tanzania, 2017).

5.1.2 Biogas development in Tanzania

The history of biogas in Tanzania can be dated back to 1975. Until now, more than 6000 domestic biogas plants have been built countrywide for domestic and commercial applications.

The domestic biogas with floating drum design was at first introduced by Small Industries Development Organization (SIDO), and then 120 biogas plants were installed between 1975 and 1984. In 1982, parastatal Centre for Agricultural Mechanization and Rural Technology (CAMARTEC) was founded for the dissemination of energy technologies in rural areas and got engaged in biogas technologies. In 1983, under the cooperation with Federal Republic of Germany, Biogas Extension Service (BES) was introduced in Tanzania. From 1009 to 1994, the dissemination project received financial support within the framework of the Special Energy Program (SEP), of which 1,000 biogas digesters were constructed. Since 1997, the biogas entered a rapidly development phase, as many organizations participated in the biogas issue. Until 2007, 2,900 biogas digesters were constructed with mainly fixed-dome design. Since 2003, the Evangelical Lutheran Church in Tanzania (ELCT) has been active in promotion of low-cost biogas digesters, where the farms received to 50% of the investment cost as credit for installing the Chinese fixed dome digester, and received the imported biogas appliances from China and India. Dar es Salaam Institute of Technology (DIT) has developed a moveable biogas digester with 4 plastic containers for rural households (see Figure 5-3). Currently, CAMARTEC is a reputable knowledge center on biogas and became the largest domestic biogas plant disseminator in Tanzania (Kusekwa, 2011).

The Africa Biogas Partnership Program (ABPP) is a partnership between Netherlands' Directorate General for International Cooperation (DGIS), Humanist Institute for Cooperation (Hivos) and SNV Netherlands Development Organization in supporting the domestic biogas program in Africa, aiming to the construction of 70,000 biogas digesters in Ethiopia, Kenya, Tanzania, Uganda, Senegal and Burkina Faso to the end of 2013. For this Purpose, DGIS provided financial support with approx. € 30 million, Hivos carried out the role of fund and program manager and SNV was responsible for the technical assistance (ABPP, 2021).

Figure 5-3 Biogas digester with 4 plastic containers designed by DIT (Kusekwa, 2011)

In May 2007, the conference “Biogas for a Better Life: An African Initiative” was held to revive the domestic biogas promotion in Tanzania. At the end of 2008, the Tanzania Domestic Biogas Program (TDBP) was started with the finance by SNV from its “Special Core Funds”, focusing on the development of the biogas sector; in 2009, the Partnership Agreement on the TDBP was signed between Hivos, ABPP's fund manager, and CAMARTEC, TDBP's National Implementing Agency (NIA). The goal of the program was to improve the life quality of rural farmers through exploiting the market and non-market benefits of domestic biogas. At the end of 2013, 12,000 biogas digesters were installed nationwide; over 95% of the constructed biogas plants were operated properly; 80% of the biogas households would have facilities that enable proper bio-slurry use; and all of the biogas digesters would have a second inlet pipe to allow future toilet connection. Up to July 2013, a total of 7,133 digesters were built with an achievement of 71% (TDBP, 2013).

From 2008 to 2011, Berlin regional group of Engineers Without Borders Germany and Mavuno from Tanzania worked together on the project "Biogas support for Tanzania (BiogaST)" (energypedia, 2014). The project object was sustainably increasing the quality of life of Tanzanians through the development and construction of decentralized domestic biogas plants to use of biogas as an energy source for cooking and other applications. The target group of this project was the rural population of Tanzania, who had the available agriculture residues and animal manure. Furthermore, the project would be complemented by appropriate environmental education activities.

5.2 Ethiopia

5.2.1 General Introduction

Covering a total area of 1,104,300 km², Ethiopia is location in the eastern Africa (FAO AQUASTAT, 2016). The climate condition in Ethiopia varies primarily with the altitude; in the lowlands it is hot with mean annual temperatures as 25°C, and in the highlands, it is relatively cool less than 7°C - 12°C. Otherwise, in Ethiopia it can be divided into 3 seasons for one year according to its different elevation, which respectively are followed by cool period, dry hot period and rainy season. While the mean annual rainfall is 848 mm in Ethiopia, generally changes with altitude, rainfall in middle and high altitudes (about 2,000 m) is much greater than 100mm in the lowlands, except for the lowlands in the west where rainfall is high (FAO AQUASTAT, 2016).

Based on the 2012 Census performed by the Central Statistical Agency of Ethiopia (CSA), the population of Ethiopia was 109.22 million in 2018, with an annual population growth rate of 2.62%. Only 20.76% of the total population lived in urban areas, and the annual rate of urbanization was 4.63% (estimated for 2015-20 est.) (The World Bank, 2019b). With an average of 4.6 persons per household, there was 22.52 million households (United Nations, 2018).

The major source of Ethiopia's economy was agriculture, which accounts for 31.11% of GDP and 67.29% of total employment (The World Bank, 2019a). The Ethiopian economy had registered a GDP of US$ 229 billion in 2018 (CIA Ethiopia, 2019). The GDP real growth rate was 6.8% in 2018 and it even had a rapid growth stage before 2016 with a rate between 8% and 11%. This growth had emanated from the growth of investment in infrastructure by government as well as agricultural and service sectors, which was resulting in significant reductions of poverty, particularly in rural areas. Although there were around 67.29% of person in Eithopia employed by agriculture, service sector surpassed it as the most main component of the GDP. Despite of rapid growth in recent years, with US$ 2,104 in 2018 est., the PPP in Ethiopia was one of the lowest in the world (CIA Ethiopia, 2019). According to the report from United Nations Development Program (UNDP), with the HDI of 0.47, Ethiopia ranks 173rd out of 189 countries, although the annual growth rate was 1.66%. GNI per capita in Ethiopia was US$ 800 (€ 685) in 2018 (The World Bank, 2020).

It was estimated that by 2017, only 14.7% of population (49.7% of population in urban areas, 5.7% in rural areas) in Ethiopia would have access to improved sanitation facility, included flush or pour-flush to a piped sewer system, septic tank or pit latrine, ventilated improved pit latrine, pit latrine with slab, or a composting toilet. However, the “health extension program (HEP)” and the expansion of education had brought significant improvement in sanitation services, especially in the last five years. Currently, Ethiopia was working to achieve the improved drinking water supply in the country, so that each Ethiopian can access to drinking water and health services. In 2017, proportion of urban water supply had reached 97% compared with 62% in rural areas, equivalent to 69% of the total population with improved drinking water supply (CIA Ethiopia, 2019).

The total energy supply in Ethiopia was 43.25 Mtoe in 2018. Biomass, mainly wood and agricultural waste, supplied about 88% of Ethiopia’s total energy supply (International Energy Agency, 2019e). The second-largest fuel source was petroleum, accounting for 8% of the total energy supply (as shown in Figure 5-4).

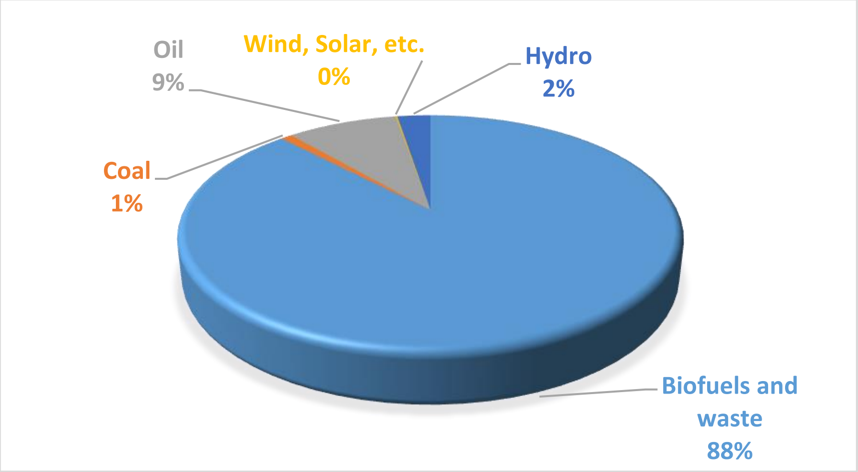

Figure 5-4 Total primary energy supply in Ethiopia in 2018 (International Energy Agency, 2019e)

Both the total energy consumption level and the electrification rates in Ethiopia were one of the lowest in the world (International Energy Agency, 2019f). Biofuels were Ethiopia's main energy sources, especially fuelwood, which still represents 76% of the cooking energy needs (Beyene, et al., 2018). Charcoal was used for daily cooking, coffee ceremonies, and indoor heating, especially on rainy season. Cow dung was used mainly for baking bread. Electricity and gas fuel has very low penetration in Ethiopia, which accounts only 5% and 1% respectively (Beyene, et al., 2018) (see Figure 5-5). Only 33% of the population was connected to the national grid (Lighting Africa, 2019). In 2018, The final consumption of electricity was 9.1 TWh, the per capita electricity consumption was only 0.1 MWh in Ethiopia, which was far lower than the world level (3.3 MWh) (International Energy Agency, 2019g).

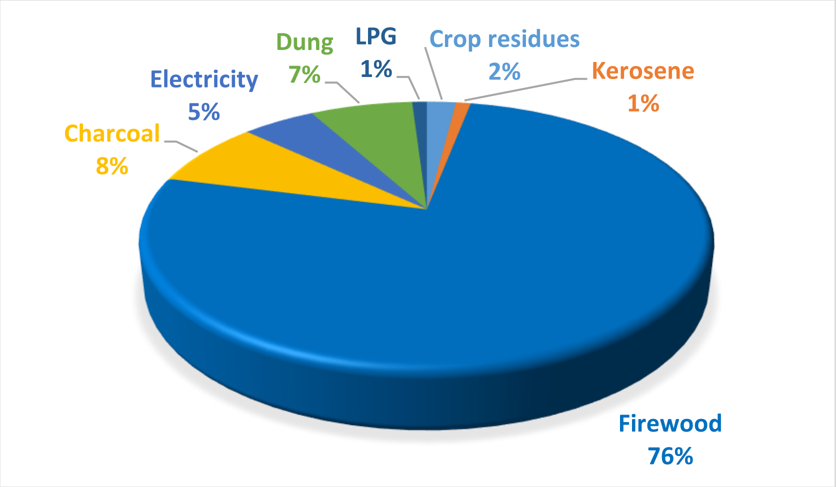

Figure 5-5 Fuels used for cooking in Ethiopia (Beyene, et al., 2018)

Agriculture is Ethiopia's pillar industry, of which the worker accounts for 77% of total employment. They mainly engaged in farming and animal husbandry, while a small amount in fisheries and forestry (The United Nations in Ethiopia, 2018).

Ethiopia's agricultural production was dominated by smallholder farming, with very backward farming methods, extensive cultivation and insufficient yield. Ethiopia's main cereal crops were corn, wheat and barley, which increased continued in the last years. The annual crop residues production in Ethiopia was also increased from 19.5 million Mg in 2010 to 29.1 million Mg in 2018 (see Table 5-3).

Table 5-3 Crops production and crop residues in Ethiopia in 2010 and 2018

	Yield 2010[1]	Yield 2016[1]	CRI[2]	Crop residue 2010	Crop residue 2016
Corn	5,481,406	10,119,847	1.0	5,481,406	10,119,847
Rice	90,412	171,854	1.5	135,618	257,781
Wheat	2,855,682	4,838,074	1.5	4,283,523	7,257,111
Barley	1,814,163	1,748,920	1.5	2,721,245	2,623,380
oats	60,283	22,123	1.0	60,283	22,123
Sugarcane	892,637	1,294,081	0.25	223,159	323,520.25
Potatos	447,333	933,109	0.25	111,833	233,277.25
Caffee	370,569	494,574	1.4	518,797	692,403.6
Sorghum	3,959,897	5,024,368	1.5	5,939,846	7,536,552
Sum	15,972,382	24,646,950		19,475,709	29,065,995

[1] (FAOSTAT, 2019a)

[2] (Lal, 2004)

Ethiopia has the largest livestock population in Africa. The area suitable for grazing accounted for more than half of the total land area. In Ethiopia, grazing was dominated by small-scale farming, scattered in life, mainly distributed in low-lying areas in eastern and southern Ethiopia. In 2018, Ethiopia had about 189 million livestock, including 62.71 million heads of cattle, 31.56 million sheep, 33.06 million goats, and 0.36 million pigs. Meanwhile, there were approx. 61.48 million poultry (see Table 5-4).

Table 5-4 Livestock population in Ethiopia from 2010, 2015 and 2018 (FAOSTAT, 2019a)

Livestock Amount	2010	2015	2018
Cow	53,382,192	57,829,953	62,706,486
Pig	31,000	34,698	35,986
Goats	22,786,946	29,704,958	33,061,808
Sheep	25,509,004	28,892,380	31,562,151
Chicken	49,287,000	60,506,000	61,482,000
Poultry total	49,287,000	60,506,000	61,482,000

Ethiopia had tradition to use chemical fertilizer to increase agricultural yields. Both past and present governments had promoted the use of fertilizers through distribution systems, promotion and credit. Ethiopia was totally dependent on imports to meet its annual fertilizer demand. In 2016, 218,223 Mg of fertilizers were imported and used in agriculture fields (FAOSTAT, 2019a). However, the sale of fertilizer was showing a declining trend, price increases were an issue in some areas, which had led to a decrease in sales.

Benefited from the government´s support and the cost recovery policies, the coverage of water supply in Ethiopia had strongly improved. In 2017, water supply coverage had risen from 19% in 1990 (11% in rural area, 70% in urban area) to 68.9% in 2017 with 97% in urban areas (within 0.5 km) and 61.7% in rural areas (within 1.5 km) (CIA Drinking water source, 2019).

The total generation of municipal solid waste in Ethiopia in 2016 was 6.73 million Mg (about 180 kg per capita). Among them, food waste accounted for 87.6%, equivalents to 5.89 million Mg (The World Bank, 2016).

5.2.2 Biogas development in Ethiopia

Some of the first biogas digesters in Africa were established in South Africa and Kenya in the 1950s. In other countries, such as Tanzania, biogas digesters were first introduced in 1975, and even more recently in other regions (South Sudan in 2001). So far, biogas digesters had been installed in several sub-Saharan countries. Biogas digesters had been installed in various situations, including commercial farms (such as in chicken and dairy farms in Burundi), a public latrine block (in Kibera, Kenya), prisons (in Rwanda), health clinics and mission hospitals (in Tanzania and Zimbabwe), and the collective cooking houses in Addis Ababa.

The first introduction of the biogas technology can be tracked back to 1979, and the first batch-type digester were being constructed at Ambo Agricultural College. Since then, about 1000 biogas plants for households, communities and governmental institutions ranging in size from 2.5 m^3 to 200 m^3 had been built up all over the country. Currently, approximately 40% of the biogas digesters were out of function. Therefore, an increasing number of people were skeptical about the development potential of biogas in Ethiopia, and the benefits for the farmers. World Vision Ethiopia had recently introduced the application of biogas under its Appropriate Agricultural Technology Promotion Initiative (AATPI) and some 150 plants had been built. As such, the total number of completed biogas plants in Ethiopia would reach 600 to 700 (Getachew, et al., 2006). Since 2007, Netherlands Development Organization (SNV) and Ethiopian Rural Energy Development and Promotion Center (EREDPC) have started a national biogas program to build on and to further develop existing institutions and organizations for biogas technology. The aim was installing 14,000 biogas plants in the four regional states in Ethiopia (Amhara, SNNPRS, Oromia and Tigray) during the first phase 2008 to 2013.

The research and demonstration project - “Income generation & climate protection by valorizing Municipal Solid Wastes in a sustainable way in emerging mega-cities” –IGNIS was funded by the German Federal Ministry of Education and Research (BMBF) within the National Research Programme "Research for Sustainable Development of the Megacities of Tomorrow - energy-and climate-efficient structures in urban growth centre” (Rymkiewicz, 2014). The overall objective of the project was that a waste management system in Addis Ababa to create through a holistic approach considering adapted technologies, environmental protection, climate protection, income generation, education and training, health and safety, raising cultural and social conditions awareness as well as the economic framework conditions. Integral part of this was the valorisation of secondary raw materials by the creation of sustainable income structures. Particular attention was given in this context of cooperation between the formal and informal sectors in the areas of waste collection, treatment and recycling. The project has been implemented since June 2008 for five years (June 2008-May 2013).

The above facts were transferred to specific pilot projects to demonstrate that there could be environmentally friendly, economically and socially sustainable (facilities-) operations in developing countries. Through continuous analysis and optimization of these pilot projects, they would be developed to best practice examples, which were intended to serve as a concrete demonstration project as well as the basis for various training and education.

Two pilot projects in IGNIS Project were related to biogas digesters: a Youth group bio-latrine and Pilot Biogas Plant in University Addis Ababa.

- Youth group Biolatrine: This pilot project was operated by a youth group in the Tesfa Ethiopia Multi-purpose community ICT center, located about 20 km away from Addis Ababa center. The fixed dome biogas plant with 18 m³ was constructed in 2004, using human toilet waste and biological waste from the cafeteria to produce biogas for cooking purposes right here (as shown in Figure 5-6). Its main purpose was to use the bio-latrine as a means of income for the youth as well as to analyze it scientifically so that it can be replicable to other areas (ENDA, 2009). In IGNIS project, the Youth Group Biolatrine would be improved by simple technical measures, for example, increasing biogas production rate by higher and constant fermenter temperature (isolation, evtl. solar panel for heating), finding additional, more efficient ways of usage of biogas and training of theoretically and practically biogas topics for youth group (AT-Verband, 2007). The bio-latrine were now fully maintained and used as energy source for the youth cafeteria. The amount of energy not only for cooking and other purpose of the cafeteria was not used at its optimal level. However, once the method for analysing biogas production had been developed and ready for application, the arrangement to collect solid waste and cow dung from the community would be finalized and sent to be fed to the bio-latrine (ENDA, 2009).

Figure 5-6 Biolatrine in Addis Abeba (ENDA, 2009)

- Pilot Biogas Plant in University of Addis Ababa: The Biogas plant would produce biogas and slurry via anaerobic fermentation from kitchen waste together with wastewater and other organic waste or liquids. The Biogas would be utilized for cooking and the slurry as fertilizer for gardening. Around 600 kg of fresh materials (10% dry matter) were daily separately collected and deployed in the biogas plant. After 22 days fermentation in the digester with constant temperature of 37°C, 550 kg/d slurry and 28 m³/d biogas, it could be obtained 182 kWh of energy. Since February 2011, this biogas plant had been installed and operating.

- Biogas plants in EPA (Ethiopia Environmental Protection Authority): A $16m^3$ biogas plant was constructed in 2008. Shaped as a fixed dome digester with cement, stone, bricks, and grass as construction materials. The biogas digester related to the toilet, which was around 100 meters away, so that the toilet waste flowed directly into the digester. Cow dung, as another input material, was collected every 2 - 4 weeks from nearly areas to EPA. The totally daily input amount was ca. 110L, and the daily biogas production was ca. $4m^3$, which contents 60% - 68% CH_4, 30% - 35% CO_2, and less than 1% H_2S. The biogas was utilized for cooking in cafeteria, and for lighting and cooking in training purpose (see Figure 5-7). Because of the no-usage of biogas in weekends, biogas was stored in 5 - 10L pressure gas cylinders. The invest cost for the whole system was around 25,000 Birr (€ 480).

Figure 5-7 Biogas plants in EPA, Addis Ababa, Ethiopia (link: Biogas plant, right: biogas stove)

In May 2007 the “Biogas for Better Live: an African Initiative” was launched in Nairobi. The “Biogas for Better Life: an African Initiative” vision was to create a successful market-oriented partnership with governments, private-sector organizations, civil society agents and international development partners in African countries (Biogas Team, 2007). The purpose of this initiative was to provide 2 million households in Africa with domestic biogas plants, offer business opportunities, and improve household livelihoods by 2020 (good health, sanitation, food security, environment and new jobs). It offered households opportunities to own, control and operate sustainable energy for their own kitchens at affordable costs. The safe, reliable and manageable technology would bring clean cooking energy for at least 10 million Africans.

To promote the uptake of domestic biogas, a National Biogas Program (NBP) was developed to disseminate domestic biogas and to develop a commercially viable market biogas sector in four selected regions (Tigray, Amhara, Oromia and SNNP) in Ethiopia. The overall goal of the national biogas program in Ethiopia was to improve the life quality, health and sanitation of rural households through utilization of biogas for cooking and lighting and use of the high value organic slurry as fertilizer. The construction and connection of toilets to domestic biogas plants have many benefits of which the improvement of the sanitary conditions, including the safe disposal of human waste and the reduction of illness induced by poor sanitation is the most significant (Josefsson, 2009). 14,000 biogas plants with the size 4 m³, 6 m³, 8 m³ and 10 m³ in form fixed dome digester was constructed in these 4 selected regions in Ethiopia during the first phase 2008 - 2013. The target groups of the project were at least 4 cows, which was equivalent to 20 kilograms of fresh manure every day, and families with water every day (Boers, 2008).

In order to spread biogas technology and increase the number of plants within 5 years, all stakeholders, such as institutions and organizations with specific roles and responsibilities would be encouraged to participate in the development of a national biogas sector. As the reason for the development of a biogas sector, a number of functions would implement. These functions included promotion and marketing, training, quality management, research and development, monitoring and evaluation, institutional support, extension, and gender mainstreaming (Boers, 2008).

The average investment cost for a 6 m^3 biogas digester is ETB 4,310 (€ 346). To encourage households to install a biogas plant, a contribution to construction cost of ETB 2,400 (€ 193) will be provided, which are borne by the federal government (10%) and external donors (90%). The investment cost remaining after deduction of the contribution to construction cost and selfhelp contribution is ETB 1,110 (€ 89) and can be financed through either cash or microcredit. Through the mobilization of carbon credits through certified emission reductions (CERs) or verified emission reductions (VERs), revenues will be generated that could contribute to the financing of the contribution to construction cost and future up-scaling of the National Biogas Program. (Boers, 2008)

Until the end of 2010, more than 120 technical people were trained, and more than 600 biogas plants were built with the financing help from SNV, national government, regional government and donors.

According to the report of 2014, more than 8,000 biogas digesters against a target of 14,500 were constructed in the first Phase (2009-2013). In addition, a large number of biogas masons were trained, some masons even set up their own company for biogas construction and services. The government has been involved and performed all the coordinating activities as well as certain other activities, such as promotion of biogas, training of masons and quality control for installations (SNV, 2014). In 2014 alone, a total of 1762 plants had been constructed. The existing household biogas plant in Ethiopia was 18,534 in 2017 (ABPP, 2021).

5.3 Bolivia

5.3.1 General Introduction

The Multinational State of Bolivia lies in west-central South America and bordered with a length of 6,743 kilometers encompassing five countries. It has a total area of 1,098,581 km², of which 1.29% are water about 15,280 km² (CIA Bolivia, 2019). The diversity of Bolivia´s climate is due to its immense variations in altitudes, from the tropics in the eastern llanos to a polar climate in the western Andes. The lowlands of Bolivia have the typical tropical climate with high humidity and temperatures. The annual average temperatures depend on the location and elevation of the area, in a range from 25°C in Llanos with a humid tropical climate to 15°C in Altiplano, condition that indicates a great diversity. In Bolivia, there is much less rainfall than in summer (annual average rainfall is 1,093 mm) (World Bank Group, 2019a).

The population in Bolivia amounts to 11,353,142 inhabitants with a growth rate of 1.4% (The World Bank, 2019c). The vast majority of the population lives in an area namely Altiplano, where is a plain on the plateau in the west of Bolivia. According to the CIA statistics, the rate of urbanization is estimated reaching 1.97% from 2015 to 2020 (CIA Bolivia, 2019).

Bolivia is one of the poorest and least developed countries in Latin America and economic growth depends on its abundant natural resource reserves. As international energy prices fluctuate, so does Bolivia´s GDP growth rate. In 2017 and 2018, the GDP achieved 37.51 and 40.28 billion Dollars while the GDP growth rate were 4.9% and 4.3% respectively. And the GDP per capita reached 3,548.59 Dollar in 2018 (The World Bank, 2019c). Bolivia's HDI had increasing from 0.655 in 2010 to 0.703 by 2018, with an annual increasing rate of 0.88%, positioning it at 114 out of 189 countries (UNDP, 2019). Bolivia's GNI per capita was US$ 3,370 (€ 2,886) in 2018 (The World Bank, 2020).

The Figure 5-8 refers to total primary energy supply (TPES) by sector in Bolivia. In 2018, the total energy supply was 9,377 Ktoe. The share of renewable energy in total primary energy supply was 9.41% in Bolivia. The natural gas accounted for 47.03%, this was trailed by the oil (43.56%) and biomass (6.85%) (International Energy Agency, 2019c). The average electricity consumption in Bolivia was 0.8 MWh per capita in 2018 (International Energy Agency, 2019g).

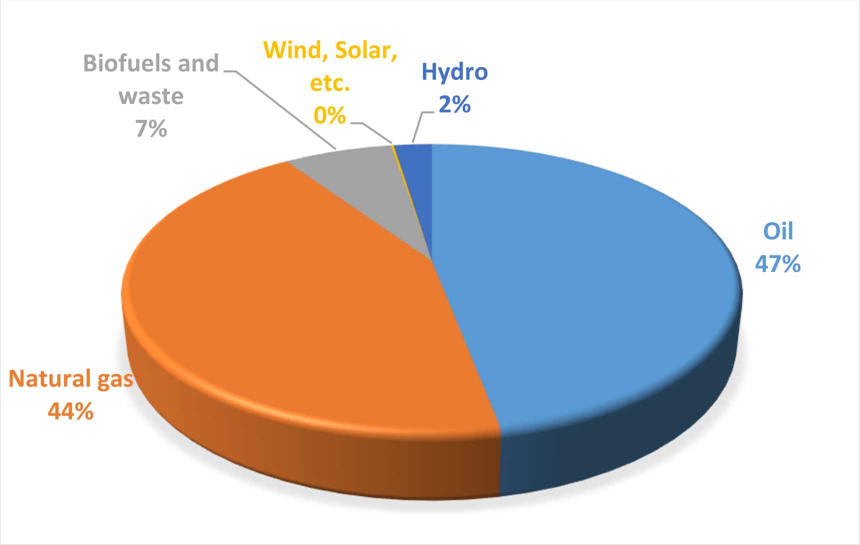

Figure 5-8 Total primary energy supply in Bolivia in 2018 (International Energy Agency, 2019c)

Figure 5-9 shows the fuels used for cooking in Bolivia, fuelwood was the most common energy source with an average coverage of 47% of the total energy demand; following was LPG with 45% and biofuels and dung with 7% (Hallberg, et al., 2015). However, the potential of decentralized electricity systems (i.e. solar photovoltaics or PV, wind, etc.) for disperse populations was recognized by the government in the Rural Electrification Plan. This component established that the service to households, schools and health facilities in areas of low population density would rely on locally available renewable energy sources (Espinoza, 2005). Many renewable energy projects from the government and private sectors were done, one of which was registered as Clean Development Mechanism projects focusing on renewable energy (IRENA, 2011).

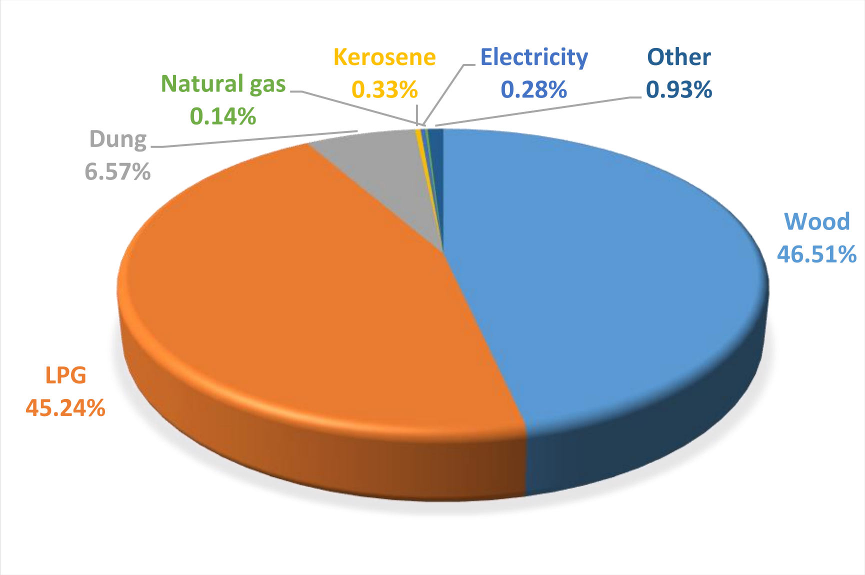

Figure 5-9 Fuels used for cooking in Bolivia (Hallberg, et al., 2015)

The agriculture in Bolivia has an important position; especially the low-lying areas around Santa Cruz are the central agricultural region of the country. The leading commercial crops are sugarcane, soybeans, potato and corn. Production in 2018 for selected crops was sugarcane 9.6 million Mg, soybeans 2.9 million Mg, potato 1.2 million Mg, and corn 1.3 Mg. The production of main crop residue in 2018 was 9.8 million Mg in Bolivia (see Table 5-5).

Table 5-5 Crops production and crop residues in Bolivia in 2010 and 2018

	Yield 2010[1] [Mg]	Yield 2018[1] [Mg]	CRI[2]	Crop residue 2010 [Mg]	Crop residue 2018 [Mg]
Corn	1,018,988	1,260,926	1.0	1,018,988	1,260,926
Rice	442,017	541,157	1.5	663,026	811,736
Wheat	241,397	301,689	1.5	362,096	452,534
Barley	49,314	46,620	1.5	73,971	69,930
Sugarcane	6,403,181	9,616,440	0.25	1,600,795	2,404,110
Potato	1,002,902	1,160,940	0.25	250,726	290,235
Soybeans	1,693,048	2,942,131	1.0	1,693,048	2,942,131
Sorghum	338,397	1,023,314	1.5	507,596	1,534,971
Sum	11,189,244	16,893,217		6,170,244	9,766,572

[1] (FAOSTAT, 2019a) [2] (Lal, 2004)

Livestock production contributed around 44% of agricultural GDP (FAO, 2005). As shown in Table 5-6, cattle numbered an estimated 9.6 million head in 2018 and dominated all livestock production. Over 70 % of all cattle were raised in the eastern plains. The pig population was estimated at 3.0 million, Santa Cruz was expected to be the location of the pork industry's future growth. There were an estimated 7.5 million sheep and 2.2 million goats in Bolivia, mostly in the highlands (FAOSTAT, 2019a).

Table 5-6 Livestock population in Bolivia from 2010, 2015 and 2018 (FAOSTAT, 2019b)

Livestock amount	2010	2015	2018
Cow	8,189,786	8,948,602	9,556,000
Pig	2,640,616	2,855,489	2,998,000
Goats	2,199,018	2,181,219	2,228,000
Sheep	8,701,465	7,453,603	7,493,000
Chicken	195,408,000	196,606,000	227,468,000
Duck	555,000	665,000	676,000
Turkey	155,000	157,000	157,000
Poultry sum	196,118,000	197,429,000	228,302,000

In recent years, the Government of Bolivia has made great efforts to increase access to safe drinking water and sanitation and to improve hygiene practices. In 2017, more than 92% of the total population can use "improved" water, 99% in urban area and 76% in rural areas respectively (UNICEF, 2019). In 2016, 2.28 million Mg of municipal solid waste has been generated in Bolivia. Food waste was the largest component of discards at 55.2 percent, which can be used as feeding material for household biogas plant (The World Bank, 2016).

5.3.2 Biogas development in Bolivia

Bolivia has extensive oil and gas reserves; thus the scarcity of energy is not an emergent problem. But one important motive for biogas plants is to use the plant for the production from organic materials to fertilizer. So the government decided to develop Biogas technology as part of agricultural production, to prevent ecosystems from the destruction agricultural.

The first biogas project began in 1986 by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) in cooperation with the Universidad Mayor de San Simon (UMSS) in Cochanamba. Until 1989 its activities were part of the supra-regional GIZ Biogas Dissemination Program. In this phase 27 plants were built and only 1 was still functioning in 1988. In this GIZ project, in the 90´s, about 60 biogas plants were built with the partner organization UMSS, particularly in the department Cochabamba. From January 1990 to the end of 1992 the biogas activities were continued as a component of the Bolivian Special Energy Program started at that time. 35 plants were built between 1989 and 1992 (ISAT and GTZ, 1999).

Because of the low temperatures, operation of biogas plants at high altitude has been a worldwide theoretical issue of biogas technology for a long time. In 2002 a draft of tubular plastic biogas digester for the regions above 2,000 m in Bolivia have been developed (see Figure 5-10).

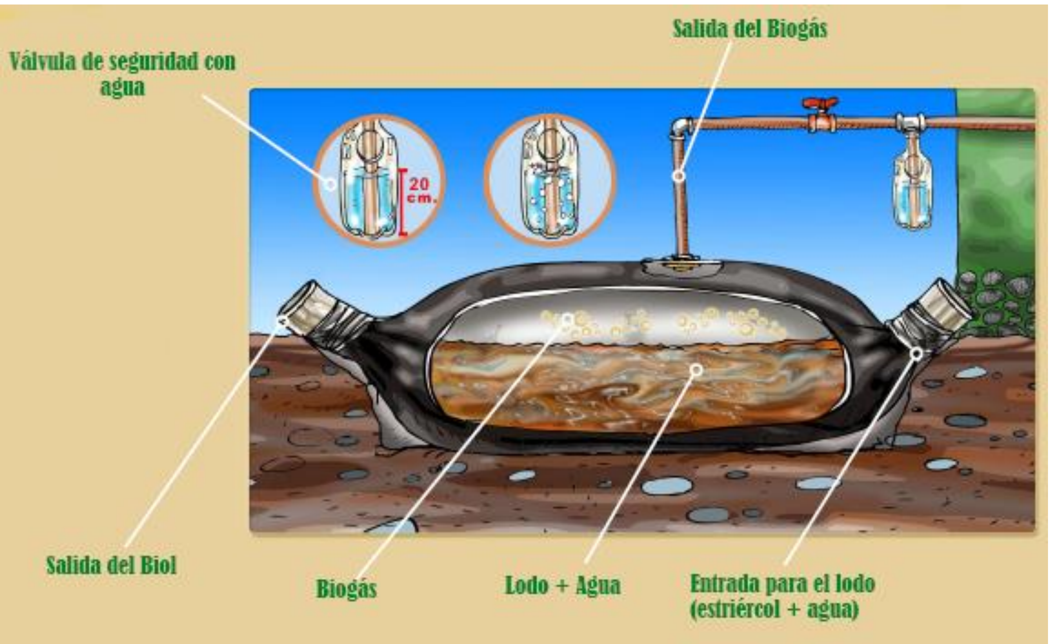

Figure 5-10 Tubular biogas digester in Bolivia (Martí-Herrero, 2010)

In 2003 the transfer of technology to a non-governmental organization (NGO) in Cochabamba was realized. At the same year, a tubular biogas digester was installed in the altiplano, 4100 m over the sea level, with ambient temperatures under 0°C. This trial proved that biogas technology had no more restrictions by the altitude, and the use of new technologies and new structure of biogas digesters could overcome this problem. During 2004-2006, this technology was verified through the construction of biogas digesters in all areas (highlands, valleys and tropical) in Bolivia. From 2002 to 2006 about 250 biogas digesters were installed by departments Cochabamba and La Paz. Currently, more than 1,000 biogas digesters are working in Bolivia, most of them are the type of tubular plastic biogas digester. The biogas digester costs 150 Dollar, in which 2/3 is paid from GIZ and 1/3 should be covered by potential biogas user (Martí-Herrero, 2008).

The tubular biogas digester has volume of 8 m³ and manufactured in gray polyethylen (PE) clothing. The digester is normally seated half underground between earthen wall and properly covered with a plastic membrane. With the daily input of raw material in a mixture of 20 kg cow manure and 60 kg water (see Figure 5-11), around 0.8 – 1.5 m³ biogas and 80 kg digestate can be produced every day (Martí-Herrero, 2010). Figure 5-12 presents the storage of biogas in big plastic bags and its utilization for cooking with the help of a very simple cooking appliance. The sludgy gets out from the outlet pipe and can be used as fertilizer for agriculture purposes such as onions, beans and potatoes plantations (see Figure 5-13).

Figure 5-11 Inlet process of biogas digester in Bolivia (Martí-Herrero, 2010)

However, the tubular biogas digester presents many problems in the aspect of application, for example: an external gas tank must be installed for the gas storage; although it is relatively small it holds, serious risks of explosion. Just cow manure is used as input material, no complex mixtures with green waste, therefore, the feedstock may contain excessive nitrogen causing a slow pace of biogas yield. As the construction material – polyethylene- is not durable, the biogas digester can only be used for 6-10 years. In addition, another serious point is to keep the digester working due to the low temperatures in winter.

Figure 5-12 Use of biogas in Bolivia (Martí-Herrero, 2010)

Figure 5-13 Output process of biogas digester in Bolivia (Martí-Herrero, 2010)

5.4 Brazil

5.4.1 General Introduction

The Federative Republic of Brazil is located in southeastern South America and Portuguese is its official language. With an area of 8,515,767 km², Brazil is the largest country in Latin America, and the world's fifth (FAO, 2021).

Brazil is located in the southern hemisphere, with opposite conditions of summer and winter to the northern hemisphere. Each year, from December to March is summer, while from June to September is winter. Brazil´s climate is diverse from equatorial in the north to temperate in the south. An average temperature is 23°C in the winter comparing with an average temperature from 26°C in summer. Generally, annual average rainfall in most of Brazil is between 1,000 mm and 1,500 mm, most of it coming in summer (World Bank Group, 2019b).

In fact, the temperature is rarely more than 32°C in the region of Amazon. As it has no obvious fluctuations between the warmest and the coldest months in a year, the annual mean temperature in this area is from 26°C to 28°C. Brazil's Amazon plain is the most humid place around the country, which has adequate rainfall throughout the year except in winter, more than 1,500 mm every year. Some southern areas have frosts in winter. Even snow may be felled on the plateau at the same time, but very rare. Central Highlands has a tropical savannah climate is dry and cold in winter, compared to summer, which is rainy season (World Bank Group, 2019b).

Brazil had about 209.47 million of population in 2018, which ranked fifth in the world. There is a low population growth rate of 0.78%. Only 13.43% of the total population lives in rural areas, with a 1.1% annual rate of urbanization, the city has increasing pressure (The World Bank, 2019d).

Thanks to the rich natural resources and abundant labor, Brazil's GDP ranked the first place in South America, and sixth in the world. In 2018, Brazil's GDP reached 1,885 billion US dollar. But its real growth rate of GDP is obvious decline by 1.3%. The average annual GDP per capita has now reached the level of around 9,001 US dollar (The World Bank, 2019d). In 2018, Brazilian service sector accounted for the largest proportion of Brazil`s GDP with 63.01%, followed by industrial sector at 18.13%. The contribution of the agricultural sector to the total GDP was only 4.42% (Statistia, 2019). In 2018, Brazil had an HDI of 0.761, which located in 79th position among all 189 countries. Between 2010 and 2018, Brazil has average annual HDI growth of 0.59% (UNDP, 2019). Brazil GNI per capita for 2018 was $ 9,080 (€ 7,776), which equivalents to € 648 per month (The World Bank, 2020).

Drinking water supply is a major challenge in Brazil, especially in the expanding cities. In 2000, 84% of the total population in Brazil had access to clean drinking water (only 46% in rural area and 91% of urban area). With the development of infrastructure, the rate of access to clean drinking water increased rapid. In 2017, 98% of the total population in Brazil had access to clean drinking water (>99% of urban population and 90% of rural population). Brazil had relatively good sanitation facility access. The sanitation facilities of 93% of residences in urban areas had been improved, while only 60% of rural residences had been done, accounting for 88% of total population (UNICEF, 2019).

As shown in Figure 5-14, the Brazilian total primary energy supply was 288.19 Mtoe in 2018, with ca. 46% corresponding to renewable sources (Wind, Solar and Biomass) (International Energy Agency, 2019b). Brazil's electricity consumption per capita was 2.6 MWh in 2018 (International Energy Agency, 2019g).

Figure 5-15 represents the fuel sources used for cooking in Brazil. With 47% of the total energy amount, LPG was the main contributor. At the same time, fuelwood as energy sources accounted also for 47%. Followed is charcoal with 4%.

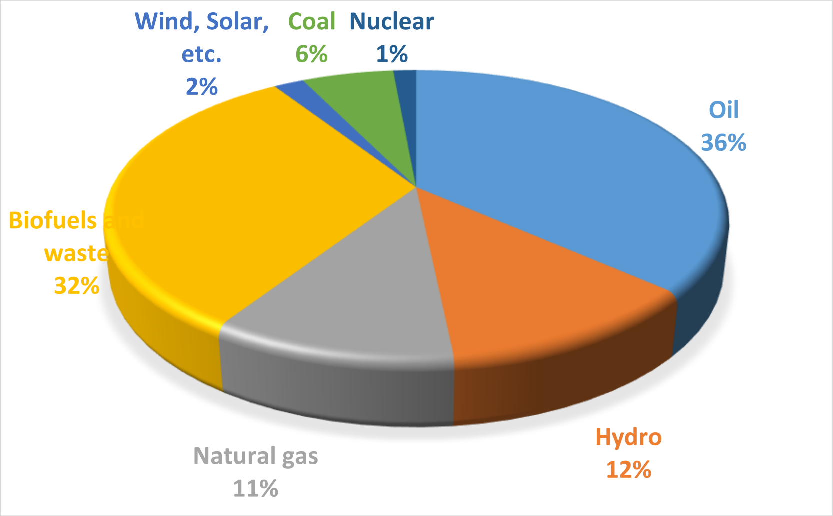

Figure 5-14 Total primary energy supply in Brazil in 2018 (International Energy Agency, 2019b)

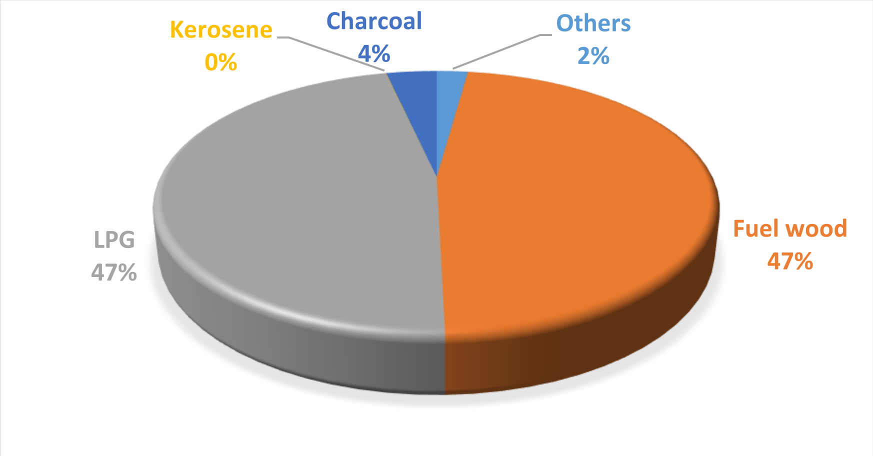

Figure 5-15 Fuels used for cooking in Brazil (Coelho, et al., 2014)

Brazil is a large-scale agricultural country; agriculture is the pillar industry of the Brazilian economy. Based on the arable land area, climate and other advantages and growth demand for agricultural products in the world, Brazil determinates the agriculture as its sustainable development strategy. As shown in Table 5-7, in 2018, the production of sugarcane reached 747.06 million Mg, followed by soybeans, corn and cassava with 117.91 million, 82.37 million and 17.88 million respectively (FAOSTAT, 2019a). The production of main crop residue reached 434.05 million Mg in 2018 in Brazil.

