Contents

List of tables

List of figures

1. Introduction

Climate Change is a reality that the world is currently facing, being developing countries more vulnerable to the impacts. The use of renewable energy surge as a response to counter this climate effects. There are promoted technologies for mitigation of greenhouse gas emissions, at the same time increases the living standards life of the communities that are depending on the agriculture to sustain their life.

Livestock manure used as a fertilizer directly to the soil can cause enormous environmental problems as an increase of pathogens, odours, contamination of watercourses, pollution. A solution to prevent those effects is anaerobic digestion process where microorganisms decompose the organic matter in the absence of oxygen producing methane for heat generation and a digested substrate known as a carbon dioxide rich in phosphorus, nitrogen, potassium and micronutrients compared to raw material improve the nutrient availability of the plants, higher fertilizer efficiency and reduce odours.

Livestock production in Cambodia plays an important role in the farmer's lives. Mainly, cattle and buffalos are used as draft power, while pigs are used for cash generation and home consumption. The households, relying on wood, car batteries and other traditional energies sources. Nearly 5 million Cambodians cannot access to the grid.

Biogas technology comes as a solution for small scale householder in Cambodia to improve their living conditions and the accessibility to reliable energy. Biogas plays an important role in the mitigation of climate change; replacement fossils fuel as oil and coal for clean energy reducing the greenhouses gases emissions.

2. Literature Review

The purpose of this literature review is to analyse the benefits of using biogas technology from livestock manure to reduce greenhouse gases emissions; a key point in the mitigation of climate change. At the same time bridge the electricity gap of the Cambodian families.

2.1 Global Warming

Global warming refers to an increase in the global temperature, along with surface air and sea surface area for a period of 30 years starting with the preindustrial era. The carbon dioxide, methane, nitrous oxide and chlorofluorocarbons (CFCs) and water vapour forming a layer that inhibits the gases pass through the atmosphere leading to an increase of temperature and then warming the planet, overpopulation caused that green gases houses as a carbon dioxide, methane, nitrous oxide. According to (Linderholm 2006, Between 1900 and 2005 a variation in the annual precipitation resulted in an increase of many regions mainly North and South America, northern Europe and Asia at the same time an increased in the areas of droughts. A study was made conclude that water vapour in the atmosphere it's a strong compound that increases the global earth temperature to 33 C°, corresponding to an 80 to 90 % of the total greenhouse effect, the contribution of methane emission its around 18 % greater than CO_2 (Kutilek & Nielsen 2019). Balance the incoming solar radiation and outgoing solar radiation, to reduce the impacts of global warming.

2.1.1 Global Warming Potential Index

Global Warming Potential Index (GWP) has been used to quantify the greenhouses gas effect of the different gases (Harvey 1993). This measures how much energy 1 ton of a gas will absorb over time, the larger it's the GWP the more the gas will warm the Earth. The period it is around 100 years is an index that provides a measure that helps policymakers to compared different reduction opportunities across several sectors and gases for example in the specific role to make greenhouses gases inventory by countries (EPA 2014).

Table 1. Greenhouse's gases potential

Greenhouse Gases	Global Warming Potential (GWPs) over 100 years
CO_2 (Carbon Dioxide)	1 Ton CO_2
CH_4 (Methane)	28-36 times potent than CO_2
N_20 (Nitrous Oxide)	265-298 times potent than CO_2
Chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6)	1000-10000 times potent than CO_2

Source: EPA 2014

2.2 Greenhouse gas effect

The driving forces of the earth system, such as ecology, climate and hydrology, are controlled by the absorption of solar radiation, which is the energy required to heat the earth (Kutilek & Nielsen 2019). The additional fluctuations caused by the movement of the earth Milankovitch cycles. Because our earth rotates every day, half of the earth will be affected by solar radiation at the same time (Kutilek & Nielsen 2019).