Table 5-7 Crops production and crop residues in Brazil in 2010 and 2018

	Yield 2010[1] [Million Mg]	Yield 2018[1] [Million Mg]	CRI[2]	Crop residue 2010 [Million Mg]	Crop Residue 2018 [Million Mg]
Corn	55.36	82.37	1.0	55.36	82.37
Rice	11.24	11.81	1.5	16.85	17.71
Wheat	6.17	5.47	1.5	9.26	8.20
Barley	0.28	0.33	1.5	0.42	0.50
Oats	0.40	0.90	1.0	0.40	0.90
Sugarcane	717.46	747.06	0.25	179.37	186.77
Soybeans	68.76	117.91	1.0	68.76	117.91
Potato	3.55	3.73	0.25	0.89	0.93
Coffee	2.91	3.55	1.4	4.07	4.97
Cassava	24.97	17.88	0.58	14.48	10.37
Sorghum	1.53	2.28	1.5	2.30	3.42
Sum	892.62	993.29		352.15	434.05

[1] (FAOSTAT, 2019a) [2] (Lal, 2004)

Brazil's pasture area is equivalent to three times the arable land, the vast expanse of the ranch is the good condition for the development of animal husbandry. Brazil's livestock industry has developed rapidly in recent years. According to the census, Brazil had totaled 213.52 million head cattle in 2018, which ranked second in the world just after India. As shown in Table 5-8, there were around 41 million heads pigs in Brazil, followed by sheep 19 million, goats 11 million and poultry 1,506 million (FAOSTAT, 2019b). The distribution of commercial pig production areas in the southern region accounted for nearly 69% (Silva, et al., 2016).

Table 5-8 Livestock population in Brazil from 2010, 2015 and 2018 (FAOSTAT, 2019b)

Livestock Amount [million pieces]	2010	2015	2018
Cow	209.54	215.22	213.52
Pig	38.96	39.80	41.44
Goats	9.31	9.62	10.70
Sheep	17.38	18.41	18.95
Poultry total	1,269.51	1,359.18	1,505.60
Chicken	1,238.91	1,326.45	1,468.35
Duck	3.70	3.66	3.47
Turkey	26.90	29.07	33.78

Brazil has a well history using fertilizers in agriculture. In 2009, fertilizers consumption in Brazil was 125.05 kg per hectare in arable lands, which is the lowest value over the past 8 years. Since 1990s, Brazil implemented the trade liberalization of fertilizer industry. Therefore, the domestic market price of fertilizers became comparable with those of imported products, with an average price of approximately US$ 128 per Mg of ammonium sulphate and ca. US$ 166 per Mg urea in 2002 (Food and Agriculture Organization of the United Nations, Rome, 2004).

In Brazil, 79.08 million Mg municipal solid waste was produced in 2016. The average, amount of MSW reached to 1.04 Mg per person per day. Food waste, which has a high organic composition, accounted for 51.4% of total municipal solid waste (The World Bank, 2016).

5.4.2 Biogas development in Brazil

In Brazil, biogas digesters were used in piggery industry from the 1970s and 1980s. Most of them were located in south and south-east Brazil, where was the most active piggery around the country. The piggery production sector demands lots of water and is generated also signature amounts of effluents. However, it is a sector with poor environmental quality, therefore pollutes the water, the soil, emits bad odors and provides a non-controlled proliferation of insects. The construction of biogas plants was a solution to improve the sanitary standards and to promote the development of swine industry (AHK Brasilien, 2019).

The most used biogas technologies in Brazil are lagoons (basins), which mainly used for the treatment of wastewater from human sanitary and swim industry. This applies to the whole country, but especially to regions where it is very warm throughout, such as in the northeast. In addition to the use of lagoons, bioreactors such as the Continuous Stirred Tank Reactor (CSTR) or the Up-flow Anaerobic Sludge Blanket (UASB) are also used, which have generally more efficient than the lagoons. The CSTR is mainly used for the fermentation of substrates with a higher density (total solids content up to 20%), such as wastewater from animal and vegetable production as well as sludge from sewage treatment plants (AHK Brasilien, 2019).

In swine farming, the wastewater contains a high concentration of organic matter, which makes anaerobic digestion to generating energy an advantage way to handle the wastewater. The covered lagoon-fermenter produces 415 m^3 of biogas in one reactor in 45 days, considering the daily production of 9.18 m^3 of waste in a farm with around 500 pigs (AHK Brasilien, 2019). Although less efficient, covered lagoon-fermenters are widely used in Brazilian pig farming due to the low maintenance costs and easy maintenance. The Figure 5-16 shows a typical lagoon-fermenter used in swine industry in Brazil.

Figure 5-16 Lagoon biogas plant for pig industry in Brazil (Henn, 2005)

As the world's largest sugarcane producer, the greatest potential for biogas in Brazil lies in the agro-industrial sector, especially in the area of sugar industry, which has waste products that arise from the production of sugar and ethanol based on sugar cane, such as filter cakes and vinasse. Anaerobic digestion is also the most efficient way of producing biogas for the treatment of sugar cane vinasse due to the pollution potential of this raw material. The enormous quantity of vinasse makes the use of UASB reactors attractive. Anaerobic lagoons can also be used; however, it takes up a lot of space with a depth of four to six meters and make temperature regulation more difficult due to the large volume. On smaller scale, biogas can also be obtained from other biomass sources, like waste from food production in general (Manioc starch and orange juice), food waste from restaurant, garden waste, poultry manure and sanitary wastewater.

Until 2018, Brazil had an installed capacity of around 15 GW in the biomass sector, spread across 566 plants, including ca. 200 biogas plants and more than 300 bioethanol plants. They were concentrated in the central and eastern regions of Brazil, as shown in the Figure 5-17. Brazil's biogas plants are mainly small and medium-sized, with a daily gas production of less than 12,500 m^3; however, there are no household biogas digesters (see Figure 5-18). In April 2016, the price for electricity generation from biogas was set at R$ 251 (ca. € 40) per MWh. In comparison, the price of natural gas was R$ 258 (ca. € 42) per MWh (23º LEILÃO DE ENERGIA NOVA A-5, 2019).

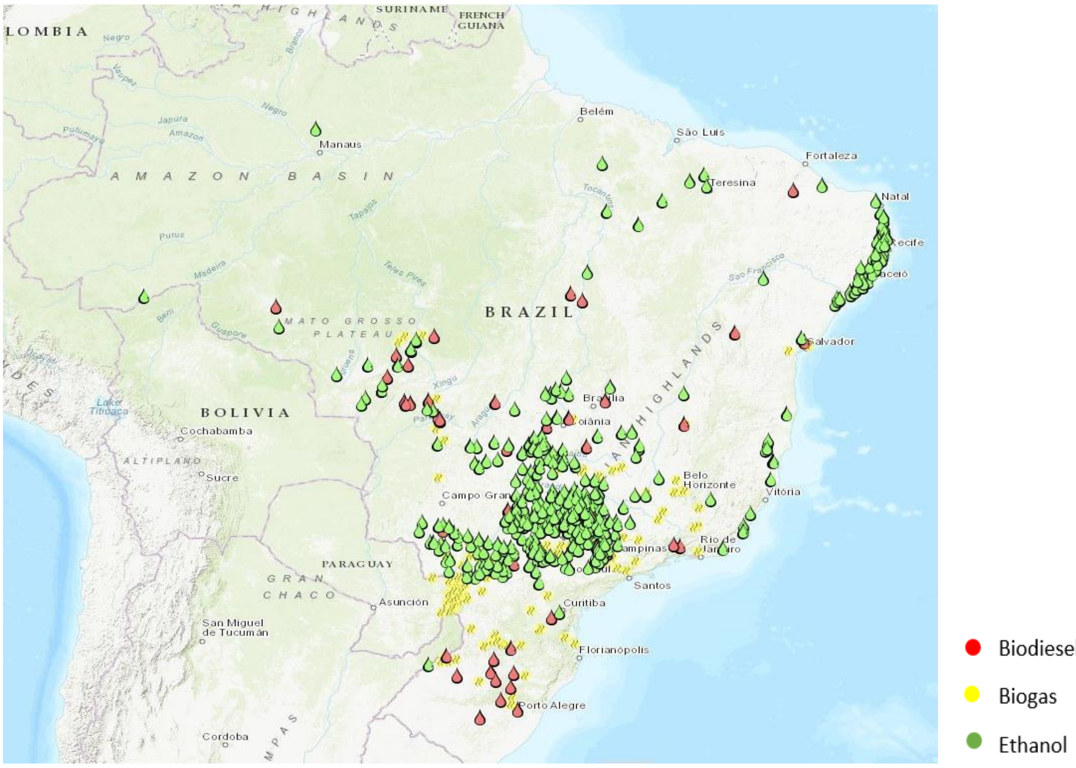

Figure 5-17 Distribution of biogas fuel plants (AHK Brasilien, 2019)

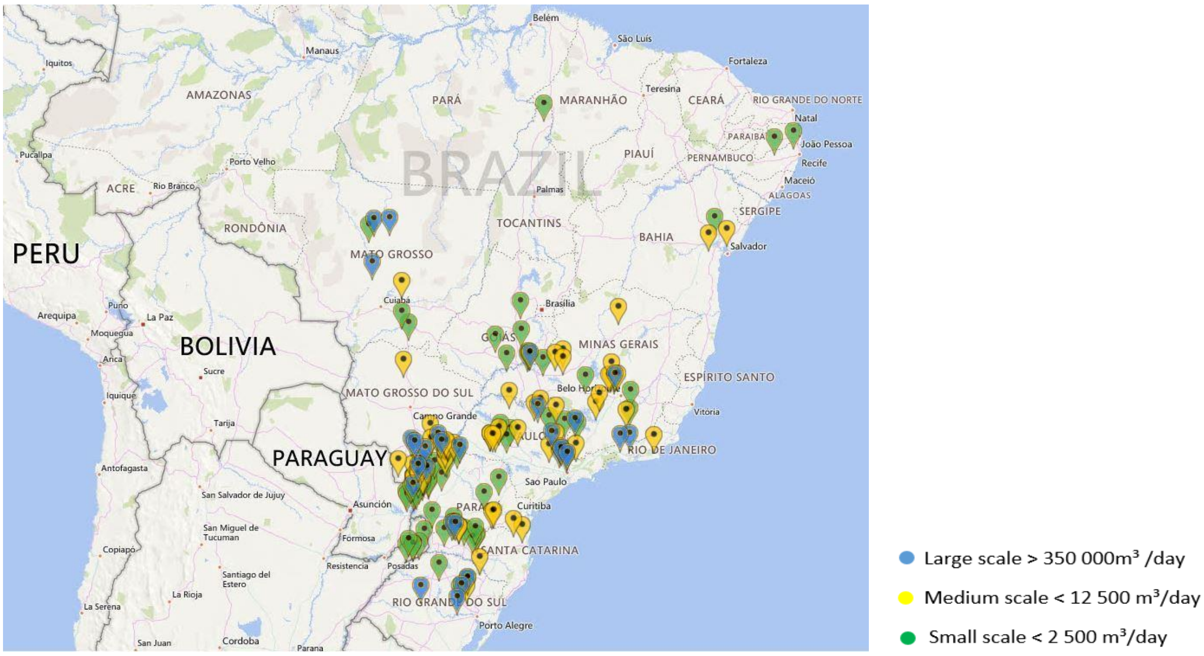

Figure 5-18 Biogas plants in Brazil (CIBiogas, 2019)

Brazilian Biogas Association (ABiogás) estimates the current annual Brazilian potential for biogas production at around 82 billion m³, 41 billion m³ are in the sugar energy sector (sugar cane and the associated organic waste), 37 billion m³ in the agricultural sector (animal manuel and straw) and 3 billion m³ in the areas of municipal wastewater and solid waste. This corresponds to 67 million toe per year or 76 billion liters of diesel, which can cover 36% of the current electrical demand (479,586 GWh). If the biogas were used to produce biomethane, it would be possible to meet 70% of the demand for diesel (60 billion liters). In about three years, from 2015 to 2018, the number of registered biogas plants increased by 117%, with biogas production even increasing by 138%. (Tratamento de agua, 2019). Accordingly, through use the biogas as an energy source, a potential of 1.03 billion Mg of CO_2 equivalent could be saved (AHK Brasilien, 2019).

State incentives are set for the development of the market for renewable energies. As early as 2002, the Brazilian government approved a program to support alternative energy resources namely Programa de Incentivo às Fontes Alternativeas de Energia Elétrica (PROINFA), that the goal is to reduce Brazil's energy dependency on hydropower and merge more than 600 MW of biomass energy into the state grid (Energypedia, Biogas in Brazil, 2019). In 2012, the Call for Strategic Research & Development Project by Brazilian Electricity Regulatory Agency (ANEEL) with the topic “Technical and commercial arrangements for the insertion of biogas electric energy generation from residues and liquid effluents in the Brazilian energy grid" were published. About US$ 185 million would support the project (ANEEL, 2012). From 2011-2014, US$ 22 billion have been invested by the government to universalize waste/wastewater treatment (Giersdorf, 2013).

Besides, frequent international cooperation also ensures the biogas promotion in Brazil. Under the bilateral agreement of energy between Brazil and Germany in 2008, many biogas projects were supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH from 2009 to now. From 2009 to 2011, German Climate Technology Initiative (GCTI) was started for Promoting Climate-Friendly Biogas Technology in Brazil (GIZ/BMZ). As part of the GCTI, this project aimed to create a more conducive framework for biogas-based energy generation in Brazil. Between 2014 and 2015, German-Brazilian Research Cooperation “New Partnerships - iNOPA” (DAAD - GIZ - CAPES) supported the Research & Development Project in area of Sustainable bioeconomy in Brazil: Bioenergy from biogas using various types of waste substrates from the Brazilian bioethanol industry. The Brazil - Germany Project to promote the energy utilization of biogas in Brazil - PROBIOGÁS - is an innovative cooperation between the Ministry of Cities and the German International Cooperation Agency (GIZ). The project had made a significant contribution to Brazil's biogas industry: laws / regulations had been improved and the first biogas project was approved at a Brazilian energy auction (Energypedia, Biogas in Brazil, 2019).

6 Development of evaluation system of transferability

6.1 Review of the transferability study

To analyze the transferability and the development prospects of the Chinese biogas technology in Africa and Latin America, it is necessary to determine the framework conditions of household biogas technology according to the characteristics of household biogas systems. Considering the differences of the regions, a transferability study should be taken into account of all relevant criteria, which includes climate, energy, material, economy, policy, technology and social aspects. For each criterion, there will be a given an integrated value, either qualitative or quantitative, in order to form the theoretical basis for predicting the transferability and development potential of the technology in the mentioned regions.

Furthermore, the economic and ecological benefits in the region are predictable, which provides a theoretical basis for the plan of biogas development. Besides, solutions are also given to the problems and conflicts existing in the regions, to facilitate the implementation and the development of biogas technology.

The methodology used for the review is explained in the following three sections:
1. Transferability study
2. Calculation of household biogas potential
3. Economic and ecological evaluation

6.2 Transferability study

Cost-utility analysis is used to construct an objective, scientific and comprehensive transferability study of household biogas digester in different regions. The transferability study is realized with the help of a set of qualitative and quantitative criteria, which is derived basic on the characteristics of Chinese household biogas systems. The transferability analysis can initiate a structured and meaningful reflection of the local condition and systematically evaluate the ability on the promotion of household biogas digesters and identify individual potential for improvement. It is also able to anticipate the opportunities, resist the risks and limit negative consequences. The transferability study can be flexibly used in all countries and regions and can be integrated and interconnected with other decision-making process.

This cost–utility analysis consists of several steps, which are criteria selection, weighting calculation and decision analysis (Davoudi, 2018). The weighting vector for each criterion is multiplied by the score of criteria to get the final score result of different regions (Davoudi, 2018).

$$AS = \sum_{i=0}^{n} c_i * W_i \qquad (1)$$

With:

AS = Final scores result of application study

i = Criterion

c_i = Score of each criterion

W_i = Weighting

6.2.1 Determination of the scope and important criterion

The aim of the transferability study is to use the representative criteria to classify, reflect and evaluate the local condition in terms of promotion of household biogas digesters. The criteria influencing the promotion of household biogas digesters are selected to reflect the possibility of establishment and operation of household biogas digester. Basis of the experience China, the basic goals of ensure proper operation and management of the biogas digester must be pursued:

- Construction of biogas digester should comply with the local climate conditions and energy demands.
- From the technical point of view, the construction of biogas plants should be qualitatively ensured, and operation of biogas plants should be maintained.
- From the economic aspect, not only the invest cost, also the maintenance cost should be ensured, here the access of credit may be a challenge for the farmers.
- Also on the social level, the biogas should be accepted by farmers and integrate into normal living.
- In the context of politic, the government support, monitoring and supervision plays an important role.

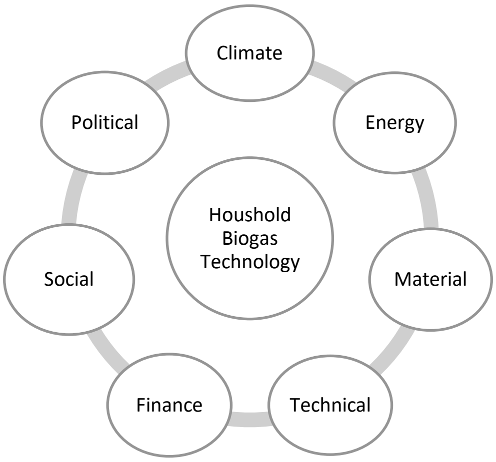

Figure 6-1 Criteria for household biogas systems

For the purposes of this cost-utility analysis, the criteria were grouped into seven different areas (see Figure 6-1)

- Climate
- Energy
- Material
- Technical
- Finance
- Social
- Political

The scope of such a system takes of all the steps in the process into account, including the planning, construction, daily operation, and maintenance as well as failure measure of biogas digester (Figure 6-2). All the criteria have different requirements at the various stages, which is listed in Table 6-1:

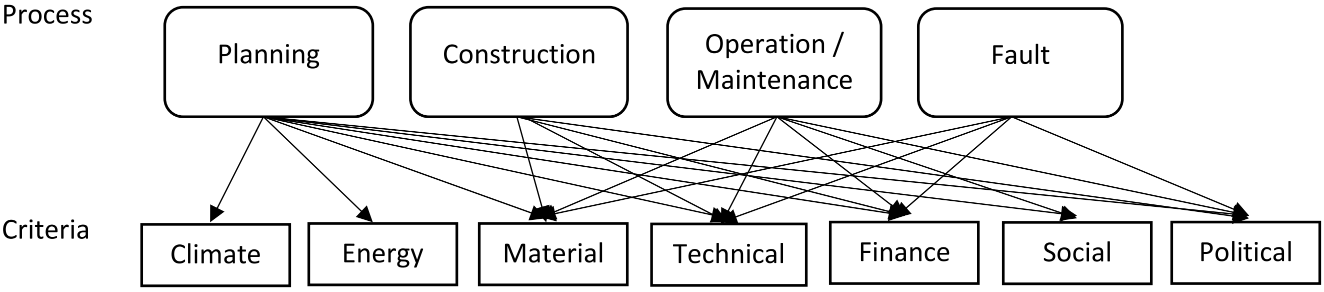

Figure 6-2 System scope of a household biogas digester

Table 6-1 Criteria of transferability analysis for development of household biogas digester

			Criteria
A	Climate	A1	Suitable climate condition: Temperature
B	Energy	B1	Scarcity of traditional energy supply for household
		B2	Requirement for the share of renewable energy
C	Material	C1	Availability of feeding material for biogas digester
		C2	Availability of water required to mix with fresh dung
		C3	Availability of space for agriculture
		C4	Availability of construction material
		C5	Availability of biogas appliance
D	Technical	D1	Availability of engineers for design and quality control
		D2	Availability of workers for construction, operation and after-sale-service
E	Finance	E1	Finance ability
		E2	Access to credit
F	Social	F1	Role of women in domestic decision-making process and life
		F2	Integration of biogas plant into normal working routine at the farm
		F3	Ethical aspects
G	Political	G1	Availability of Standards, laws and regulations on biogas technology
		G2	Political will of the Government to support a national biogas program
		G3	Monitoring and supervision

A. Climate:

A1. Temperature: Temperature is the most important external factor of biogas fermentation. The speed of anaerobic decomposition is faster, and production of methane is higher while a suitable temperature can make a microbial proliferation strong and vital. The rural household biogas digesters should be maintained at the fermentation temperature which is above 10°C. Natural non-suitable area is mainly the alpine region (high latitude or high altitude). The regions with low temperature but without any insulation measures are not suitable for constructing of household biogas digesters.

B. Energy:

B1. Scarcity of traditional energy supply for household: The potential biogas users are low- and middle-income families; those who still face problems with the access to electricity or gas grid. The families, which have the problem of scarcity of traditional cooking fuels can promote a biogas program to solve the cooking energy problem. The areas which have rich fossil energy resources or forest resources, do not have the need to develop biogas production technology.

B2. Requirement of increasing the share of renewable energy: Due to the limitation of traditional energy sources, the development of renewable energy is a sustainable development trend. Even countries or regions with sufficient supply of clean energy will have the requirement to develop renewable energy. Biomass energy with the advantage of no limitation of weather (compared to solar and wind energy) can realize a demand-oriented flexible energy production (Szarka, et al., 2013). Thus, the require of increasing the share of renewable energy may be a motivation for promotion of household biogas digesters.

C. Material:

C1. Availability of feeding material: As the most important material basis for the fermentation process, 20 kg of fresh biomass (animal manure, agriculture waste, kitchen waste or toilet waste) should be collected and fed into an 8m^3 household biogas digester. The moderate scattered breeding is the most important source for getting the manure.

C2. Availability of water: Fetching water is required to mix with the daily input of 20 kg of fresh dung in a 1:1 ratio, which means that 20 kg of water per day should not be further away than 2 to 3km, which equivalents to less than 20 to 30 walk minutes. Although drinking water sources are ideal for biogas fermentation process, unprocessed water sources like river water, well water are also usable for the biogas digester.

C3. Availability of space for agriculture: The own farmland of potential biogas users is very important. It can provide straw as a raw material for the biogas digesters. Additionally, as another important product of biogas digester, digestate with rich nutrients should be used on agricultural crops to enhance crop yields and reduce the use of chemical pesticides.

C4. Availability of construction material: Sufficient supply of the construction materials is very essential for the construction of biogas digesters. Many African and Latin American countries do not have their own factories producing construction materials. Instead, they mainly rely on imports. This leads to scarcity of supplies and the increased price of construction materials, which is not conducive for the construction of the digester. Although some local people can make their own home bricks, the tightness of the construction of the digester will decline. Digesters with other construction materials such as plastic or fiberglass digesters would be a good choice.

C5. Availability of biogas appliance: The basic biogas appliances are the biogas lamp and biogas stove, as well as the rice cooker for some areas with rice as the staple food. These biogas appliances are essential for direct use of biogas. Thus, local producers who produce biogas appliance or import/export companies, which import these appliances are required. Besides, parts such as pipeline, switches, valves, biogas pressure gauge and biogas filter need to be provided. This will lead to new or existing manufactories joining the production of biogas appliance and accessories, which may supply to other regions and even export to other countries while meeting the local needs.

D. Technique:

D1. Availability of engineers for design and quality control: Biogas engineers are the staffs who engage in the design of the biogas plant, quality control, operation and management, technical guidance and sampling of the rural biogas program.

D2. Availability of workers for construction, operation and after-sale-service: Biogas workers are the staffs who engage in the construction of rural biogas construction, installation of equipment, quality inspection, stating debugger, maintenance and repair. Biogas engineers and workers are in direct contact with the majority of farmers. Therefore, some farmers should be available for daily operation of biogas digester, who have the systematic theoretical knowledge of biogas production, operating skills, professional ethics and legal awareness.

E. Finance:

E1. Finance ability: The investment cost for the construction of biogas digester is in comparison not so high as the other technology. However, not all families can afford it at once. Farmers need to finance or take part in investment costs and annual maintenance costs of biogas digester, even with loans and other national funding.

E2. Access to credit: The family without finance ability should identify and verify the source of funding which can possibly come from credit institutes, government or private institutions that are interested in the local green projects.

F. Social:

F1. Role of women in domestic decision-making process and life: Women are the main beneficiaries of the digesters. There will be lots of time spent on fuelwood collection and firing preparation will be saved, and the health and sanitation situations will be improved. Therefore, role of women in domestic decision-making process and life has a very important association for the construction of digesters. In the families with low status of women, men often do not consider these measures to improve women's lives. Thus, they are unwilling to invest in a biogas digester.

F2. Integration of biogas plant into normal working routine at the farm: Household biogas digesters should be accounted as part of the domestic infrastructure. It combines with the farmer's daily lives, which can solve the pollution problem of manure or provide energy for cooking and lighting, fodder for the livestock and also fertilizer for crop growing. Both of people´s lives and production have participation of biogas digesters.

F3. Ethical aspect: Biofuels production from biomass is usually argued if it breaches basic human rights and environmental security. It may cause problems such as food shortage, endanger of local food security or destruction of ecosystems and natural resources which are critical to the health and subsistence of people (Nuffield Council on Bioethics, 2011). Compare with biodiesel and bioethanol, biogas is mainly produced from organic waste. This makes biogas a more ethical option for use in energy production (Nevzorova, et al., 2019). Acceptance and usage of gas generated from animal waste and human waste may be another dispute in ethical issues (Boers, 2008).

G. Politic:

G1. Availability of standards, laws and regulations on biogas technology: Formulation and implementation of standards and regulations are an important basis to achieve secure biogas production, supervision and management by the governments. Each stage of the construction of biogas digester should follow detailed laws and regulations. The duties and obligations of various authorities should be defined clearly to ensure the digesters are properly built and fit for operation and future maintenance. Furthermore, the regulations on safe operation of biogas digester and safe use of appliance should be also available.

G2. Political will of the government to support a national biogas program: In all the countries in the world, the government's policy determines the development of the country. National policy of development of new energy, clean energy and environmental protection will strongly support the promotion of biogas technologies such that state subsidies and supervision for research and development of new technologies or other factors. Political will of the government to support a national biogas program play a crucial role for the promotion of household biogas digesters.

G3. Monitoring and supervision: Improved project management can ensure the long/term normally working of biogas digester, which includes monitoring of digester construction and operation, regular inspection by the decentralized biogas office, training of biogas user, consulting, and technical support by biogas engineering etc.

6.2.2 Score of transferability study

According to the characterization of household biogas systems in China, requirement for each criterion that are important for promotion and maintaining the household biogas systems are identified for each area and evaluated using quantitative and qualitative scores. As shown in Table 6-2, criterion is scored according to 0-1 scale. Generally, there are requirement for each criterion, which benefits or promote the household biogas technology. Thus, the score gets higher if it more filling the requirement.

Table 6-2 Score for criteria of transferability study

	Criteria / Score	0	0.25	0.5	0.75	1
A1	Suitable climate condition	<0°C	0-10°C	10-15°C	15-20°C	>20°C
B1	Scarcity of traditional energy supply for household	fully other energy	more other energy	certain other energy	few other energy	no other energy
B2	Requirement of increasing the share of renewable energy	no requirement	few requirement	certain requirement	more requirement	fully requirement
C1	Availability of feeding material for biogas digester	no input material	few present material	certain present of material	more present of material	fully available input material
C2	Availability of water	no water	long distance of water access	certain water access	largely available water	fully access to water
C3	Availability of space for agriculture	no garden	to 100 m³	100-200m³	200-400m³	>500m³
C4	Availability of construction material	no construction material	few construction material	certain construction material	more construction material	fully available construction material
C5	Availability of biogas appliance	no biogas appliance	few biogas appliance	certain biogas appliance	almost all biogas appliance	fully available biogas appliance
D1	Availability of engineers for design and quality control	no technical person	few technical person	certain technical person	largely available technical person	fully available technical person
D2	Availability of workers for construction, operation and after-sale-service	no workers	few workers	certain workers	more workers	fully available trained workers
E1	Finance ability	no finance ability	few finance ability	certain finance ability	more finance ability	full finance ability
E2	Access to credit	no credit	few credit	certain credit	more credit	access to credit
F1	Role of women in domestic decision-making process and life	no influence	few influence	certain influence	more influence	fully influence
F2	Integration of biogas plant into normal working routine	no influence	few influence	certain influence	more influence	fully influence
F3	Ethical aspect	no influence	few influence	certain influence	more influence	fully influence
G1	Availability of Standards, laws and regulations on biogas technology	no regulations	few regulations	certain regulations	more regulations	all regulations
G2	Political will of the Government to support a national biogas program	no support	few support	certain support	more support	fully support
G3	Monitoring and Supervision	no monitoring	few monitoring	certain monitoring	more monitoring	fully monitoring

6.2.3 Weighting and Scenario of the transferability analysis

The criteria weighting play an important role by cost–utility analysis. The weighting will rely on professional knowledge and subjective judgement.

Enough suitable feeding materials ensure the long-term operation of biogas digester and thereby the biogas productive rate. Therefore, it accounts for 20% of weighting. Another material metrics, like water, biogas appliance or construction materials accounts for 2.5% respectively. Regarding the energy issues, scarcity of traditional energy supply for household is an essential reference point (with 15% weighting), then it is the most motivation to build up the household biogas digester. On the economic level, the investments for biogas digester might be the most important factor of consideration for farmers whether they are willing to build biogas digester. Thus, the finance ability occupies the relatively higher weighting as well (with 15% weighting), and the potential assessment to credit has priority with weighting of 10%. Similarly, in technical aspect, availability of engineer and technical worker are related to various aspect of the whole biogas project: planning, construction, control, and after-sale-service. This criterion can be easily improved through extreme support; therefore, the weighting of technical aspect is relatively lower. Finally, the adaptability of social aspect is of equal importance as the adaptability of local policies. According to the experience in China, the governance or supervision of household biogas digester by biogas officer is also essential, its weighting accounts for 5%.

As a result, material aspect accounts to the biggest proportion. Therefore, in this calculation for the transferability study, material criterion is more important than financial one, followed by energy and politic criterion. Climate, technique, and social criterion has the same weighting. The weighting of criteria of transferability study are summarized in Table 6-3.

Table 6-3 Weighting for criteria of transferability study

		Criteria	Weighting	Weighting total
A1	Climate	Suitable climate condition	5.0%	5.0%
B1	Energy	Scarcity of traditional energy supply for household	15.0%	20.0%
B2		Requirement of increasing the share of renewable energy	5.0%	
C1	Material	Availability of feeding material for biogas digester	20.0%	30.0%
C2		Availability of water	2.5%	
C3		Availability of space for agriculture	2.5%	
C4		Availability of construction material	2.5%	
C5		Availability of biogas appliance	2.5%	
D1	Technical	Availability of engineers for design and quality control	2.5%	5.0%
D2		Availability of workers for construction, operation, and after-sale-service	2.5%	
E1	Finance	Finance ability	15.0%	25.0%
E2		Potential users have access to credit	10.0%	
F1	Social	Role of women in domestic decision-making process and life	1.7%	5.0%
F2		Integration of biogas plant into normal working routine	1.7%	
F3		Ethical aspect	1.7%	
G1	Political	Availability of Standards, laws and regulations on biogas technology	2.5%	10.0%
G2		Political will of the Government to support a national biogas program	2.5%	
G3		Monitoring and supervision	5.0%	

Because the country surveyed has a vast territory, affecting with natural conditions, economic development and population, the conditions in different regions will be different. Therefore, four scenarios are given for each criterion: best condition, worst condition, and national general condition (conditions for more than 80% population) and national average condition.

6.2.4 Sensitivity analysis

Sensitivity analysis is a common tool used to calculate the degree of input variables effect on the output values (Davoudi, 2018). It is often applied in decision-making of investment projects. The general principle is to change the score of criteria that leads the influence on the results. Sensitivity analysis of weightings places emphasis on discovering the advantages and disadvantages of a certain regions on transferability of household biogas digester. For the criteria score, as mentioned in chapter 6.2.3, from worst case to best case of each criterion are taken as the changing range. Furthermore, 8 variants of weighting are introduced to conduction the sensitivity analysis.

As shown in Table 6-4, alternative option of weighting for sensitivity analysis helps the decision-making to figure out the weakness and to develop solutions for improvement or substitution. The weighting calculation mentioned in Table 6-3 is taken as option I. Besides that, an average weighting of all criteria is considered as the alternative option II. The option III, IV, V, VI, VII and VIII of different weighting are reflected the extreme important (80%) of energy, material, technical, finance, social, and politic issues, respectively. The details of weighting value of sensitivity scenarios I to VIII are listed in Table 6-5.

Table 6-4 Description of sensitivity scenarios I to VIII

Sensitivity scenarios	Description
I	Weighting according to Chinese experience and subjective judgement
II	average weighting of all criteria
III	extreme important weighting (80%) of energy aspect
IV	extreme important weighting (80%) of material aspect
V	extreme important weighting (80%) of technical aspect
VI	extreme important weighting (80%) of finance aspect
VII	extreme important weighting (80%) of social aspect
VII	extreme important weighting (80%) of political aspect

Table 6-5 Scenarios of weighting for sensitivity analysis

	I		II		III		IV		V		VI		VII		VIII	
Criteria	Weight	total	Weight	total	Weight	total	Weight	total	Weight	total	Weight	total	Weight	total	Weight	total
A1	5.0%	5.0%	5.6%	5.6%	5.0%	5.0%	5.0%	5.0%	2.5%	2.5%	5.0%	5.0%	2.5%	2.5%	5.0%	5.0%
B1	15.0%	20.0%	5.6%	11.1%	70.0%	80.0%	2.5%	5.0%	2.5%	2.5%	2.5%	5.0%	2.5%	2.5%	2.5%	5.0%
B2	5.0%		5.6%		10.0%		2.5%		0.0%		2.5%		0.0%		2.5%	
C1	20.0%	30.0%	5.6%	27.8%	3.0%	5.0%	60.0%	80.0%	3.0%	5.0%	3.0%	5.0%	3.0%	5.0%	3.0%	5.0%
C2	2.5%		5.6%		0.5%		5.0%		0.5%		0.5%		0.5%		0.5%	
C3	2.5%		5.6%		0.5%		5.0%		0.5%		0.5%		0.5%		0.5%	
C4	2.5%		5.6%		0.5%		5.0%		0.5%		0.5%		0.5%		0.5%	
C5	2.5%		5.6%		0.5%		5.0%		0.5%		0.5%		0.5%		0.5%	
D1	2.5%	5.0%	5.6%	11.1%	0.0%	0.0%	0.0%	0.0%	40.0%	80.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
D2	2.5%		5.6%		0.0%		0.0%		40.0%		0.0%		0.0%		0.0%	
E1	15.0%	25.0%	5.6%	11.1%	2.5%	5.0%	2.5%	5.0%	2.5%	5.0%	40.0%	80.0%	2.5%	5.0%	2.5%	5.0%
E2	10.0%		5.6%		2.5%		2.5%		2.5%		40.0%		2.5%		2.5%	
F1	1.7%	5.0%	5.6%	16.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	26.7%	80.0%	0.0%	0.0%
F2	1.7%		5.6%		0.0%		0.0%		0.0%		0.0%		26.7%		0.0%	
F3	1.7%		5.6%		0.0%		0.0%		0.0%		0.0%		26.7%		0.0%	
G1	2.5%	10.0%	5.6%	16.7%	1.7%	5.0%	1.7%	5.0%	1.7%	5.0%	1.7%	5.0%	17%	5.0%	20.0%	80.0%
G2	2.5%		5.6%		1.7%		1.7%		1.7%		1.7%		1.7%		20.0%	
G3	5.0%		5.6%		1.7%		1.7%		1.7%		1.7%		1.7%		40.0%	

6.3 Biogas model

For the regions which are suitable for the proposed biogas technology, the following biogas model can be used as a reference, which is successfully utilized in China. Further modifications can be done according to the local conditions.

As shown in Figure 6-3, the biogas digester is built under the animal husbandry and toilet, so that human or animal excrement and vegetable waste are used as the raw material in the biogas digester. The biogas can be used for household lighting, cooking, and also for a heating lamp in the animal husbandry and vegetable cultivation. Digestate can be utilized as fertilizer in a vegetable cultivation, or as the feed for livestock such as a fishpond. The animal husbandry and vegetable cultivation offer food for the household, and the remaining product can be sold in the market. Within the dividing line shown in Figure 6-3 is the observation area, including biogas digester, household, garden and livestock breeding. The economic analysis, the ecological and social analysis will be involved in this observation area.

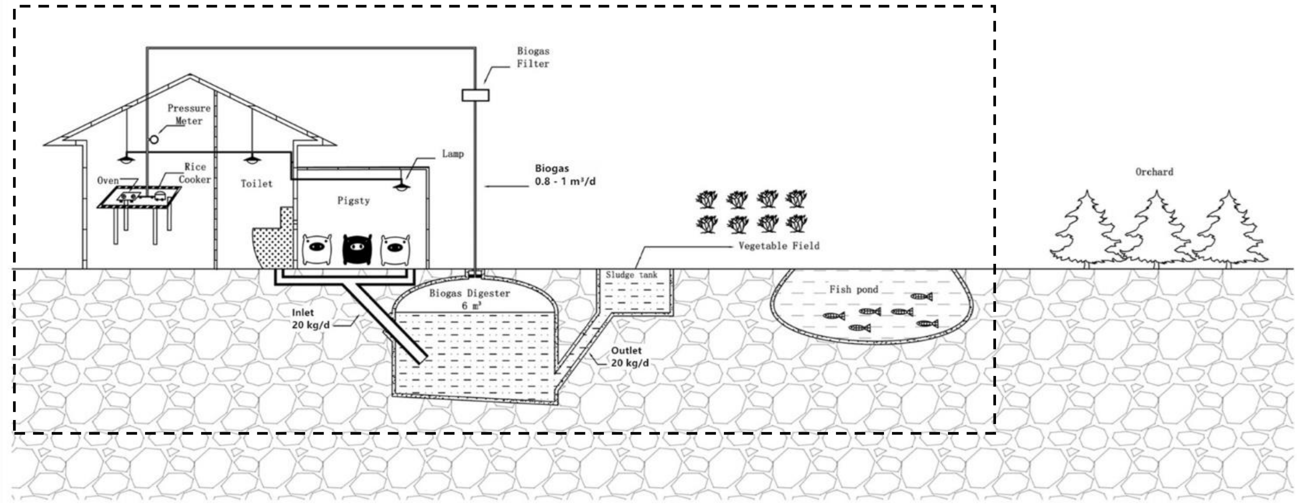

Figure 6-3 Household biogas model according to Chinese household biogas technology

To understand the material flow better, a more detail material flow balance analysis must be created. The analysis basically follows a static modeling which requires knowledge of the processes of transformation; as well as the relationships of the input material and output product (biogas and digestate). Figure 6-4 gives a brief overview for the material flow in the household biogas systems.

Governance frameworks represent the interrelated relationships, function, and influences upon the institution. Sustainable governance framework for biogas ensures the success of the project its goals (Al Seadi, et al., 2018). The model of governance framework for household biogas technology is developed according to rich experiment in China, as shown in Figure 6-5. It integrates three authorities responsible for the biogas plant: central government, biogas office and farmers. Besides financial incentives, the biogas plant is governed by policies, legislation, and regulations, combined with implementation of know-how and good practices. Each authority has its own functions and tasks. The central government is responsible for the establishment of a fully legislative environment; the financing; and the monitoring. The biogas office plays an important role for the preliminary investigation, planning, construction, quality control and also training for the farmers. The farmers must finance part of the investment cost for the construction, and perform the input and output process every day.

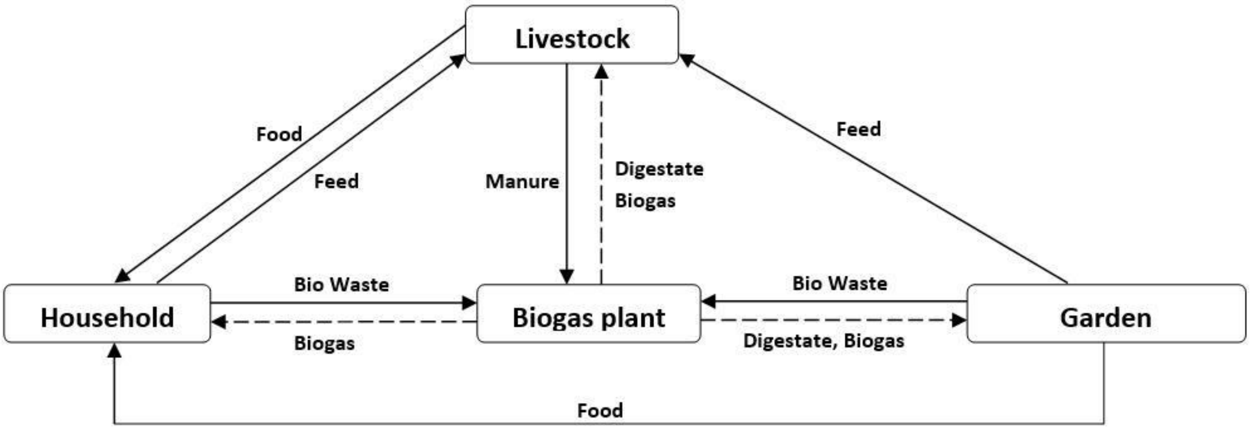

Figure 6-4 Model of the material flow of household biogas digester

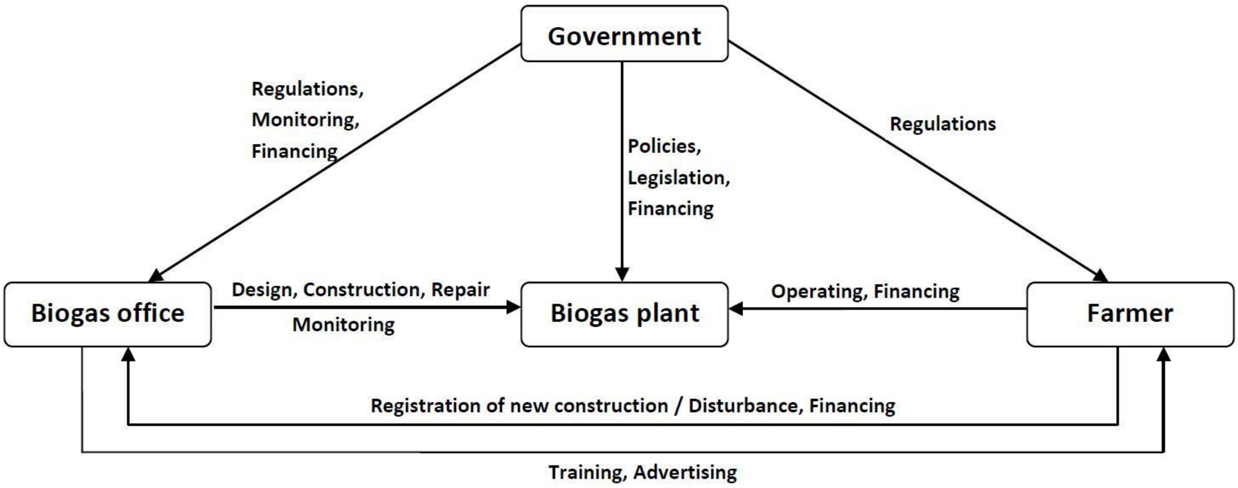

Figure 6-5 Model of the governance framework for household biogas digester

6.4 Calculation of the potential of biogas digester

All results obtained from the preliminary investigation and checklist will be presented in the form of a table. For the countries which are suitable for biogas, the biogas potential will be calculated from 2010 to 2050. Following equation is used for the prognoses of the potential household biogas plant:

$$BP = \sum_{i=0}^{n} a_i * X_i \tag{2}$$

With:

BP = Potential of household biogas plant

i = items with relationship with biogas plant

a_i = suitable percentage on biogas plant

- a_c = percentage of suitable household according to climate factors
- a_e = percentage of suitable household according to energy factors
- a_m = percentage of suitable household according to material factors
- a_t = percentage of suitable household according to technical factors
- a_f = percentage of suitable household according to finance factors
- a_w = percentage of suitable household according to social factors
- a_p = percentage of suitable household according to political factors

X_i = Household amount

Biogas potential estimates for 2005 to 2018 are based on data from various statistical sources in China, Tanzania, Bolivia and Brazil. And the biogas potential calculations for 2019 to 2050 are based on the patterns of change in the historical data and they are followed in the prognose for the years 2019 to 2050.

6.5 Economic evaluation

Economic assessment is a whole process of calculation, analysis, demonstration, and conclusion for the economic rationality of a project. It is an important part of transferability studies of household biogas projects. Taking into consideration the national economy, planning of the biogas projects and current technology; a comprehensive economic evaluation has been proposed. This has been done through calculation, analysis, and comparison. It also provides a reliable basis for decision-making and optimization process.

Investment costs, revenues and payback period of the household biogas project is calculated and compared for economic assessment:

- Project costs, including one-time investment costs and operating costs
- Project revenues, refers to the direct and indirect annual revenue of project
- Payback period, refers to the time to cover the total investment needed for the project, it is an important indicator to reflect the true ability to repay the project.

The calculation can be divided into three parts: basic data, economic aspect and ecological aspect, among which the calculation of basic data provides the premise for other calculations. Type and number of livestock animals and size of the family should be given as input data, which corresponds to the number of raw materials. As a results, the size of the biogas digester, the amount of produced biogas and digestate, as well as further electricity power can be estimated.

The content of the calculation of the economic aspect includes the items of cost and benefits. Giving the salary of biogas worker and price of construction materials, the investment cost as well as the maintenance cost can be calculated. As the most direct benefits for the biogas user, the biogas value, digestate value and payback period are most interesting and can be estimated. For this, the concept of energy mixture, price of traditional fuel, price of fertilizer and price of food are needed. The amount of reduction of the CO_2 emission and forest deforestation will be counted as ecological aspect.

6.5.1 Assumption

For the comparison of economic, ecological, and social benefits of a household biogas digester in the selected countries, some assumptions have been taken. The following calculation will be based on a family of four members (2 adults and 2 children), several animals, and a garden of 500 m^3. In this $8m^3$ biogas plant that could produce about 340 m^3 of biogas every year. Besides biogas, approximately 9,700 kg of high quality digestate is produced annually.

In Table 6-6, the concept for the use of biogas China is presented, which is divided to 2 parts: for cooking and lighting. The assumption here is that a biogas stove with 2.79 KW (GB/T 3606-2001, 2001) is used for cooking for 1.5 hours a day, and a total 0.72 m^3 of biogas should be consumed per day. The remaining 0.21 m^3 of biogas could then be available for illumination of the biogas lamp with 0.41 KW (NY/T 344-1998, 1998) for about 3 hours. The demand of biogas for the biogas lamp and biogas stove can be calculated with the following equation:

$$BA = \frac{ABA * PBA * WT}{NCV_{biogas}} \tag{3}$$

With:

BA = Biogas demand [m^3/d]

ABA = amount of the biogas applicant [pieces]

PBA = power of the biogas appliance [kW]

WT = working time [h/d]

NCV_{biogas} = biogas net calorific value (here: 6.3 kWh/m^3 under standard condition 0°C and 10^5 Pa)

Table 6-6 Concept for the use of biogas and digestate

Assumption: 8 m^3 biogas digester	Use	Usage duration [h/d]	Power [kW]	Amount	Biogas consumption [m^3/d]	Biogas consumption [m^3/a]
Biogas	Biogas stove	1.5	2.79	1	0.72	263
	Biogas lamp	3.0	0.41	1	0.21	77
Sum					**0.93**	**340**

Assumption: 8 m^3 biogas digester	Use	Consumption [kg/d]	Consumption [kg/a]
Digestate	As fertilizer	19	6,935
	as an additive material in pig feed	7.5	2,735
Sum		**26.5**	**9,700**

6.5.2 Cost for biogas plant

The total investment for biogas plant mainly consists of the expenses for the 3 main parts: the construction materials, personnel cost and biogas apparatus (see Table 6-7). The operating cost of household biogas plant can be divided to personal cost for inspections, repair and training and also to replace material cost (see Table 6-8).

Annuity should be determined with the acquisition value, working life and annual interest rate. Here the working life of household biogas digester is assumed as 15 years, and the interest is assumed with 6%. The annuity factor is 0.103, which can be checked in Table A-14 in annex Table A-14.

Table 6-7 Investment cost of household biogas plant

Investment cost	Details
Construction material	Metal, brick, cement, sand, pipe tec.
Personnel cost	Personnel cost for design, construction, starting of biogas digester etc.
Biogas apparatus	Gas pressure meter, biogas lamp, biogas stove etc.

Table 6-8 Operating cost of household biogas plant

Annual operating costs	Details
Operation costs	• Carrying out routine inspections of biogas; • Staff costs for substrate incorporation and substrate application • Fault diagnosis; • Elimination of technical failures and faults; • Dissemination of knowledge about the safety in use of the biogas plant; • Training on biogas technology, integrated use of digestate, cultivation and rearing technologies, maintenance and repair of facilities and equipment for farmers
maintenance costs	Cost of maintenance materials and exchange of spare parts (About 5% of the total construction cost of the biogas plant) Materials for winter insulation

$$A = Ko * Sn \tag{4}$$

$$Sn = \frac{i}{1-(\frac{1}{1+i})^n} \tag{4-1}$$

With:

A = Annuity
Ko = Total debt to be repaid (invest cost) [€]
Sn = Annuity factor
n = Repayment period [year]
i = Annual interest rate [%]

6.5.3 Benefits of biogas plant

The economic benefits of the household biogas plant can be divided to benefits of biogas and benefits of digestate. The benefits of biogas are reflected in saving cost of energy for daily cooking and lighting. Furthermore, increases in agricultural production and livestock as a result of the use of digestate are another economic benefit. Therefore, the annual benefits of household biogas plant are summarized in the Table 6-9.

Table 6-9 Annual revenue of household biogas plant

Revenue	Details
Biogas value	As alternative energy for cooking As alternative energy for lighting
Digestate value	Saved cost as fertilizer More income of agricultural production More income of livestock

Therefore, the benefits of biogas plant can be calculated as:

$$BBP = BV_c + BV_l + BG + BL + BF \tag{5}$$

With:

BBP = Benefits of biogas plant [€/a]

BV_c = Biogas value as saving energy cost for cooking [€/a]

BV_L = Biogas value as saving energy cost for lighting [€/a]

BG = Benefits of garden [€/a]

BL = Benefits of livestock [€/a]

BF = Benefits of fertilizer [€/a]

Benefits of biogas

The estimation of the benefits of biogas equals to the savings of energy cost as the substitute fuel for cooking and lighting.

Through the use of biogas, the utilization of raw coal, fuelwood, straw, Liquefied Petroleum Gas (LPG) and etc, can be significantly reduced. For the calculation of the amount of substitution of fuels by biogas, the following equation is used:

$$VAE = \frac{CV_{biogas} * TE_{biogas}}{CV_{AE} * TE_{AE}} \tag{6}$$

With:

VAE = Substitution rate

CV_{biogas} = Calorific value of biogas [MJ/m^3]

TE_{biogas} = Thermal conversion efficiency of the biogas oven [%]

CV_{AE} = Calorific value of alternative energy [MJ/Unit]

TE_{AE} = Thermal conversion efficiency of the oven [%]

Table 6-10 shows the energy savings through the substitution of domestic fuel by biogas. An 8 m^3 of biogas plant could annually produce 340 m^3 of biogas. If all 340 m^3 of the biogas could be replaced instead of the combustion of raw coal, fuelwood, and straw, it would save 540 kg of raw coal or 884 kg fuelwood or 1,942 kg straw annually.

Table 6-10 Energy saving by substitution of traditional fuels by biogas (8m^3 biogas digester)

	Biogas	The substitution of household fuels by biogas						
		Charcoal	Fuelwood	Straw	Liquid gas LPG	Electricity	Dung	Oil product
Unit	m^3	kg	kg	kg	kg	kWh	kg	kg
Average net calorific value[1] [MJ/Unit]	22.8	30	16	13.5	45.5	3.6	14.5	43
Thermal conversion efficiency of the oven[1]	58%	28%	32%	17%	56%	75%	12%	45%
Substitution rate		1.59	2.60	5.71	0.52	4.86	7.53	0.68
Average annual amount [Unit/a]	340	540	884	1,942	175	1,651	2,562	366

[1] (Malla, et al., 2014)

However, not all households use only one energy sources. Thus, the value of biogas depends directly on the value of all substituted fuels. The assumed fuel mix (the share of the substituted fuel in the total energy supply) and the fuel price vary from country to country. The value of biogas as substituted fuels can be calculated in terms of economic value, which takes the full market price of the substituted fuel into account:

$$BV_c = \sum AC_i * EPC_i \qquad (7)$$

With:

BV_c = Economic value of biogas as saving energy cost for cooking [€/a]

i = substituted fuel

AC = amount of energy sources for cooking [kg/a]

EPC = Price of energy sources [€/kg]

The electricity is mostly used for lamp, television, fridge or other electronic appliances. Because of the limit of biogas appliance, the biogas can be just substituted for lighting. As the assumption mentioned, one biogas lamp will be replaced for one normal lamp with 60 W or LED lamp with 10 W. As the new energy-saving lighting products, the lobal market share of LEDs increase rapidly in the last 10 years, which reaches 69% of household lighting around the world (Statistia, 2021b). Therefore, the energy cost for lighting will be calculated by substitution of LED lamp. The value of biogas for lighting is the saved energy cost of the lamp for 3 hours per day, which is calculated based on following equation. As the electricity is a pure commercial energy source, the financial share distributes 100%.

$$BV_L = AL * PL * WT * EP_L \tag{8}$$

With:

BV_L = Benefits of biogas as saving energy cost for lighting [€/a]
AL = number of lamps [pieces]
PL = power of the lamp [kW/piece]
WT = working time [h]
EP_L = electricity price for lighting [€/kWh]

Benefits of digestate

The minimum feeding rate is 20 kg of dung and 20 liters of water. The active volume of a 4 m^3 digester is 3,200 liters, giving a maximum required hydraulic retention time of 80 days. Thus, around 40kg digestate will be produced every day. The digestate is still an excellent fertilizer after fermentation, which is rich in nutrients such as nitrogen, phosphorous, humus, supporting better soil quality and higher crop yields.

Due to the decomposition and breakdown of parts of its organic content, digestate provides fast-acting nutrients that easily enter to soil mixture, thus becoming immediately available for the plants. Most agriculture products appear to react favorably to digestate fertilization. Increases in agricultural production as a result of the use of bio-fertilizer of 6 - 16% have been report (Kumar, et al., 2015). For calculation of the benefits of digestate for more production in garden, 15% of increasing yield is assumed and following equation is used:

$$BG = GA * FY_b * FY_i * FP \tag{9}$$

With:

BG = Benefits of garden [€/a]
GA = garden area [m^2] (here assumption: 500 m^2)
FY_b = garden fruit yield [kg/m^2] with digestate
FY_i = increased garden fruit yield with digestate [%] (hier FY_i = 15%)
FP = garden fruit price [€/kg]

Besides the utilization of digestate in garden, there is still a big surplus of digestate after fertilization. Thus, the digestate can be utilized as feeds for livestock. Because of the rich nutrients in digestate and its better absorption by animals, they grow better and quicker, thus results in more income by livestock, which counts for more income of slaughter (Kumar, et al., 2015). For better comparison between the countries, as mentioned in chapter 6.5.1, 10% more income for household with one cow are considered (Kumar, et al., 2015).

$$BL = LA * LY_b * LY_i * \mathrm{LP} \tag{10}$$

With:

BL = Benefits of livestock [€/a]
LA = number of livestock [pieces]
LY_b = Livestock yield [kg/pieces]
LY_i = Increasing livestock yield with digestate [%] (here LY_i = 10%)
LP = Livestock price [€/kg]

Meanwhile, the cost for chemical fertilizers and pesticides can be saved. The benefits of biogas user on fertilizer items relates to used fertilizer amount and fertilizer price.

$$BF = GA * FA * FP \tag{11}$$

With:

BF = Benefits of fertilizer [€/a]
GA = garden area [here: 500 m^2]
FA = Fertilizer use amount [kg/ m^2]
FP = Fertilizer price [€/kg]

6.5.4 Discounted payback period

In economic factors, the investment return period and total benefits of biogas plant are critical points on the evaluation done by the potential biogas user. Payback period (PP) is time required to recover the initial investment. The longer the payback period, the greater the risk of the project. Discounted payback period (DPP) is a variation of payback period which uses discounted cash flows instead of nominal cash flows, while calculating the time an investment takes to pay back. Compared to the payback period, that it takes into account the time value of money. It accounts for the present value of each cash inflow in each period by a suitable discount rate. Annual effective discount rate, an alternative measure of interest rates to the standard annual interest rate. Here, the discount rate is considered as 6% (European Commission, 2008), thus, DPP can be calculated as following equation (European Commission, 2008):

$$\mathrm{DPP} = \frac{-\ln\left(1 - \frac{Ko * i}{(BBP - OC)}\right)}{\ln\left(1 + i\right)} \tag{12}$$

With:

DPP = Discounted payback period [year]
Ko = Total debt to be repaid (invest cost) [€]
i = The discount rate = 0.06
BBP = Benefits of biogas plant [€/a]
OC = Operating costs [€/a]

6.6 Ecological analysis

6.6.1 Impact on the nature and forestry

As mentioned in chapter 3.3.6.1, household biogas digesters contribute to environmental development as follows:

- Substituting conventional fuels and reduction of fuelwood use contributes to checking deforestation and reduces forest encroachment,
- Reduction of the emission of greenhouse gasses,
- Substituting of synthetic fertilizer, which improves soil texture, thus reducing degradation, and reduces the need for further land encroachment.
- Improvement of rural environment due to the better manure management practices, which reduce ground and surface water pollution, odor and improve aesthetics.

Reduction of use of fuelwood through utilization of biogas can contribute save the forest area. The area of forest conservation can be calculated with the density of fuelwood and the forest growing stock:

$$FC = SW * DW * FGS \tag{13}$$

With:

FC = Forest conservation [m³]
SW = Saved amount of wood [kg]
DW = Density of fuelwood [kg/m³]
FGS = Forest growing stock [m³/ha]

Because of the difficulties of data collection in Africa and Latin American countries, the consistent data for fuelwood density is assumed. Consider of the properties of fuelwood such as splitting, ignition and moisture content, eucalyptus is quite suitable as fuelwood. The density of eucalyptus varies from 500 kg/m^3 to 1200 kg/m^3 (Brock, et al., 2004), of which 600 kg/m^3 is assumed as the density of eucalyptus in this study. With rich forest resource, the average forest growing stock in Latin America reach 178 m^3/ha, while in Africa 128 m^3/ha and in Asia only 93 m^3/ha (FAO, 2016).

6.6.2 Reduction of Green House Gas

With the replacement of energy sources of coal, fuelwood, straw and animal dried manure, the use of biogas contributes to reduction of greenhouse gas (CO_2 equivalent) (Zhang, et al., 2005). For the calculation of the GHG emission reduction (CO_2 equivalent) through use of biogas is the difference of the released GHG emission in the combustion of conventional energy sources and biogas. The calculation formula for the GHG emissions released during the combustion of fuel is:

$$GHG = FC * EF \tag{14}$$

with:

GHG = Greenhouse gas emissions of a certain type of fuel [kg]

FC = Amount of fuel in the combustion [kg or kWh]

EF = Standard emission factors of greenhouse gas on a given type of fuel [g gas/kg or g/kWh] (Table 6-11)

Table 6-11 GHG emission (CO_2 equivalent) factors for different fuels

Emission factor	Coal	Fuelwood	Straw	LPG	Electricity	Oil product	Biogas
CO_2 Emission factor[1] [kg CO_2/MJ]	381	390	366	239	*	266	148
Calorific value[2] [MJ/kg fuel]	15	15	14.4	46.3	3.6	42.6	22.5
CO_2 Emission factor [g CO_2/kg fuel or g/kWh]	1,588	1,625	1,464	3,074	537	3,148	925

[1] (BAFA, 2019)

[2] (energie-lexikon, 2020), (agrarplus, 2020), (FNR, 2020)

* Country-specific emission factors for electricity are listed in Table 6-12

Since the source of electricity generation differs from country to country (Brander, et al., 2011), the GHG emissions (CO_2 equivalent) factors for electricity generation is defined for each individual country as listed in Table 6-12.

Table 6-12 Country-specific GHG emissions (CO_2 equivalent) factors for electricity (Brander, et al., 2011)

Country	GHG emissions (CO_2 equivalent) factors [gCO_2/kWh]
Bolivia	535.95
Brazil	92.85
China	977.33
Ethiopia	119.35
Tanzania	267.16

7 Results and Discussion

7.1 Biogas in China

7.1.1 Transferability analysis in China

With the strong support of the central and local governments and the assistance of international organizations, the household biogas technology has been developed rapidly in China. The technical, material and finance support are also available throughout the country, which has the fully score 1.0 for these criteria. In climate aspect, China has a middle score of 0.5, because of the cold winter in north and west China, which is not suitable for biogas technology. The score for energy issues "scarcity of traditional energy supply for household" remains also lower, then the energy supply in rural area has improved in the last years. The score for each criterion according to national average condition is summarized in Table 7-1. Together with the weighting of criteria, the result of the transferability analysis in China is 0.76.

Table 7-1 Score of each criterion and results of transferability in China

		Criteria	Score	Result
A1	Climate	Suitable climate condition	0.50	0.03
B1	Energy	Scarcity of traditional energy supply for household	0.25	0.04
B2		Requirement for the share of renewable energy	0.75	0.04
C1	Material	Availability of feeding material for biogas digester	0.75	0.15
C2		Availability of water	1.00	0.03
C3		Availability of space for agriculture	0.75	0.02
C4		Availability of construction material	1.00	0.03
C5		Availability of biogas appliance	1.00	0.03
D1	Technical	Availability of engineers for design and quality control	1.00	0.03
D2		Availability of workers for construction, operation and after-sale-service	1.00	0.03
E1	Finance	Finance ability	1.00	0.15
E2		Access to credit	0.75	0.08
F1	Social	Role of women in domestic decision-making process and life	0.75	0.01
F2		Integration of biogas plant into normal working routine at the farm	1.00	0.02
F3		Ethical aspect	1.00	0.02
G1	Political	Availability of Standards. laws and regulations on biogas technology	1.00	0.03
G2		Political will of the Government to support a national biogas program	1.00	0.03
G3		Monitoring and supervision	1.00	0.05
Sum				**0.76**

Due to the vast territory of China, the economies, populations, and resources of different region are vastly different. Therefore, criteria's scores are somewhat different considering the local situation of each region. The natural conditions in some regions in China are not suitable for biogas plant, such as the northern regions of China with cold temperatures, the best score in terms of climate is 0.05 and in the worst case is 0.01. Eastern China with developed energy supply condition has lower score of 0.01 for development of household biogas digester. On the contrary, because of the urgent needs of clean energy in western China, the score is 0.20. Similarly, the regions with different material conditions have score bandwidth from 0.16 to 0.30. In sum up, the minimum and maximum results of different schemes vary between 0.53 and 1.00 (see Table 7-2). The results of national general condition (with 0.81), which covers the areas with 80% of population, is higher than the national average condition (with 0.76).

Table 7-2 Results of 4 scenarios in China

	Criteria	Worst	Best	Average	General
A	Climate	0.01	0.05	0.03	0.05
B	Energy	0.01	0.20	0.08	0.08
C	Material	0.16	0.30	0.24	0.24
D	Technical	0.04	0.05	0.05	0.05
E	Finance	0.19	0.25	0.23	0.25
F	Social	0.04	0.05	0.05	0.05
G	Political	0.08	0.10	0.10	0.10
Sum		**0.53**	**1.00**	**0.76**	**0.81**

Table 7-3 Results of sensitivity analysis in China

Variation / scenario	Worst	Best	Average	General
I	0.53	1.00	0.76	0.81
II	0.61	1.00	0.86	0.90
III	0.14	1.00	0.41	0.44
IV	0.52	1.00	0.78	0.80
V	0.71	1.00	0.95	0.97
VI	0.68	1.00	0.84	0.97
VII	0.71	1.00	0.89	0.97
VIII	0.68	1.00	0.94	0.97

The final results of all variation might change when altering any criteria score or weighting. The results of sensitivity analysis for China with the bandwidth of worst case and best case considering different weighting are shown in Table 7-3 and graphically indicated as follows in Figure 7-1 as well. It is significantly indicated that, except for variation III (extreme weighting of energy), the results according to the average condition in China shows less sensitive, which varies between 0.76 and 0.95, no matter how the weightings changes. The results basis of 80% population is even better (between 0.80 and 0.97). If the energy aspect is particularly important, some regions in China has only score of 0.14. Thus, decision-making will not support the development of household biogas digester which can be explained by the satisfy energy supply in rich area. In the best case in China, the evaluation score of China always remains unchanged with 1.00, even the worst case, the comprehensive score ranges from 0.52 and 0.71.

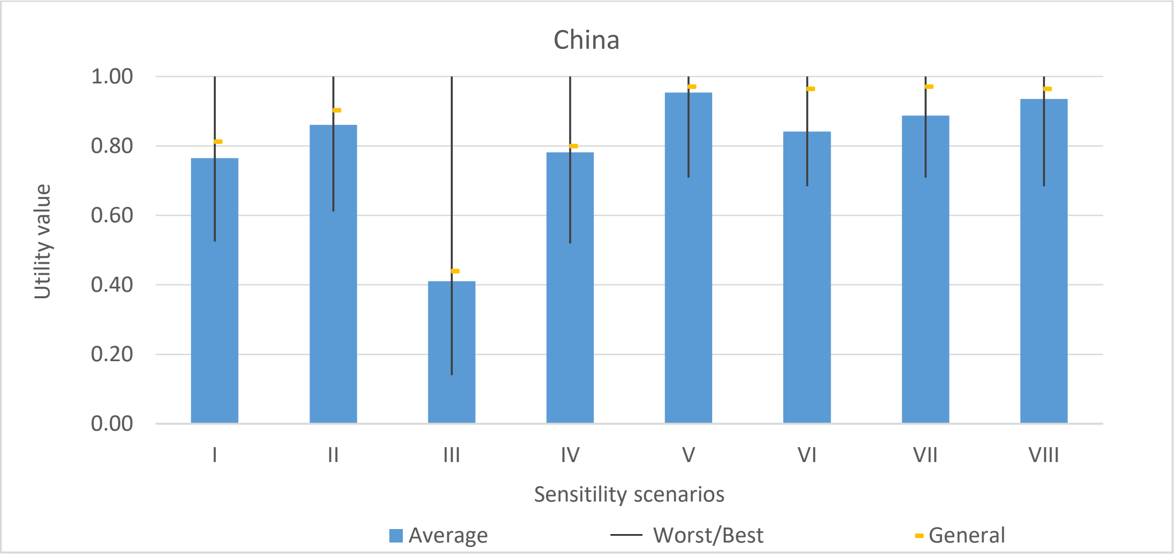

Figure 7-1 Results of sensitivity analysis in China

7.1.2 Potential of household biogas digesters in China

According to the calculation method mentioned in chapter 6.4, biogas potential estimates for 2005 to 2018 are based on data from various statistical sources. China's appropriate households for the biogas development was about 80.92 million by 2010, which accounted to 24.14% of the total households.

In 2018, among of 141 million household in rural area in China around 71.8% of them hold livestock, which provided enough fresh input material for biogas plant (MOA, 2019). Under the nature condition, only 5% of the household located in the climate non-suitable zone, and around 13.6% of the household did not have the access of water sources (WHO, 2019). Meanwhile, there were 17.9% of the household with abundant other energy sources, which were also not suitable for household biogas plant (Yearbookchina, 2020). Therefore, the potential biogas digesters in China were 68.97 million in 2018, equaled to 19.77% of total national households.

The biogas potential calculations for 2019 to 2050 are prognosed based on the patterns of change. With the natural growth of the population, China's total population will reach of 1,407.97 million and 1,396.63 million respectively in 2020 and 2050 according to the estimations of the National Bureau of Statistics. Secondly, more and more farmers have the financial ability to build biogas digesters as the national farmers' income level synchronizes. However, because of the urbanization, rural farmers will decrease in China. Various analytical results show that China has entered a stage of rapid development of urbanization, which would sustain a vicinity of 15 years. By the year of 2020 and 2050, the proportion of urban residents in China will reach 61% and 85% and the rural population will be reduced to 546.77 million and 210.11 million for the two years mentioned respectively. The number of rural households will be reduced to 136.69 million and 52.53 million households (National Bureau of Statistics of China, 2018).

Moreover, with the improvement of farmers' income level, high-income farmers have the ability to consume commercial energy, such as electricity and natural gas. As the result of reducing the dependence of household biogas, those farmers are not appropriate as the focus target for household biogas construction. In China, low- and middle-income farmers are the main target for household biogas development. Additionally, with the development of centralized farming, the numbers of China’s backyard farmers and the farmers, who are no longer engaged in pigs and cattle farming or depend on it as a fixed source of income, will be reduced. From this point of view, suitable households for the development of biogas will be reduced. As the new growth in biogas production shifted to medium- and large-scale biogas plants at more concentrated livestock holding. Moreover, central biogas plant for more households together has advantage with continue input and stable biogas production, it is also a trend of biogas development in rural area of China.

Table 7-4 Potential of household biogas digesters in China from 2020 to 2050

Items / Year	2020	2030	2040	2050
Total households [million]	351.99	361.25	358.73	349.16
Potential of household biogas digesters [million]	67.24	55.15	36.32	19.85
Proportion of total households [%]	19.10%	15.27%	10.12%	5.69%

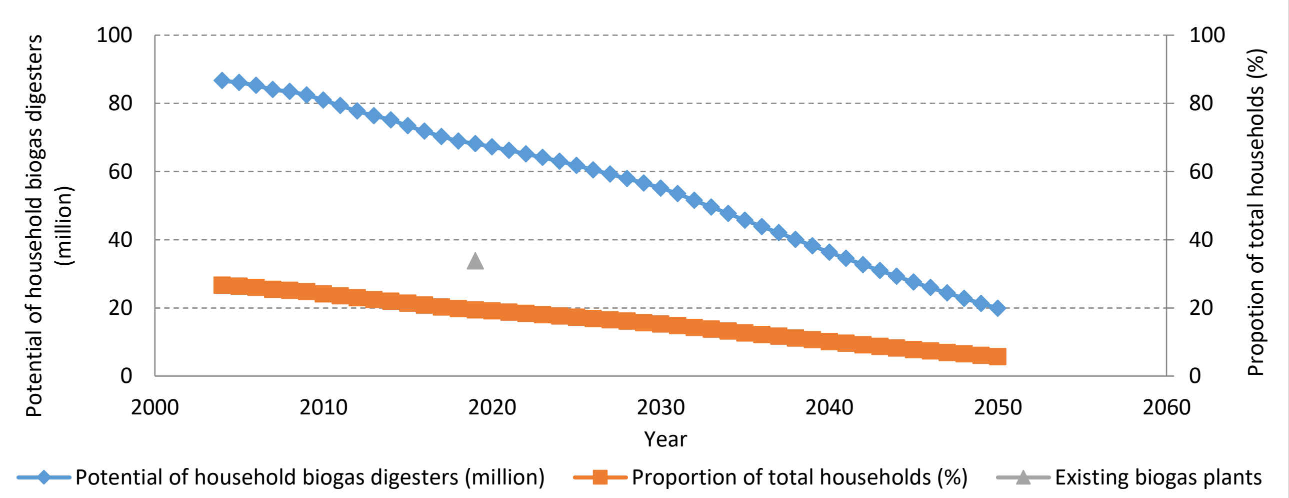

Figure 7-2 Potential of household biogas digesters in China

The potential of household biogas digesters in China from 2020 to 2050 are summarized in Table 7-4. In conclusion of the mentioned four aspects, the farmers who are suitable for the development of biogas in China plunge to 67.24 million households by 2020. This is followed by a constant decrease, with the suitable households for the development of biogas dropping to the total scale of 19.85 million households in 2050. The proportion of total rural household presents also the same declining trend. The number of rural household biogas digesters in China in 2019 was 33.80 million (Yearbookchina, 2020), which represents roughly 50% of the potential biogas digesters (as shown in Figure 7-2).

7.1.3 Economic analysis

7.1.3.1 Investment cost

The total investment costs for a household biogas plant are detailed in Table 7-5. Overall, around € 912 should be invested for a biogas plant in China.

Table 7-5 Total investment for the biogas plant in China

Position		Amount	Unit	Unit Price [€]	Costs [€]
Construction material	Cement (Portland Cement 425)	1	[t]	60	60
	Sand (medium)	2	[m^3]	10	20
	Gravel	2	[m^3]	10	20
	steel reinforcement	20	[kg]	0.5	10
	brick	600	[Piece]	0.05	30
	Pipe (PVC) (Input, Output)	1	[Set]	15	15
Personal costs	2x construction worker (for excavation, construction, painting, installation of biogas plant)	10	[d]	22	440
	1x technicians (technical instructions, wiring, starting of biogas plant)	7	[d]	35	245
Accessories	Biogas stove	1	[Set]	15	15
	Biogas lamp	1	[Piece]	10	10
	Biogas pressure gauge	1	[Piece]	3	3
	Desulfurizer	1	[Piece]	15	15
	Gas processing and control unit	1	[Piece]	5	5
	Biogas-pipe (PE), circuit and associated accessories	1	[Set]	20	20
	Sealing material	2	[kg]	2	4
Sum					**912**
Financial assistance from the state					**120**

In Table 7-6, the annual operating costs in southern China are presented. Overall, the annual cost of operation and maintenance is approximately € 162, of which, € 88 for the personnel costs of the substrate input and output process, € 28 for personnel costs of maintenance and € 46 for the procurement of maintenance materials and the spare parts.

Table 7-6 Annual operating costs of household biogas digester in China

Annual operation costs	Details	Costs [€/a]
Operation costs	Staff costs for the input and output process	88
	Maintenance personnel costs	28
Maintenance costs	Cost of maintenance materials and the replacement parts (about 5% of the total construction cost of the biogas plant)	46
Sum		**162**

7.1.3.2 Benefits of biogas

The calculation method of the biogas value for cooking based on the type of substituted fuel, the substitution rate, the assumed fuel mix (the share of the substituted fuel in the total energy supply, which has shown in chapter 3.1.3, Figure 3-5) and the fuel price is shown in Table 7-7. In the rural areas of China, almost all the fuel for the cooking is sourced from fuelwood or agriculture residues such biomass. The value of 263 m³ biogas for cooking is € 16.96.

Table 7-7 Biogas value for cooking (BV_c) in China

Assumption: 8m³ biogas digester, 263 m³ biogas for cooking

Biogas replacement	Substitution ratio	Fuel mix	Substitution amount	Fuel price [€/Unit]	Biogas Value (BV_c) [€]
Charcoal [kg]	1.59	1.7%	7.10	0.09	0.64
Fuelwood [kg]	2.60	81.5%	557.55	0.00	0.00
LPG [kg]	0.52	10.3%	13.94	0.83	11.57
Electricity [kWh]	4.86	6.2%	79.17	0.06	4.75
Sum					**16.96**

The electricity is mostly used for lamp, television, fridge or other electronic appliances. Because of the limit of biogas appliance, the biogas can be only substituted for lighting. As the assumption mentioned, one biogas lamp will be replaced for one LED lamp with 10 W. The value of biogas for lighting is the saved energy cost of the LED lamp for 3 hours per day, which is € 0.66 per year (see Table 7-8).

Table 7-8 Biogas value for lighting (BV_L) in China

Assumption: $8m^3$ biogas digester, 77 m^3 biogas for lighting

	amount	Power [W]	Working time [h]	Electricity price [€/kWh]	Biogas value (BV_L) [€/a]
Lamp	1	10	3	0.06	0.66

All in all, with the annual biogas yield of 340 m^3, the financial biogas value as substituted fuel is in total around € 17.62, including € 0.66 for lighting and € 16.96 for other fuel sources for cooking (see Figure 7-3). As shown in Table 7-9 the value of 1 m^3 of biogas can be also estimated for € 0.05.

Table 7-9 Biogas value in China ($8m^3$ biogas digester)

	Volume [m^3]	Value [€]
Biogas for cooking (per year)	263	16.96
Biogas for lighting (per year)	77	0.66
Biogas value [€/a]		17.62
Biogas value [€/m^3]		**0.05**

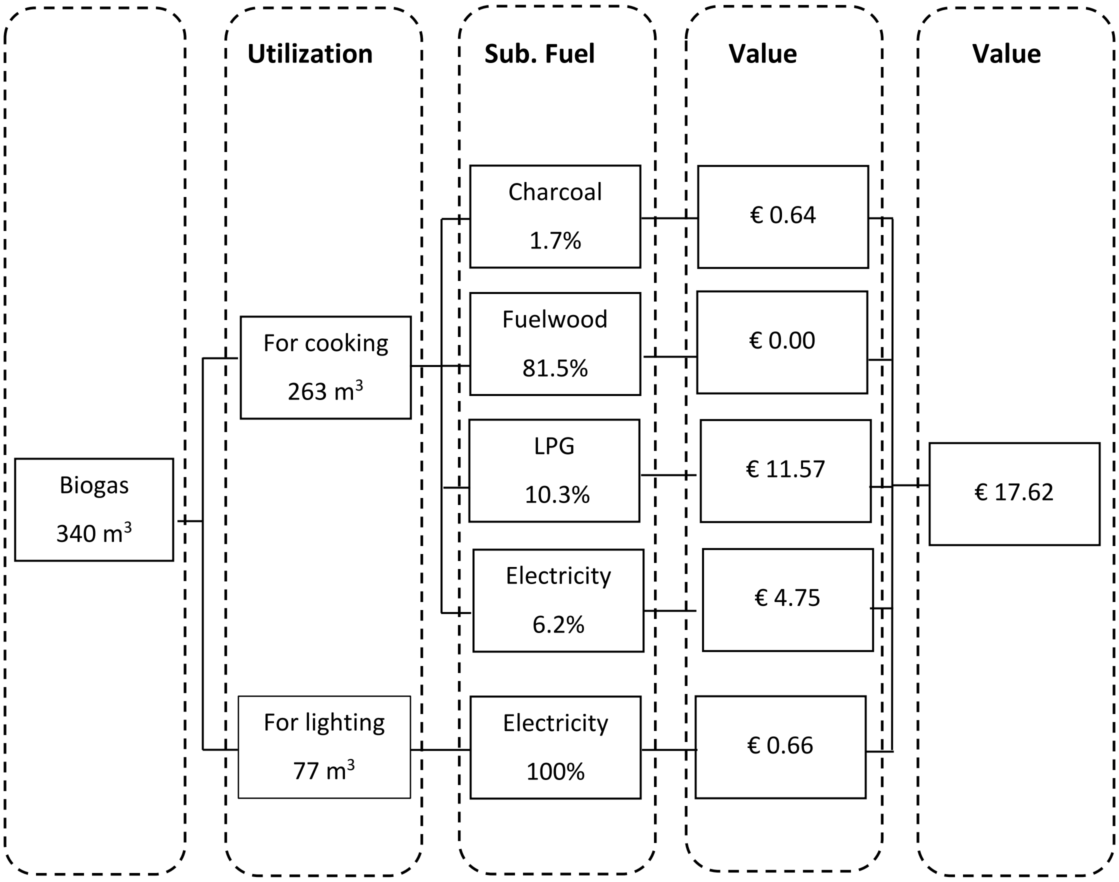

Figure 7-3 Value of biogas in China

7.1.3.3 Benefits of digestate

According to the calculation equation 9 to 11 (see chapter 6.5.3), in China, the annual produced amount and value of the fruit is in increase, accounting as benefits of garden (BG) for € 180 per year. Meanwhile, the digestate can be also utilized as feeds for livestock, which counts to € 385.84 for more income of slaughter as benefits of livestock (BL).

Meanwhile, the cost for chemical fertilizers can be saved. 0.05 kg of fertilizer is used for 1 m^2 fields (The World Bank, 2017b) , with the average unit price of 0.3 €/kg (ScienceNet, 2018), which results in around € 7.5 per year as benefits of fertilizer (BF) that can be saved for 500 m^2 fields.

7.1.3.4 Summary of economic analysis

The results from the above tables, income and savings from the biogas plant are summarized in the following Table 7-10. Through the use of biogas in China, a 4-person household could have an income of about € 591 per year. With the investment cost of € 912 for a biogas plant (with annuity of € 93.94) and annual operating cost of € 162, the invest cost will be covered after 2.34 years.

Table 7-10 Summary table of economic analyze for an 8 m^3 biogas digester in China

Invest	**Details**	**Costs [€]**
Invest costs	Construction cost for biogas plant	912 (once only)
Annuity	Working life with 15 years and interest of 6%	93.94
Operation costs	Maintenance cost and material costs for fitting materials	162

Income and savings	**Details**	**Costs [€/a]**
Alternative energy	Replacement of the raw coal and savings in fuel costs: Biogas value for cooking (BV_c)	16.96
	Save power by using the biogas lamps in the household: Biogas value for lighting (BV_L)	0.66
Benefits of livestock (BL)	More income for slaughter	385.84
Benefits of garden (BG)	Increased annual production value	180.00
Benefits of fertilizer (BF)	Saving of fertilizer	7.50
Sum [€/a]		**590.96**

Discounted Payback Period (DPP) [a]	**2.34**
GNI [€/a]	**8,238**

7.1.4 Ecological analysis

7.1.4.1 Impact on the nature and forestry

The substitution of fuelwood by biogas contributes the reduction of fuelwood shock and reduces the deforestation. Thus, the biodiversity, the remaining forests and reforestation are obtained.

In Table 7-11, the amounts of saved fuelwood and received forest area are listed. Due to the biogas use concept, biogas users with biogas plant can save 558 kg (Table 7-7) fuelwood for burning annually. This corresponds to the conservation of a forest area of 100 m^2.

Table 7-11 Forest conservation according to usage concept of 340 m^3 biogas (8 m^3 digester) in China

Saved amount of wood [kg]	Density of fuelwood [kg/m^3]	Forest growing stock [m^3/ha]	forest conservation (FC) [m^2]
558	600	93	**100**

7.1.4.2 Reduction of Green House Gas

Table 7-12 GHG reduction according to usage concept of 340 m^3 biogas (8 m^3 digester) in China

GHG reduction by biogas (CO_2 equivalent)	Raw coal	Fuelwood	LPG	Electricity	Biogas
Unit	[kg]	[kg]	[kg]	[kWh]	[m^3]
Average annual amount [unit/a]	7	558	14	90	340
CO_2 Emission Factor [g/unit]	1,588	1,625	3,074	977	925
Annual amount of CO_2 emissions [kg/a]	11	906	43	88	315
Annual amount of CO_2 emissions (Consideration of neutral biomass) [kg/a]	11	0	43	88	0
Reduction of annual amount of CO_2 emissions from biogas [kg/a]	142				

Besides the deforestation, reduction of greenhouse gas is one of the most important ecological aspects of the utilization of biogas. With the parameter of GHG emission factor and the substituted among different fuels, the amount GHG emission that is being reduced can be calculated. According to the biogas usage concept (as shown in Table 6-6) during the combustion of 340 m^3 of biogas annually 734 kg GHG (CO_2 equivalent) is reduced. Considering of the natural GHG property of biomass, only the reduced amount of GHG caused by raw coal, LPG and electricity are accounted to real GHG reduction. 142 kg of Greenhouse gas are reduced per year. The concrete GHG reduction in China is presented in Table 7-12.

7.2 Biogas in Tanzania

7.2.1 Transferability study in Tanzania

Table 7-13 summarized the score of each criterion in Tanzania and the results were calculated based on the score and their weight outlined in Table 7-13. With tropical climate, the average temperature in most area of Tanzania remains between 20°C - 25°C all year-round. It is an optimum condition for biogas technology. Therefore, Tanzania gets a high score 1.00 in climate issues.

Most of the livestock in Tanzania are kept by traditional (small) owners, who provide input materials for biogas plant. Although the rich water resources, the availability of water in Tanzania is critical. Only 59% of the rural populations has access to an improved water source (Deloitte, 2016). In recent years, with the rapid development of the economy in Tanzania, industry and real estate led to the development of the building materials market. Biogas appliance and fitting materials were supplied by Centre for Agricultural Mechanization and Rural Technology (CAMARTEC) in Tanzania Domestic Biogas Program (TDBP, 2013). Thus, the score of criteria about availability of material get an intermediate value of 0.5. The biogas history in Tanzania began in 1975. According to the TDBP, 16,800 biogas users and 5,142 professional technicians have been trained. Therefore, the technical factors are not a barrier for biogas dissemination (TDBP, 2013).

Although a household biogas digester requires not much investment, for the households in rural areas are still a very large overhead. Not all families can afford such a large one-time investment. So that, score of 0.25 is given for the criteria of finance ability for household biogas digester in Tanzania. A small credit for the potential biogas user is very necessary. However, such credits are available primarily for the public sector. It is uncommon in rural households, especially on the agriculture side, such as the purchase of fertilizer and pesticides or invest in the biogas digester (Karina Derksen-Schrock, 2011). Recently, the Rural Energy Agency was established under the Ministry of Energy and Minerals with the aim of increasing access rate of energy in rural Tanzania, to which extent a Rural Energy Fund was established (Ng'wandu, et al., 2009). Thus, the political issue of transferability study gets an intermediate value of 0.5.