A broad explanation of Green House Gas Emissions is the energy balance from the earth. The Earth has to emit the same quantity of energy back to space, some of the infrared radiances pass through the atmosphere but most of them are remitted and absorbed by the greenhouses gases molecules and clouds in all directions, this effect warms the earth surface and global atmosphere (IPCC 2007).

2.3 Climate Change and its impacts

The change in the weather patterns for a long period of at least 30 years lead to a change in the climate system, starting for change in the weather patterns that threaten food production, an increase of water level, frequency of extreme events like droughts and hurricanes, heat waves, also negative effects in human health, for developing countries more vulnerable, are unprecedented and global in scope caused for the concentration of greenhouse gas.

Impacts caused by climate change in regions around the world have been a subject of investigation for several years. A compilation of themes will be mentioned in this section:

According to IPCC (2014), an increase in sea-level rise was measured from 1901 to 2010 since the middle of the 19^{th} century, showing an unprecedented increase of 0.17-0.21 m. On the same line, IPCC (2007) observed from 1961 to 2003 arisen in the global temperature by 0.10 C°. In 2016 the World Health Organization (WHO) detected 12.6 million of deaths accounting for 23 % of the total deaths worldwide found driving forces linked with climate change. The damaged caused by climate change is estimated between 2-4 billion/year by 2030. Although the habitat of species is being affected for example time of flowering of the trees has been changed and egg-laying has been altered their home ranges. Oceans become more acidic affecting marine biodiversity and impacted the fisheries of the communities.

IPCC (2007) presented a series of compilation of impacts in Asia. Firstly, a decline of fresh water mainly in South, East and Southeast Asia affecting the crop production, high temperature led to a decline in rice yield, recurrences of heat stress affecting the livestock production. Secondly, its focus on fisheries and aquaculture, one of the main impacts is coastal flooding affecting aquaculture and availability of fisheries, risk of extreme events in the aquatic environment and economic losses with the scarcity of the decline of freshwater aquaculture. Impacts in forestry as an increase of frequency of fires leading with the extinction of valuables species and ecosystems. A specific case is India that was hit for heat waves in 2002, 2003 and 2005. Pakistan and Bangladesh in 2005 had between May and June maximum temperatures of 45 C°, and 50 C°, led to hundreds of deaths.

Prediction for 2050 had already been made for IPCC, warming in a high emissions scenery correspond to 2-3 C°, while warming in all emissions scenario is 1-2 C°. Those changes have a negative impact on human society; overall freshwater availability, agriculture, for that reason mitigation is required to limit the emissions of greenhouses gases to prevent more irreversible effects in the climate system.

According to NAPA (2006), Cambodia has been affected by floods that have accounted for 70 % of rice production losses between 1998 and 2002 with 20 % accounted losses by drought. In coastal areas saline intrusion and water salinization are common issues. A survey was conducted in 7 provinces of Cambodia related with malaria and the finding were that 12% of the families contracted malaria during the dry season and 8% during dry and wet season. Almost 63% of households contracted malaria during the wet season, 12% during the dry season. Battambang province has been identified vulnerable to droughts and floods also the majority of villages are limited on the understanding of climate change and adaptation without acquaintance on climate resilient agriculture crops, leading to affect the rural development opportunities and negative impacts in agriculture activities. Although villages have experienced water shortages and lack of financial support influenced the strength of coping in climate change.

The lack of strong policies to adapt and mitigate climate change will lead to accelerated negative impacts. Without strong mitigation measures, the increase in climate phenomena will cause irreversible losses.

2.4 Mitigation policies

Methods of mitigation and adaptation are crucial for tackling climate change. Adaptation will be an important part of combating climate change, but mitigation is critical to reducing gas emissions and harmful effects, and for this, the government needs to take intervention measures.

Policies have been applied to reduce greenhouse gases emissions. Two approaches have been considered according to Dessler (2016):

Carbon Tax: In this approach, the companies can emit large quantities of greenhouse gases but the government will charge for every gas or gases emitted, it’s a mechanism to reduce the greenhouses gases emissions in a way that the companies compromise to fulfil the law and reduce their emissions. This system is applied to fossil fuels, using an excise tax on coal and petroleum then the price of the tax will reach the market and, where the end receiver will finally pay, the credit will be generated if the carbon is produced in the way that it not released into the atmosphere. The weakness of this system is the generation of new taxes and the compromise of the companies to fulfil the regulations.