Table 7-13 Score of each criterion and Results of transferability study in Tanzania

		Criteria	Score	Result
A1	Climate	Suitable climate condition	1.00	0.05
B1	Energy	Scarcity of traditional energy supply for household	0.75	0.11
B2		Requirement for the share of renewable energy	0.50	0.03
C1	Material	Availability of feeding material for biogas digester	0.50	0.10
C2		Availability of water	0.50	0.01
C3		Availability of space for agriculture	0.75	0.02
C4		Availability of construction material	0.50	0.01
C5		Availability of biogas appliance	0.50	0.01
D1	Technical	Availability of engineers for design and quality control	0.50	0.01
D2		Availability of workers for construction, operation and after-sale-service	0.50	0.01
E1	Finance	Finance ability	0.25	0.04
E2		Access to credit	0.50	0.05
F1	Social	Role of women in domestic decision-making process and life	0.50	0.01
F2		Integration of biogas plant into normal working routine at the farm	0.50	0.01
F3		Ethical aspect	0.50	0.01
G1	Political	Availability of Standards, laws, and regulations on biogas technology	0.25	0.01
G2		Political will of the Government to support a national biogas program	0.50	0.01
G3		Monitoring and supervision	0.25	0.01
Sum				**0.51**

Tanzania with results of 0.51 has insufficient conditions compare to China. Nevertheless, whether from energy, material, technical or political aspects, Tanzania shows considerable enthusiasm to develop biogas technology. With the stronger awareness of environment and renewable energy there is, the more the weakness can be improved through international support or cooperation.

Most regions of Tanzania have the temperature above 20°C all year round. Therefore, the score of climate issue in worst and best case has no significant different (worst case of 0.04, best case of 0.05). Due to the different economic conditions of regions, the scores in terms of material, technique, and finance, vary greatly between worst and best case. The results of 4 scenarios in Tanzania can be reviewed in Table 7-14, the results of transferability study vary between 0.38 in worst case and 0.72 in best case. The result of national average condition has no significant different with the results for condition of 80% population.

Table 7-14 Results of 4 scenarios in Tanzania

		Worst	Best	Average	General
A	Climate	0.04	0.05	0.05	0.05
B	Energy	0.13	0.19	0.14	0.10
C	Material	0.12	0.23	0.16	0.16
D	Technical	0.01	0.03	0.03	0.03
E	Finance	0.06	0.15	0.09	0.13
F	Social	0.02	0.04	0.03	0.03
G	Political	0.01	0.04	0.03	0.04
Sum		**0.38**	**0.72**	**0.51**	**0.53**

As can be seen in Table 7-15 and Figure 7-4, Tanzania has advantage for promotion of household biogas digesters in the aspect of energy issues, which can be explained by the unsatisfied energy supply. It results the score of 0.62 in worst case and even 0.92 in best case. The data demonstrates that Tanzania would be unsuitable for household biogas digester if the weighting of finance is greater, the worst case of variation VI has relatively lower final score of 0.29. The results in variation II average weighting of criteria as well as variation IV extreme material weighting shows less sensitive in Tanzania. Not sufficient condition of politic issues lies to the lower results from 0.14 to 0.51, which is disadvantage for promotion of household biogas digesters in Tanzania.

Table 7-15 Results of sensitivity analysis in Tanzania

	Worst	Best	Average	General
I	0.38	0.72	0.51	0.53
II	0.29	0.71	0.51	0.54
III	0.62	0.92	0.69	0.52
IV	0.42	0.75	0.53	0.55
V	0.27	0.54	0.51	0.51
VI	0.29	0.66	0.42	0.52
VII	0.34	0.81	0.51	0.51
VIII	0.14	0.51	0.38	0.48

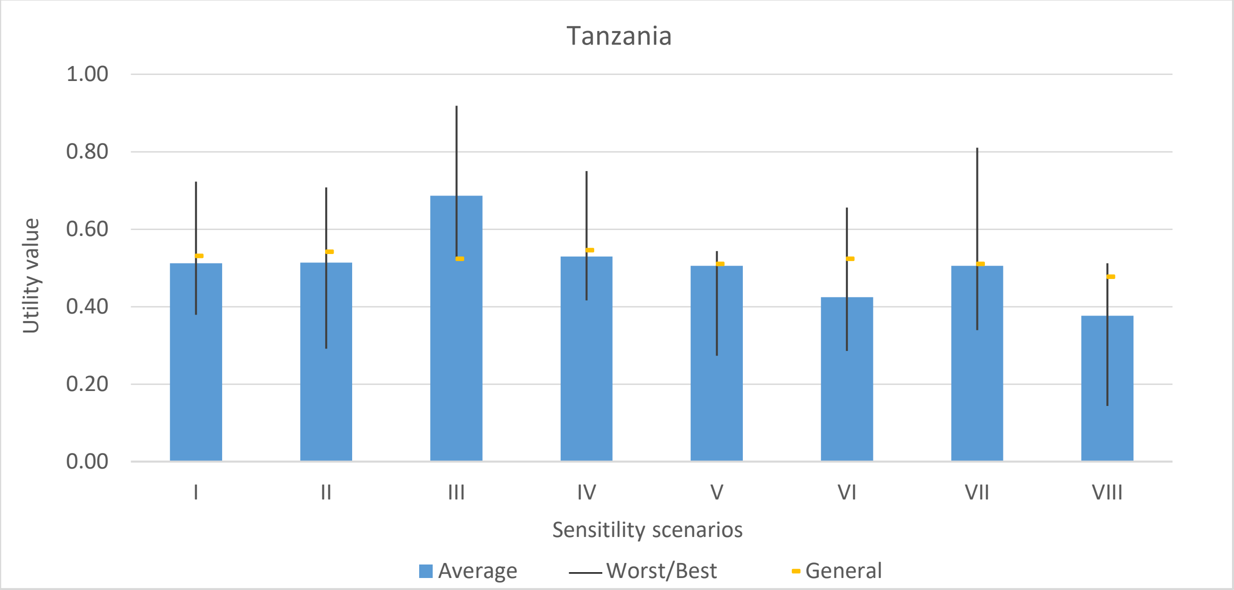

Figure 7-4 Results of sensitivity analysis in Tanzania

7.2.2 Potential of household biogas digesters in Tanzania

As mentioned in chapter 6.4, under consideration of aspects of climate, feedstock, technology, social and economic, the potential households for Tanzania can be calculated. Climate factor, especially the temperature in Tanzania is not a limited issue for the safe operation of a biogas digester. With the average temperature of 20°C - 25°C, Tanzania has typically a tropical climate (National Bureau of Statistics Tanzania, 2017). Therefore, 100% of the households in Tanzania are suitable for biogas technology from the climate aspect, especially for the underground digester. As mentioned in chapter 5.1.1, only 66.88% of the total population had access to an improved water source. However, 72.7% of agriculture populations can receive improved water within 30 minutes of walking distance in 2007 (K. Nkonya, 2008). With an annual growth rate of 0.7% (World Bank Group, 2018), the number was increased to 80.4% in 2018. From the social and economic factors, 82.40% of the farmers without other renewable energy sources or commercial energy supply were accounting to be potential biogas users (International Energy Agency, 2019d). Some families (73.6% of total population) had the ability to finance the biogas digester (World Bank Group, 2019). These two types of farmers accounted only for 60.6% of the total household.

As results, Tanzania had 11.73 million households in 2018. Only 3.14 million households hold 1-10 large livestock, which were suitable for the development of household biogas from the feedstock sources for biogas fermentation. Among the scattered farmers, 80.4% of them had access to water sources and 60.6% belonged to the energy and social conditions of suitable areas. Therefore, the potential household biogas digesters were 0.93 million units, accounting for 7.94% of the total number of households.

In Tanzania with the 3% of natural growth of the population, it will reach 59.81 million in 2020 and 133.90 million in 2050. Thus, the number of households increases to 12.46 million in 2020 and 27.90 million in 2050.

Agriculture mainly contributes to a part of GDP in Tanzania, which is also the main target for the next 50 years. With the development of agriculture and increase of income, the number of small holders will increase to 2.48 million in 2020 and 5.99 million in 2050. With an annual growth rate of 0.7% (World Bank Group, 2018), more and more households have water sources within 2km, which are suitable for the development of biogas. With the increase of income, more farmers have the ability of financing the biogas plant (World Bank Group, 2019). However, there are also some families have capability of consuming commercial clean energy such as electricity and natural gas; where their dependence on household biogas-decreases. From the above aspects, the suitable households for small biogas digesters increase slowly, accounting for 1.01 million in 2020 and 2.61 million in 2050 (as shown in Table 7-16). Figure 7-5 presents the trends of biogas potential and their proportion of total households in Tanzania. Until the end of 2017, the number of household biogas digesters in Tanzania was 6,441, which is still far from the potential number (ABPP, 2021)

Table 7-16 Potential of household biogas digesters in Tanzania from 2020 to 2050

Items / Year	2020	2030	2040	2050
Total households [million]	12.46	16.70	21.86	27.90
Potential of household biogas digesters [million]	1.01	1.45	2.01	2.61
Proportion of total households [%]	8.07%	8.67%	9.20%	9.36%

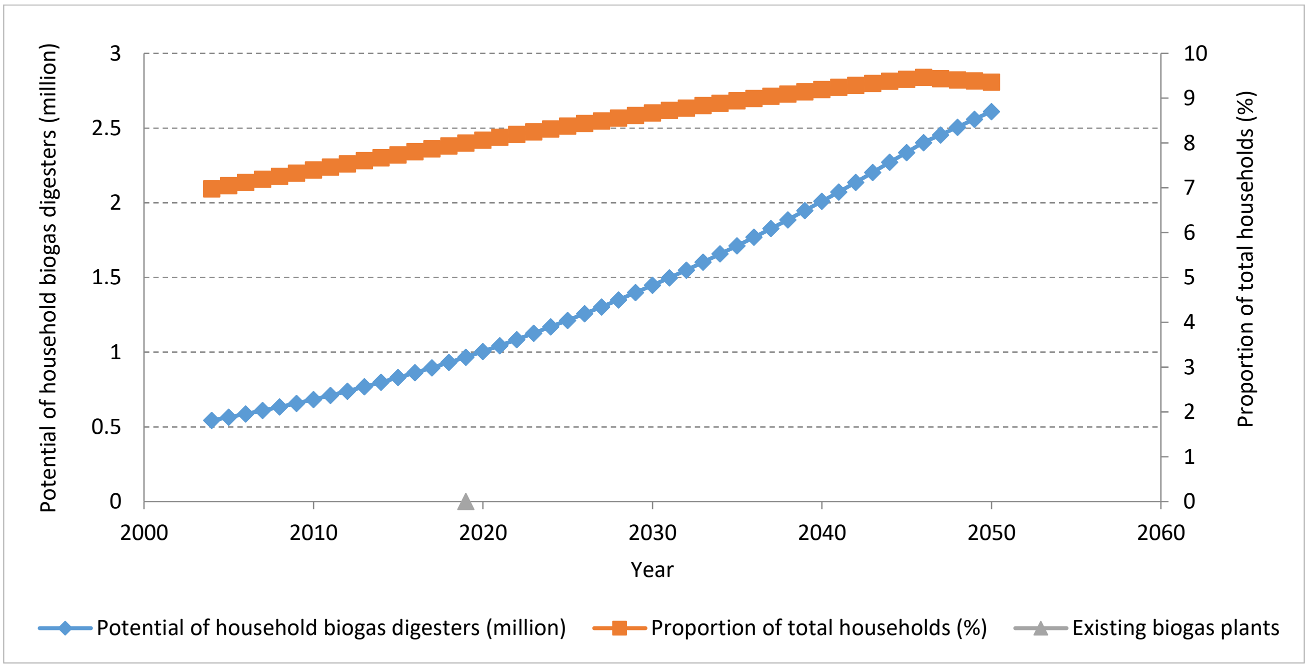

Figure 7-5 Potential of household biogas digesters in Tanzania

7.2.3 Economic analysis

7.2.3.1 Invest cost of household biogas digester

The investment cost of household biogas digester is relative to the price of construction materials and personal cost. With the development of economy and society in Tanzania, there are more and more infrastructure projects. The scarcity of building material causes the continuous increase of construction materials' prices. The price of cement reaches to approximately 84 €/Mg, a lightweight cement block to 0.95 €/pieces and steel is in fact around 0.8 €/kg (CAITEC, 2019a). In Tanzania, ordinary workers have a monthly salary of about 160,000 shillings (€ 64), and the engineer or scientists have better payment of 310,000 shillings (€ 125) (CAITEC, 2019a). Therefore, the average cost of a cement-brick-built biogas digester with 8 m^3 is approximately € 437.

The annual maintenance cost with around € 44 includes the personal cost for regular check by technicians, the cost for fitting materials and cost for the biogas appliance.

7.2.3.2 Benefits of biogas plant

The economic benefit of household biogas digesters can be calculated with the benefits of digestate and the benefits of biogas.

The same concept for usage of biogas as in other countries will be considerate (as shown in Table 6-6). 263 m^3 of biogas is used for cooking and 77 m^3 of biogas is used to light one biogas lamp for 3 hours per day. As shown in Table 7-17, with the fuel price, the substitution ratio and the assumed fuel mix, the value of biogas in Tanzania can be calculated. The value of 263 m^3 biogas for cooking is € 17.31.

Table 7-17 Biogas value for cooking (BV_c) in Tanzania

Assumption: 263 m^3 biogas for cooking

Biogas replacement	Substitution ratio	Fuel mix	Substitution amount	Fuel price [€/Unit]	Biogas value (BV_c) [€]
Charcoal [kg]	1.59	12.24%	51.15	0.04[1]	2.25
Fuelwood [kg]	2.60	75.26%	514.86	0.00	0.00
LPG [kg]	0.51	10.68%	14.45	0.91[2]	13.15
Electricity [kWh]	4.86	1.82%	23.24	0.08[2]	1.91
Sum					**17.31**

[1] (Ishengoma, et al., 2016), [2] (CAITEC, 2019a)

As another important benefit for the farmers, usage of biogas brings the lighting for many farmers. According to the biogas usage, 77 m³ of biogas can be used for one biogas lamp for 3 hours per day for the whole year. Therefore, a LED lamp can be replaced, and electricity cost can be saved. The value of 77 m³ biogas for lighting in Tanzania is ca. € 0.90 (see Table 7-18). Table 7-19 and Figure 7-6 summarized the value of biogas in Tanzania. According to the concept of usage of 340 m³ of biogas, biogas has a total value of € 18.21 in Tanzania. The value of 1 m³ of biogas is € 0.05.

Table 7-18 Biogas value for lighting (BV_L) in Tanzania

Assumption: 8m³ biogas digester, 77 m³ biogas for lighting					
	Amount	Power [W]	Working time [h]	Electricity price [€/kWh]	Biogas value (BV_L) [€/a]
Lamp	1	10	3	0.08	0.90

Table 7-19 Biogas value in Tanzania (8m³ biogas digester)

	Volume [m³]	Value [€]
Biogas for cooking (per year)	263	17.21
Biogas for lighting (per year)	77	0.90
Biogas value [€/a]		18.21
Biogas value [€/m³]		**0.05**

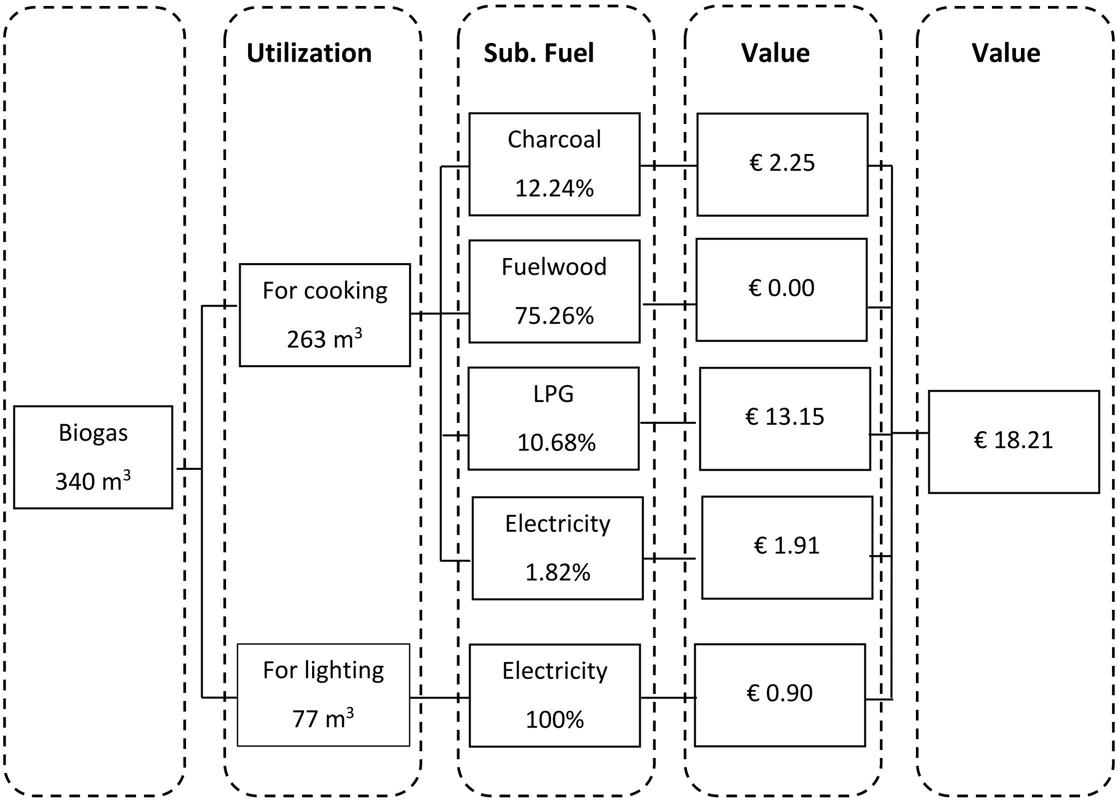

Figure 7-6 Biogas value in Tanzania

The value of digestate:

As mentioned in chapter 6.5.3, the value of digestate include 3 parts: the income of better agriculture yields as benefits of garden (BG), the benefits of livestock income of more livestock products and the benefits of fertilizer (BF).

Digestate is rich in nutrients and can be substitutes of fertilizer. The price of fertilizer in Tanzania is around € 0.4 per kilogram (africafertilizer, 2020). With the annual demand of 0.00126 kg of fertilizer per square meter (The World Bank, 2017b), 0.63 kg of fertilizer is necessary, thus, € 0.25 can be saved through the usage of digestate.

Besides the fertilizer, the digestate can be used as feed for livestock, leading to the quick and better growth of animals. With the average beef meat price and the assumption of one cow, the digestate has the value of € 136 per year. For cultivation, the annual production value of the crops, vegetables and flowers with better yields is increased, which accounts also for € 120 per year.

Table 7-20 Summary table of economic analyze for an 8 m^3 biogas digester in Tanzania

Invest	**Details**	**Costs [€]**
Investment costs	Construction cost for biogas plant	437 (Once only)
Annuity	Working life with 15 years and interest of 6%	45.01
Operation costs	Maintenance cost and material costs for fitting materials	44

Income and savings	**Details**	**Costs [€/a]**
Alternative energy	Replacement of the raw coal and savings in fuel costs: Biogas value for cooking (BVc)	17.31
	Save power by using the biogas lamps in the household: Biogas value for lighting (BV_L)	0.90
Benefits of livestock (BL)	More income for slaughter	136.11
Benefits of garden (BG)	Increased annual production value	120.00
Benefits of fertilizer (BF)	Saving of fertilizer	0.25
Sum [€/a]		**274.57**

Discounted Payback Period (DPP) [a]	**2.07**
GNI [€/a]	**874**

Table 7-20 presents the brief of the economic aspect of a household biogas plant with the invest cost, operation cost, incomes and savings. Around € 437 must be invested for an 8 cubic meter biogas digester (annuity of € 45.01) and the maintenance cost is € 44 per year. The annual economic benefit of usage of a biogas digester is € 275, therefore, after 2.07 years, the invest cost can be covered.

7.2.4 Ecologic analysis

According to the biogas use concept for an 8m^3 biogas digester, 515 kg fuelwood is substituted by biogases each year, which equivalents for to the conservation of the forest area of 67.04 m^2 (see Table 7-21).

Table 7-21 Forest conservation according to usage concept of 340 m^3 biogas (8 m^3 digester) in Tanzania

Save the amount of wood [kg]	Density of fuelwood [kg/m^3]	Forest growing stock [m^3/ha]	Forest conservation (FC) [m^2]
515	600	128	**67.04**

The substitution of other fuels by combustion of biogas producing from an 8m^3 biogas digester could achieve an amount of annual GHG reduction of 657 kg. However, considering of the natural CO_2 property of biomass, only 135 kg of GHG emission (CO_2 equivalent) will be reduced (see Table 7-22).

Table 7-22 GHG reduction according to usage concept of 340 m^3 biogas (8 m^3 digester) in Tanzania

GHG reduction by biogas (CO_2 equivalent)	Raw coal	Fuelwood	LPG	Electricity	Biogas
Unit	[kg]	[kg]	[kg]	[kWh]	[m^3]
Average annual amount [unit/a]	51	515	14	34	340
CO_2 Emission Factor [g/Unit]	1,588	1,625	3,074	267	925
Annual amount of CO_2 emissions [kg/a]	81	837	44	9	315
Annual amount of CO_2 emissions (Consideration of neutral biomass) [kg/a]	81	0	44	9	0
Reduction of annual amount of CO_2 emissions from biogas [kg/a]	135				

7.3 Biogas in Ethiopia

7.3.1 Transferability study in Ethiopia

Ethiopia has relatively good natural conditions for biogas technology, that score is 0.75. Although the problem of scarcity of clean energy supply in Tanzania, the needs for biomass utilization is not urgent due to the enough hydro power. Therefore, the score in items of scarcity of traditional energy supply is 0.75, but the needs for share of renewable energy gets only score of 0.25.

In Ethiopia, small livestock farmer has access to input material for biogas plant. Normal construction materials, sand, grit, stone, and brick are available in Ethiopia. The basic biogas appliance - biogas lamp and biogas stove – cannot be provided by local manufacturing companies, which were donated for supporting the biogas promotion in Ethiopia from other countries. Thus, score for material aspect is in middle level (score of 0.5). As the biogas technology has developed rapidly only since the last 10 years, and the main part of the biogas program has been supported by foreign governments or organizations, this technology is still not yet mature in Ethiopia. Therefore, the score of technical aspect is 0.25.

There are currently no laws or regulations regarding biogas. For development of the renewable clean energy and reduction of the greenhouse gas effect, these government offices are always eager for supporters for any domestic biogas program. However, that the capacity of these organizations, in terms of operating funds, infrastructure and manpower, may be insufficient to effectively support a larger initiative. Through the stakeholder consultation and a national workshop organized by the umbrella organization for Microfinance Institutions (MFIs), the Association of Ethiopian Microfinance Institutions (AEMFI), regional MFIs indicated their willingness to provide credit to biogas rural households. Providing microfinance for biogas is considered a ‘low’ risk investment (Boers, 2008). In sum up, the score of political and financial aspect are 0.25, respectively.

The specific scores of each criterion in Ethiopia's transferability study for household biogas development as well as the results considering the weighting of criteria are listed in the Table 7-23. The result of transferability study of household biogas digester in Ethiopia is 0.46, which is confirmed that, natural advantages, abundant resources and lack of energy have proven that Ethiopia is quite suitable for the development of household biogas, which requires further government support and closer international cooperation in issues of finance and technique.

Table 7-23 Score of each criterion and Results of transferability study in Ethiopia

		Criteria	Score	Result
A1	Climate	Suitable climate condition	0.75	0.04
B1	Energy	Scarcity of traditional energy supply for household	0.75	0.11
B2		Requirement for the share of renewable energy	0.25	0.03
C1	Material	Availability of feeding material for biogas digester	0.50	0.10
C2		Availability of water	0.50	0.01
C3		Availability of space for agriculture	0.75	0.02
C4		Availability of construction material	0.50	0.01
C5		Availability of biogas appliance	0.25	0.01
D1	Technical	Availability of engineers for design and quality control	0.25	0.01
D2		Availability of workers for construction, operation and after-sale-service	0.25	0.01
E1	Finance	Finance ability	0.25	0.04
E2		Access to credit	0.25	0.03
F1	Social	Role of women in domestic decision-making process and life	0.50	0.01
F2		Integration of biogas plant into normal working routine at the farm	0.50	0.01
F3		Ethical aspect	0.50	0.01
G1	Political	Availability of Standards, laws and regulations on biogas technology	0.25	0.01
G2		Political will of the Government to support a national biogas program	0.50	0.01
G3		Monitoring and supervision	0.25	0.01
Sum				**0.46**

Table 7-24 presents the results of 4 scenarios of transferability analysis in Ethiopia. The regions in Ethiopia with the best conditions for household biogas digester, reach the final score of 0.77, although the worst case has score of 0.28. The enormous difference is reflected in economics and materials issues, which occupy also large weighting in transferability study. There is hardly any difference between the results of national average condition (with 0.46) and national general condition for 80% of population (with 0.48).

Table 7-24 Results of 4 scenarios in Ethiopia

		Worst	Best	Average	General
A	Climate	0.04	0.05	0.04	0.04
B	Energy	0.09	0.20	0.14	0.10
C	Material	0.13	0.28	0.15	0.16
D	Technical	0.01	0.04	0.01	0.03
E	Finance	0.00	0.13	0.06	0.10
F	Social	0.01	0.04	0.03	0.03
G	Political	0.01	0.04	0.03	0.03
Sum		**0.28**	**0.77**	**0.46**	**0.48**

Because of the poverty and economic backwardness in Ethiopia, variation VI has a significant drop in final score from 0.57 to 0.08. Considering of the shortage of technic workers or engineers in some area in Ethiopia, it shows disadvantage of construction of household biogas plants (with the results of 0.26). As demonstrated in Table 7-25 and Figure 7-7 as well, the final comprehensive evaluation score is sharply increased if increasing the weighting of energy issues. Results of national average condition and general condition of 80% population causes relatively less influence on final scores.

Table 7-25 Results of sensitivity analysis in Ethiopia

	Worst	Best	Average	General
I	0.28	0.77	0.46	0.48
II	0.25	0.74	0.44	0.50
III	0.44	0.95	0.67	0.50
IV	0.41	0.90	0.50	0.52
V	0.26	0.75	0.29	0.49
VI	0.08	0.57	0.31	0.41
VII	0.26	0.75	0.49	0.49
VIII	0.13	0.52	0.36	0.36

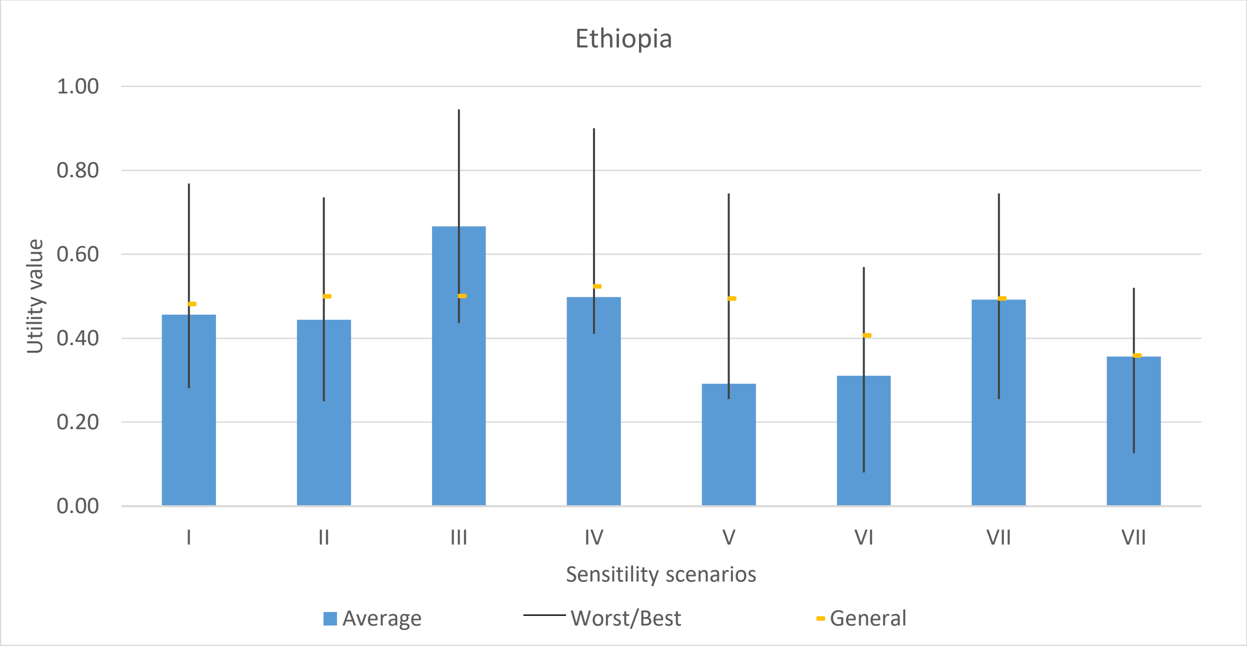

Figure 7-7 Results of sensitivity analysis in Ethiopia

7.3.2 Potential of household biogas digesters in Ethiopia

With the calculation method in chapter 6.4, to estimate of rural biogas potential in Ethiopia, many of factors such as climate, materials, technology, financing and social aspect must be considered. With respect to materials, the potential households must ensure the daily fresh materials of 20 kg for feedstock to the biogas digester. Ethiopia´s agriculture and livestock contribute not only to rural areas, but also to urban farmers. In 2018, there were 25.40 million households in whole Ethiopia. Out of the 17.78 million households keeping livestock, 70% own 2 to 15 livestock (FAO, 2017). Thus, the country is suitable for the development of household biogas digesters in around 12.44 million households.

Climate factor, especially temperature is one of the main parameters for the safe operation in a biogas digester. In most of the regions of Ethiopia, the average temperature is 15°C - 20°C (FAO AQUASTAT, 2016). Although it would drop to 0°C at midnight, it is not a problem for an underground digester. Therefore, 100% of the households in Ethiopia are suitable for biogas technology from the climate aspect.

The availability of water to get a mixture of 20 kg fresh materials with 1:1 ratio also plays an important role for the calculation of biogas potential. Practically, the water source should be located within 20 to 30 minutes of walking distance. In Ethiopia, 69% of population have safe water pipe (CIA Drinking water source, 2019).

Regarding the energy supply, 2 types of farmers are not suitable for development of household biogas digesters: the farmers with other renewable energy sources such as solar, wind, or micro-hydro resources, because they should use totally that energy. Furthermore, the case of some rich farmers that have clean commercial energy supply are also not considered to be suitable. These two types of farmers account only for 8% of the total nation (International Energy Agency, 2019f).

Economical aspects also affect the number of households suitable for having these digesters. Some farmers still do not have the economic ability of construction of a biogas plant or awareness of biogas benefits. Those mentioned categories of farmers are about 24% of the total population in Ethiopia (Teka, 2021), which are not appropriate for biogas development.

In total, Ethiopia had 25.40 million households in 2018. From the feedstock sources for biogas fermentation, the farmers suitable for the development of household biogas were 12.44 million households. Among the scattered farmers, 69% of them distribute on water access suitable areas, 8% and 24% belong to the energy and economic conditions of suitable areas, respectively. Therefore, according to the synthesizing analysis of suitability, the farmers who have the proper conditions for this implementation are 5.74 million households, accounting for 22.60% of the total number of households.

For the calculation of potential biogas users, parameters such as population, economy, water sources, and social aspects must be considered. With the high natural growth of the population the number of households increases rapidly as well, reaching 26.69 million in 2020 and 46.66 million households in 2050.

According to the increase of income and improvement of water availability, more and more households are suitable for the development of biogas. However, more and more farmers have the ability of commercial clean energy consumption such as electricity and natural gas; their dependence on household biogas is decreasing. Additionally, due to the change of livestock form to centralized farming, the backyard farmers will be reduced. From the above aspects, the suitable households for household biogas digester will increase slowly, accounting for 6.22 million in 2020 and 14.59 million in 2050.

The increase of suitable households for biogas development is slower than the increase of total amount of households. Therefore, the proportion of suitable households for the development of biogas is declining. The existing household biogas plant in Ethiopia was 18,534 in 2017 (ABPP, 2021), which represents only 0.34% of potential farmers. The numbers of suitable households for development of biogas from 2020 to 2050 are shown in Table 7-26 and the trends of biogas potential are shown in Figure 7-8.

Table 7-26 Potential of household biogas digesters in Ethiopia from 2020 to 2050

Items / Year	2020	2030	2040	2050
Total households [million]	26.69	33.37	40.12	46.66
Potential of household biogas digesters [million]	6.22	8.91	11.84	14.59
Proportion of total households [%]	23.32%	26.69%	29.50%	31.28%

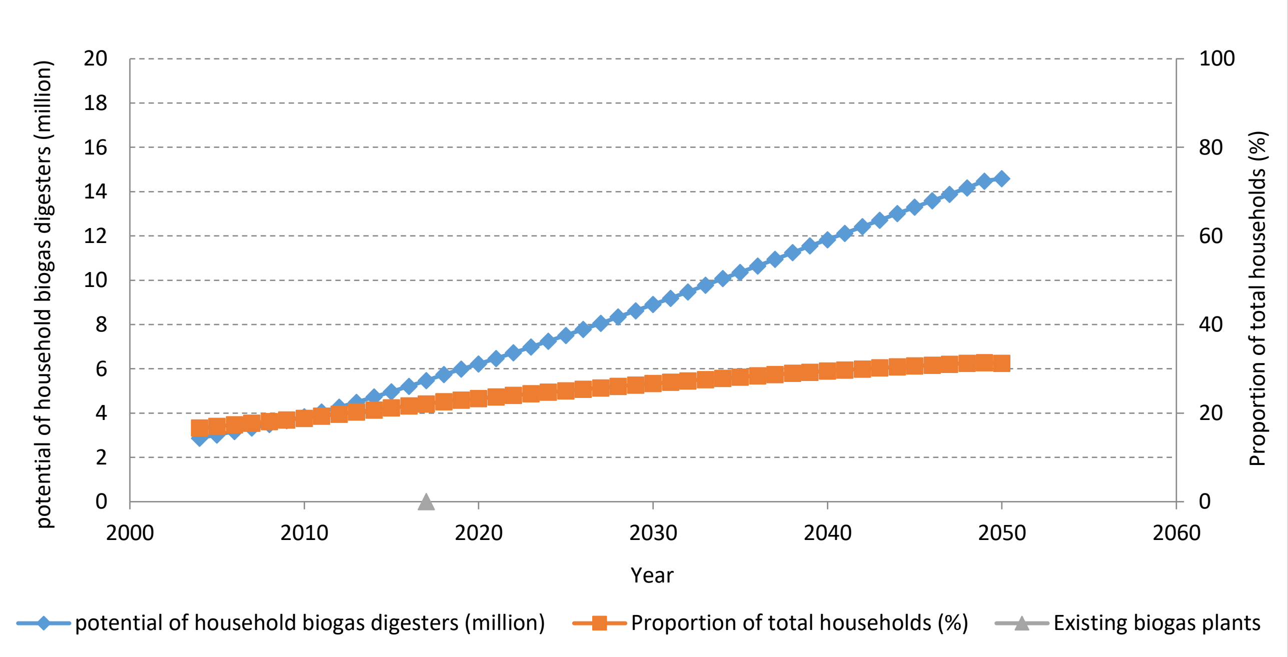

Figure 7-8 Potential of household biogas digesters in Ethiopia

7.3.3 Economic analysis

7.3.3.1 Investment costs of household biogas digester

The high investment cost of a biogas digester is one of the main constrains for the dissemination of biogas technology in Ethiopia (Boers, 2008). The cost of a biogas digester has increased due to general inflation, the price increment of cement and fitting materials. The construction of biogas digesters in Ethiopia is basically cement-brick-built. With the establishment of new cement factories, it can be expected that the price of cement to reduce in the future. Thus, the investment costs of an 8 m³ biogas digester is € 375. The maintenance costs include the personal cost for regular check done by technicians, costs for fitting materials and costs for biogas appliance. It accounts for € 37 per year.

7.3.3.2 Savings and income

The value of biogas can be estimated as the substitute fuel for cooking and lighting separately (chapter 6.5.3). To compare the biogas value in Ethiopia with other countries, the same concept for usage of biogas as shown in Table 6-6 will be considered. 263 m^3 of biogas is used for cooking and 77 m^3 of biogas is lighted with one biogas lamp for 3 hours per day. The calculation of the value of biogas for cooking is based on the fuel price; the substitution ratio and the assumed fuel mix (see Table 7-27). The value of 263 m³ biogas for cooking is around € 11.41. The electricity costs for lighting can be saved through the usage of biogas. Table 7-28 presents the important parameters by replacement of LED lamp and the saved electricity costs. The value of 77 m³ biogas for lighting is € 0.35, which is only a small part of the energy cost.

Table 7-27 Biogas value for cooking (BV_C) in Ethiopia

Assumption: 263 m³ biogas for cooking

Biogas replacement	Substitution ratio	Fuel mix	Substitution amount	Fuel price [€]	Biogas value (BV_C) [€]
Charcoal [kg]	1.59	8%	33.43	0.20[1]	6.62
Fuelwood [kg]	2.60	76%	519.93	0.00	0.00
Crop residue [kg]	5.71	2%	30.05	0.00	0.00
Electricity [kWh]	4.86	5%	63.85	0.03[2]	2.04
Oil product [kg]	0.68	1%	1.78	0.67[1]	1.19
LPG [kg]	0.51	1%	1.35	1.15[1]	1.56
Dung [kg]	7.53	7%	138.71	0.00	0.00
Sum					**11.41**

[1] (Asfaw, 2012) [2] (CAITEC, 2019c)

Table 7-28 Biogas value for lighting (BV_L) in Ethiopia

Assumption: 8m³ biogas digester, 77 m³ biogas for lighting					
	amount	Power [W]	Working time [h/d]	Electricity price [€/kWh]	Biogas value (BV_L) [€/a]
Lamp	1	10	3	0.032	0.35

Biogas value in Ethiopia is summarized in Table 7-29 and Figure 7-9. With the assumption of 340 m³ biogas produced from 8m³ biogas digester, the saving of substitution of fuels is € 11.76. The value of 1 m³ biogas can be also estimated for € 0.04.

Table 7-29 Biogas value in Ethiopia (8m³ biogas digester)

	Volume [m³]	Economic Value [€]
Biogas for cooking (per year)	263	11.41
Biogas for lighting (per year)	77	0.35
Biogas value [€/a]		11.76
Biogas value [€/m³]		**0.04**

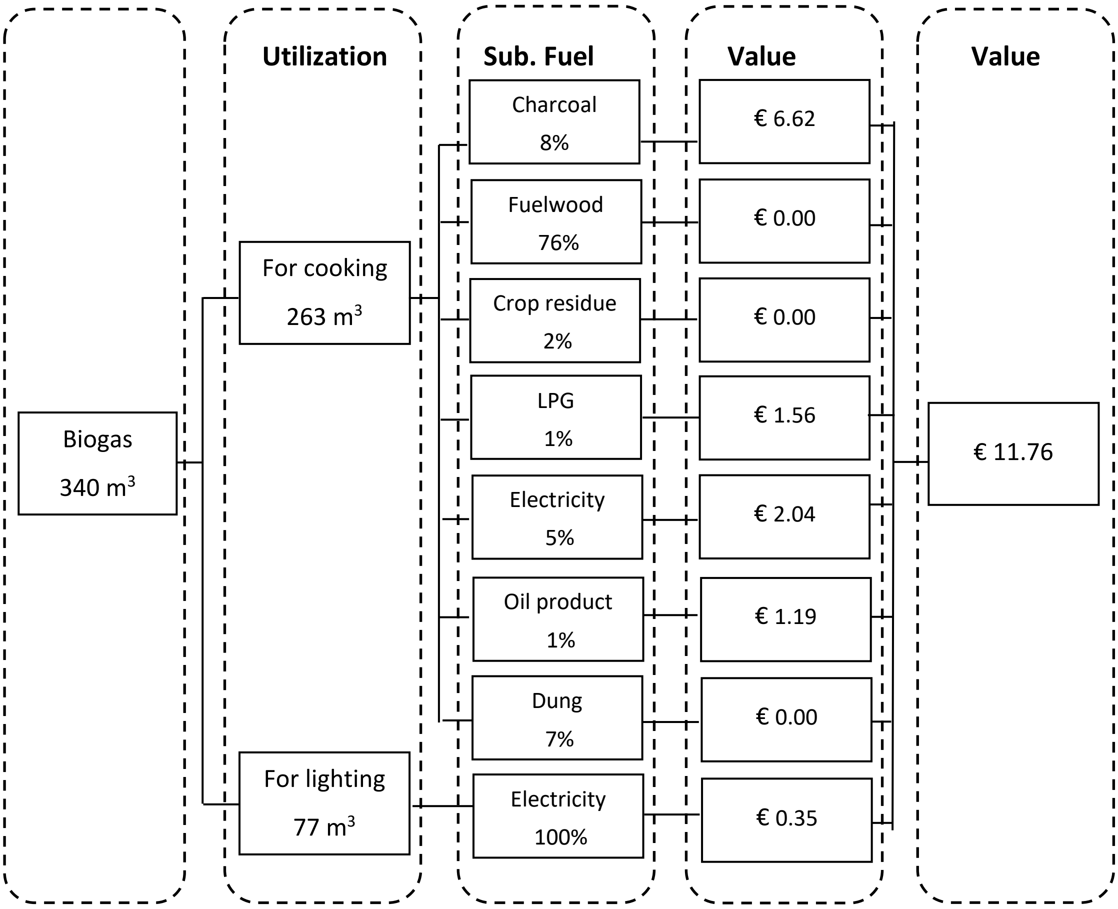

Figure 7-9 Value of biogas in Ethiopia

Value of the digestate: Ethiopia has the tradition of using fertilizers; therefore, the use of fertilizer would save the cost of chemical fertilizer. With the unit price of fertilizer of € 0.3 per kg (Yamano, et al., 2010), the saving price of 0.72 kg fertilizer for 500 m^3 yards is around € 0.22 per year, of which 0.00144 kg fertilizer per m^3 yard (The World Bank, 2017b).

Additionally, the fertilizer can be used as feed for livestock helping to decrease the cost of feeds. Regarding the livestock, digestate has the value of € 326 per year. For cultivation, the annual production value of the fruits with better yields is increased, which accounts also for € 90 per year.

In a word, around € 375 must be invested for a biogas plant of 8 m^3 biogas digester with 500 m^3 yard and the maintenance costs is € 37 per year. With the total annual savings of € 428 as shown in Table 7-30, the payback period is 1.02 years.

Table 7-30 Summary table of economic analyze for an 8 m^3 biogas digester in Ethiopia

Investment	**Details**	**Price [€]**
Investment costs	Construction cost for biogas plant	375 (once only)
Annuity	Working life with 15 years and interest of 6%	36.25
Operation costs	Maintenance cost and material costs for fitting materials	37

Income and savings	**Details**	**Price [€/a]**
Alternative energy	Replacement of the raw coal and savings in fuel costs: Biogas value for cooking (BVc)	11.41
	Save power by using the biogas lamps in the household: Biogas value for lighting (BV_L)	0.35
Benefits of livestock (BL)	More income for slaughter	326.42
Benefits of garden (BG)	Increased annual production value	90.00
Benefits of fertilizer (BF)	Saving of fertilizer	0.22
Sum [€/a]		**428.40**

Discounted Payback Period (DPP) [a]	**1.02**
GNI [€/a]	**685**

7.3.4 Ecological analysis

As previously mentioned in chapter 6.6.1, according to the biogas use concept, fuelwood is substituted by biogas reducing the deforestation and protecting the biodiversity. 520 kg fuelwood for burning annually can be saved, equivalents to the conservation of the forest area of ca. 68 m^2 (see Table 7-31).