Emission Trade systems: Are commonly known as a cap and trade system that place a cap on the emissions, thus system fix the quantity of the emission but not the price of allowance of the emissions under the government, allow to emit 1 ton of greenhouse gases to the atmosphere. One of the benefits of the system is the transfer to the wealth consumers to the government. Although the government can use the incomes to help in a new technology caused for depletion in energy from cap and trade system.

Government in developed countries has already implemented mitigation strategies as mentioned above, a fulfil of emissions procedures it is crucial to maintain a mechanism to increase resilient of climate change. Developing countries has been compromised in reduce their emission, considering voluntary policies an example is Costa Rica that according to NEDDS projects (2010), 90 % of the country electricity is presently being produced from renewable sources. Costa Rica was the pioneer of stablish a Program of Environmental Services (PSA) to control the higher deforestation rates, giving a tax for each carbon emission reduced from preserved the forest and restored degrade forests. Since 1997 Costa Rica, carbon tax has been generated 26.5 million in income every year where the government pay to farmers and landowner for rainforest protection and goods restauration. On the other hand Cambodia started the REDD+ program with the goal to provide guidance to received based payments. Ones of the important achievements during 2008- 2016 was the understanding of the importance to have existing and planned national government policies, frameworks and plans associated to sustainable development, resilient agriculture, conservation and low carbon development pathways (UNFCCC, 2017).

2.4.1 Clean Development Mechanism (CDM)

A mechanism developed for the United Nations Framework Convention on Climate Change (UNFCCC) for emission reduction projects in developing countries, whose emissions are equivalent to a ton of CO_2 emission reduction certificates. Industrial countries are conducting trade and transactions to meet the emission reduction targets set by the Kyoto Protocol. The main objective is sustainable development and reduction of emissions, so that industrialized countries can achieve the goal of reducing restrictions. The clean development mechanism aims to provide funding for developing countries to implement the Kyoto Protocol adaptation projects and programs, mainly under the protection of the UNFCCC Fund for Adapting to Vulnerable Countries.

According to CDM, UNFCCC (2019). Cambodia presented several projects to reduce their emissions. Until now three projects are registered, focus on biogas and methane fired power generation. The total expected amount reduction of greenhouse gas emissions from those projects is 90,331 ton of CO_2 equivalent per annum on average. The main issues in the implementation are regarding the lack of government support, corruption for the focal point entity being the local government, rejections from UNFCCC resulting in a delayed in applying measures in the reduction of emissions.

2.4.2 Nationally Appropriate Mitigation Actions (NAMAS)

The United Nations Framework Convention on Climate Change (UNFCCC) assigns a voluntary country option to follow the views of national governments and take any compromise actions to reduce emissions. There are many options, for example, actions for different sectors, strict policies. NAMA provides financial, technical and cooperative assistance to achieve the 2020 emission reduction target. Under the protection of the United Nations Framework Convention on Climate Change, there are two ways to register at the national and group levels. It is a platform for receiving funds and formulating zero-carbon emission projects.

Cambodia has developed two NAMAS, one is focus on Sustainable Charcoal and the other is focus on Energy efficiency in the Garment industry in Cambodia (NAMA Database 2015). The projects are under development will result in the reduction of greenhouses gases emissions and the compromise of the country to enhance an economy zero carbon emissions.