Table 7-31 Forest conservation according to usage concept of 340 m³ biogas (8 m^3 digester) in Ethiopia

Save the amount of wood [kg]	Density of fuelwood [kg/m^3]	Forest growing stock [m^3/ha]	Forest conservation (FC) [m^2]
520	600	128	**67.70**

Table 7-32 shows the results of reducing GHG (CO_2 equivalent) in Ethiopia. The substitution of other fuels by combustion of biogas could achieve an amount of annual GHG reduction of 661 kg from an 8 m^3 biogas digester. However, considering the natural CO_2 property of biomass, 86 kg GHG emission (CO_2 equivalent) will be reduced.

Table 7-32 GHG reduction according to usage concept of 340 m³ biogas (8 m^3 digester) in Ethiopia

GHG reduction by biogas (CO_2 equivalent)	Raw coal	Fuelwood	Crop residue	Electricity	Oil product	LPG	Dung	Biogas
Unit	[kg]	[kg]	[kg]	[kWh]	[kg]	[kg]	[kg]	[m^3]
Average annual amount [unit/a]	33	520	30	75	2	1	139	340
CO_2 Emission Factor [g/unit]	1,588	1,625	1,464	119	3,148	3,074	105	925
Annual amount of CO_2 emissions [kg/a]	53	845	44	9	6	4	15	315
Annual amount of CO_2 emissions (Consideration of neutral biomass) [kg/a]	6	0	0	9	6	4	15	0
Reduction of annual amount of CO_2 emissions from biogas [kg/a]	86							

Improvement of rural environment: The human and animal manure are treated in fermentation process, in which the discharged untreated directly to the fields and results in pollution of the surface and groundwater.

Thus, the rural outdoor environmental situation can be improved. Indoor air pollution, mainly smoke caused by combustion of traditional fuels is minimized, resulting in a better indoor environment and a reduction of eye and lungs illnesses.

7.4 Biogas in Bolivia

7.4.1 Transferability study in Bolivia

Bolivia has relatively good climatic conditions, which scores 0.5 for the transferability study. In addition to LPG, biomass play an important role in the energy supply in Bolivia. Therefore, Bolivia has still a shortage of clean energy supply in rural areas (Hallberg, et al., 2015). Therefore, Bolivia is quite suitable for the development of biogas plants to solve the energy deficit (score of 0.5 for energy aspect). On average, a small farmer in Bolivia keeps 5 livestock (Rapsomanikis, 2015), from which the residues are available as feeding material in biogas digesters. Nevertheless, apart from feeding material, there are other determinants of biogas digesters in material issues, such as water and construction material, of which the availability lie in middle level with score of 0.5. However, heavy dependence on imported biogas stoves and biogas lamps biogas appliance results the lower score in criteria of availability of biogas appliance (score of 0.25).

Bolivia counts with few engineers in biogas sector from universities, or from foreign organizations like Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH or Netherland`s non-governmental organization (NGO). By organizing biogas training courses, several biogas workers have been trained for biogas plants construction and follow-up services. Because of the limited number of technical persons, so the score is only 0.25.

Although the value of biogas and digestate are a significant part of the finance for construction and daily operation, farmers in many of the visited areas need credit as a feasible financing option. In the past, farmers did have a reputation of being reluctant to take loans. The situation has improved since, but the extent to which this reluctance may still hamper a biogas promotion, which gets only score 0.25 in finance issue. The renewable energy does not have a very long history in Bolivia; there are neither standards nor regulations, laws on biogas technologies. The Bolivian government’s efforts to improve delivery of energy services to the poor have been quite intensive in recent years.

The score of each criterion as well as the results of transferability which were calculated based on the score of each criterion and their weighting are reviewed in Table 7-33. With the results of 0.41, Bolivia shows disadvantage for development of the household biogas technology, especially in terms of technic, finance and politic.

Even few changes of conditions in different regions bring up quite different results. For instance, the climate issues get quite different score in deferent regions, because of the different temperature in high and low altitude in Bolivia. Just 0.13 score obtain the regions with leakage of material, the farmers with best access to material attain the score of 0.29. Similarly, the obviously difference scores are given in terms of technical, finance, social and political between best case and worst case (see Table 7-34). In sum up, the results of transferability in Bolivia varies between 0.33 and 0.81. The general result for 80% population with 0.52 convinced that, the most region in Bolivia has no advantage condition for promotion of biogas digester.

Table 7-33 Score of each criterion and results of transferability study in Bolivia

		Criteria	Score	Result
A1	Climate	Suitable climate condition	0.50	0.03
B1	Energy	Scarcity of traditional energy supply for household	0.50	0.08
B2		Increase the share of renewable energy	0.50	0.03
C1	Material	Availability of feeding material for biogas digester	0.50	0.10
C2		Availability of water	0.50	0.01
C3		Sufficient space for agriculture	0.75	0.02
C4		Availability of construction material	0.50	0.01
C5		Availability of biogas appliance	0.25	0.01
D1	Technical	Availability of engineer for design and quality control	0.25	0.01
D2		Availability of worker for construction, operation and after-sale-service	0.25	0.01
E1	Finance	Finance ability	0.25	0.04
E2		Access to credit	0.25	0.03
F1	Social	Role of women in domestic decision-making process and life	0.50	0.01
F2		Biogas plant can be integrated into normal working routine at the farm	0.50	0.01
F3		Ethical aspect	0.75	0.01
G1	Political	Availability of standards, laws, and regulations on biogas technology	0.25	0.01
G2		Political will of the Government to support a national biogas program	0.50	0.01
G3		Monitoring and supervision	0.25	0.01
Sum				**0.41**

Table 7-34 Results of 4 scenarios in Bolivia

		Worst	Best	Average	General
A	Climate	0.01	0.05	0.03	0.03
B	Energy	0.09	0.19	0.10	0.11
C	Material	0.13	0.29	0.15	0.16
D	Technical	0.01	0.04	0.01	0.03
E	Finance	0.06	0.15	0.06	0.13
F	Social	0.02	0.05	0.03	0.04
G	Political	0.01	0.06	0.03	0.03
Sum		**0.33**	**0.81**	**0.41**	**0.52**

As demonstrated in Table 7-35 and Figure 7-10, the results of sensitivity analysis with national average condition in Bolivia shows, there are three variations have less sensitivities to final results, which are variation II (same weighting of all criteria), variation III (extreme weighting of energy) and variation IV (extreme weighting of material). If decision makers prefer household biogas digester in Bolivia, the emphasis could be put on several aspects, especially the availability of finance- and technic support. The results indicates that the household biogas digester performs better in the case that social suitability obtains more emphasis than other aspect.

Table 7-35 Results of sensitivity analysis in Bolivia

	Worst	Best	Average	General
I	0.33	0.81	0.41	0.52
II	0.28	0.81	0.43	0.56
III	0.42	0.93	0.48	0.52
IV	0.40	0.93	0.48	0.52
V	0.26	0.76	0.28	0.49
VI	0.26	0.67	0.29	0.50
VII	0.39	0.89	0.55	0.69
VIII	0.11	0.62	0.34	0.36

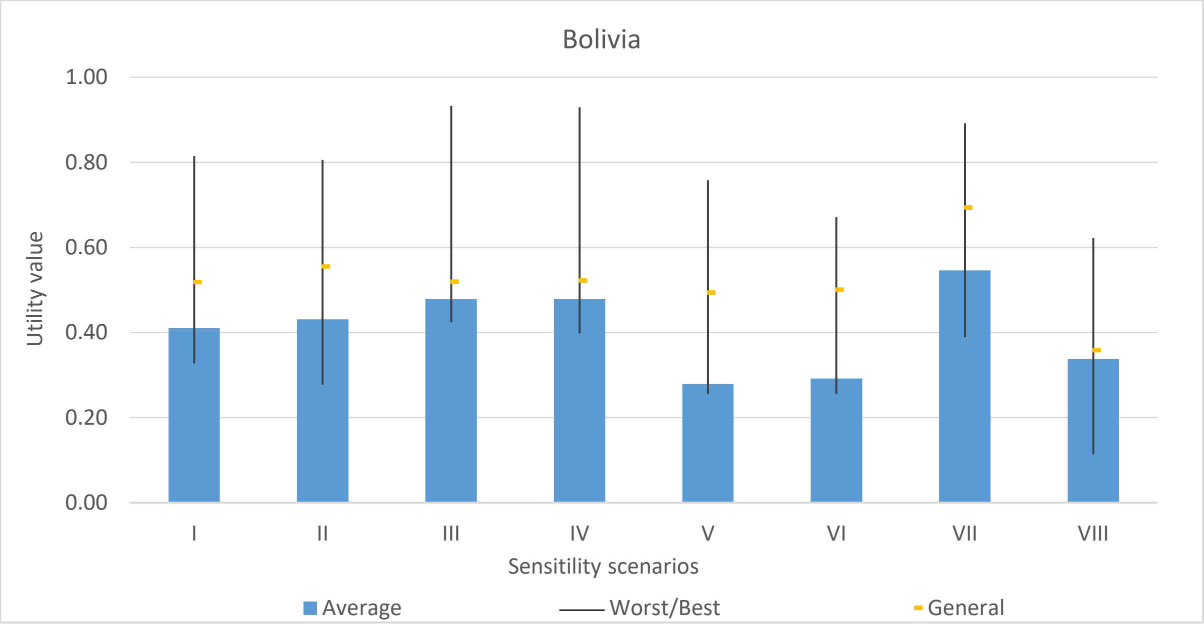

Figure 7-10 Results of sensitivity analysis in Bolivia

7.4.2 Potential of household biogas digesters in Bolivia

As mentioned in chapter 6.4, to estimate the potential of household biogas digesters, the number of households with 4 or more cattle is taken in consideration. As substrate, manure of all stabled animals (pigs, cows, donkeys, horses) would do it equally well. The moderate dispersion farming is an important condition of the rural household biogas. In 2010, Bolivia's small agriculture farmers were 0.91 million households (Rapsomanikis, 2015). In 2018, there were 3.15 million households in Bolivia, of which 31.5% engage as smallholder (Instituto Nacional de Estadistica , 2021).

The availability of manure as substrate for the installation is not the only technical parameter. Equally important is the availability of process water. The feedstock of digesters must be kept more than 90% moisture content; this is a necessary condition for normal operation of digesters, so the protection of water resources should be ensured also. In 2018, 85% of the population can use "improved" water (OLAS, 2021).

Appropriate temperature window (temperature of air and soil) is a necessary condition for the digesters over the winter safely uptime. In west-south areas in Bolivia, because of the high altitude, the average temperature in the coldest month is generally less than – 15°C - 20°C. Under bitterly cold climatic conditions, even if the plant is constructed in a fully enclosed warm lap, it cannot be ensured that digesters won´t being damaged by the cold in winter. These types of regions basically belong to the areas where the development of rural household biogas is non-suitable, where that is 28% of the country (IBP, 2017).

Following the energy-economic point of view, the farmers who are non-suitable for the implementation of biogas plants mainly include the following four categories: First, the areas that are rich in hydro and wind resources should make full use of this energy. Second, the pool farmers still don´t have the ability of construction of a biogas plant. Those mentioned two categories of farmers are about 35% (IRENA, 2021) and 23.40% (Macrotrends, 2021) of the distributed farmers in Bolivia, respectively.

Bolivia accounted for nearly 3.15 million households in 2018. From the sources of biogas fermentation feedstock, the farmers, that were suitable for the development of household biogas were 0.99 million households. Among the scattered farmers, 28% of them were located in the climate non-suitable areas, 15% on water access non-suitable areas, 35% belonged to the energy conditions of non-suitable areas and 23.4% had no economic ability. Therefore, according to this analysis of suitability, the farmers who had the proper conditions for the development of biogas across the rural areas, were 0.30 million households, accounting for 9.60% of the total number of households.

In the future, with the natural growth of the population and the improvement of economic level, more and more households will be suitable for the development of biogas. However, biogas constructions focus mainly on low-and middle-income farmers. High-income farmers have access to the ability of commercial energy consumption such as electricity and gas; hence their dependence on household biogas is decreasing. Additionally, with the development of the rural economy and the urbanization processing, the backyard farmers will be reduced. They are no longer engaged with pigs, cattle farming, where they are no longer the main fixed source of income for farmers. More and more farming population is working now in factories in the city, therefore, the proportion of suitable households for the development of biogas is declining. Till 2018, there was only 0.62% of potential farmers have built household biogas digesters in Bolivia, equals 1,750 biogas digesters, which showed great potential for the development of biogas digesters (Martí-Herrero, 2019).

The numbers of suitable households for development of biogas from 2020 to 2050 are shown in Table 7-36, and the trends of biogas potential are shown in Figure 7-11.

Table 7-36 Potential of household biogas digesters in Bolivia from 2020 to 2050

	2020	2030	2040	2050
Total households [million]	3.25	3.74	4.21	4.61
Potential of household biogas digesters [million]	0.33	0.41	0.37	0.29
Proportion of total households with livestock [%]	10.20%	10.95%	8.87%	6.20%

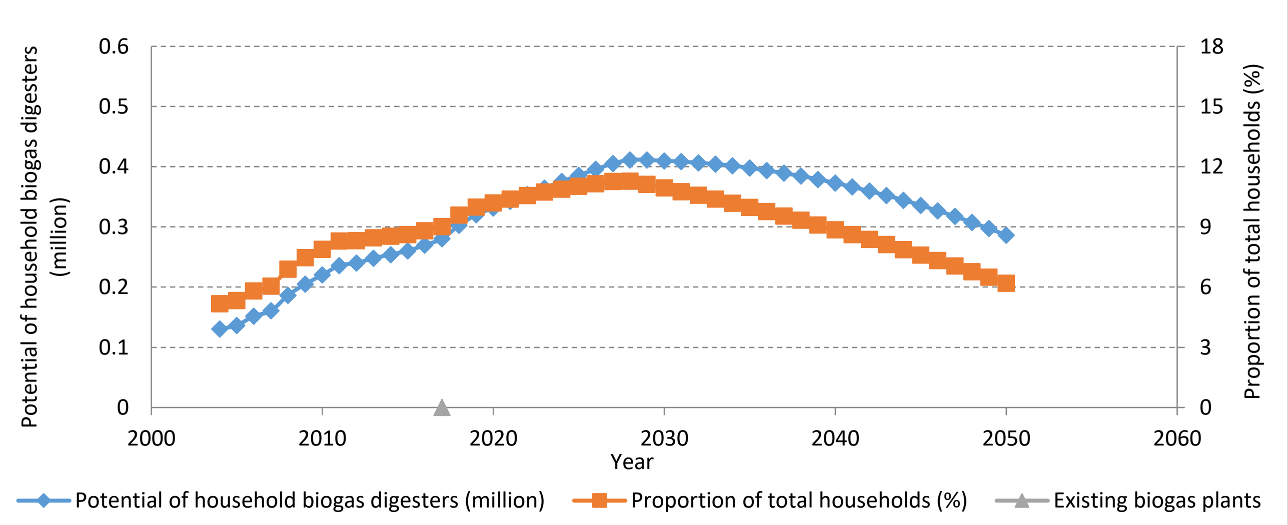

Figure 7-11 Potential of household biogas digesters in Bolivia

7.4.3 Economic analysis

7.4.3.1 Invest cost of household biogas digester

The price of construction materials and personal costs play a vital role for the calculation of the invest-cost of household biogas digesters. As in most African and Latin American countries, construction materials' prices have increased in the last years due to more demand of infrastructure projects and the increasing import and transport cost. The average cost of cement-brick-built biogas digester with 8 m³ is approximately € 1,112. For regular maintenance, there are personnel cost and cost for fitting materials, which accounts for around € 168 per year.

7.4.3.2 Saving and income

The unquestionable benefits for biogas users are the economic benefits of household biogas digester regarding, the monetary value of biogas and value of digestate.

Same calculation methods have been taken for Bolivia. The estimation of the monetary value of biogas equals to the saving of energy cost as it is substituted for fuel for cooking and lighting. Similar concept is applied for the usage of biogas in other countries which will be considered as well (as shown in Table 7-37). As an example, 263 m^3 of biogas are used for cooking with one biogas stove and 77 m^3 of biogas are lighted with one biogas lamp for 3 hours per day. As mentioned in chapter 5.3.1, biogas can be used in household for cooking as substitution of 47% of fuelwood, 45% of LPG and 7% of dung. The value of 263 m³ biogas for cooking is around € 17.72.

Table 7-37 Biogas value for cooking (BV_C) in Bolivia

Assumption: 8m^3 biogas digester, 263 m³ biogas for cooking

Biogas replacement	Substitution ratio	Fuel mix	Substitution amount	Fuel price [€]	Biogas value (BV_C) [€]
Fuelwood [kg]	2.60	46.51%	318.18	0.00	0.00
Electricity [kWh]	4.86	0.28%	3.58	0.09[1]	0.34
LPG [kg]	0.51	45.24%	61.22	0.28[2]	17.14
Oil product [kg]	0.68	0.33%	0.59	0.41[3]	0.24
Dung [kg]	7.53	6.57%	130.19	0.00	0.00
Sum					**17.72**

[1] (CAITEC, 2019d), [2] (CEIC, 2020), [3] (GlobalPetrolPrices, 2020)

For lighting, the biogas has the value of saving cost for one LED lamp of 3 hours per day. The value of 77 m³ biogas for lighting in Bolivia is ca. € 1.04 (see Table 7-38).

Table 7-38 Biogas value for lighting (BV_L) in Bolivia

Assumption: 8m^3 biogas digester, 77 m³ biogas for lighting					
	Amount	Power [W]	Working time [h]	Electricity price [€/kWh]	Biogas value (BV_L) [€/a]
Lamp	1	10	3	0.09	1.04

As shown in Table 7-39 and Figure 7-12, according to the concept of usage of 340 m^3 biogas, biogas has the total value of € 18.76 in Bolivia, which corresponding € 0.06 for 1 m³ biogas.

Table 7-39 Biogas value in Bolivia (8m^3 biogas digester)

Assumption: 8m^3 biogas digester, 340 m³ biogas		
	Volume [m³]	Economic Value [€]
Biogas for cooking (BV_C) (per year)	263	17.72
Biogas for lighting (BV_L) (per year)	77	1.04
Biogas value [€/a]		18.76
Biogas value [€/m³ Biogas]		**0.06**

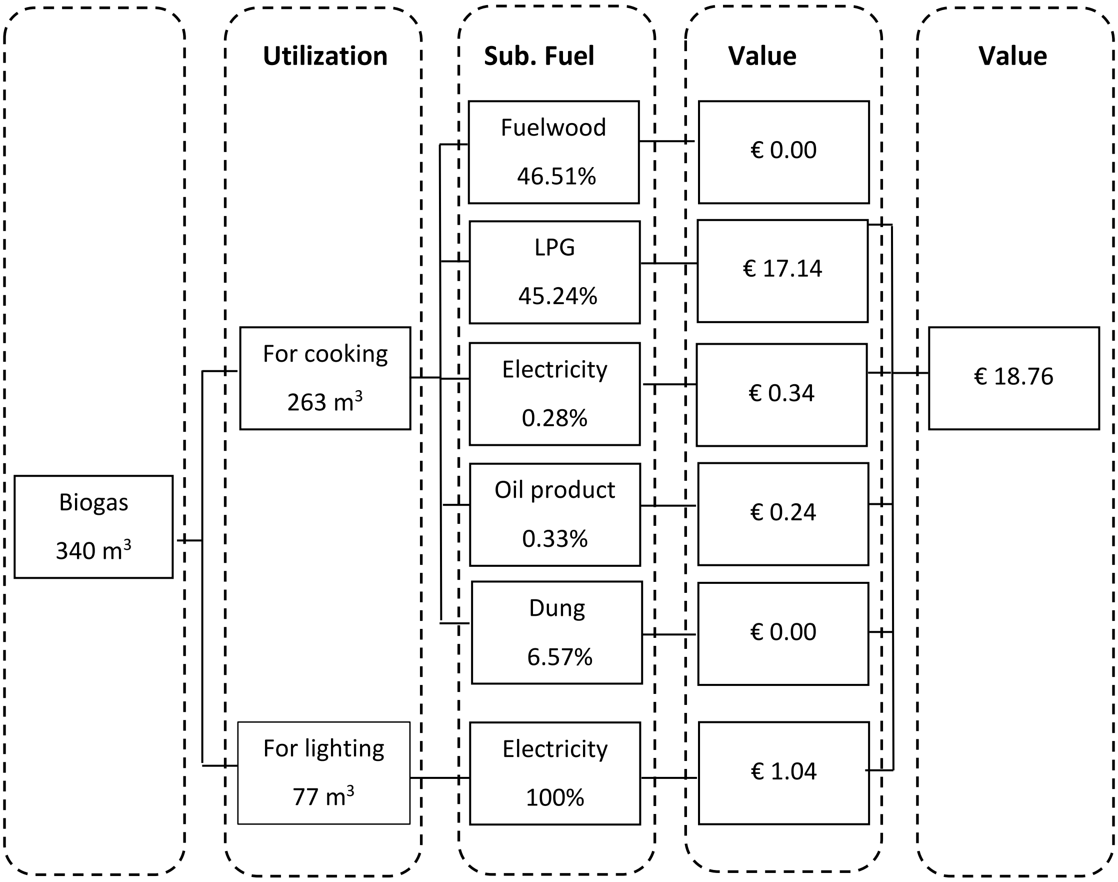

Figure 7-12 Biogas value in Bolivia

The value of digestate includes more income of better agriculture yields and the saving of cost of fertilizer. Around 40 kg digestate can be produced per day, which is enough for its utilization as fertilizer. The price of fertilizer in Bolivia is around € 0.6 per kilogram (Bnamericas, 2019). With the annual demand of 0.76 gram fertilizer per square meter (The World Bank, 2017b), 150 kg fertilizer is necessary. Thus, € 0.23 can be saved though the usage of digestate.

Additionally, digestate´s value as more income from livestock and cultivation being obtained, which is resulted by quick and better growth of animals and better crops yields. Thus, with the average meat price and crop price, digestate has the value of € 207 and € 150 per year for livestock and cultivation respectively.

As shown in Table 7-40, the economic aspect of household biogas plant with the invest cost, operation cost, incomes and savings are listed. Around € 1,112 must be invested for an 8 m^3 biogas digester where the annuity is € 115, and maintenance cost is € 168 per year. The annual economic benefits of usage of biogas digester reach € 376; the payback period is 6.64 years.

Table 7-40 Summary table of economic analyze for an 8 m^3 biogas digester in Bolivia

Invest	**Details**	**Costs [€]**
Investment costs	Construction cost for biogas plant	1112 (Once only)
Annuity	Working life with 15 years and interest of 6%	114.54
Operation costs	Maintenance cost and material costs for fitting materials	168

Income and savings	**Details**	**Costs [€/a]**
Alternative energy	Replacement of the raw coal and savings in fuel costs: Biogas value for cooking (BVc)	17.72
	Save power by using the biogas lamps in the household: Biogas value for lighting (BV_L)	1.04
Benefits of livestock (BL)	More income for slaughter	206.77
Benefits of garden (BG)	Increased annual production value	150.00
Benefits of fertilizer (BF)	Saving of fertilizer	0.23
Sum [€/a]		**375.76**

Discounted Payback Period (DPP) [a]	**6.64**
GNI [€/a]	**2,886**

7.4.4 Ecological analysis

Besides of the economic benefits, household biogas digesters have many positive impacts for ecological and social status for biogas users, which includes protection of forest, reduction of greenhouse gas, reduction of lunge and eye disease, reduction of domestic workload, improvement of rural environment and sanitary situations etc.

According to the biogas use concept, 318 kg fuelwoods are substituted by biogases each year. As mentioned in chapter 6.6.1, with the average density of fuelwood of 600 kg/m³ and the forest growing stock in Latin America of 178 m³/ha (FAO, 2016), 30 m² forests can be conserved (Table 7-41).

Table 7-41 Forest conservation according to usage concept of 340 m³ biogas (8 m³ digester) in Bolivia

Save the amount of wood [kg]	Density of fuelwood [kg/m³]	Forest growing stock [m³/ha]	Forest conservation [m²]
318	600	178	**29.79**

The greenhouse gas production due to the combustion of fuelwood or straw can be also reduced by the utilization of biogas. With the parameter of GHG emission factor and among the fuels, the GHG emission can be calculated respectively. Due to the fuel use concept, the annual GHG emissions of all substituted fuels reach 729 kg. Therefore, 414 kg GHG emission can be reduced. However, considering of the natural CO_2 property of biomass, 211 kg GHG emission (CO_2 equivalent) will be reduced (see Table 7-42).

Table 7-42 GHG reduction according to usage concept of 340 m³ biogas (8 m³ digester) in Bolivia

GHG reduction by biogas (CO_2 equivalent)	Fuelwood	LPG	Electricity	Oil product	Dung	Biogas
Unit	[kg]	[kg]	[kWh]	[kg]	[kg]	[m³]
Average annual amount [unit/a]	318	61	15	1	130	340
CO_2 Emission Factor [g/unit]	1,625	3,074	536	3,148	105	925
Annual amount of CO_2 emissions [kg/a]	517	188	8	2	14	315
Annual amount of CO_2 emissions (consideration of neutral biomass) [kg/a]	0	188	8	2	14	0
Reduction of annual amount of CO_2 emissions from biogas [kg/a]	211					

7.5 Biogas in Brazil

7.5.1 Transferability study in Brazil

The natural conditions in Brazil are not limiting factors for promotion of biogas technology, which has score of 0.75. Brazil has the best energy supply system in Latin America, even in rural area. Thanks to the hydro-energy, the demand of biogas as renewable energy is not so emergent. Moreover, the large amount of waste from the relatively centralized breeding in Brazil is more suitable for medium-size biogas plant. As a result, energy and feeding material aspect accounts to the biggest barrier for household biogas dissemination (with the score of 0.00). With the competent local and foreign suppliers, the requirements of the most building materials can be met. The existing biogas plants in Brazil are mainly large scale. There are almost no household biogas plants; the market of biogas appliance like biogas lamp and biogas stove are almost empty, which gets the score of 0.25. Many credit facilities provided by the government, bank, private credit units or foreign institutions aimed at developing sustainable energy, especially the renewable energy. Unfortunately, such credits have relatively few experiments not common for the household biogas sector. As can be seen, the technical, social and political support in Brazil has advantage with the score of 0.5 to 0.75. In summary, the results of transferability study for household biogas plant in Brazil is not satisfied, with the 0.35 is the lowest score within these five countries (as shown in Table 7-43).

Table 7-43 Score of each criterion and Results of transferability study in Brazil

		Criteria	Score	Result
A1	Climate	Suitable climate condition	0.75	0.04
B1	Energy	Scarcity of traditional energy supply for household	0.00	0.00
B2		Increase the share of renewable energy	0.25	0.01
C1	Material	Availability of feeding material for biogas digester	0.00	0.00
C2		Availability of water	0.75	0.02
C3		Sufficient space for agriculture	0.75	0.02
C4		Availability of construction material	0.75	0.02
C5		Availability of biogas appliance	0.25	0.01
D1	Technical	Availability of engineer for Design and quality control	0.50	0.01
D2		Availability of worker for construction. operation and after-sale-service	0.50	0.01
E1	Finance	Finance ability	0.50	0.08
E2		Access to credit	0.50	0.05
F1	Social	Role of women in domestic decision-making process and life	0.75	0.01
F2		Biogas plant can be integrated into normal working routine at the farm	0.75	0.01
F3		Ethical aspect	0.75	0.01
G1	Political	Availability of Standards, laws and regulations on biogas technology	0.50	0.01
G2		Political will of the Government to support a national biogas program	0.50	0.01
G3		Monitoring and supervision	0.50	0.03
Sum				**0.35**

Similarly, each criterion can be different evaluated in different region in Brazil. For the best case in Brazil, energy, material, as well as finance aspect has the significant advantages than the worst case. The result varies between 0.33 and 0.71, and the results of national average condition with 0.35 is nearly the worst case (see Table 7-44). The transferability study of national general condition of 80% population results 0.39. Obviously, most regions in Brazil are not suitable for household biogas digester.

Table 7-44 Results of 4 scenarios in Brazil

	Criteria	Worst	Best	Average	General
A	Climate	0.04	0.05	0.04	0.04
B	Energy	0.01	0.08	0.01	0.01
C	Material	0.06	0.15	0.06	0.06
D	Technical	0.03	0.05	0.03	0.04
E	Finance	0.13	0.25	0.13	0.15
F	Social	0.04	0.05	0.04	0.04
G	Political	0.03	0.08	0.05	0.05
Sum		**0.33**	**0.71**	**0.35**	**0.39**

As demonstrated in Table 7-45 and Figure 7-13, the final scores of changing the weightings are significantly changed in Brazil. Due to the relatively good energy supply in Brazil, it also has no very urgent needs of development of household biogas digester, which impact the scoring level. As can be seen, the extreme weighting of energy in variation III has greatly impact on the results, bandwidth from 0.12 to 0.42. Likewise, another big shortcoming in Brazil for household biogas digester is the unsuitable feeding material. The result would become worse if the weighting of material aspect is higher (Variant IV with results of 0.20 – 0.52). The results almost remain unchanged even if the weighting is changed by extreme weighting of finance, politic or technique aspect.

Table 7-45 Results of sensitivity analysis in Brazil

	Worst	Best	Average	General
I	0.33	0.71	0.35	0.39
II	0.47	0.88	0.51	0.56
III	0.12	0.42	0.13	0.13
IV	0.20	0.52	0.22	0.23
V	0.47	0.95	0.48	0.69
VI	0.47	0.94	0.48	0.58
VII	0.67	0.95	0.68	0.69
VIII	0.33	0.80	0.48	0.49

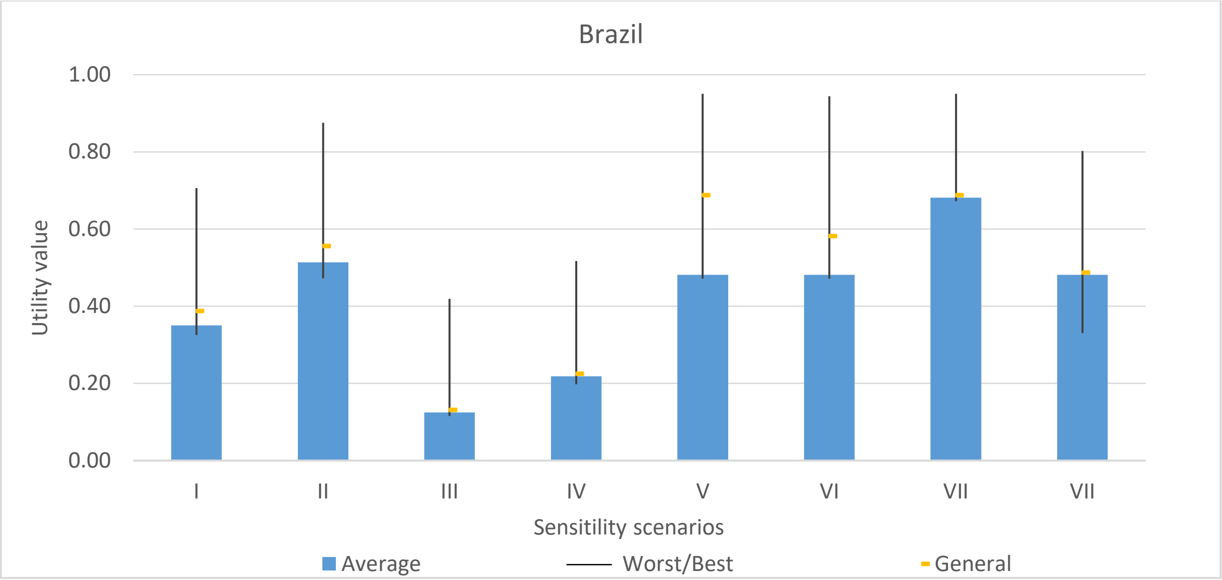

Figure 7-13 Results of sensitivity analysis in Brazil

7.5.2 Potential of household biogas digesters in Brazil

Brazil is the largest country in Latin America, ranking fifth in the world in terms of population. The total population of Brazil in 2018 was 209.47 million (The World Bank, 2019d). With an average of 3 persons in a household, Brazil had totally 69.82million households in the country. Only 13.96% of the total population lived in rural areas. With a low population growth rate of 0.82% and a 1.1% annual rate of urbanization (The World Bank, 2019d), the amount of household in rural area will drop to 9.25 million in 2020 and 5.61 million in 2050.

80% of Brazil's territory is located in tropical climate. Northern Brazil has tropical weather with the average temperature 27°C - 29°C. In the southern sub-tropical regions, the average temperature is 16°C -19°C (MFA, 2020). However, fix-dome-digester is built at least 2m depth underground, for which temperature is not a limit issue. Therefore, the favorable climate conditions are the basis for Brazil`s suitability for household biogas plant.

Availability of process water is a necessary condition for normal operation of digesters. As mentioned in chapter 5.4.1, the rate of the water supply in the rural areas stands at 90% in 2017 (UNICEF, 2019). From 2000 to 2007, the rate of access to clean water increased from 46% to 90%. At this rate of development, until 2022 around 100% of the rural population should access safety drinking water. Additionally, as a humid country Brazil has abundant rainfall, rural residents are also very easy to access water from river, well and other natural water sources. Therefore, water supply is not a limited issue for development of biogas technology.

According to the agricultural census, there are approximately 1.07 million smallholders in Brazil in year 2017 (21.18% of the total), with an average less than 2 hectares land (IBGE, 2017). Regarding to dairy farms, Brazil has a ratio of 1.08 animals per hectare of total pasture (Millen, et al., 2011). These farmers have enough space for their own garden, which is suitable for use of digestate as fertilizer for vegetables or crops in garden, otherwise, there are enough livestock to supply the raw materials for biogas digesters. They are suitable farmers to develop household biogas digesters. With the development of centralized breeding in Brazil, the smallholder will be decrease to 20.92% in 2020 and 18.37% in 2050 (IBGE, 2017).

Brazil has the best energy supply system in Latin America. In 2016, the fuels most used in households for cooking were LPG (93.2%), fuelwood (3.2%), gasworks gas (2.9%), charcoal (0.71%) and electricity (0.05%) (Gioda, 2019). Therefore, the whole Brazil has relatively developed energy supply system, even in rural areas. Only 3.2% of households, which use fuelwood as cooking fuels, are biogas potential user. Following the socio-economic point of view, some farmers don´t have the ability of construction of a biogas plant. In 2015, 8.7% of the population, who lies under poverty lines, accounts to unsuitable household for biogas development. Brazil’s poverty population is reduced by 0.09% per year (Statista, 2020). Hence, the poverty headcount ratio at poverty lines amounts to 8.3% in 2020 and 5.6% in 2050, respectively.

In summary, Brazil has total 9.25 rural households in 2020. Among them, 20.92% (corresponds 1.94 million households) has available feedstock for biogas digester. Besides, 97.34% of them accounts to water access suitable areas, 3.2% belong to the energy conditions of suitable areas and 91.74% have economic ability. Therefore, according to this analysis of suitability, only 0.06 million households in rural area in Brazil have the proper conditions for the development of household biogas digester, accounting for 0.08% of the total number of households. Until 2050, the proportion of suitable households for the development of biogas is declining to 0.04%., which corresponds to 0.03 million household. The existing small biogas digester in Brazil was only 514 in 2020 (Biogasdata, 2021), which equals to 0.93% of suitable household.

The numbers of suitable households for development of biogas in Brazil from 2020 to 2050 are shown in Table 7-46, and the trends of biogas potential are shown in Figure 7-14.

Table 7-46 Potential of household biogas digesters in Brazil from 2020 to 2050

	2020	2030	2040	2050
Total households [million]	71.02	75.92	78.77	79.80
Potential of household biogas plants [million]	0.06	0.05	0.04	0.03
Proportion of total households [%]	0.08	0.07	0.05	0.04

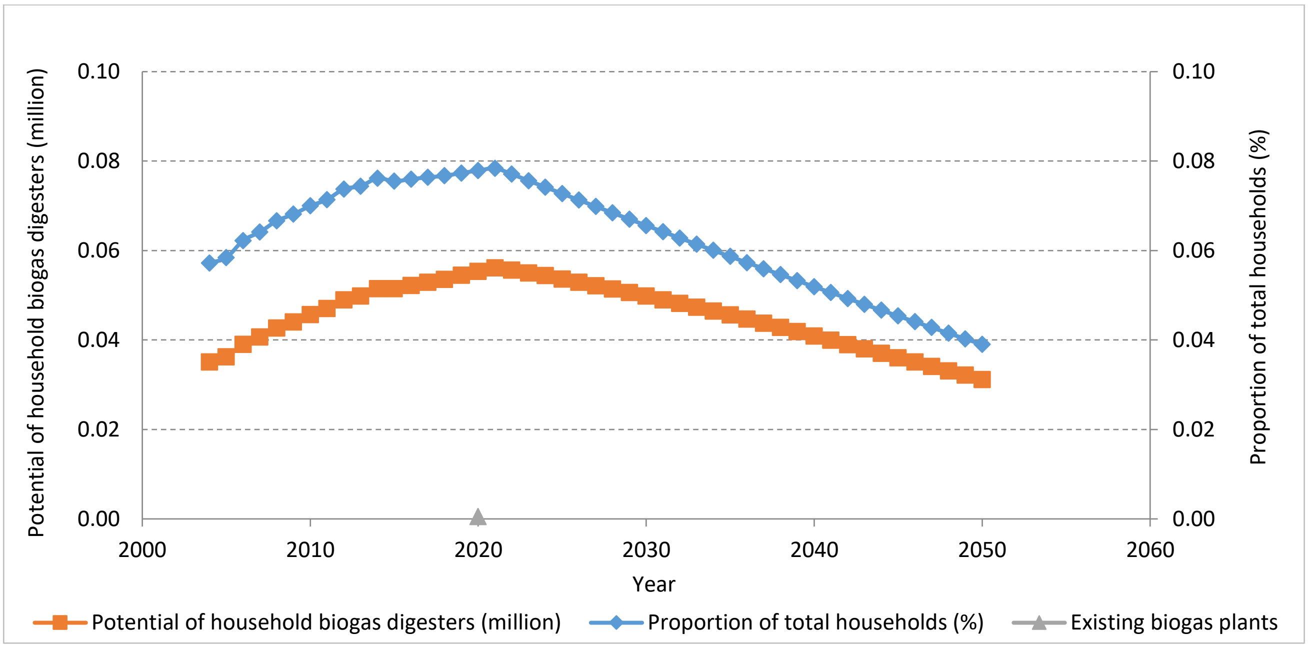

Figure 7-14 Potential of household biogas digesters in Brazil

7.5.3 Economic analysis

7.5.3.1 Invest cost of household biogas digester

In Brazil, the construction materials required for the construction of cement-brick-built biogas digesters are sufficient. the price of construction materials is cement is about € 80 per ton and steel € 18 per kg (CAITEC, 2019b). In Brazil, construction workers have a monthly salary of about 998 Brazilian real (€ 160), and the engineer have better salary of 6,500 Brazilian real (€ 1,050) per month (Salario, 2020). Therefore, the cost of an 8 m^3 cement-brick-built biogas digester in Brazil is € 767, and the maintenance cost accounts for € 105 per year.

7.5.3.2 Saving and income

Same calculation methods as mentioned in chapter 6.5.3 have been taken for Brazil. The value of biogas can be calculated as fuels for cooking as substitution of 3.50% charcoal, 47.44% of fuelwood, 49.03% of LPG and 0.03% oil product. The value of 263 m^3 biogas for cooking is around € 29.64 (see Table 7-47).

Table 7-47 Biogas value for cooking (BV_C) in Brazil

Assumption: 263 m³ biogas for cooking per year					
Biogas replacement	Substitution ratio	Fuel mix	Substitution amount [kg]	Fuel price [€]	Biogas value (BV_C) [€]
Charcoal	1.59	3.50%	14.63	0.80	11.70
Fuelwood	2.60	47.44%	324.54	0.00	0.00
LPG	0.51	49.03%	66.35	0.27	17.91
Oil product	0.68	0.03%	0.05	0.50	0.03
Sum					**29.64**

The value of biogas for lighting can be calculated as saving cost for electricity, which is used for one lamp of 3 hours per day. The value of 77 m³ biogas for lighting in Brazil is ca. € 0.88 per year (see Table 7-48).

Table 7-48 Biogas value for lighting (BV_L) in Brazil

Assumption: 8m³ biogas digester, 77 m³ biogas for cooking					
	Amount	Power [W]	Working time [h]	Electricity price [€/kWh]	Biogas value (BV_L) [€/a]
Lamp	1	10	3	0.08	0.88

As shown in Table 7-49 and Figure 7-15 according to the concept of usage of 340 m³ biogas, biogas has the total value of € 30.52 in Brazil. The value of 1 m³ biogas is € 0.09.

Table 7-49 Biogas value in Brazil (8m³ biogas digester)

Assumption: 8m³ biogas digester, 263 m³ biogas for cooking		
	Volume [m³]	Economic Value [€]
Biogas for cooking (BV_C) (per year)	263	29.64
Biogas for lighting (BV_L) (per year)	77	0.88
Biogas value [€/a]		30.52
Biogas value [€/m³]		**0.09**

The price of fertilizer in Brazil is around € 0.26 per kilogram (Indexmundi, 2020). With the annual demand of 18.6 gram fertilizer per m² (The World Bank, 2017b), € 2.37 can be saved though the usage of digestate instead of DAP fertilizer. With the calculation method in chapter 6.5.3, increased income resulted by usage of digestate has the value of € 180 and € 144 per year for livestock and agriculture respectively.

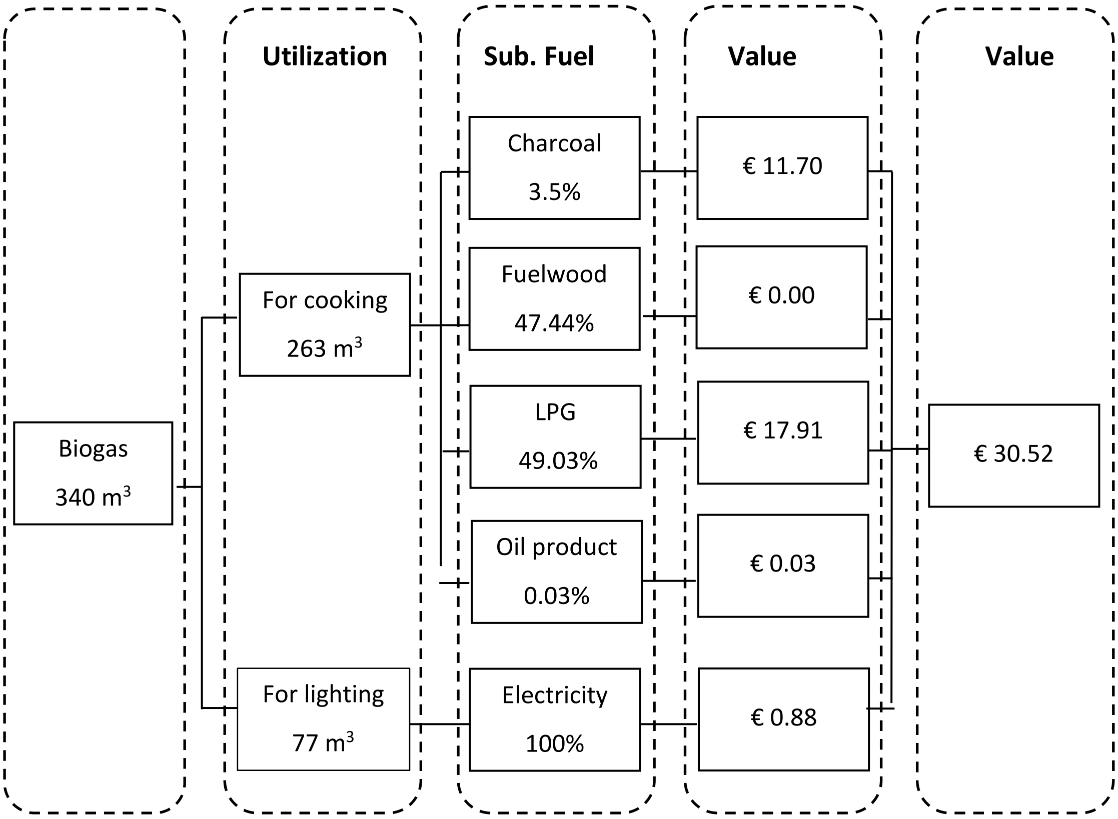

Figure 7-15 Value of biogas in Brazil

Table 7-50 Summary table of economic analyze for an 8 m^3 biogas digester in Brazil

Invest	**Details**	**Price [€]**
Investment costs	Construction cost for biogas plant	767 (once only)
Annuity	Working life with 15 years and interest of 6%	79.00
Operation costs	Maintenance cost and material costs for fitting materials	105

Income and savings	**Details**	**Price [€/a]**
Alternative energy	Replacement of the raw coal and savings in fuel costs: Biogas value for cooking (BVc)	29.64
	Save power by using the biogas lamps in the household: Biogas value for lighting (BV$_L$)	0.88
Benefits of livestock (BL)	More income for slaughter	180.19
Benefits of garden (BG)	Increased annual production value	144.00
Benefits of fertilizer (BF)	Saving of fertilizer	2.37
Sum [€/a]		**357.08**

Discounted Payback Period (DPP) [a]	**3.46**
GNI [€/a]	**7,787**

In summary, the economic analyze of biogas digester in Brazil are listed in Table 7-50. The invest cost for an 8 m^3 household biogas digester accounts € 767, meanwhile the maintenance cost is € 105 per year. With the annual economic benefits of usage of biogas and digestate of € 357.08, the payback period is 3.46 years.

7.5.4 Ecological analysis

In Brazil, according to the fuel mixture, the usage of biogas from an 8 m^3 household biogas digester can save 325 kg fuelwood each year. With the average density of fuelwood of 600 kg/m^3 and the forest growing stock in Latin America of 178 m^3/ha (FAO, 2016), 30.39 m^2 forests can be saved (Table 7-51).

Table 7-51 Forest conservation (FC) according to usage concept of 340 m^3 biogas (8 m^3 digester) in Brazil

Save the amount of wood [kg]	Density of fuelwood [kg/m^3]	Forest growing stock [m^3/ha]	Forest conservation (FC) [m^2]
325	600	178	**30.39**

With the usage of biogas for cooking and lighting, 228 kg GHG emission (CO_2 equivalent) will be reduced in one family with an 8 m^3 biogas digester in Brazil per year (see Table 7-52). Among them, LPG contributes the most to reducing GHG emissions.

Table 7-52 GHG reduction according to usage concept of 340 m^3 biogas (8 m^3 digester) in Brazil

GHG reduction by biogas (CO_2 equivalent)	Charcoal	Fuelwood	Electricity	LPG	Oil product	Biogas
Unit	[kg]	[kg]	[kWh]	[kg]	[kg]	[m^3]
Average annual amount [unit/a]	15	325	11	66	0.05	340
CO_2 Emission Factor [g/Unit]	1,588	1,625	93	3,074	3,148	925
Annual amount of CO_2 emissions [kg/a]	23	527	1.02	204	0.17	315
Annual amount of CO_2 emissions (Consideration of neutral biomass) [kg/a]	23	0	1.02	204	0.17	0
Reduction of annual amount of CO_2 emissions from biogas [kg/a]	228					

7.6 Summary of results and analysis

According to the introduction of basic situations and the analyses of the criteria in the check list in different regions, the transferability of household biogas digesters will be presented and compared. There is an intuitive comparison based on the advantages and disadvantages of each country, providing a good theoretical basis for future improvements. Furthermore, the results of the calculations, which include the investment costs, maintenance costs and economic benefits of household biogas digesters will be also compared, which is the basic information for international cooperation as well as for the potential investors.

7.6.1 Compare of transferability study

The score of each criterion in selected countries are listed in Table 7-53. Most of criterion in China gets the highest superiority (0.75 – 1.00), which should be recommended. In the contrast, Tanzania and Ethiopia scores high in climate and energy aspect, it has significant disadvantages in the issues of finance, technology and politic. Bolivia has relatively worse performances in all independent aspects, consequently leading to the dissatisfied scores. Although other conditions in Brazil performs very well, which makes it get the higher score, but the energy demand and feeding material supply earns the least score.

Table 7-53 Score of each criterion in selected countries

		Criteria	China	Tanzania	Ethiopia	Bolivia	Brazil
A1	Climate	Suitable climate condition	0.50	1.00	0.75	0.50	0.75
B1	Energy	Scarcity of traditional energy supply for household	0.25	0.75	0.75	0.50	0.00
B2		Increase the share of renewable energy	0.75	0.50	0.25	0.50	0.25
C1	Material	Availability of feeding material for biogas digester	0.75	0.50	0.50	0.50	0.00
C2		Availability of water	1.00	0.50	0.50	0.50	0.75
C3		Sufficient space for agriculture	0.75	0.75	0.75	0.75	0.75
C4		Availability of construction material	1.00	0.50	0.50	0.50	0.75
C5		Availability of biogas appliance	1.00	0.50	0.25	0.25	0.25
D1	Technical	Availability of engineer for Design and quality control	1.00	0.50	0.25	0.25	0.50
D2		Availability of worker for construction, operation and after-sale-service	1.00	0.50	0.25	0.25	0.50
E1	Finance	Finance ability	1.00	0.25	0.25	0.25	0.50
E2		Access to credit	0.75	0.50	0.25	0.25	0.50
F1	Social	Role of women in domestic decision-making process and life	0.75	0.50	0.50	0.50	0.75
F2		Biogas plant can be integrated into normal working routine at the farm	1.00	0.50	0.50	0.50	0.75
F3		Ethical aspect	1.00	0.50	0.50	0.75	0.75
G1	Political	Availability of Standards, laws and regulations on biogas technology	1.00	0.25	0.25	0.25	0.50
G2		Political will of the Government to support a national biogas program	1.00	0.50	0.50	0.50	0.50
G3		Monitoring and supervision	1.00	0.25	0.25	0.25	0.50

The Table 7-54 and Figure 7-16 present the comparison of transferability study for household biogas digesters in China, Tanzania, Ethiopia, Bolivia, and Brazil. Considering other factors, China with more than 40 years of experiments and as the model country of household biogas digesters, has a high result of 0.76. Because of a relatively long history of biogas and with more international cooperation, Tanzania has result of 0.51, while Ethiopia with almost the same conditions is counted among 0.46. Because of the technical factors that are not good and low availability of material, Bolivia accounted for the countries with worse conditions (results of 0.41) for household biogas promotion. Because of the significant disadvantage of energy and feeding material issues, Brazil gains worst grades within five countries. Nevertheless, this type of digesters can be constructed and spread in these regions with the improved economic and social conditions or cooperation of foreign organizations.

Table 7-54 Results of criteria of transferability study of selected countries

		Criteria	China	Tanzania	Ethiopia	Bolivia	Brazil
A1	Climate	Suitable climate condition	0.03	0.05	0.04	0.03	0.04
B1	Energy	Scarcity of traditional energy supply for household	0.04	0.11	0.11	0.08	0.00
B2		Increase the share of renewable energy	0.04	0.03	0.03	0.03	0.01
C1	Material	Availability of feeding material for biogas digester	0.15	0.10	0.10	0.10	0.00
C2		Availability of water	0.03	0.01	0.01	0.01	0.02
C3		Sufficient space for agriculture	0.02	0.02	0.02	0.02	0.02
C4		Availability of construction material	0.03	0.01	0.01	0.01	0.02
C5		Availability of biogas appliance	0.03	0.01	0.01	0.01	0.01
D1	Technical	Availability of engineer for Design and quality control	0.03	0.01	0.01	0.01	0.01
D2		Availability of worker for construction, operation and after-sale-service	0.03	0.01	0.01	0.01	0.01
E1	Finance	Finance ability	0.15	0.04	0.04	0.04	0.08
E2		Access to credit	0.08	0.05	0.03	0.03	0.05
F1	Social	Role of women in domestic decision-making process and life	0.01	0.01	0.01	0.01	0.01
F2		Biogas plant can be integrated into normal working routine at the farm	0.02	0.01	0.01	0.01	0.01
F3		Ethical aspect	0.02	0.01	0.01	0.01	0.01
G1	Political	Availability of Standards, laws and regulations on biogas technology	0.03	0.01	0.01	0.01	0.01
G2		Political will of the Government to support a national biogas program	0.03	0.01	0.01	0.01	0.01
G3		Monitoring and supervision	0.05	0.01	0.01	0.01	0.03
Sum			**0.76**	**0.51**	**0.46**	**0.41**	**0.35**

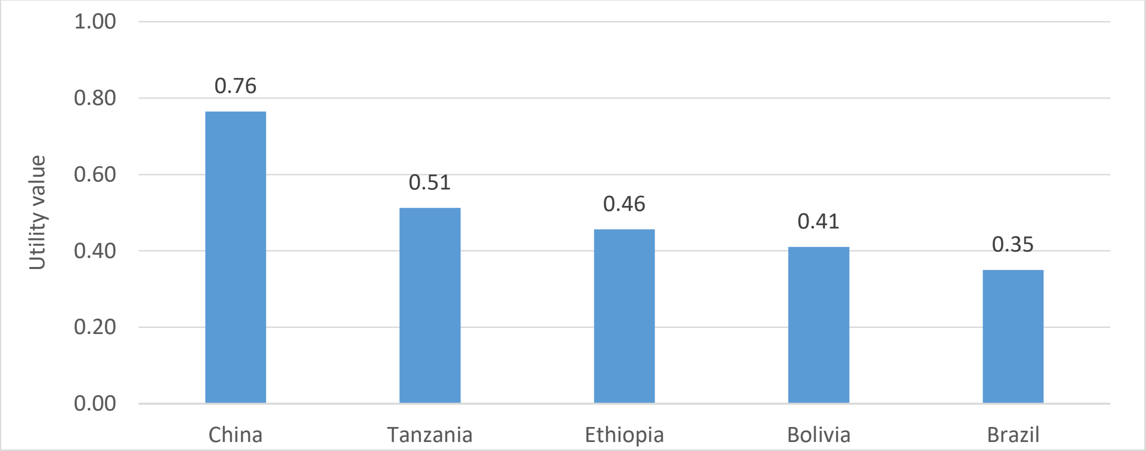

Figure 7-16 Results of transferability study of selected countries

The results of comparison of each criterion in selected countries are summarized in Table 7-55. Brazil gets the lowest scores in both energy suitability and material suitability, causing that the worst final results of transferability analysis.

Table 7-55 Results of transferability study of criteria in selected countries

	China	Tanzania	Ethiopia	Bolivia	Brazil
Climate	0.03	0.05	0.04	0.03	0.04
Energy	0.08	0.14	0.14	0.10	0.01
Material	0.24	0.16	0.15	0.15	0.06
Technic	0.05	0.03	0.01	0.01	0.03
Finance	0.23	0.09	0.06	0.06	0.13
Social	0.05	0.03	0.03	0.03	0.04
Politic	0.10	0.03	0.03	0.03	0.05
Sum	**0.76**	**0.51**	**0.46**	**0.41**	**0.35**

The countries in Africa – Ethiopia and Tanzania - have better climate conditions than in China (see Figure 7-17). High-altitude areas of Bolivia and northern China are not suitable for household biogas development due to the cold winter, so the scores of these two countries are relatively low.

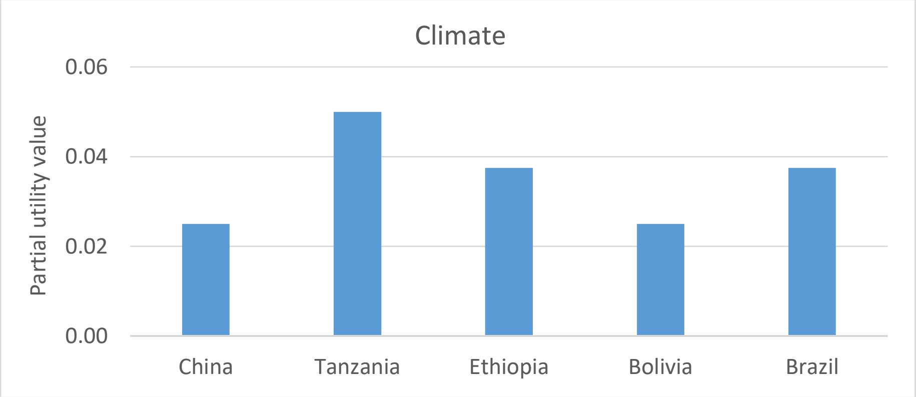

Figure 7-17 Compare of climate items of selected countries

The shortage of energy supply leads to high score in Tanzania and Ethiopia in energy items for development of household biogas digester, which is a great need to develop biogas to solve the energy problem. Brazil with relatively good energy supply also even in rural area shows the unsatisfied conditions for household biogas digester (see Figure 7-18).

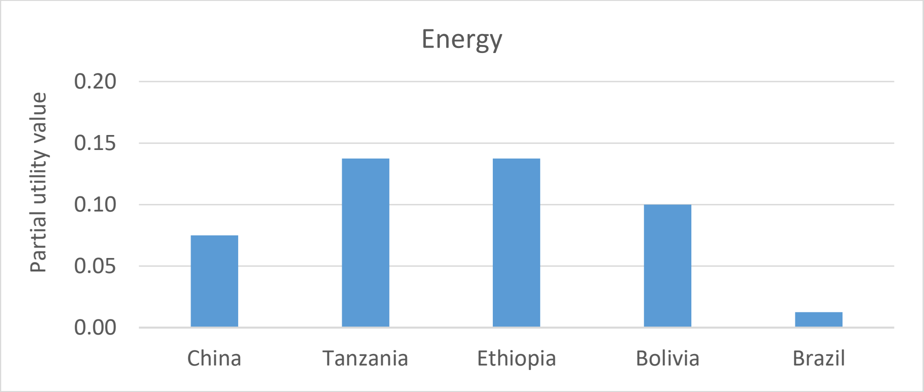

Figure 7-18 Compare of energy items of selected countries

Due to relatively central and bigger livestock holding in Brazil, there are less feeding material for household biogas digester. Therefore, Brazil has the lowest score in the items of material. Thanks to the availability of feeding material and biogas appliance, China has the highest score (see Figure 7-19). Tanzania, Ethiopia and Bolivia get the relatively good scores in material suitability.

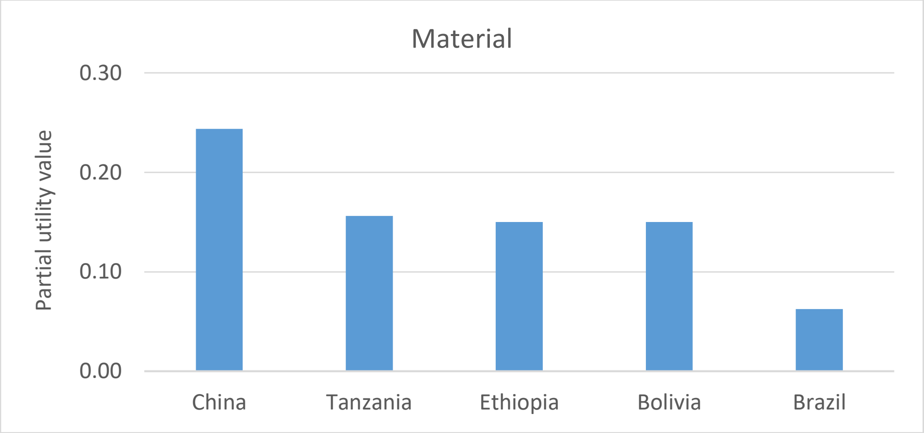

Figure 7-19 Compare of material items of selected countries

Regarding to the items of technic, China has relatively better performances among five countries, consequently leading to the ideal results. Due to the international biogas project in Tanzania and Brazil, there is little difference in technical suitability. In contrast, Ethiopia and Bolivia has significant disadvantages and obtains inferior ranking (see Figure 7-20).

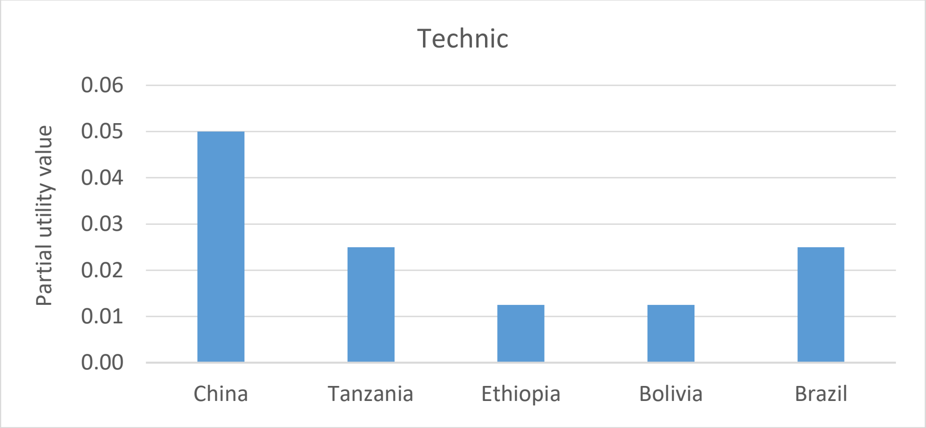

Figure 7-20 Compare of technic items of selected countries

Finance as the important aspect for decision-making of development of household biogas digester. According to the ranking, China and Brazil are superior in finance suitability, while Ethiopia and Bolivia are at the lowest positive. Therefore, the finance support from government or access to credit should be improved (see Figure 7-21).

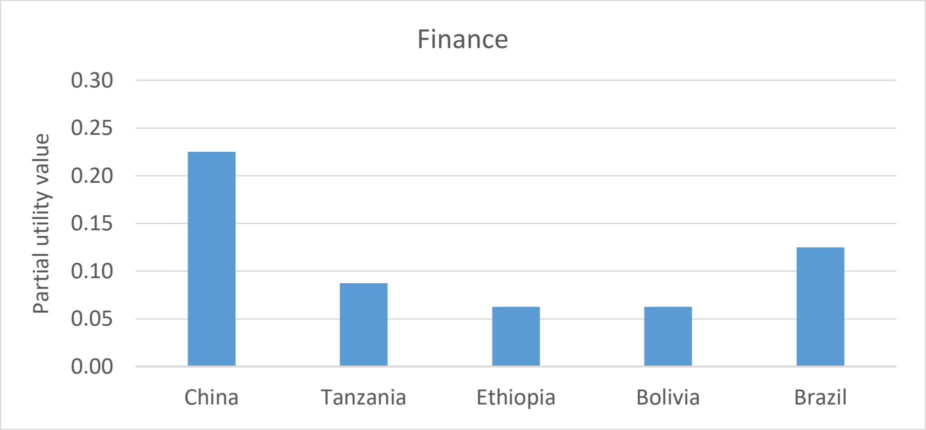

Figure 7-21 Compare of finance items of selected countries

As shown in Figure 7-22, similarly, China and Brazil are still better than other three countries in social-feasible aspect. Nevertheless, the situation of women role in life has significant improved in last years in Latin-America and Africa. Biogas is mainly produced from organic waste and does not cause problems such as food shortage or loss of biodiversity. This makes biogas a more ethical option as energy sources (Nevzorova, et al., 2019).

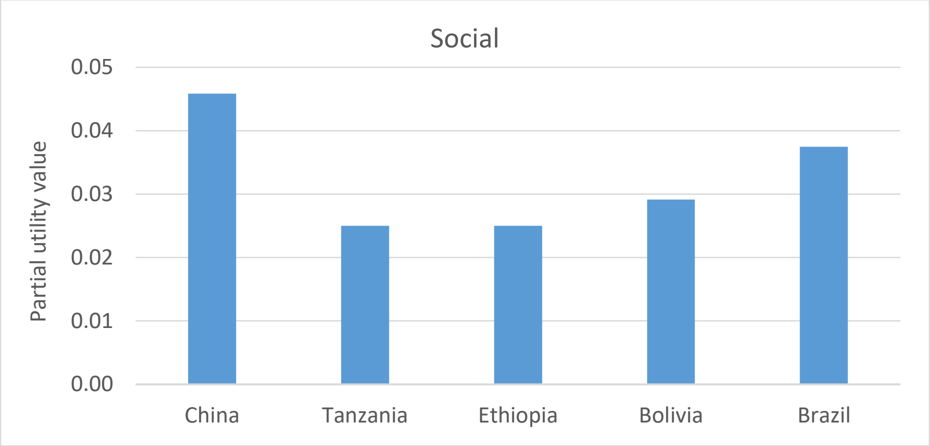

Figure 7-22 Compare of social items of selected countries

As can be seen in Figure 7-23, China has the biggest advantage and is far ahead of other countries with the score of 0.10 in this politic aspect, while Tanzania, Ethiopia and Bolivia have the similar marks (approximate 0.03). Brazil with relatively complete legal system, ranks second place with score of 0.5.

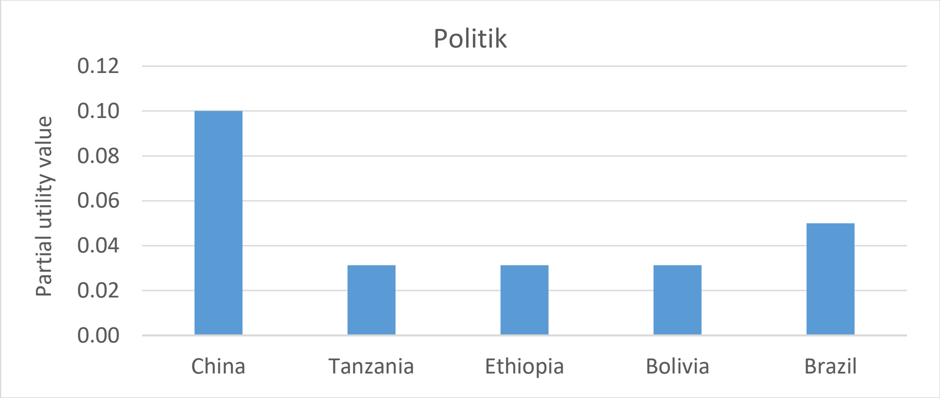

Figure 7-23 Compare of politic items of selected countries

Table 7-56 and Figure 7-24 presents the results of 4 scenarios of transferability analysis. Ethiopia has widest range from 0.28 to 0.77. Tanzania shows the smallest various between different regions. The worst case from selected countries is in Ethiopia with result of 0.28, while the best case is in China with the result of 1.0. Even the worst case in China represents better result than other 4 countries in general situation.

Table 7-56 Results of 4 scenarios of selected countries

	Average	Worst	Best	General
China	0.76	0.53	1.00	0.81
Tanzania	0.51	0.38	0.72	0.53
Ethiopia	0.46	0.28	0.77	0.48
Bolivia	0.41	0.33	0.81	0.52
Brazil	0.35	0.33	0.71	0.39

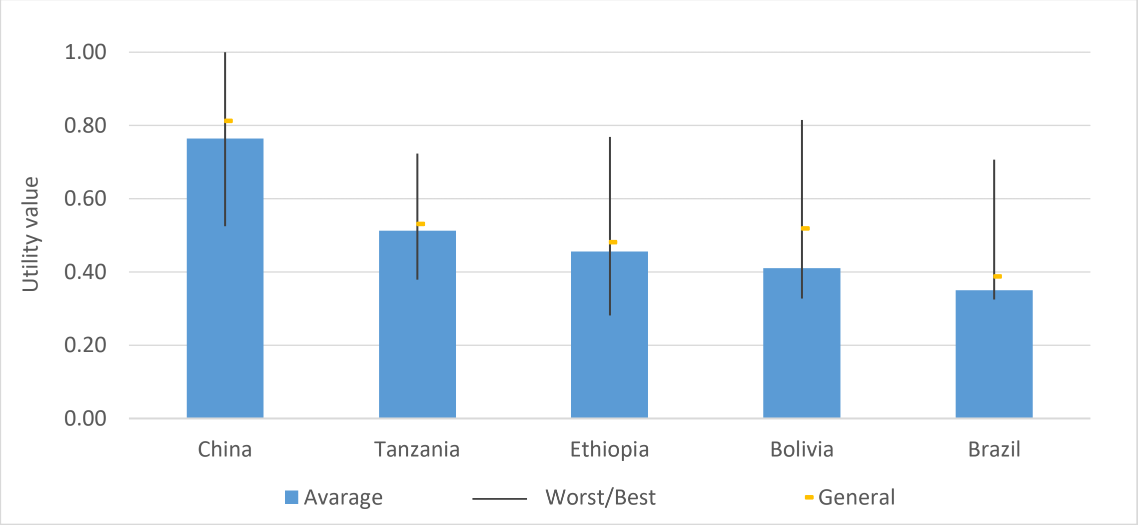

Figure 7-24 Results of 4 scenarios of selected countries

To sum up, the results of sensitivity analysis are shown in Table 7-57 and graphical in Figure 7-25 and Figure 7-26. According to Figure 7-25, Tanzania and Ethiopia have urgent needs of biogas digesters because of the lack of clean energy supply (variant III), despite the weakness of financial ability. For instance, Ethiopia and Bolivia would be the worst choice within five countries when the weighting of finance is extreme high (variant VI), but Brazil has much advantage than other countries, just behind China. Brazil performs worst in the case that energy and raw material suitability obtains more emphasis. Another biogas technology like medium- large biogas plant should be considered due to the raw material issue in Brazil. In the case that politic or technic issues is especially taken into account (variant VIII and variant V), Ethiopia and Bolivia have the worst performance in the five countries.

Table 7-57 Results of sensitivity study of selected countries

Scenario	China	Tanzania	Ethiopia	Bolivia	Brazil
I	0.76	0.51	0.46	0.41	0.35
II	0.86	0.51	0.44	0.43	0.51
III	0.41	0.69	0.67	0.48	0.13
IV	0.78	0.53	0.50	0.48	0.22
V	0.95	0.51	0.29	0.28	0.48
VI	0.84	0.42	0.31	0.29	0.48
VII	0.89	0.51	0.49	0.55	0.68
VIII	0.94	0.38	0.36	0.34	0.48

As shown in Figure 7-26, the ranking indicates that, China remains the best results except energy suitability. The different weighting variation cause relatively less changes in Tanzania, which always has the relatively good results for household biogas digester transferability. It can be also concluded that Bolivia has the lower ranking among these countries regardless the changing of weighting of criteria.

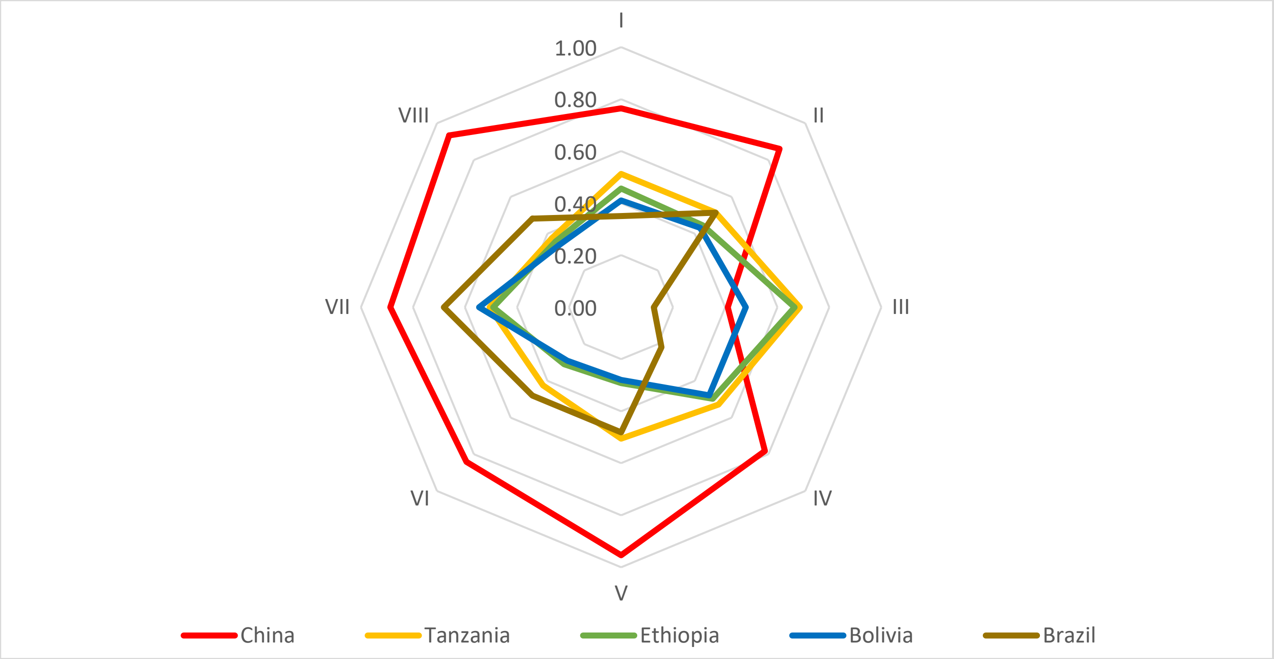

Figure 7-25 Results of sensitivity analysis of different criteria weighting

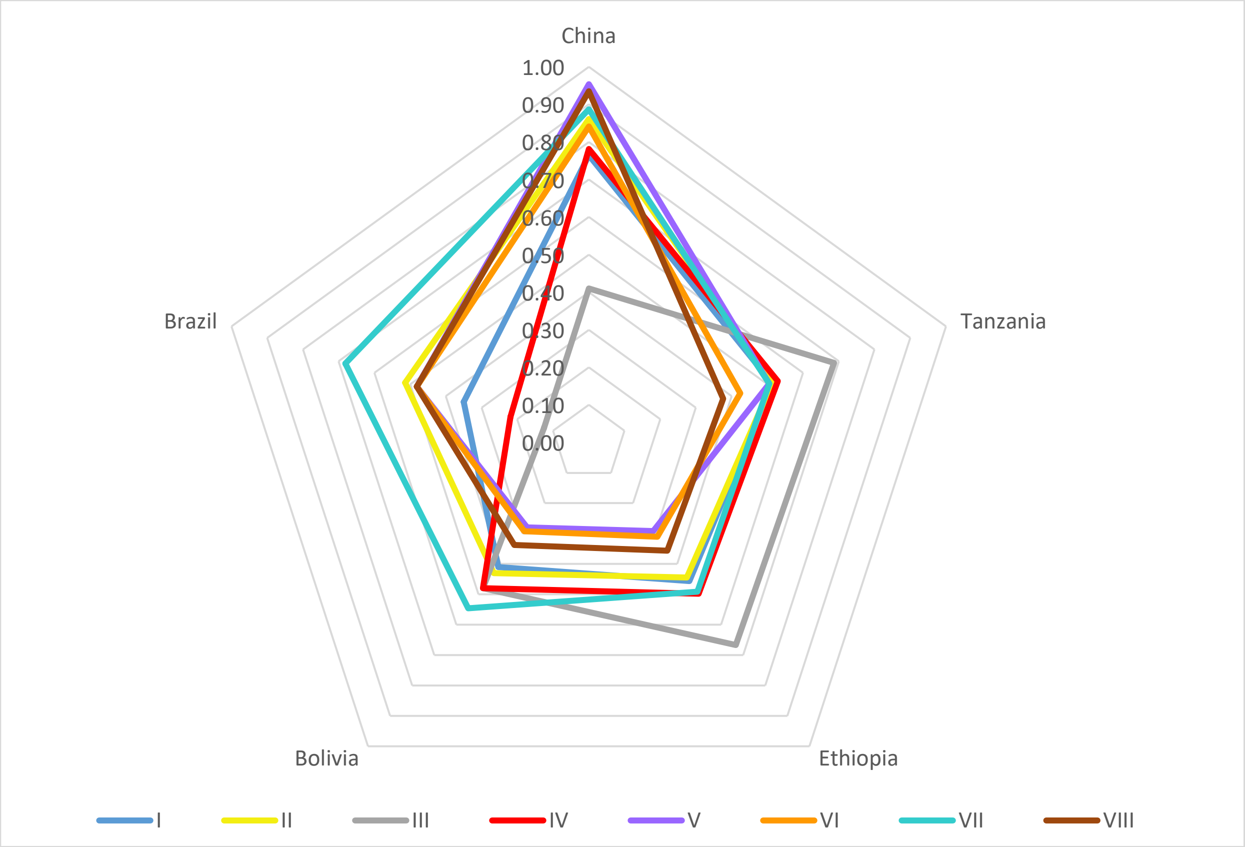

Figure 7-26 Results of sensitivity analysis of different countries

7.6.2 Compare of biogas potential

The potential of household biogas digesters in suitable countries is estimated according to the population amount, climate conditions, economic status, political and social development as well as material and technical availability (equation 2 in chapter 6.4). The slow population growth in China and the rapid urbanization at the meantime leads to a decrease in the potential household biogas digesters. Similar results are shown in Brazil, which drops to only 0.03 million potential household biogas digesters in 2050. For Tanzania, Ethiopia, Bolivia and Brazil, household biogas digesters are not only for rural areas, but also suitable for the household in urban or suburban zones. Due to the relatively slower development of economic and strong dependence on agriculture sector, the potential of household biogas digesters in Tanzania and Ethiopia will maintain an increasing trend in the next 40 years (shown in Figure 7-27). Especially in Ethiopia, the potential biogas digesters will reach 14.59 million in year 2050, which is more than 4 times compared to year 2010 (see Table 7-58).

Table 7-58 Potential of household biogas digesters in China, Tanzania, Ethiopia, Bolivia and Brazil

Year/Country	China (million)	Tanzania (million)	Ethiopia (million)	Bolivia (million)	Brazil (million)
2010	80.92	0.68	3.84	0.22	0.05
2020	67.24	1.01	6.22	0.33	0.06
2030	55.15	1.45	8.91	0.41	0.05
2040	36.32	2.01	11.84	0.37	0.04
2050	19.85	2.61	14.59	0.29	0.03

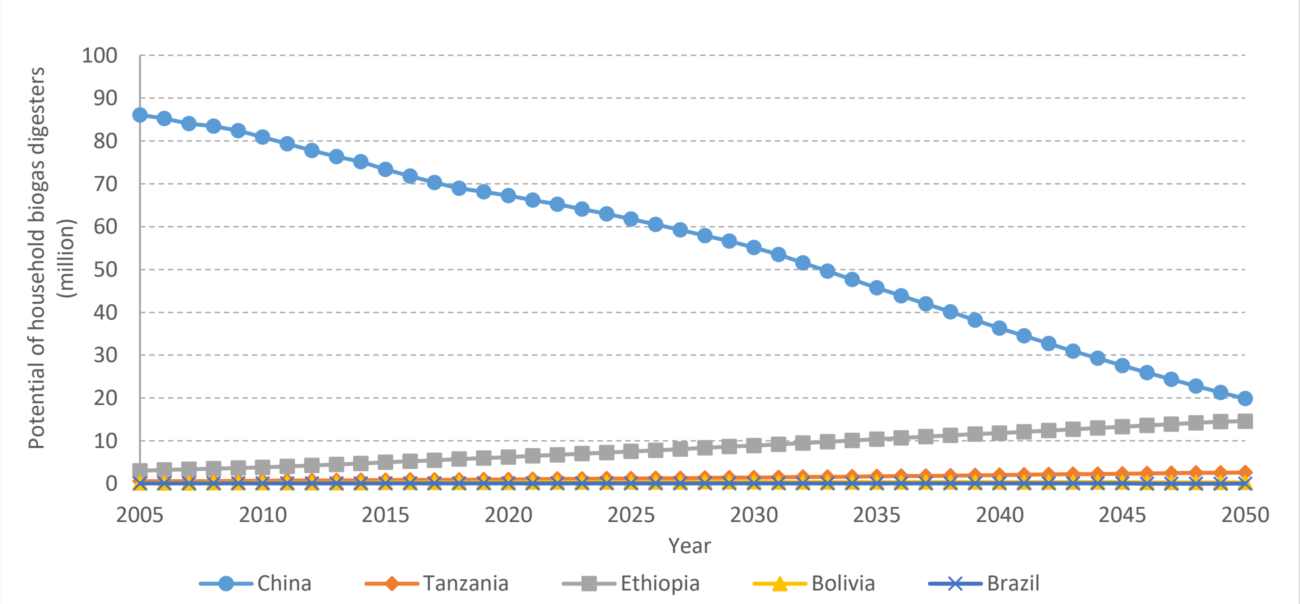

Figure 7-27 Potential of household biogas digesters in China, Tanzania, Ethiopia, Bolivia and Brazil

The following Table 7-59 and Figure 7-28 show the percentage of potential household biogas digesters of total households in China, Tanzania, Ethiopia, Bolivia and Brazil. The declining potential of percentage of household biogas digesters in China is proved the tendenz to medium- and large biogas plant. In Ethiopia, the percentage value has remained at around 25% - 30%, this relatively high value shows that, household biogas technology may be a good development direction. Tanzania is the only one having upward curve among five countries. The government`s attention, supply, and responsibility will accelerate the promotion and implementation of household biogas technology. In Bolivia, although the slowly increasing potential of household biogas digesters, the total population climbs even sharply, therefore, the proportion of total households has a decreasing the trend. The proportion of total household in Brazil remains extremely low and represents the same decreasing tendency. The household biogas technology is not an attractive renewable energy for Brazil, rather prefer medium- and large high-tech biogas plant or other renewable energy sources.

Table 7-59 Percentage of potential household biogas digesters of total households in China, Tanzania, Ethiopia, Bolivia and Brazil

Year/Country	China	Tanzania	Ethiopia	Bolivia	Brazil
2010	24.14%	7.40%	18.85%	7.89%	0.07%
2020	19.10%	8.07%	23.32%	10.20%	0.08%
2030	15.27%	8.67%	26.69%	10.95%	0.07%
2040	10.12%	9.20%	29.50%	8.87%	0.05%
2050	5.69%	9.36%	31.28%	6.20%	0.04%

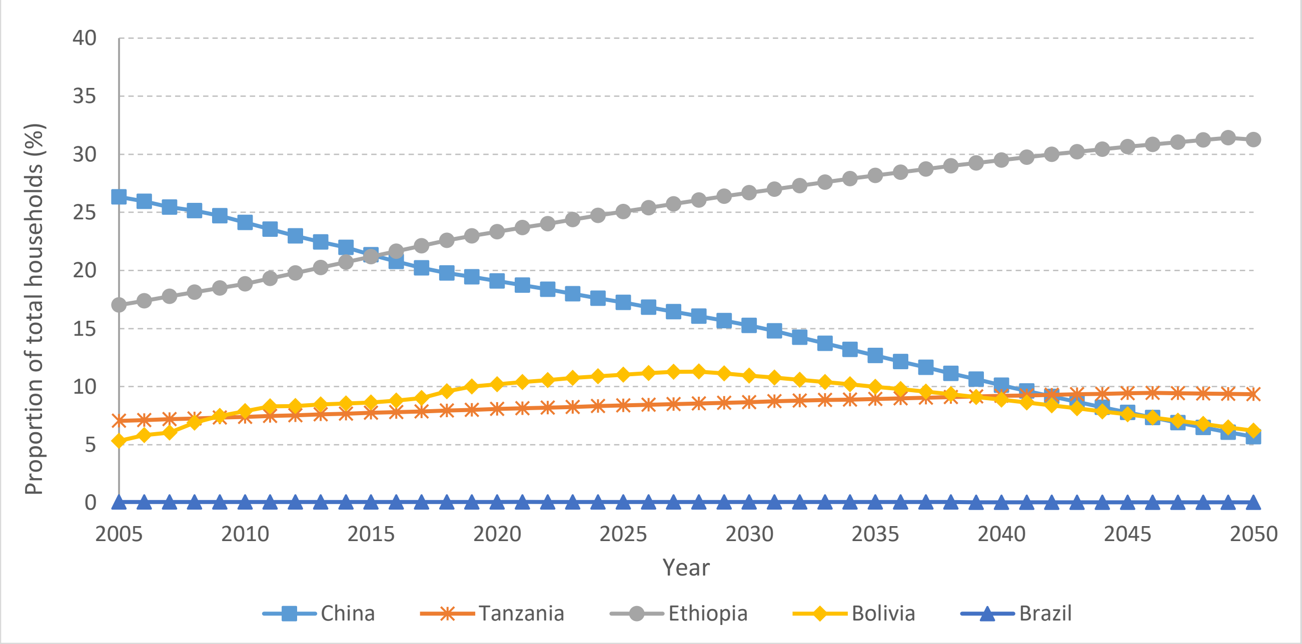

Figure 7-28 Proportion of potential biogas digesters of total households in China, Tanzania, Ethiopia, Bolivia, and Brazil

7.6.3 Compare of economic aspect

7.6.3.1 Compare of investment costs

The investment cost for biogas digester depends intensively on the price of construction materials and the personal salary. The investment costs for an 8m³ household biogas plant in China have a contribution of around € 912, while the operation costs are around € 162 (Table 7-60). Tanzania and Ethiopia with lower price of construction materials and the lower salary of workers, lead to decrease of the price. Therefore, the investment costs for biogas digester are relatively lower with € 437 and € 375 respectively, which equivalents to more than 50% of GNI. In Bolivia, because of the high salary, less local manufactures and less importers, the investment costs are even more than that in China. The invest cost of household biogas digester for Brazilian is at a mid-to-high level with € 767, but it accounts less than 10% compared to GNI.

Table 7-60 Compare of investment costs and operation costs of 8m³ household biogas digester

Invest	Details	China	Tanzania	Ethiopia	Bolivia	Brazil
Investment costs [€]	Construction cost for biogas plant	912	437	375	1,112	767
Annuity [€]	Working life with 15 years and interest of 6%	94	45	39	115	79
Operation costs [€/a]	Maintenance cost and material costs for fitting materials	162	44	37	168	105
GNI [€/a]	Gross National Income of family	8,238	874	685	2,886	7,787
Ration Invest/GNI		11.07%	50.00%	54.74%	38.53%	9.85%

The absolute investment cost does not directly reflect whether people have the ability to invest in it. Therefore, it is necessary to compare it with national income to assess the feasibility of this biogas technology. As shown in Figure 7-29, the results of the comparison of invest and GNI in selected countries are quite different. Although the amount of investment cost of household biogas digester in China and Brazil is quite high, it contributes only one-tenth of the GNI. Therefore, such relatively stress less investment would be a feasible biogas project. In Bolivia, the biogas digester makes up about 30 percent of the entire family budget. The willing of farmers in Tanzania and Ethiopia to invest around one-half of the GNI for household biogas digester, is relatively stress and difficult. Therefore, strongly finance support from government or Institutes in Bolivia, Tanzania and Ethiopia are very necessary and welcome.