2.5 The Greenhouse gases emissions from livestock

2.5.1. Carbon dioxide

The carbon dioxide sources of emissions are confined manure, and exhalation of the animal. The carbon dioxide produced by the animals it is resulting from energy metabolism, whereas the relation between the animal feed and the quality of nutrients in the diet. On the other hand, the amount of CO_2 from the manure it produced into outbuilding for a long time such as slatted houses. The amount produced its lower in comparison from the CO_2 production from livestock. (Pedersen et al. 2008). A study conducted by Philip and Nicks (2015) found that 70 % of total emissions from pig's farms account for fattening periods, while lactation, pregnancy and weaning contribute to 10 % of total emissions. Total greenhouse gases emissions correspond to 448.3 kg CO_2 per slaughter and 4.87 kg CO_2 per carcass.

2.5.2. Enteric Methane

Product for the enteric fermentation, a natural procedure take place where fungi, bacteria, protozoa are inside of the forepart stomach of the animal in the rumen, the plants and biomass are breaking down part of the fermentation process. Plants in the rumen it converted by fatty acids then pass to the reticulum and go to the liver to finally step the circulatory system. This allows the animal to switch the high amount of cellulose and hemicellulose material. The final product of the fermentation process that is a residual gas is removed from the rumen by eructation producing higher amount of methane and carbon dioxide (McAllister & Newbold 2008). Enteric emission represents 30 % of global methane emission (FAO 2017) being 28 times powerful than CO_2.

2.5.3. Methane from manure storage

According to IPCC (2006), guidelines, methane emission is produced due to the improper treatment of storage and manure. The decomposition of manure undergoes throughout anaerobic treatment and storage process producing CH_4. These conditions mostly occur when the animals are confined as a farm, beef feedlots, poultry farms and when the manure its disposal as a liquid form. The manure decomposes in anaerobic form as a liquid manure might turn a major amount of CH_4. The temperature and retention time are influenced factors in the quantity of methane produced. On the other hand, when the manure its storage in solid form such as piles to decay in aerobic conditions with a few emissions of methane.

2.5.4. Nitrous oxide from manure storage

Manure is an organic material that is used to fertile land, consists of faeces and urine of domestic livestock, with or without accompanying litter such as hay, bedding or straw (Britannica, 2021).

The emissions of N_2O happens through combined nitrification and denitrification nitrogen contained within excrement, it depends on the nitrogen and carbon substances of fertilizer and treatment procedures (IPCC 2006). Nitrification, the oxidation of ammonia nitrogen to nitrate nitrogen is a fundamental prerequisite for the emanation of N_2O from storage manure (IPCC 2006). An important source of N_2O released in the manure treatment, is estimated for 5 % of all global N_2O emissions (Owen & Silver 2015). Manure storage emissions depends on the amount of nitrogen emitted and time of storage (Merino et al. 2011).

2.6 Livestock mitigation Greenhouse's gases strategies in Cambodia

Strategies for GHG mitigations are in place, focus on the productivity of the animal and the quality of food given to produce rumen fermentation. According to Hristov et al. 2013 appropriate treatment of forage, such as shredding, steaming, is essential to ensure the reduction of intestinal methane and improve forage digestibility. On the other hand, essential oils improve feed conversion efficiency and affect the viability of microbes in the rumen to distinguish between high and low CH_4 emissions (Grainger & Beauchemin 2011).

Storage of manure, it is one of the ways to control the emission of greenhouses gases coming from direct agriculture and is a solution to reduce the number of gases emitted. One of the effective ways to manage manure is using furrow floor outside of the storage facility combined with rubbing of manure, particularly in cattle and pigs (Gorssi et al. 2018), this practice has the benefit to reduce nitrous oxide and methane by 55 and 41 %. (Mohankumar Sajeev et al. 2018). In the case of poultry manure, use housing with girdle scrapers reduce greenhouses gases emissions (Fournel et al. 2012).

Anaerobic digestion for production of biogas is one of the optimal solutions to manage manure, used for providing electricity at the same time work as a fertilizer. A studied show that anaerobic digestion has a yield of 30 % reduction in greenhouse gases emissions in comparison with traditional handling manure (Battini et al. 2014).