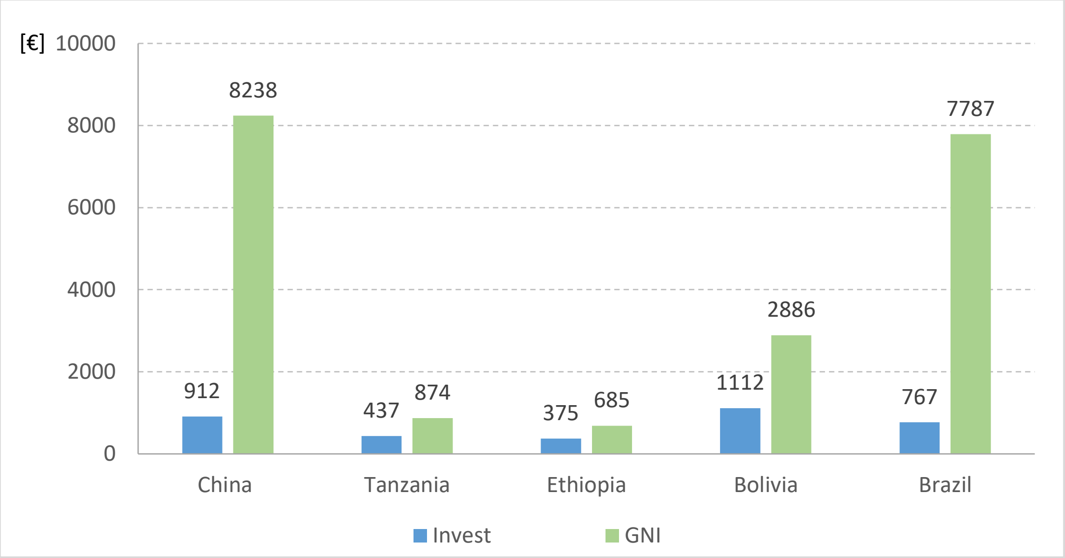

Figure 7-29 Compare of invest cost of 8m^3 household biogas digester in selected countries with GNI

7.6.3.2 Compare of economic benefits

For the calculation of economic benefits in different regions, the same concept of usage of biogas (Table 7-61) should be assumed, and the energy mix for cooking (Table 7-62) should be represented according to the energy supply situations in these regions. On the basis of the concept of biogas use and energy mix is used for cooking, the saving costs of biogas as an alternative energy will be calculated and compared.

Table 7-61 Concept of use of biogas

	Amount	Power [kW]	Working time [h]	Biogas demand [m³/d]	Biogas demand [m³/a]
Biogas stove	1	/	1.5	0.72	263
Biogas lamp	1	0.41	3.0	0.21	77
Sum					340

Table 7-62 Compare of energy mix for cooking in China, Ethiopia, Tanzania, Bolivia and Brazil

	Charcoal	Fuelwood	Crop residue	LPG	Oil product	Electricity	Dung
China	2%	82%	-	10%	-	6%	-
Tanzania	12%	75%	-	11%	-	2%	-
Ethiopia	8%	76%	2%	1%	1%	5%	7%
Bolivia	-	47%	-	45%	0.33%	0.28%	7%
Brazil	4%	47%	-	47%	0.03%	-	-

The fuelwood, manure and straw are mainly available for free for farmers, while the commercial energies such as coal, liquid gas and electricity are relatively expensive, thus, the saving costs lead strongly to consider the proportion of commercial energy in energy mix. Farmers in Bolivia utilize much more electricity for cooking than in other countries, since to the value biogas is relatively higher. The economic benefits from livestock and cultivation depend strongly on the price of agricultural and sideline products. The agricultural production yield and its quality enhanced by biogas users, make the income increase proportionally. In contrast to the income from cultivation, because of the higher price of meat in Africa, the income from agriculture is more than that in China or Bolivia. As shown in Table 7-63, the economic benefits from an 8 m³ biogas digester reach € 591 per year in China, which equivalent 7.17% of GNI. The payback period for investment in China is around 2.34 years. In Ethiopia, with lower investment costs and relatively higher benefits of the household biogas digester, it needs only 1.02 years for the recovery of the investment. The benefits of an 8m³ biogas digester accounts 62.54% of GNI. For the recovery of the investment in Tanzania, it needs 2.07 years. In contrast, farmers in Bolivia have the highest investment costs, although the income by usage of biogas and digestate, the payback period is 6.64 years. The payback period for Brazilian`s invest of household biogas plant is 3.46 years. Compared with GNI, the economic advantage through household biogas digester accounts only 4.58%.

Table 7-63 Compare of economic benefits and payback period

Income and savings	Details	China	Tanzania	Ethiopia	Bolivia	Brazil
alternative Energy [€/a]	Replacement of the raw coal and savings in fuel costs	16.96	17.31	11.41	17.72	29.64
	Save power by using the biogas lamps in the household	0.66	0.9	0.35	1.04	0.88
Livestock [€/a]	More income for slaughter	386	136	326	207	180
Cultivation [€/a]	Increased annual production value	180	120	90	150	144
Digestate [€/a]	Saving of fertilizer	7.5	0.25	0.22	0.23	2.37
Sum [€/a]		590.96	274.57	428.40	375.76	357.08
Payback Period [year]		2.34	2.07	1.02	6.64	3.46
GNI [€/a]	Gross National Income of family	8,238	874	685	2,886	7,787
Ratio of Benefit/GNI		7.17%	31.42%	62.54%	13.02%	4.58%

7.6.3.3 Compare of economic aspect

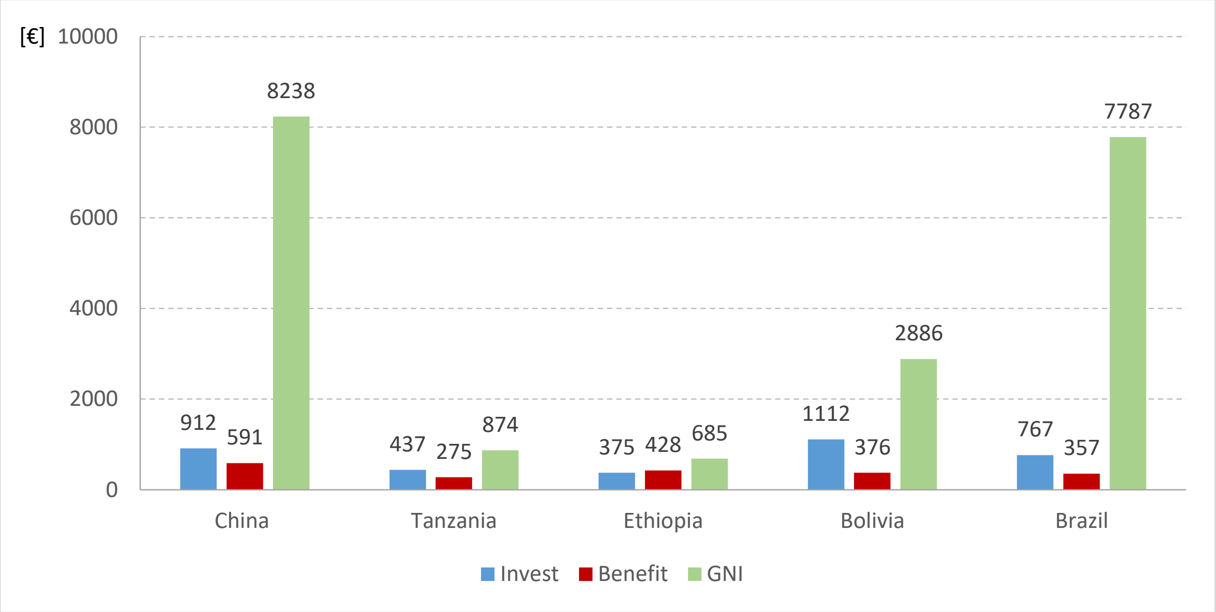

Figure 7-30 Compare of the invest and economic benefits with GNI

Figure 7-30 summarize the results of comparison of invest cost and economic benefits with GNI in selected countries. Since countries have different economic level, the ratio of cost/GNI and income/GNI is the most intuitive parameter to identify the advantages and disadvantages in economic aspect. As shown in Figure 7-31, the invest cost accounts 11.1% of GNI in China, which means less pressure in economic issues for farmers to install the household biogas digester. Tanzania´s farmer spend 50% of GNI to install the household biogas digester, while the economic benefits accounts 31.4% of GNI. It can be interesting for the famers, who may access credit or subsidy. In Ethiopia, high invest cost may influence into decision making process of install household biogas digester, but the economic benefits with 62.5% of GNI can effectively shortens the payback period. In the contrast, the install of household biogas digester in Bolivia has the disadvantage of higher invest cost (38.5% of GNI) and less benefit (13% of GNI), therefore, it is not a good choice considering the economic aspect. In Brazil, although the less economic benefits (4.6% of GNI), the invest cost accounts less than 9.9%, which carries less risk, it can be a good investment.

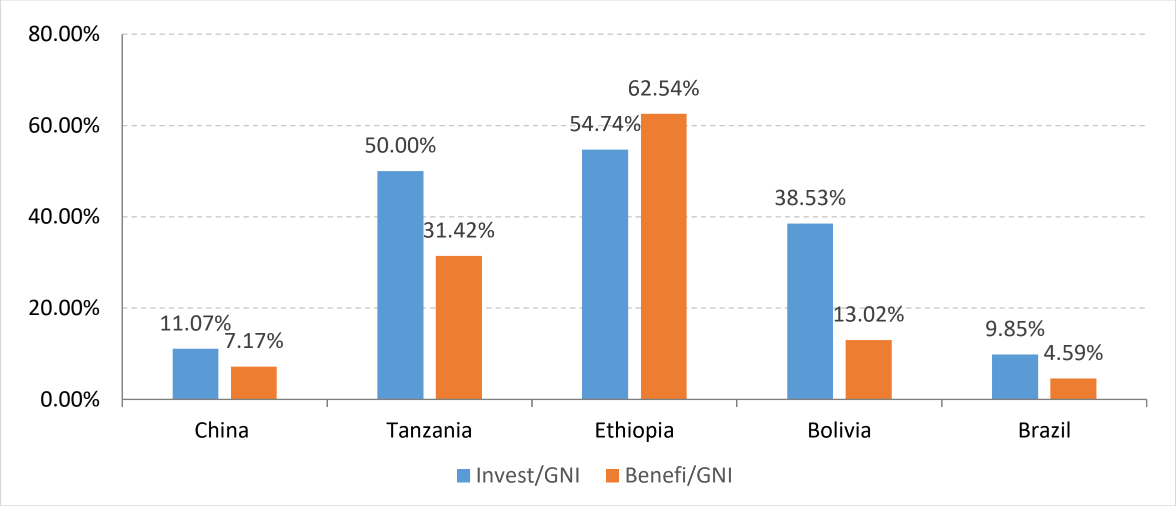

Figure 7-31 Ratio of Invest/GNI and Benefit/GNI

7.6.4 Compare of ecological and social aspect

Biogas as clean renewable energy can be combusted to replace fossil fuels, reducing CO_2, SO_2, NO_x and other harmful gases, which is significant for reducing greenhouse gas emissions and mitigation of global warming. Assuming the biogas usage concept for 340 m^3 produced from 8 m^3 biogas digester and also considering the energy mix concept; the reduction of annual GHG emission (CO_2 efficient) can be calculated and compared. As represented in Table 7-64, there are not significantly differences between Ethiopia and Tanzania on the reduction of annual CO_2 emission in different regions with average ca. 660 kg per year. Considering of the neutral property of biomass for contribution to CO_2 emission, only the CO_2 emissions from fossil energy source are counted to real CO_2 emission. Therefore, the reductions of annual CO_2 emission are 142 kg/a, 135 kg/a, 86 kg/a and 211 kg/a in China, Ethiopia, Tanzania and Bolivia respectively (as shown in Figure 7-32).

Table 7-64 Compare of reduction of annual CO_2 emission

	China	Tanzania	Ethiopia	Bolivia	Brazil
Reduction of annual CO_2-Emission [kg/a]	734	657	661	414	441
Reduction of CO_2 Emission, considerate of neutral biomass [kg/a]	142	135	86	211	228

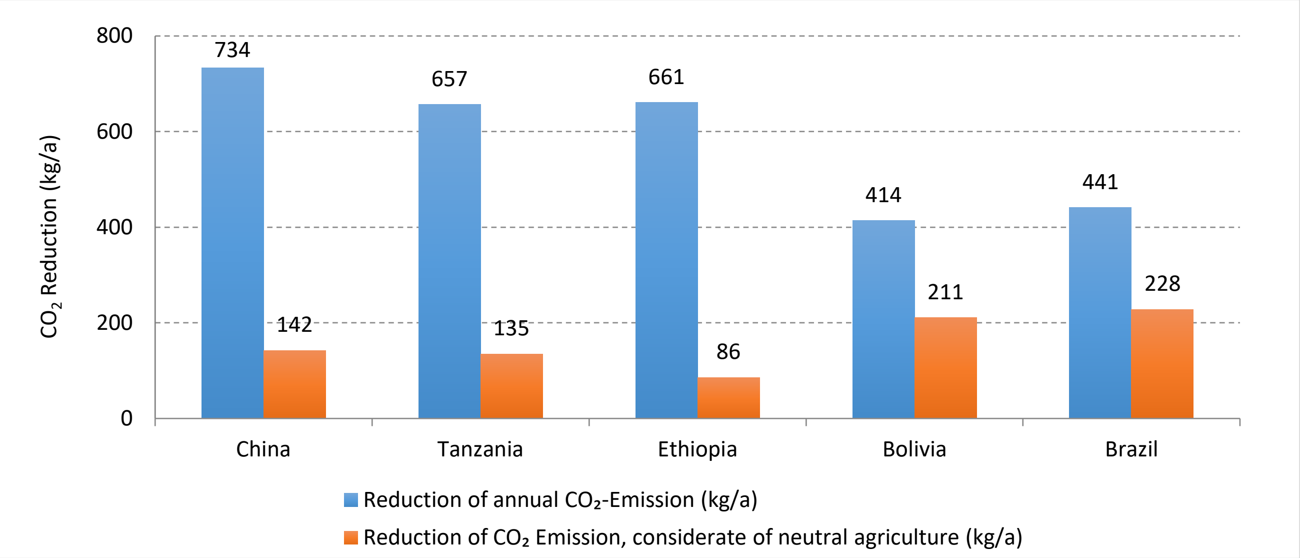

Figure 7-32 Compare of CO$_2$ emission reduction

The substitution of fuelwood by biogas contributes the reduction of fuelwood shock and reduces the deforestation. Thus, the biodiversity, the remaining forests and reforestation are obtained. Due to the different energy mix in each country, the consumption of fuelwood and saving quantity of forest resources are quite different, 30 m^2 - 100 m^2 per year (as shown in Table 7-65).

Table 7-65 Compare of forest conservation

	China	Tanzania	Ethiopia	Bolivia	Brazil
Reduction of usage of fuelwood [kg/a]	558	515	520	318	325
Density of fuelwood [kg/m^3]	600	600	600	600	600
Forest growing stock [m^2/ha]	93	128	128	178	178
Forest conservation [m^2]	100	67	68	30	30

7.7 Challenges and suggestions

While the promotion and application of biogas technology in Africa and Latin America has a good potential, there are still numerous problems and challenges in the sustainable promotion, which are shown as results from the transferability analysis:

1. Feedstock factors

   A certain amount of animal manure must be fed into the biogas digester after its construction. Livestock manure such as cow dung and pig manure are usually used as the main raw materials, so enough raw materials can ensure long-term operation of biogas digesters.

   Due to the large scale of the families, the requirements of biogas digester are also large and the need for more animal manure is imperative to meet the daily production of biogas, which means more feeding livestock.

   As the breeding needs adequate feedstock and water, the result is a great pressure for poor farmers. Some farmers in Africa and Latin America have no awareness that, other agricultural waste materials can be used, such as crop stalks that can be fermented to produce biogas. Additionally, in terms of regular maintenance, labor needed by potential biogas users also increases the farmers' concerns.

   In areas with concentrated livestock, high-tech biogas projects with medium or large-sized should be considered instead of household biogas digesters. Because of the large amount of manure and their easier collection, large-scale biogas projects are more suitable in order to solve the environmental problems caused by manure and also to relieve the energy pressure.

2. High initial investment cost

   According to the specifications of the biogas digester and the availability of government funding. Each potential biogas user needs to invest for the construction of the biogas digester. In African and Latin American counties, 40% of the country's population lives below the poverty line, so the initial investment cost may be a major bottleneck in the spread of biogas technology in Africa and Latin America.
   Larger household biogas digesters for more family members require also higher investment costs. In this case, only few families of the top of the pyramid can afford the expenses of biogas digesters. In order to subsidize the development of biogas technology and to strength its regional adaptability in Africa and Latin America, reliable and easy credit policies and measures should be established and adopted by all social sectors.

   Microfinance, such as from small businesses or private funds are easily ignored. Because of the lower profit, the involvement on big business in the areas of household biogas digesters are very limited. Inadequate investment subsidize will affect potential farmers abandoning their plans to build digesters and furthermore it has a negative impact on the promotion of biogas technology.

3. Lack of information sharing and the newest information on biogas technology research

   Currently, a lot of general information on biogas technology can be found on internet, but it is still difficult to get the official data and technical information from the governments in Africa and Latin America. One of the obstacles to develop anaerobic technologies in Africa is the lack of data, assessment and information shared due to governmental factors. Universities and government agencies often shelve some of biogas technology research programs due to lack of funds. These circumstances will not only conduct to the promotion of biogas technology, but also hamper the cooperation between developed and developing countries in this field. Although there are large opportunities and biogas potential in rural areas in Africa and Latin America, it has been indicated that due to the lack of early research and development work, many companies and foreign institutions of the biogas industry cannot enter to the biogas market in this region.

4. Political and security factors

   Security threats caused by social unrest may be one reason of slow promotion of biogas technology in Africa (Cyimana, et al., 2013). Historical and practical reasons lead to imbalance economic and political development in different region in African. Many countries are presented with tribal and religious conflicts, regional conflicts, rebels or other dangerous problem, which results in a high rate of criminal offenses and deterioration of security situation. Many countries in Africa would shelter displaced persons and refugees, such as the Democratic Republic of the Congo, Uganda, Kenya and Sudan and other countries. Some African countries also have terrorist activities. Lots of people or companies are often reluctant to invest in the region's long-term projects. The insecurity factor associated sometimes with food safety crisis would hinder the social and economic development and have direct or indirect negative impacts on the development of biogas technology.

The following suggestions could be given to solve these problems:

1. Strengthen and improve the government's attention

   Development of biogas is a basic national policy of countries´ social development. The attention of government plays a very crucial role on the successful promotion and application of household biogas digesters. The government should give preferential treatment or support from the policy, regulatory, financial, taxation and other aspects. Additionally, the government should take the function of macro-monitoring, organization and leadership. From the national government to the various provinces, cities and even in rural areas, all levels should establish appropriate biogas office. The biogas office gives specific requirements and is responsible for project register, organization and implementation, financial management, technical training, promotion, inspection and acceptance. The success of the household biogas project is inseparable with the government's attention, responsibility and strict scientific management.

2. Application of mature technologies and equipment guarantee the quality of biogas digesters

   By biogas digester design, it should be chosen as advanced as possible and as a reliable fermentation process. Meanwhile, economical and sophisticated construction technology and equipment should be used. Well-qualified and professional engineers and technicians should be carefully selected for the construction. All the construction steps, which do not meet the quality requirements, must be started all over again. Multiple inspections is required to ensure the quality of project.

3. Adjust measures to local conditions and obtain local materials

   In the implementation of the construction and technical training programs, the principle “Adjust measures to local conditions and obtain local materials” should be fully adopted. Selection of the type of biogas digester, construction materials, bacteria enrichment, pretreatment process of raw materials and so on, are determined according to the specific local conditions, such as temperature, soil, groundwater and construction techniques of local workers.

4. Improvement of project management
   a. Preparatory work must be done. First of all, research and transferability studies must be done, which include the necessity, applicability, construction content, technologies, financing, implementation and management of the biogas project. Meanwhile, well publicity about the advantage of the household biogas digesters should be orchestrated to increase the awareness and participation of farmers for the construction of rural household biogas.
   b. Well procurement. Biogas appliance, accessories or other equipment should be purchased strictly in accordance to the design criteria. Products with good quality and best price should be chosen.
   c. Establishment of a complete file of biogas users. Each biogas user must establish a profile, which is kept by biogas office of each level such as rural areas, districts, provinces or ministries respectively. At the construction of the digester, all the important information should be engraved in the fixed facilities such as the name of biogas user, part number, construction time, responsible person, which should remain consistent with the files in biogas office, in order to verify the acceptance and after tracking service.
   d. Broaden funding sources and raise funds. The biogas office at all levels should actively solve the financial problem for potential biogas users, such as micro-loans from micro credit and private

companies. Non-Governmental Organizations etc. should ensure the completion of promotion and implementation of household biogas digesters.

e. Strengthen the management of project funds. Subsidy from government, loans from banks or lending institutions should be properly managed and used by biogas office to ensure the smooth implementation of the project. The biogas office should create a publicity system for the fund management, so the current situation of construction, subsidy and distribution can be published. Additionally, finance, allocation, distribution and use of the funds should be audited and checked by relevant financial departments of each level.
f. Complete the project acceptance. After the completion of the construction, the leading group of the biogas office should do the acceptance within five days in accordance with the relevant standards. and register within 3 days after acceptance.
g. Strengthen the management after construction. Biogas office is responsible for regular maintenance and periodic inspection of biogas digesters after the construction to ensure the properly operation. Biogas office should give consulting and support to biogas users when they have any problem. The pathological digester should be diagnosed and repaired immediately.

5. Improvement of the existing technology and equipment

   With the innovation of international sciences and technology, biogas technology and equipment are also constantly developing. The actual technology and equipment should be adopted.

6. Training of highly qualified technical and managerial personnel team

   To promote biogas technology in developing countries, a training of several highly qualified personnel with well awareness of management and technology is necessary. These people should meet the following conditions:

   a. Should be conscientious, dedicated professionals, who are able to work and live in the areas with difficult conditions, and should have capabilities for teamwork and coordination, and foreign affairs.
   b. Should have wider professional knowledge. Specifically, engineers engaged in design and construction should be able to design and draw general small building modifications; calculate the engineering quantities and the project budget. In addition, each biogas office should have 1 to 2 professional biogas workers, who are responsible of maintenance and repair of biogas digester, biogas appliance, and pipeline.
   c. Should have knowledge on international cooperation and project management.
   d. Should have basic skills of foreign language (English), computer literacy and driving certificates and practical experience.

7. Strengthen advocacy and training

   The biogas workers, technicians and biogas users should participate in the training programs where they can take the advantage of radio, television, live demonstrations, distribution of materials. This way biogas users can master knowledge for safe use of biogas and biogas appliance and better utilization of biogas slurry to enhance the comprehensive benefits.

8. Conduct extensive international cooperation and exchanges

   Government should send technicians to other counties with rich biogas experiences in order to learn more advanced and latest biogas technologies, which can combine with the country's specific situation to formulate development plans of household biogas projects according to their national conditions.

8 Summary, conclusions and outlook

8.1 Summary and conclusions

Due to the limited resources of fossil and nuclear energy sources as well as significant environmental impacts causing by use of fossile energy, it is necessary to change the primary energy sources to reach a sustainable energy supply in terms of environmental and climate protection. Biogas can be a valuable contribution in the transition to renewable energies and can also help to improve the energy supply situation in developing and emerging countries in rural regions from an environmentally and socially responsible perspective. In rural areas of several developing and emerging countries, household biogas plants have been in operation for many years, which usually uses animal manure, toilet waste and kitchen waste from household as input material. The biogas is directly used for cooking, lighting, or heating, additionally the digestate could be used as fertilizer back to yard or garden.

Through more than 40 years of research and practice in terms of promotion and application of decentral biogas technology, the technique is far developed. By the end of 2019, around 33.80 million household biogas plants had been counted in China in the form of fixed-dome type digester with volume of 6 m³ - 10 m³, throughout the country. The experience in China shows that biogas technology has not only economic benefits, but also an impact on aspects of energy, environment, agricultural production, socio-economic development, health and sanitation. Sharing the experience of the household biogas plant will be an important contribution to the promotion of biogas technology and the realization of sustainable energy supply.

There are lots of publications based on research and investigations on the topic of household biogas digesters, which are supporting the basic information and advancement of this technologies. However, the literature did not provide a systemic detail characterization of the decentral biogas technology, which can be summarized in a model of a household biogas digester for promotion of this technology, and for assessment of the risks and opportunities of biogas development. Furthermore, there is currently no method for verifying the transferability of biogas technology that allows for straightforward decision making by government or self-monitoring by farmers. So far, the research focus was on the extermination of biogas potential, but has not related their economical, ecological, and social benefits of each household biogas digester, which can be as the most important motivation for potential biogas user.

Based on the above-mentioned aspects, the aim of this dissertation was to provide an overview of the concrete framework for household biogas system, to evaluate the transferability to other comparable regions and to determine the potential and the economic-social benefits. For this purpose, it was particularly important to answer the following research questions:

- What are the important conditions and parameters of household biogas digester systems?
- What are the practical benefits of household biogas systems?
- Which regions are suitable for promotion of household biogas systems?
- How to evaluate the transferability of the household biogas systems to other regions systematically?
- Where are the weaknesses and strengths points of these regions? What is the potential for improvement compared to the status quo?
- How much potential for household biogas digesters are there in these regions to which the transferability will be proved?

Based on official data about policies and measures in this dissertation interview surveys were conducted with the person responsible of biogas user, biogas technical person, relevant government departments, colleges and universities.

Considerations of climate, geographic and socio- economic conditions, 29 biogas digesters in south, north and west area of China have been investigated during the year 2009 to 2011. Temperature and pH value had been determinate by on-site experiments. Additional laboratory experiments were conducted for sampled biogas and digestate. The results show that, all the 29 household biogas digesters in China are underground fixed-dome digester form. With the input material of animal manure, toilet waste and organic waste of kitchen, the biogas digester produces daily around 1 m^3 biogas, which is enough for the household utilization. There was no odor by all the biogas digesters. No matter of the season times or location of biogas digester, the pH value in biogas digesters remain between 7 and 8. The inside temperature of the biogas digester in south of China remains more than 20°C, while it is only 10°C - 15°C in winter in north of China. The CH_4 content of biogas has barely a difference between regions and season times between 50% and 60%.

On the basis of the analysis for the characteristics of household biogas systems in China, the comprehensive evaluation system of transferability was established, which can be approached in many scenarios: technology understanding, decision-making by government and self-check by farmer. Here, cost–benefit analyses were used to construct an objective, scientific and comprehensive transferability study of a household biogas digester in different regions. The suitable climate condition, demand of clean energy supply and accessibility of material as the most important criteria were taken into account. Besides, the financial, technical, social, and political conditions were also considered. Criteria were scored according to a 0 - 1 scale, the score gets higher if it is more fulfilling the requirement for promotion of household biogas digesters. China, Tanzania, Ethiopia, Bolivia, and Brazil were chosen for processing the identical transferability analysis. Furthermore, sensitivity analysis with different weightings places emphasis on discovering the advantages and disadvantages of a certain regions on transferability of household biogas digester and developing solutions for improvement. Therefore, eight variants of weighting were introduced to conduction the sensitivity analysis. The local situation analysis (best case, worst case, average conditions and general conditions for 80% of population) of all criteria were also essential in order to get the suggestions about improving this technology when the weightings keep constant.

This feasibility study provided preliminary conclusions on the framework conditions of household biogas digester that were identified as common to the comparable regions. These framework conditions, which were described as a biogas model and can be used as basic criteria for installation and operation of household biogas digester. The transferability analysis can be generic used by all levels, whether for energy strategy by decision-makers, or for identifying deficiencies for improvement, or a self-assessment by farmers. The conclusions of the research questions examined can be summarized as follows.

- The important conditions and parameters of household biogas digester systems are that the standard operation and the complete management shall be guaranteed. In order to ensure a stable biogas process, standard operation is essential, including stable input and output process, safety usage of biogas and digestate, proper insulation measurement for winter. Regular maintenance and overhaul of digester body, gas pipe and biogas appliance by professional workers can extend the lifetime of the biogas digester. Besides, promulgation and implementation relevant policies and standards can regulate the biogas system. Significantly support and capital input from government encourage the investment and development of biogas digester.

- China’s experience of household biogas systems, which comes from lots of practices with longtime management and service system, shows that, the household biogas plant has much advantages. The household biogas technology contributes to clean energy supply and sustainable climate protection (reducing of greenhouse gas effect) by valorizing biowaste treatment. There are not only economic benefits, but also an impact on aspects of agricultural production, socio-economic development, health, and sanitation. It can reduce the reliance on firewood, which leads to remove the pressure on forests. Burning less wood, straw and coal can improve indoor air quality and especially positively impacted the health of human. The biogas digestate still retains the plant nutrients and used as an organic fertilizer in agriculture, replacing of chemical fertilizer can further enhances greenhouse gas reduction. Besides, the household biogas technology has the advantage of simply operation and economically cost-effective.

Therefore, this biogas system is applicable as a low-tech biogas model to be promoted and applied in a wide range of developing countries and emerging countries, especially in Africa and Latin America.

- A comprehensive evaluation system of transferability with cost-utility analysis and sensitivity analysis was established. The criteria influencing establishment and operation of household biogas digester were selected, which include climate, energy, material, technical, finance, social and political. According to framework conditions for all the steps in biogas process (planning, construction, operation and management and fault) concrete criteria of transferability analysis were developed. The results proved that the promotion and application of Chinese household biogas technology is feasible in most countries in Africa and Latin America. China achieves the highest score of 0.76 in comparison with other countries in terms of Chinese household biogas technology and many years of experience. Because of a relatively long history of biogas development and more international cooperation, Tanzania and Ethiopia have the middle score of 0.51 and 0.46. In contrast, insufficient technical factors and less availability of materials lead Bolivia to be one of the countries with the worse conditions for the promotion of household biogas digesters. Household biogas plants are not an interesting solution for Brazil, since Brazil, with sufficient hydroelectricity, is already well supplied with renewable energy, and thus Brazil get the lowest result (with 0.35) among the five countries. According to the analysis above, it is proved that this simply transferability analysis can provide reliably and valuable results aiming to various decision-making process.

- According to the results of transferability analysis, it is proved that the promotion and application of household biogas technology is feasible in most countries in Africa and Latin America. The smallholder in energy-scarce areas is preferred as suitable farmers to build the household biogas digester. Daily 20 kg of feeding material (animal manure, agriculture waste, kitchen waste or toilet waste) should be fed into an 8m^3 household biogas digester and the produced biogas and digestate can be also used for domestic purposes. Therefore, the moderate scattered breeding is the most important source for getting the feeding materials. Although some farmers face the problem of financial or technical shortages, it can be improved through the support of the government and other institutions.

- According to calculation of potential of household biogas digesters, we can clearly see that the biogas market in Africa and Latin America has outstanding potential, even considering the water, climate, economic and social factors. The slow population growth in China and the rapid urbanization at the meantime leads to a decrease in the potential household biogas digesters, which drops from 67.24 million in 2020 to 19.85 million in 2050. Due to the relatively slower development of economic and strong dependence on agriculture sector, the potential of household biogas digesters in Tanzania and Ethiopia will maintain an increasing trend in the next 40 years. Especially in Ethiopia, the potential biogas digesters will reach 14.59 million in year 2050, which is more than 4 times compared to year 2010. The potential of household biogas digesters in Brazil represents the decreasing tendency with extremely low value from 0.06 million in 2020 to 0.03 million in 2050.

- Despite of the willing and potential, there can be still numerous problems and challenges in the sustainable promotion. First, the government must pay attention to the policy regulations. A biogas standard system can guarantee the promotion and application of household biogas digesters. Besides, the initial investment cost may be a major bottleneck in the spread of biogas technology in Africa and Latin America. For example, Ethiopia and Tanzania´s farmer should spend more than 50% of GNI to install the household biogas digester. Therefore, it is necessary to increase finance subsidize from government or access possibility to credit. Regarding to inadequate technology support, besides international cooperation and exchange, improved project management with regular inspection by the decentralized biogas office can ensure the normally working of biogas digester. For these issues, the government should take the function of macro-monitoring, organization and leadership.

The simultaneous development of medium- or large biogas plant for several households together is another option for the longtime and accelerated development of biogas technology. The regions with more centralized animal breeding should consider medium- or large high tech biogas plants. The areas, which are rich in solar, wind, hydro and geothermal resources, should take advantage of those resources and due to local conditions develop that renewable energy.

8.2 Outlook

The new knowledge from the characterization of Chinese household biogas technology and the review of transferability in other regions has lots of possible applications. Concurrently, with the theoretical and experimental developments of biogas technology, new questions and request are spawned. Further implementation and research work can therefore be derived from the present work:

- Comparison with other decentral technologies

The transferability study, which is based on the Chinese biogas experience, can be further adjusted more flexible and adapted to local conditions. Even it can be combined with different biogas technologies or with other new energy sources to give a comprehensive solution for stable energy supply and environment protection. Further comparison of Chinese household biogas technology with other decentral biogas technologies, such as floating biogas plant from India, Half-Dome digester from Nepal, finished biogas plant etc., should be conducted. Individual concepts for each region with the most suitable biogas model should be developed.

- Upscaling with central and high-tech biogas technology

Construction of central biogas plant for big farmers or many small households together shows more efficiency. Biogas generated by central biogas plant could have other utilization opportunities, such as the conversion into electricity, heat and biofuel. Automatic operating and management are also welcome for farmers. Nevertheless, farmers' willingness and attitude towards building central biogas plants depend on a series of economic, social and technological factors. Therefore, the applicability and potential analyses should be conducted.

- Upscaling with combination with other renewable energies

In addition to biomass energy, wind, solar, hydro, tidal, and geothermal energy accounts also to renewable energy sources. In accordance with local resource conditions and demand of social development, and on the premise of protecting the environment and ecosystems, reasonable selection and utilization of renewable energy sources are required to maximize the use of resources, adjust the energy structure, and protect the environment. Therefore, the combination of biomass energy with other renewable energies or energy system such systemically approaches may be very interesting and should be conducted.

- Implementation of transferability study of other regions

The transferability analysis has so far only conducted in 5 selected countries. It should be approached in more other regions and levels, for example in Europe or Asia, in small village or self-check by farmer. Based on different local condition and requirement, the weighting value can be adjusted with different value, so that can provide reliably and valuable results aiming to various decision-making process.

- Integration of other parameters like nutrients, water, energy

Biogas system as an energy system should be integrated with other items to form a sustainable bioeconomic cycle, for example, water, nutrients, and other energies. Further research should focus on identify the effect and interact within these items, as well as the effect on people, animals and soil in the system. A sustainable bio economy concept should be developed, which combines the biogas system with other items achieving optimally cycle of nutrients and water under considering the climate protection.

- Potential and methods of optimization of household biogas digester

The potential and methods of optimization of household biogas digester should be determined. For example, integrated with pressure alarm and methane sensor, which provide a safer operation and better control system. Similarly, heating system and stirring equipment can increase the better biogas yield. Furthermore, flexible biogas production aims to recover the different energy demand within a day. A flexible feeding management or flexible storage in biogas plant can realize the demand-oriented energy supply.

- Further promotion of the household biogas technology

Recognizing the multiple benefits of household biogas technology will accelerate the promotion of this technology. Combined with government support and subsidies, pilot plant or pilot area in developing and emerging countries should be installed. Creation of network and platform also helps the development and promotion of biogas systems. For example, the Asia-Pacific Training Center established since 1981 by Chinese Biogas Institute, should be used as a platform for know-how-transfer in the issues of construction and maintenance of household biogas digester. It can provide a comprehensive promotion program of research, technical support, training, and demonstration. Besides, the implementation of household biogas digesters will lead to new or existing manufactories joining the production of biogas appliance and accessories. A market for repair and maintenance services can be developed. Continuous improvement of existing services and equipment can be competitive in the international market.

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Annex

A-1 Questionnaire for investigation of biogas digester in China

Table A-1 Questionnaire for investigation of biogas digester in China

Information about the location
Province, city, municipality: Geography conditions: Average temperature in winter and summer: Agriculture: Size of families : Income of Families: Energy source for cooking: Energy source for lighting:
Structure (If possible. please provide layout)
Volume: Form: Construction material: Pipe material: Distance between the digester and appliances: Insulation in winter: Check valve:
Operation
Composition of the input material: Amount of input material: Input Method: Output method and frequency: stirring:
Use of biogas
Amount of biogas per day: Composition of biogas: Application:
Use of digestate
Amount of digestate per day: Application:
Ecological and economic aspects
Investment costs: Operating costs: Energy demand for use of biogas: Saved fossil energy: Time for cooking previously: Time for cooking with biogas:

A-2 Results of investigation of biogas digester in China

Investigation of biogas digester in south of China in lingli City

Biogas digester	No.1	No.2	No.3	No.4	No.5	No.6	No.7
Situation of Place	South of China	South of China	South of China	South of China	South of China	South of China	South of China
Place	lingli city	lingli city	lingli city	lingli city	lingli city	lingli city	lingli city
Investigation time	Sep. 2010	Sep. 2010	Sep. 2010	Sep. 2010	Sep. 2010	Sep. 2010	Sep. 2010
Situation of Family	2 adults, 2 kids	2 adults, 1 kid	2 adults, 2 kids	5 adults, 1 kid	4 adults, 2 kids	4 adults, 2 kids	3 adults, 2 kids
Livestock	1 cow	2 pigs	2 cows	4 pigs and 10 chickens	3 cows	4 pigs	2 pigs
Type of biogas digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester
Size	6 m^3	6 m^3	8 m^3	9 m^3	8 m^3	8 m^3	6 m^3
Year of construction	2008	2008	2004	2004	2005	2004	2008
Input substrate	Cow manure, Toilet waste	pig manure, Toilet waste	Cow manure, Toilet waste	Pig & Chicken manure, Toilet waste	Cow manure, Toilet waste	Pig manure, Toilet waste	Pig manure, Toilet waste
Input substrate [kg/day]	4 kg	4 kg	8 kg	8 kg	10 kg	8 kg	4 kg
Input water [kg/day]	10 kg	10 kg	12 kg	12 kg	10 kg	12 kg	10 kg
Output biogas [m^3/day]	0.6 - 0.8 m^3	0.8 - 1 m^3	0.8 - 1 m^3	0.8 - 1 m^3	0.8 - 1 m^3	0.8 - 1 m^3	0.6 - 0.8 m^3
Output digestate [kg/day]	14 kg	14 kg	20 kg	20 kg	20 kg	20 kg	14 kg
pH Value in winter	7.45	7.36	7.85	7.38	7.25	7.67	7.41
Temperature in winter [°C]	22.5	21.3	25.2	21	19.6	22.6	25.8
CH_4 content in winter [%]	51%	54%	55%	57%	54%	55%	51%
CO_2 content in winter [%]	48%	45%	44%	42%	45%	44%	48%
pH Value in summer	7.61	8.03	7.44	7.84	7.65	7.73	7.59
Temperature in summer [°C]	29.1	28.6	27.1	25.2	29.1	26.3	26.4
CH_4 content in summer [%]	52%	53%	56%	55%	53%	53%	55%
CO_2 content in summer [%]	47%	46%	43%	44%	46%	46%	44%
Odor	No	No	No	No	No	No	No
N content in digestate [mass-%]				0.17%			
P content in digestate [mass-%]				0.15%			

Investigation of biogas digester in south of China in Hechi City

Biogas digester	No.8	No.9	No.10	No.11	No.12	No.13	No.14	No.15
Situation of Place	South of China	South of China	South of China	South of China	South of China	South of China	South of China	South of China
Place	Hechi city	Hechi city	Hechi city	Hechi city	Hechi city	Hechi city	Hechi city	Hechi city
Investigation time	Feb. 2011	Feb. 2011	Feb. 2011	Feb. 2011	Feb. 2011	Feb. 2011	Feb. 2011	Feb. 2011
Situation of Family	4 adults, 2 kids	4 adults, 1 kid	3 adults, 1 kid	3 adults, 1 kid	4 adults, 2 kids	4 adults, 1 kid	2 adults, 2 kids	2 adults, 1 kid
Livestock	2 cows	3 cows	2 cows	2 pigs and 10 chickens	2 cows	2 cows	1 cow	1 cow
Type of biogas digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester
Size	9 m^3	8 m^3	8 m^3	6 m^3	8 m^3	8 m^3	6 m^3	6 m^3
Year of construction	2006	2004	2005	2008	2008	2005	2008	2008
Input substrate	Cow manure, Toilet waste	Cow manure, Toilet waste	Cow manure, Toilet waste	Pig & chicken manure, Toilet waste	Cow manure, Toilet waste	Cow manure, Toilet waste	Cow manure, Toilet waste	Cow manure, Toilet waste
Input substrate [kg/day]	8 kg	10 kg	5 kg	5 kg	8 kg	8 kg	4 kg	4 kg
Input water [kg/day]	10 kg	10 kg	11 kg	10 kg	10 kg	10 kg	10 kg	10 kg
Output biogas [m^3/day]	0.8 - 1 m^3	0.8 - 1 m^3	0.8 - 1 m^3	0.6 - 0.8 m^3	0.8 - 1 m^3	0.8 - 1 m^3	0.6 - 0.8 m^3	0.6 - 0.8 m^3
Output digestate [kg/day]	18 kg	20 kg	16 kg	15 kg	18 kg	18 kg	14 kg	14 kg
pH Value in winter	7.26	7.48	7.15	7.17	7.42	7.11	7.18	7.29
Temperature in winter [°C]	23.6	21.5	20.7	22.4	21.6	18.9	24.1	23.8
CH_4 content in winter [%]	51%	54%	51%	50%	57%	53%	53%	51%
CO_2 content in winter [%]	48%	45%	48%	49%	42%	46%	46%	48%
pH Value in summer	7.74	7.25	7.81	7.79	7.12	7.5	7.83	7.86
Temperature in summer [°C]	29	24.1	28.8	27.4	25.8	26.9	28.6	28.8
CH_4 content in summer [%]	57%	54%	58%	51%	51%	53%	57%	55%
CO_2 content in summer [%]	42%	45%	41%	48%	48%	46%	42%	44%
Odor	No	No	No	No	No	No	No	No
N content in digestate [mass-%]			0.30%					
P content in digestate [mass-%]			0.11%					

Investigation of biogas digester in north of China in Hulunbeier City

Biogas digester	No.16	No.17	No.18	No.19	No.20	No.21	No.22	No.23
Situation of Place	North of China	North of China	North of China	North of China	North of China	North of China	North of China	North of China
Place	Hulunbeier City	Hulunbeier City	Hulunbeier City	Hulunbeier City	Hulunbeier City	Hulunbeier City	Hulunbeier City	Hulunbeier City
Investigation time	Aug. 2009	Aug. 2010	Aug. 2011	Aug. 2012	Aug. 2013	Aug. 2014	Aug. 2015	Aug. 2016
Situation of family	3 adults, 1 kid	4 adults, 2 kids	4 adults, 1 kid	2 adults, 1 kid	2 adults, 2 kids	4 adults, 1 kid	3 adults, 1 kid	3 adults, 1 kid
Livestock	4 pigs	2 cows	4 pigs and 5 chickens	3 pigs	2 cows and 10 chickens	2 cows	3 pigs and 5 chickens	2 cows
Type of biogas digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester
Size [m^3]	6 m^3	8 m^3	6 m^3	6 m^3	8 m^3	8 m^3	6 m^3	8 m^3
Year of construction	2000	2008	2004	2004	2005	2008	2005	2002
Input substrate	Pig manure, Toilet waste	Cow manure, Toilet waste	Pig & chicken manure, Toilet waste	Pig manure, Toilet waste	Cow & chicken manure, Toilet waste	Cow manure, Toilet waste	Pig & chicken manure, Toilet waste	Cow manure, Toilet waste
Input substrate [kg/day]	5 kg	8 kg	6 kg	5 kg	8 kg	8 kg	5 kg	8 kg
Input water [kg/day]	7 kg	10 kg	8 kg	7 kg	10 kg	10 kg	7 kg	10 kg
Output biogas [m^3/day]	0.6 - 0.8m^3	0.8 - 1 m^3	0.6 - 0.8m^3	0.6 - 0.8m^3	0.8 - 1 m^3	0.8 - 1 m^3	0.6 - 0.8m^3	0.8 - 1 m^3
Output digestate [kg/day]	12 kg	18 kg	14 kg	12 kg	18 kg	18 kg	12 kg	18 kg
pH Value in winter	7.02	7.2	7.39	7.25	7.14	7.06	7.21	6.85
Temperature in winter [°C]	12.5	11.5	10.9	13.5	13.8	11.5	13.7	10.5
CH_4 content in winter [%]	52%	55%	56%	54%	52%	58%	53%	54%
CO_2 content in winter [%]	42%	44%	43%	45%	39%	41%	46%	42%
pH Value in summer	7.09	7.46	7.51	7.24	7.47	7.75	7.9	7.42
Temperature in summer [°C]	23.4	24.5	25.3	22.4	22.8	26.9	25.1	23.6
CH_4 content in summer [%]	56%	57%	56%	55%	59%	52%	53%	56%
CO_2 content in summer [%]	42%	42%	43%	44%	39%	47%	46%	42%
Odor	No	No	No	No	No	No	No	No
N content in digestate [mass-%]	0.21%							
P content in digestate [mass-%]	0.21%							

Investigation of biogas digester in west of China in Urumqi City

Biogas digester	No.24	No.25	No.26	No.27	No.28	No.29
Situation of Place	West of China	West of China	West of China	West of China	West of China	West of China
Place	Urumqi City	Urumqi City	Urumqi City	Urumqi City	Urumqi City	Urumqi City
Investigation time	Sep. 2011	Sep. 2010	Sep. 2009	Sep. 2012	Sep. 2013	Sep. 2014
Situation of Family	3 adults, 2 kids	4 adults, 2 kids	3 adults, 1 kid	4 adults, 2 kids	2 adults, 1 kid	3 adults, 2 kids
Livestock	2 cows	2 pigs	2 cows and 1 horse	1 cow and 1 horse	1 cow and 2 horse	4 pigs and 1 horse
Type of biogas digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester	fixed-dome digester
Size	8 m³	6 m³	8 m³	8 m³	8 m³	8 m³
Year of construction	2004	2005	2004	2008	2005	2008
Input substrate	Cow manure, Toilet waste	Pig manure, Toilet waste	Cow & horse manure, Toilet waste	Cow & horse manure, Toilet waste	Cow & horse manure, Toilet waste	Pig & horse manure, Toilet waste
Input substrate [kg/day]	6 kg	4 kg	6 kg	6 kg	6 kg	8 kg
Input water [kg/day]	8 kg	6 kg	9 kg	8 kg	8 kg	8 kg
Output biogas [m³ /day]	0.8 - 1m³	0.6 - 0.8m³	0.8 - 1m³	0.8 - 1m³	0.8 - 1m³	0.8 - 1m³
Output digestate [kg/day]	14 kg	10 kg	15 kg	14 kg	14 kg	16 kg
pH Value in winter	7.14	7.34	7.05	6.89	6.97	7.08
Temperature in winter [°C]	8.8	10.5	9.6	8.9	6.8	11.5
CH_4 content in winter [%]	55%	51%	52%	54%	51%	52%
CO_2 content in winter [%]	44%	48%	40%	45%	48%	47%
pH Value in summer	7.14	7.45	7.5	7.38	7.89	7.36
Temperature in summer [°C]	20.1	24.3	21.6	21.9	23.9	24.5
CH_4 content in summer [%]	57%	56%	58%	53%	54%	56%
CO_2 content in summer [%]	42%	43%	40%	46%	45%	43%
Odor	no	no	no	no	no	no
N content in digestate [mass-%]			0.22%			
P content in digestate [mass-%]			0.13%			

A-3 Standards of experiments

GB 6920—86 Water Quality—Determination of pH Value—Glass Electrode Method (MEP China GB/T 6920-86, 1987)

This method is used for the determination of pH value of drinking water, surface water and wastewater. The glass electrode method uses two electrodes, a saturated calomel electrode as a reference electrode. a glass electrode as the indicator electrode, to determine the pH of a solution by measuring the voltage (potential) between them. This method is the one most commonly used for pH measurement, since the potential quickly reaches equilibrium and shows good reproducibility, and because the method can be used on various types of solutions, with oxidizing or reducing substances having very little impact on the result.