Systems as a rotation grazing are being encouraged as a good solution for the reduction of nitrous oxide and increase forage production (Gorssi, et al. 2018). Moreover, productivity, control of disease and diet of the livestock, has a huge impact in controlling the gases emitted to the atmosphere, good manage of nutrition and genetic breeding need promoted to ensure a mitigation strategy (Gorssi, et al. 2018).

2.7 Livestock Manure

The animal waste includes excreta such as urine and faeces, waste feed, drinking water, hair and soil. The amount of manure depends on the age of the animal, the productivity of the animal, the type of animal digestive system and diet (forage or grains). Manure is a useful fertilizer by-product produced by animals and poultry as a source of natural matter and fertilizer for crop and pasture (IPELC 2019).

2.7.1 Chemical composition of livestock manure

A large number of nutrients pass through the animals and are finally completed in the form of fertilizers. Depending on the number and type of animal, phosphorus is 60 %, nitrogen 70 % and potassium 80 %. These nutrients are being recycled for crops. Fertilizers also involve other nutrients, such as magnesium, sulphur, and calcium (SARE 2012).

2.7.2 Environmental impacts of livestock manure

The wastewater generated during the excretion of livestock and poultry manure is released into the river channel, causing eutrophication, deteriorating water quality, damaging aquatic organisms and increasing algae populations threatens the consumption of water and ecosystems.

Pathogens move to the groundwater produced by leaching of nitrate from dung fields caused a deterioration of water quality. The accumulation of nutrients in the soil affects the quality and areas such as wetland and swamps are highly impacted by biodiversity losses and pollution.

2.7.3 Health risks produced from livestock waste

Livestock manure increase the possibility of spreading disease because of the high content of nutrients, especially nitrate, which can cause health hazards to adult drinking water and reduce the body function of livestock (Kumar et al. 2013). Dangerous pathogens have been found in manure as Listeria monocytogenes, Yersinia enterocolitica, Escherichia coli. Streptococcus spp. and protozoa Giardia lamblia and Cryptosporidium parvum from cattle, sheep. Residues from poultry, wild birds, are a potential source of Salmonella spp bacteria and Campylobacter Jejuni. Manure has to be handled correctly to avoid contamination (Penstate Extension 2015). Air pollution is generated from Ammonia release of manure. During a study conducted in Cambodia for (Ström et al., 2018) in a survey taking in account 204 people related with manure management in cattle and pig, a trace of Salmonella enterica were found in 9.7 % of the manure and *Ascarius Sum* and *Tricuris suis* respectively 1.6 % and 3.4 % in manure showing a high risk of diseases for the families.

2.7.3.1 Heavy metals

Heavy metals from animal husbandry are released in the soil. Particularly, case of copper (Cu), which is essential for the animals. Other heavy metals emitted as a pollutant are cadmium (Cd), nickel (Ni), lead (Pb), found in sewage sludge, chemical fertilizers, feeds correspond to a 90 % of those minerals is excreted by the manure (Ogbuewu, et al. 2012). To add on that (Zhou et al. 2005), found that mercury (Hg), copper (Cu) and Zinc (Zn) in faecal use related to health problems and have high risks to humans and the environment in Southeast Asia and Europe.

2.8 Traditional uses of livestock manure

The soil is rich in nutrient-rich livestock manure and needs to be properly managed. Furthermore, animal waste has positive environmental benefits, such as controlling erosion and leaching, increasing the carbon content in the soil, and reducing the leaching of nitrate. Dung fertilizers contain macronutrients and micronutrients need for the plant to grow also improve the soil structure that allows the plant to get the water, decrease water stress, soil erosion and improve water retention (IPELC 2019).

2.9 Procedures for a correct manure management

The method of threatening livestock waste is the key to reducing the environmental and health effects of applying fertilizer directly to the soil. Compilation of topics are mentioned below.

2.9.1 Biological Treatment

Is a method to eliminate hazards through controlling the microbiological activity which made the manure harmless. Is divided in compost and vermicompost

Composting is a process of rapid oxidation of organic matter using microorganism under the thermophilic stage that releases heat, water and carbon dioxide. One of the advantages is odourless material, practical to handle and storage because reduced the weight and volume (Palma,2019).