GB11901-89 Water Quality-Determination of suspended substance-Gravimetric method (MEP China GB 11901-89, 1990)

This standard applies to suspended solids measurement of surface water. groundwater and also domestic sewage and industrial wastewater. Suspended solids of water samples are trapped on filter with pore size of 0.45um. and dried at 103°C -105°C.

GB11914-89 Water Quality-Determination of the chemical oxygen demand-Dichromate method (MEP China GB 11914-89, 1990)

This standard specifies the method for determination of chemical oxygen demand of water. applies to all types of water samples with a COD value more than 30 mg/L. The determination limit of the undiluted water samples is up to 700mg/L. The sample is fully oxidized by potassium dichromate under certain conditions relating the corresponding concentration of oxygen in dichromate. which is consumed by dissolved substances and suspended solids in water samples.

A known amount of potassium dichromate solution is added in water samples. After the oxidation of sample. unrestored potassium dichromate solution is titrated by ferrous ammonium sulfate; with the indicator of 1.10-phenanathrolinemonohydrate. the amount of ferrous ammonium sulfate will be determinate. equals the consumption of oxygen.

HJ 636-2012 Water Quality-Determination of total nitrogen-Alkaline potassium persulfate digestion UV spectrophotometric method (MEP China HJ 636—2012, 2012)

The determination of total nitrogen uses usually the oxidation method with persulfate. in which the organic nitrogen and inorganic nitrogen compounds are converted into nitrate. Decomposition reaction of potassium persulfate in an aqueous solution at above 60°C is conducted as is shown in the following equations, hydrogen ions and oxygen are built:

$K_2S_2O_8+H_2O \rightarrow 2KHSO_4+1/2O_2$

$KHSO_4 \rightarrow K^{-1}+HSO_4^-$

$HSO_4^- \rightarrow H^++SO_4^{2-}$

The absorbance was measured at a wavelength of 220nm and 275nm UV with spectrophotometry. According to the equation of $A=A_{220}-2A_{275}$ and the molar absorptivity of 1.47 × 103 L/(mol*cm), absorbance values of nitrate and the total nitrogen content could be calculated.

GB 11903-89 Water Quality-Determination of colority (MEP China GB 11903-89, 1990)

This standard specifies the two methods for the determination of colors. It determines the color of sample after 15min clarification. PH has a relatively big influence on color; therefore, pH value shall be determined when determining color.

1. Platium-cobalt colorimetry is based on international standards ISO 7887-1985 "Water Quality-Determination of Colority". Platium-cobalt colorimetry is applicable to such water as clean water, slightly polluted water with yellow color, relatively clean surface water and groundwater as well as drinking water.
2. Dilution method is applicable to surface water with serious pollution and industrial wastewater.

The two methods must be employed separately and are not comparable. The current standard is not applicable when the color of sample is not consistent with the color of standard solution.

Platinum-cobalt colorimetry

Color is measured by visual comparison of the sample with platinum-cobalt standards. One unit of color is that produced by 1 mg/L platinum in the form of the chloroplatinate ion.

Dilution method

Color degree is measured as the dilution times when it is diluted with distilled water until hardly to optically distinguish any difference between diluted colored water and distilled water as a standard.

GB11893-89 Water Quality – Determination of total phosphorus- Ammonium molybdate spectrophotometric method (MEP China GB11893-89, 1990)

The standard specifies the ammonium molybdate spectrophotometric method that employs potassium peroxydisulfate (ornitric acid - perchloric) as oxidant to digest unfiltered water sample and determine the total phosphorus (TP) level. TP includes dissolved, granular, organic and inorganic phosphorus. The current standard is applicable to surface water, sewage and industrial effluent. Under neutral conditions, the potassium persulfate solution reacts at high pressure and more than 120℃ as following reaction:
$K_2S_2O_4 + H_2O \rightarrow 2KHSO_4 + [O]$
Thus, all phosphorus in the water, such as organic phosphorus inorganic phosphorus, suspended solids is oxidized into the orthophosphate, which can be determinate by spectrophotometer.

GB/T 14675-93 Air Quality-Determination of odor-Triangle odor bag method (MEP China GB/T 14675-93, 1994)
This standard specifies the determination of odor concentration from exhaust of odor pollution sources and ambient air samples with human olfactory method. The method is not restricted by the number of types of odor substances. scope of concentration and proportion of contained substances.

Odor concentration is a quantitative indicator of the odor. which is tested by the human olfactory organ. In this method. odor concentration is measured in diluted times and the tester distinguishes the dilution of samples. which is serially diluted with clean air.

In the triangle odor bag method. Two bags are filled with clean air. and the other is filled with tested samples and clean air with certain dilution concentration. Tester should take a sniff at these three bags and identify the bag with sample. Then the sample bag should be progressively diluted. sniffed and identified until the odor concentration is lower. that the tester cannot identify it any more and the experiment should be stopped. The diluted times of the sample and clean air can be defined as the threshold. Each sample should be measured simultaneously by at least 4 testers. Odor concentration can be calculated based on the average threshold of all tester members.

GB 13200-91 Water Quality-Determination of turbidity (MEP China GB 13200-91, 1992)
The standard is based on and adopts the international standard ISO 7027-1984 "Water quality-Determination of Turbidity". The standard specifies 2 methods for the determination of turbidity of water. The first method is spectrophotometry and applicable to drinking water, natural water and water with high turbidity. Its lowest detection limit is 3 grads. The second method is a visual comparison method and is applicable to low turbidity water such as drinking water and water from drinking water sources with detection limit of 1 grad. There shall be no scrap and particles prone to

precipitation in the water. If the vessels in use are not clean or contain dissolved bubbles or color substance, it will interfere with the results.

Spectrophotometry

At appropriate temperature. 1g/100ml hydrazine sulfate and 10g/100ml of hexamethylenetetramine polymerize to form a white polymer. which can be used as standard solution with the turbidity of 400 degrees. Then absorptiometry is measured and compared with the sample. so that the turbidity of samples can be drawn.

Visual turbidimetry

The turbidity of 1mg diatomite in 1000ml water is defined as 1 degree. The turbidity of sample can be identified through visual comparison with diatomite standard solution.

HJ 505—2009 Water Quality—Determination of biochemical oxygen demand after 5 days (BOD_5) for dilution and seeding method (MEP China HJ 505-2009, 2009)

This standard stipulates the determination of biochemical oxygen demand after 5 days (BOD_5) by dilution and seeding method. This standard shall apply to the determination of biochemical oxygen demand in surface water, industrial wastewater and domestic wastewater.

Biochemical Oxygen Demand refers to dissolved oxygen consumption by microbial decomposition of oxidizable substances in water. especially organic matter. The sample should be placed in a completely sealed bottle and cultured for 5 days at a temperature of 20 degrees, concentration of dissolved oxygen in water samples are measured before and after the culture. Dissolved oxygen consumption can be determined as the difference of the concentration of dissolved oxygen before and after culture. The BOD_5 is defined with the units of mg/L.

If the organic content in the sample is high and BOD_5 concentration is greater than 6mg/L. dilution of the sample before determination is required. The industrial wastewater containing no or less micro-organisms, such as acidic wastewater, alkaline water or hot water, should be vaccinated by BOD_5 determination in order to introduce microbes for decomposition of organic matter in wastewater.

HJ/T 347-2007 Water Quality - Determination of fecal coliform - manifold zymotechnics and filter membrane (MEP China HJ/T 347– 2007, 2007)

This standard specifies manifold zymotechnics and filter membrane method for the determination of fecal coliform in surface water, groundwater and wastewater.

Multiple tube fermentation method

Multiple tube fermentation method is based on the most probable number referred MPN to represent the experimental results. In fact, it is a method based on statistical theory for estimation of E. coli density of sample.

Membrane filtration method

Membrane filtration used in this method is a microporous film. The sample is injected into the sterile filter (pore size 0.45um) and bacteria are trapped in the film after filtration. Filter with bacteria is affixed to the culture medium under temperature of 44.5 degrees, the number of bacterial colonies grown on the membrane is counted, and the number of fecal coliforms per 1L of sample can be calculated.

GB / T 19524.2-2004 Determination of ascaris eggs mortality of fertilizer

This standard specifies the determination of mortality of ascaris eggs in fertilizer. The sample is mixed with basic solution in order to isolate the ascaris eggs. Ascaris eggs can be collected by floating liquid, which have higher density than the eggs, so that ascaris eggs float on the surface of the solution and the amount can be finally identified.

A-4 Standards of biogas in China

Table A-2 Standards of household biogas plant (China Biogas Society, 2018)

Standard	Standard-Nr.	Standard Name
National	GB/T 4750-2002	Collection of standard design drawings for household anaerobic digesters
National	GB/T 4751-2002	Specification for check and acceptance of the quality for household anaerobic digesters
National	GB/T 4752-2002	Operation rules for construction of household anaerobic digesters
National	GB/T 3606-2001	Domestic biogas stove
National	GB/T 7636-1987	Standard on design of biogas pipelines for peasant household
National	GB/T 7637-1987	Operation rules of construction and installation of biogas pipelines for peasant household
National	GB/T 7959-1987	Sanitary Standard for the non-hazardous treatment of night soil
National	GB 5084-2005	Standards for irrigation water quality
National	GB 18877-2009	Organic-inorganic compound fertilizer
National	GB 19379-2012	Hygienic specification for rural household latrine
Industry	NY/T 90-2014	Household-scaled technology rules of biogas fermentation
Industry	NY/T 344-2014	Household biogas lamp
Industry	NY/T 465-2001	Household-scaled Biogas & integrated farming system, specification on design, construction and use for southern model
Industry	NY/T 466-2001	Household-scaled Biogas & integrated farming system, specification on design, construction and use for northern model
Industry	NY 525-2012	Organic fertilizer
Industry	NY/T 858-2014	Household biogas pressure meter
Industry	NY/T 859-2014	Desulfurizer of domestic biogas
Industry	NY/T 860-2004	Digester sealing coatings
Industry	NY/T 1496.1-2007	Biogas transmission system for rural household part1: Thermoplastic pipes
Industry	NY/T 1496.2-2007	Biogas transmission system for rural household part2: Thermoplastic pipe fittings
Industry	NY/T 1496.3-2007	Biogas transmission system for rural household part3: Thermoplastic valves
Industry	NY/T 1496.4-2014	Biogas transmission system for rural household part4: Design and installation specifications
Industry	NY/T 1638-2008	Biogas cooker
Industry	NY/T 1639-2008	Technology criterion on rural biogas digester and three renovations
Industry	NY 1699-2009	Technical specifications for household anaerobic digesters of fiberglass reinforced plastics
Industry	NY 1700-2009	Determination of methane and carbon dioxide in biogas – gas chromatography
Industry	NY/T 2450-2013	Material and technology conditions of household biogas digester

Standard	Standard-Nr.	Standard Name
Industry	NY/T 2451-2013	Specifications of household biogas digester operation and maintenance
Industry	NY/T 2452-2013	Household-scaled biogas & integrated farming system-specification on design, construction and use for northwest model

Table A-3 Standards of medium- und large sized biogas projects (China Biogas Society, 2018)

Standard	Standard-Nr.	Standard Name
National	GB 18596-2001	Discharge standard of pollutants for livestock and poultry breeding
National	GB/T 29488-2013	Medium/high-power biogas generating set
Industry	NY/T 667-2011	Classification of scale for biogas engineering
Industry	NY/T 1168-2006	Technical Requirement for non-hazardous treatment of animal manure
Industry	NY/T 1220.1-2006	Technical code for biogas engineering Part1: Process design
Industry	NY/T 1220.2-2006	Technical code for biogas engineering Part2: Design of biogas supply
Industry	NY/T 1220.3-2006	Technical code for biogas engineering Part3: Construction and acceptance
Industry	NY/T 1220.4-2006	Technical code for biogas engineering Part4: Operation and maintenance
Industry	NY/T 1220.5-2006	Technical code for biogas engineering Part5: Evaluation of quality
Industry	NY/T 1220.6-2014	Technical code for biogas engineering Part6: Safety using
Industry	NY/T 1221-2006	Technical specification for operation maintenance and safety of biogas plant in scale animal and poultry farms
Industry	NY/T 1222-2006	Criterion for designing if biogas plant in scale livestock and poultry breeding farms
Industry	NY/T 1223-2006	Biogas-powered generating sets
Industry	NY/T 1700-2009	Determination of methane and carbon dioxide in biogas – gas chromatography
Industry	NY/T 1702-2009	Technology specifications of biogas digester for domestic sewage treatment
Industry	NY/T 1704-2009	Biogas power generation technology criterion
Industry	NY/T 2371-2013	Technical code for rural centralized biogas supply plant
Industry	NY/T 2141-2013	Construction operational regulation of crop straw anaerobic digestion engineering
Industry	NY/T 2142-2013	Process design code of crop straw anaerobic digestion engineering
Industry	NY/T 2372-2013	Code for operation and maintenance of crop straw biogas plant
Industry	NY/T 2373-2013	Code for quality acceptance of crop straw biogas plant
Industry	NY/T 2374-2013	Technical code of post-treatment of digested sludge and slurry from biogas plant
Industry	NY/T 2596-2014	Anaerobic digested fertilizer
Industry	NY/T 2597-2014	Collection of standard design drawings of biogas digester for domestic sewage treatment
Industry	NY/T 2598-2014	Technical specifications for gasholder on biogas plants
Industry	NY/T 2599-2014	Code for acceptance of biogas plants on large-scare livestock and poultry farms
Industry	NY/T 2600-2014	Equipment’s type selection for biogas plants on diversified scales of livestock and poultry farms

GB 7636-87 Standard on design of biogas pipelines for peasant household

GB 7637-87 Operation rules of construction and installation of biogas pipelines for peasant household

it proves the requirements of the design, installation, quality inspection and maintenance of gas transmission and distribution system of the rural household biogas digester, it is applicable to the gas transmission and distribution system of rural household biogas digester.

GB/T 4751-2002 Specification for check and acceptance of the quality for household anaerobic digesters:

This standard specifies the content, methods and requirements of selection of the cast-in-place concrete, brick masonry or reinforced concrete prefabricated materials to build the biogas digester as well as the content, methods and requirements of quality inspection and acceptance of the sealing layer construction of household biogas digesters.

GB/T 4752-2002 Operation rules for construction of household anaerobic digesters:

This standard specifies the requirements of site selection for biogas digester, quality requirements of construction material, technical requirements and general acceptance of construction technology of sealing layer of biogas digesters and others.

GB/T 4750-2002: Collection of standard design drawings for household anaerobic digesters:

This standard gives the construction design of rural household biogas digesters and supporting technology for the construction. It is applicable to the construction of household biogas digesters across the country with the various types of soil and different weather conditions. Design parameters: when the inner pressure in digester is 8000 (or 4000) Pa. leakage rate should be less than 3% within 24h; under normal circumstances, the volumetric gas production rate is 0.2-0.4m^3/d.m^3; gas storage volume is 50% of the daily gas production; use life expectancy is 20 years or more.

GB/T 3606-2001 Domestic biogas stove:

This standard specifies the technical requirements, test methods and inspection rules of household biogas stoves. The Standard applies to the household gas stoves, which rated heat flow not less than 2.33 kW (2000kcal/h). Basic design parameters: biogas pressure before the stove is defined as 800Pa or 1600Pa; stove thermal efficiency is greater than 55%; two eyes stove should be a main fire, the rated thermal flow is not less than 2.79kW (2400kcal / h).

GB 7959-87 Sanitary Standard for the non-hazardous treatment of night soil:

This standard applies sanitize evaluation for the harmless treatment of both urban and rural waste, manure and provide design parameters for the construction of waste and excreta disposal plants.

GB 5084-2005: Standards for irrigation water quality:

It provides quality requirements, testing and analysis methods of irrigation water. That applies to surface water. Groundwater treated aquaculture wastewater and industrial wastewater from the processing of agricultural products as irrigation water.

Biogas transmission system for rural household
NY/T 1496.1-2007: part1: Thermoplastic pipes.
NY/T 1496.2-2007: part2: Thermoplastic pipe fittings.
NY/T 1496.3-2007: part3: Thermoplastic valves:

It provides the requirements, test methods, inspection rules, packaging, marking, transportation and storage for gas transmission system as hose, plastic pipe fittings and plastic switch, of which the main raw material is polyethylene (PE) or polyvinyl chloride (PVC). It proves material, resin content, the proportion of regrind, density of various pipe fittings; it is suit for the environmental conditions in the pressure 12kPa and temperature of 40°C or less.

NY/T 1699-2009: Technical specifications for household anaerobic digesters of fiberglass reinforced plastics:

This standard specifies technology requirements, test methods, inspection rules and signs. Transportation, and other content for anaerobic digesters of fiberglass reinforced plastics, which using a glass fiber as reinforced material and resin as its matrix. It is suitable for household biogas digesters of fiberglass and digester arch of fiberglass, which is formed by contact molding (manual injection), sheet molding compound (SMC) compression molding, resin transfer molding (RTM).

NY/T 1700-2009: Determination of methane and carbon dioxide in biogas - gas chromatography:

This standard specifies test methods of methane and carbon dioxide in the biogas. It requires hydrogen gas as carrier gas with purity of not less than 99.9%, and also requires the preparation of standard gas with ratio of methane to carbon at 60:40.

NY/T 1638-2008: Biogas cooker:

This standard specifies technical requirements, test methods of the biogas rice cooker and its inspection rules, signs, packaging, transport and storage. Rice cooker with 800 or 1600Pa pressure is required; household rice cooking should have the thermal flow not less than 0.8kW, thermal efficiency should be greater than 60%; it should have insulation properties and a safety device (flame and temperature control).

NY/T 1639-2008: Technology criterion on rural biogas digester and three renovations:

It is suitable for construction of rural household biogas digesters and renovations of livestock pens, toilets and kitchen. In accordance with the local conditions, livestock pens, toilets and kitchens should be renovated with the construction of biogas digester; Human toilet should be built next to the livestock and poultry sheds and connected to the biogas digester inlet with pipe. Biogas digesters should be built under the animal houses and human toilet, so that human and animal feces flow through the pipeline automatically into the biogas digester.

NY/T 466-2001: Household-scaled Biogas & integrated farming system. specification on design. construction and use for northern model:

This standard applies to the area north from latitude 32 ° and alpine mountains in low latitude. It provided the essential of design and construction for the biogas digester, pig pens and greenhouse; acceptance, startup, operation and safety matters of biogas digesters; as well as the management of pig pens, pig feeding and integrated management measures of solar greenhouse.

NY/T 465-2001: Household-scaled Biogas & integrated farming system. specification on design, construction and use for southern model:

This standard specifies the households with the overall design of the Rural Energy Ecological Engineering Southern mode, building requirements, the management of pig house, orchard and digesters, also comprehensive utilization method of digestate. Apply to farmers and orchard farm in the Southern Hills.

NY/T 860-2004: Digester sealing coatings:

This standard specifies the technology requirements, test methods, inspection rules of seal coating of household digesters, as well as its packaging, marking, transportation and storage requirements. It is suitable for seal coating of concrete or brick structure of sealed inside household digesters. Requirement of seal coating: sealing material strength grade reaching 42.5MPa; alkali and acid resisting; the impermeability and affinity; storage stability.

NY/T 859-2004: Desulfurizer of household biogas:

This standard specifies the technology requirements, test methods, inspection and logo, packaging and transportation of iron oxide as desulfurizer for household biogas desulfurization. It is suitable for desulfurization of rural household biogas digesters and household biogas digesters group with less than 10kPa pressure. The desulfurizer should be easy to replace and should be sealed and decay; its capacity must be greater than 2L.

NY/T 858-2004: Biogas pressure meter:

This standard specifies the technical requirements, test methods, inspection rules and signs, packaging and storage of biogas pressure meter. Requirement of the pressure meter: normal working temperature is -25℃ ~ +55℃; range between 0-16kPa; corrosion resistance.

NY/T 90-1988: Technology rules of biogas fermentation for household in rural areas:

This standard applies to all types of household hydraulic digesters. It specifies requirements of starting of biogas digester, warming insulation, the large refueling and safety management.

NY/T 344-1998: Household biogas lamp:

It provides for the classification and nomenclature of household biogas lamps, as well as its technical requirements, test methods, inspection rules, signs and packaging. It is applicable to the lighting gas lamps with rated pressure under 2400Pa. its heat load does not exceed 525W (450kcal/h). Technical requirements: it cannot have tempering. when the pressure is 0.5 times of the rated pressure; it cannot have open flames when the pressure is 1.5 times of the rated pressure; combustion noise does not exceed 55dB what under 1.5 times the rated pressure; the surface temperature of the nozzle took over should not exceed 70 °C.

NY 525-2012: Organic fertilizer:

It specifies the appearance of organic fertilizer requirements, its component requirements, test methods, inspection rules, logo, packaging, transport and storage. Apply to organic fertilizer made by fermentation, which using manure, animal and plant residues as raw materials.

GB 18877-2009: Organic-inorganic compound fertilizer:

It specifies the requirements, test methods, inspection rules, labeling, packaging, transportation and storage of organic - inorganic compound fertilizer. Apply to organic - inorganic compound fertilizer is mixture of inorganic fertilizers and organic fertilizers, which made by fermentation process with manure, animal and plant debris, agricultural waste and other organic matter as raw materials.

A-5 Results of transferability analysis

Table A-4 Score of criteria in China with worst, best, average and general case

		Criteria	Worst	Best	Average	General
A1	Climate	Suitable climate condition	0.25	1.00	0.50	1.00
B1	Energy	Scarcity of traditional energy supply for household	0.00	1.00	0.25	0.25
B2		Increase the share of renewable energy	0.25	1.00	0.75	0.75
C1	Material	Availability of feeding material for biogas digester	0.50	1.00	0.75	0.75
C2		Availability of water	0.75	1.00	1.00	1.00
C3		Sufficient space for agriculture	0.25	1.00	0.75	0.50
C4		Availability of construction material	0.75	1.00	1.00	1.00
C5		Availability of biogas appliance	0.75	1.00	1.00	1.00
D1	Technical	Availability of engineer for Design and quality control	0.75	1.00	1.00	1.00
D2		Availability of worker for construction, operation and after-sale-service	0.75	1.00	1.00	1.00
E1	Finance	Finance ability	0.75	1.00	1.00	1.00
E2		Potential users have access to credit	0.75	1.00	0.75	1.00
F1	Social	Role of women in domestic decision-making process and life	0.75	1.00	0.75	1.00
F2		Biogas plant can be integrated into normal working routine at the farm	0.75	1.00	1.00	1.00
F3		Ethical aspect	0.75	1.00	1.00	1.00
G1	Political	Availability of Standards. laws and regulations on biogas technology	0.75	1.00	1.00	1.00
G2		Political will of the Government to support a national biogas program	0.75	1.00	1.00	1.00
G3		Monitoring and supervision	0.75	1.00	1.00	1.00

Table A-5 Results of transferability analysis in China with different scenario

			Worst	Best	Average	General
A1	Climate	Suitable climate condition	0.01	0.05	0.03	0.05
B1	Energy	Scarcity of traditional energy supply for household	0.00	0.15	0.04	0.04
B2		Increase the share of renewable energy	0.01	0.05	0.04	0.04
C1	Material	Availability of feeding material for biogas digester	0.10	0.20	0.15	0.15
C2		Availability of water	0.02	0.03	0.03	0.03
C3		Sufficient space for agriculture	0.01	0.03	0.02	0.01
C4		Availability of construction material	0.02	0.03	0.03	0.03
C5		Availability of biogas appliance	0.02	0.03	0.03	0.03
D1	Technical	Availability of engender for Design and quality control	0.02	0.03	0.03	0.03
D2		Availability of worker for construction, operation and after-sale-service	0.02	0.03	0.03	0.03
E1	Finance	Finance ability	0.11	0.15	0.15	0.15
E2		potential users have access to credit	0.08	0.10	0.08	0.10
F1	Social	Role of women in domestic decision-making process and life	0.01	0.02	0.01	0.02
F2		Biogas plant can be integrated into normal working routine at the farm	0.01	0.02	0.02	0.02
F3		ethical aspect	0.01	0.02	0.02	0.02
G1	Political	Availability of Standards, laws and regulations on biogas technology	0.02	0.03	0.03	0.03
G2		Political will of the Government to support a national biogas program	0.02	0.03	0.03	0.03
G3		Monitoring and supervision	0.04	0.05	0.05	0.05
Sum			0.53	1.00	0.76	0.81

Table A-6 Score of criteria in Tanzania with worst, best, average and general case

		Criteria	Worst	Best	Average	General
A1	Climate	Suitable climate condition	0.75	1.00	1.00	1.00
B1	Energy	Scarcity of traditional energy supply for household	0.75	1.00	0.75	0.50
B2		Increase the share of renewable energy	0.25	0.75	0.50	0.50
C1	Material	Availability of feeding material for biogas digester	0.50	0.75	0.50	0.50
C2		Availability of water	0.00	0.75	0.50	0.75
C3		Sufficient space for agriculture	0.50	1.00	0.75	0.75
C4		Availability of construction material	0.25	0.75	0.50	0.50
C5		Availability of biogas appliance	0.00	0.50	0.50	0.50
D1	Technical	Availability of engender for Design and quality control	0.25	0.50	0.50	0.50
D2		Availability of worker for construction, operation and after-sale-service	0.25	0.50	0.50	0.50
E1	Finance	Finance ability	0.25	0.50	0.25	0.50
E2		Potential users have access to credit	0.25	0.75	0.50	0.50
F1	Social	Role of women in domestic decision-making process and life	0.25	0.75	0.50	0.50
F2		Biogas plant can be integrated into normal working routine at the farm	0.50	1.00	0.50	0.50
F3		Ethical aspect	0.25	0.75	0.50	0.50
G1	Political	Availability of Standards, laws and regulations on biogas technology	0.00	0.50	0.25	0.25
G2		Political will of the Government to support a national biogas program	0.25	0.75	0.50	0.50
G3		Monitoring and supervision	0.00	0.25	0.25	0.50

Table A-7 Results of transferability analysis in Tanzania with different scenario

			Worst	Best	Average	General
A1	Climate	Suitable climate condition	0.04	0.05	0.04	0.05
B1	Energy	Scarcity of traditional energy supply for household	0.11	0.15	0.11	0.08
B2		Increase the share of renewable energy	0.01	0.04	0.03	0.03
C1	Material	Availability of feeding material for biogas digester	0.10	0.15	0.10	0.10
C2		Availability of water	0.00	0.02	0.01	0.02
C3		Sufficient space for agriculture	0.01	0.03	0.02	0.02
C4		Availability of construction material	0.01	0.02	0.01	0.01
C5		Availability of biogas appliance	0.00	0.01	0.01	0.01
D1	Technical	Availability of engineer for Design and quality control	0.01	0.01	0.01	0.01
D2		Availability of worker for construction, operation and after-sale-service	0.01	0.01	0.01	0.01
E1	Finance	Finance ability	0.04	0.08	0.04	0.08
E2		Access to credit	0.03	0.08	0.05	0.05
F1	Social	Role of women in domestic decision-making process and life	0.00	0.01	0.01	0.01
F2		Biogas plant can be integrated into normal working routine at the farm	0.01	0.02	0.01	0.01
F3		Ethical aspect	0.00	0.01	0.01	0.01
G1	Political	Availability of Standards, laws and regulations on biogas technology	0.00	0.01	0.01	0.01
G2		Political will of the Government to support a national biogas program	0.01	0.02	0.01	0.01
G3		Monitoring and supervision	0.00	0.01	0.03	0.03
Sum			0.38	0.72	0.51	0.53

Table A-8 Score of criteria in Ethiopia with worst, best, average and general case

		Criteria	Worst	Best	Average	General
A1	Climate	Suitable climate condition	0.75	1.00	0.75	0.75
B1	Energy	Scarcity of traditional energy supply for household	0.50	1.00	0.75	0.50
B2		Increase the share of renewable energy	0.25	1.00	0.25	0.50
C1	Material	Availability of feeding material for biogas digester	0.50	1.00	0.50	0.50
C2		Availability of water	0.25	0.75	0.50	0.75
C3		Sufficient space for agriculture	0.50	1.00	0.75	0.75
C4		Availability of construction material	0.25	0.75	0.50	0.50
C5		Availability of biogas appliance	0.00	0.50	0.25	0.50
D1	Technical	Availability of engineer for Design and quality control	0.25	0.75	0.25	0.50
D2		Availability of worker for construction, operation and after-sale-service	0.25	0.75	0.25	0.50
E1	Finance	Finance ability	0.00	0.50	0.25	0.50
E2		Access to credit	0.00	0.50	0.25	0.25
F1	Social	Role of women in domestic decision-making process and life	0.25	0.75	0.50	0.50
F2		Biogas plant can be integrated into normal working routine at the farm	0.25	0.75	0.50	0.50
F3		Ethical aspect	0.25	0.75	0.50	0.50
G1	Political	Availability of Standards, laws and regulations on biogas technology	0.00	0.50	0.25	0.25
G2		Political will of the Government to support a national biogas program	0.25	0.75	0.50	0.50
G3		Monitoring and supervision	0.00	0.25	0.25	0.25

Table A-9 Results of transferability analysis in Ethiopia with different scenario

			Worst	Best	Average	General
A1	Climate	Suitable climate condition	0.04	0.05	0.04	0.04
B1	Energy	Scarcity of traditional energy supply for household	0.08	0.15	0.11	0.08
B2		Increase the share of renewable energy	0.01	0.05	0.03	0.03
C1	Material	Availability of feeding material for biogas digester	0.10	0.20	0.10	0.10
C2		Availability of water	0.01	0.02	0.01	0.02
C3		Sufficient space for agriculture	0.01	0.03	0.02	0.02
C4		Availability of construction material	0.01	0.02	0.01	0.01
C5		Availability of biogas appliance	0.00	0.01	0.01	0.01
D1	Technical	Availability of engineer for Design and quality control	0.01	0.02	0.01	0.01
D2		Availability of worker for construction, operation and after-sale-service	0.01	0.02	0.01	0.01
E1	Finance	Finance ability	0.00	0.08	0.04	0.08
E2		Access to credit	0.00	0.05	0.03	0.03
F1	Social	Role of women in domestic decision-making process and life	0.00	0.01	0.01	0.01
F2		Biogas plant can be integrated into normal working routine at the farm	0.00	0.01	0.01	0.01
F3		Ethical aspect	0.00	0.01	0.01	0.01
G1	Political	Availability of Standards, laws and regulations on biogas technology	0.00	0.01	0.01	0.01
G2		Political will of the Government to support a national biogas program	0.01	0.02	0.01	0.01
G3		Monitoring and supervision	0.00	0.01	0.01	0.01
Sum			0.28	0.77	0.46	0.48

Table A-10 Score of criteria in Bolivia with worst, best, average and general case

		Criteria	Worst	Best	Average	General
A1	Climate	Suitable climate condition	0.25	1.00	0.50	0.50
B1	Energy	Scarcity of traditional energy supply for household	0.50	1.00	0.50	0.50
B2		Increase the share of renewable energy	0.25	0.75	0.50	0.75
C1	Material	Availability of feeding material for biogas digester	0.50	1.00	0.50	0.50
C2		Availability of water	0.25	1.00	0.50	0.75
C3		Sufficient space for agriculture	0.50	1.00	0.75	0.75
C4		Availability of construction material	0.25	0.75	0.50	0.75
C5		Availability of biogas appliance	0.00	0.75	0.25	0.25
D1	Technical	Availability of engineer for Design and quality control	0.25	0.75	0.25	0.50
D2		Availability of worker for construction, operation and after-sale-service	0.25	0.75	0.25	0.50
E1	Finance	Finance ability	0.25	0.50	0.25	0.50
E2		Access to credit	0.25	0.75	0.25	0.50
F1	Social	Role of women in domestic decision-making process and life	0.50	1.00	0.50	0.75
F2		Biogas plant can be integrated into normal working routine at the farm	0.25	0.75	0.50	0.75
F3		Ethical aspect	0.50	1.00	0.75	0.75
G1	Political	Availability of standards, laws and regulations on biogas technology	0.00	0.50	0.25	0.25
G2		Political will of the Government to support a national biogas program	0.25	0.75	0.50	0.50
G3		Monitoring and supervision	0.00	0.50	0.25	0.25

Table A-11 Results of transferability analysis in Bolivia with different scenario

			Worst	Best	Average	General
A1	Climate	Suitable climate condition	0.01	0.05	0.03	0.03
B1	Energy	Scarcity of traditional energy supply for household	0.08	0.15	0.08	0.08
B2		Increase the share of renewable energy	0.01	0.04	0.03	0.04
C1	Material	Availability of feeding material for biogas digester	0.10	0.20	0.10	0.10
C2		Availability of water	0.01	0.03	0.01	0.02
C3		Sufficient space for agriculture	0.01	0.03	0.02	0.02
C4		Availability of construction material	0.01	0.02	0.01	0.02
C5		Availability of biogas appliance	0.00	0.02	0.01	0.01
D1	Technical	Availability of engineer for Design and quality control	0.01	0.02	0.01	0.01
D2		Availability of worker for construction, operation and after-sale-service	0.01	0.02	0.01	0.01
E1	Finance	Finance ability	0.04	0.08	0.04	0.08
E2		Access to credit	0.03	0.08	0.03	0.05
F1	Social	Role of women in domestic decision-making process and life	0.01	0.02	0.01	0.01
F2		Biogas plant can be integrated into normal working routine at the farm	0.00	0.01	0.01	0.01
F3		Ethical aspect	0.01	0.02	0.01	0.01
G1	Political	Availability of Standards, laws and regulations on biogas technology	0.00	0.01	0.01	0.01
G2		Political will of the Government to support a national biogas program	0.01	0.02	0.01	0.01
G3		Monitoring and supervision	0.00	0.03	0.01	0.01
Sum			0.33	0.81	0.41	0.52

Table A-12 Score of criteria in Brazil with worst, best, average and general case

		Criteria	Worst	Best	Average	General
A1	Climate	Suitable climate condition	0.75	1.00	0.75	0.50
B1	Energy	Scarcity of traditional energy supply for household	0.00	0.25	0.00	0.00
B2		Increase the share of renewable energy	0.25	0.75	0.25	0.25
C1	Material	Availability of feeding material for biogas digester	0.00	0.25	0.00	0.00
C2		Availability of water	0.75	1.00	0.75	1.00
C3		Sufficient space for agriculture	0.50	1.00	0.75	0.50
C4		Availability of construction material	0.50	1.00	0.75	0.75
C5		Availability of biogas appliance	0.00	0.50	0.25	0.25
D1	Technical	Availability of engineer for Design and quality control	0.50	1.00	0.50	0.75
D2		Availability of worker for construction, operation and after-sale-service	0.50	1.00	0.50	0.75
E1	Finance	Finance ability	0.50	1.00	0.50	0.50
E2		Access to credit	0.50	1.00	0.50	0.75
F1	Social	Role of women in domestic decision-making process and life	0.75	1.00	0.75	0.75
F2		Biogas plant can be integrated into normal working routine at the farm	0.75	1.00	0.75	0.75
F3		Ethical aspect	0.75	1.00	0.75	0.75
G1	Political	Availability of Standards, laws and regulations on biogas technology	0.50	0.75	0.50	0.50
G2		Political will of the Government to support a national biogas program	0.25	1.00	0.50	0.50
G3		Monitoring and supervision	0.25	0.75	0.50	0.5

Table A-13 Results of transferability analysis in Brazil with different scenario

			Worst	Best	Average	General
A1	Climate	Suitable climate condition	0.04	0.05	0.04	0.04
B1	Energy	Scarcity of traditional energy supply for household	0.00	0.04	0.00	0.00
B2		Increase the share of renewable energy	0.01	0.04	0.01	0.01
C1	Material	Availability of feeding material for biogas digester	0.00	0.05	0.00	0.00
C2		Availability of water	0.02	0.03	0.02	0.03
C3		Sufficient space for agriculture	0.01	0.03	0.02	0.01
C4		Availability of construction material	0.01	0.03	0.02	0.02
C5		Availability of biogas appliance	0.01	0.03	0.01	0.01
D1	Technical	Availability of engineer for Design and quality control	0.01	0.03	0.01	0.02
D2		Availability of worker for construction, operation and after-sale-service	0.01	0.03	0.01	0.02
E1	Finance	Finance ability	0.08	0.15	0.08	0.08
E2		Access to credit	0.05	0.10	0.05	0.08
F1	Social	Role of women in domestic decision-making process and life	0.01	0.02	0.01	0.01
F2		Biogas plant can be integrated into normal working routine at the farm	0.01	0.02	0.01	0.01
F3		Ethical aspect	0.01	0.02	0.01	0.01
G1	Political	Availability of Standards, laws and regulations on biogas technology	0.01	0.02	0.01	0.01
G2		Political will of the Government to support a national biogas program	0.01	0.03	0.01	0.01
G3		Monitoring and supervision	0.01	0.04	0.03	0.03
Sum			0.33	0.71	0.35	0.39

A-6 Annuity factor for economic analysis

Table A-14 Annuity factor

Year / Interest	3%	4%	5%	6%	7%	8%	9%	10%
1	1.030	1.040	1.050	1.060	1.070	1.080	1.090	1.100
2	0.523	0.530	0.538	0.545	0.553	0.561	0.568	0.576
3	0.354	0.360	0.367	0.374	0.381	0.388	0.395	0.402
4	0.269	0.275	0.282	0.289	0.295	0.302	0.309	0.315
5	0.218	0.225	0.231	0.237	0.244	0.250	0.257	0.264
6	0.185	0.191	0.197	0.203	0.210	0.216	0.223	0.230
7	0.161	0.167	0.173	0.179	0.186	0.192	0.199	0.205
8	0.142	0.149	0.155	0.161	0.167	0.174	0.181	0.187
9	0.128	0.134	0.141	0.147	0.153	0.160	0.167	0.174
10	0.117	0.123	0.130	0.136	0.142	0.149	0.156	0.163
15	0.084	0.090	0.096	0.103	0.110	0.117	0.124	0.131
20	0.067	0.074	0.080	0.087	0.094	0.102	0.110	0.117

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