According to Muralikvishna and Manicka, 2017; vermicomposting is a process of convert organic matter, common residues into humus by the action of earthworms. One of the benefits of vermicompost are mention below:

- potential source of farmers of an additional income
- additional uses as an animal feed
- improve soil structures and control of plant pathogens
- improve aeration and water hold capacity of the soil

Anaerobic digestion is a biochemical process using microorganisms to degrade organic matter into a gaseous mixture result of carbon dioxide and methane called biogas in an anaerobic condition (Palma 2019).

2.9.2 Enzymatic fermentation into ethanol:

Manure is characterized by the high fibre content of 50 %. Fibre it converted into sugar through a biochemical process as hydrolysis of fibre components (cellulose and hemicellulose), into simple sugars, that late are converted to fuel ethanol via the biochemical process.

2.10 Biogas as a solution of biowaste management

Biogas is a positive resource of energy, use to convert biomass, a rich environmental source in clean energy being able to reach the lack for energy demand in the most vulnerable communities present as a solution for small scale householders and an optimal treatment to manage livestock manure.

2.10.1 Biogas Production

The production of biogas consists in the breakdown of organic matter through an anaerobic biologic process. It is mainly composed of methane and carbon dioxide. Methane is equivalent to 50-85%, representing a huge energy source (Sindhu et al. 2019). In developed countries, biogas is produced on a large scale for electricity and commercial biogas plants. In developing countries, biogas is especially used for the lighting and cooking. (Scarlat et al. 2018).

2.10.2 Stages of Anaerobic digestion

The main key of anaerobic digestion is the conversion of organic matter (pollutants) or COD (chemical oxygen demand) with the action of anaerobic bacteria into methane in the absence of oxygen (Abdelgadir et al.2014).

The process of Anaerobic digestion is divided into three steps:

Hydrolysis: This process is characterized by the decomposition of organic materials in simple monomers by the action of hydrolytic enzymes (Ersahin et al. 2011).

Acidogenesis: The bacteria fermented transform simpler organic acids in organic acids and nitrogen and by the action of acetogenic bacteria the volatiles organic acid is transformed in acetate.

Acetogenesis: The organic acids for the second stage it transformed into hydrogen, carbon dioxide and acetic acid by the action of the acetogenic bacteria.

Methanogenesis: The final process consists in the production of methane and carbon dioxide by the methanogenic bacteria. Methanogenesis is influenced by different parameters such as temperature, feeding rate, temperature change, pH and composition for feedstock. The results products are 30 % of carbon dioxide, hydrogen and 70 % of methane originate from acetate. (Al Seide et al. 2008).

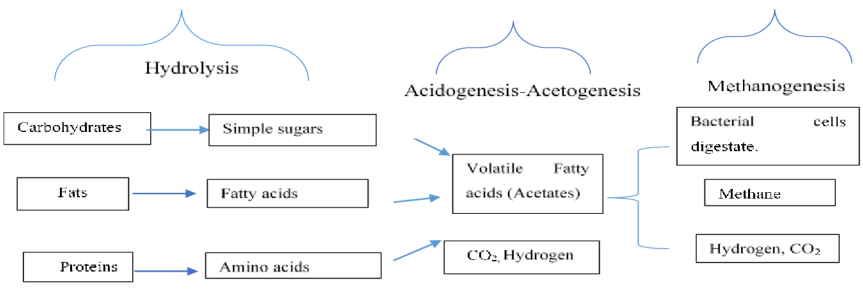

Figure 1. Summary of stage of anaerobic digestion (Adopted from Santibañez & Bustamante 2011)

The microorganisms such as bacteria require a certain temperature range to grow as a thermophilic (45°C -70°C), mesophilic (25 °C-45 °C), and psychrophilic that work below 25 °C. It's important to provide conditions for the anaerobic digestion process, which is usually depends on the raw materials and heating system in the digestion process.

2.10.3 Types of waste feedstocks

There are three types of biomasses used as waste materials to produce biogas (Claudis Da Costa, 2013).

1. The substrate of agriculture origin as a feed waste, harvest waste, liquid manure and energy crops.
2. Organic waste from municipalities and private householders, food waste, market waste.
3. By-products from industrial plants as a glycerine, food processing or waste from fat separator.

2.10.4 ***Advantages and disadvantages of Anaerobic digestion***

Anaerobic digestion is a process that reduce the amount of organic load through a series of biological reactions that result in a depollution of livestock manure with highest levels of purification.

Table 2. Advantages and disadvantages of Anaerobic Digestion.

Advantages	Disadvantages
▪ Digestive fluids from biogas production can be used as fertilizers, with the same nutrient content as fertilizers, which brings a solution to replace chemical fertilizers and reduces methane emissions and nutrient loss. ▪ Reduce odours and reduce pathogens that may lead to animal and human health risks (Scarlat et al. 2018). ▪ It produces renewable energy in the form of , biogas and the effect of fertilizer is longer than that of untreated organic waste.	▪ The inefficient process will produce a strong odour. ▪ For small-scale households, compared with large-scale households, due to the large investment required, it is more expensive (IPTTS 2020). ▪ It's not possible to convert higher proportion of carbon in the biomass than the amount can achieve using gasification.

Source: IPTTS 2020, Scarlat et al. 2018

2.10.5 Biogas composition and impurities

The two major components of biogas are methane (CH_4) and carbon dioxide (CO_2), as others gases such as oxygen(O_2), water vapour, hydrogen sulphide(H_2S) and ammonia (NH_3). (OSU 2014). Existing of impurities can cause problems in the production of biogas. The amount of H_2S is corrosive for electricity generation, high concentration of O_2 is explosive, chlorine is toxic and siloxanes leads to a formation of quartz that causes deposits in surfaces such as blocking the soils, making difficult for the plant get the required amount of water for grow properly.

Table 3. Differences biogas compositions between developing and developed countries.

Compound	Chemical	Developed countries	Developing countries
Methane	CH_4	50-80	55-75
Carbon dioxide	CO_2	25-45	30-45
Hydrogen Sulphide	H_2S	10-30000 ppm	
Nitrogen	N_2	0-10 %	
Oxygen	O_2	0.1-2 %	
Water Vapour	H_2O	0-10 %	
Ammonia	NH_3	0.01-25 mg/m^3	

Source: World Bank 2019

2.10.6 Biogas utilization

The use of biogas comes in two ways: raw or improved. One of the main raw uses is cooking and lighting in small scale householders replacing wood and diesel, kerosene and gasoline for electricity generation, for example, biogas installation has been successful in several countries, the case of Nepal providing a solution of cooking and lighting (Gautam et al. 2009).

One of the uses of upgraded biogas is the switch of raw gas to biomethane for vehicle fuel production important for its low emissions and prevention of air pollution. Although biogas can be used as a fuel for portable generators.

Researchers have been evaluated over time the potential to use biogas technology in the way for a crucial solution to tackle global climate change, reducing emissions by 10-13 % of the world emissions (WBA, 2019).

During an evaluation of the mitigation potential of biogas in two countries of Asia (Bhattacharya et al. 1997) found that using livestock manure produce 7,730 Gg of CH_4, 1,290,000 Gg of CO_2 and 179 Gg of N_2O residues using biogas as a replacement of kerosene has a substantial reduction of emissions by 53.1 % CH_4 of, 19.5 % CO_2 and 61.1% NO_2 resulting in a positive contribution for the mitigation of climate change.

2.11 Biogas Plants for processed livestock manure

The type of biodigester depends in technology that varies the country in country, depending in climatic conditions, affordability and energy availability. According to location, size and function of biodigester are classified in, Al Seadi et al. (2008).

2.11.1 Householders biogas plants (small-scale plants)

This type of plants use feedstock originate from the households and small farming activity to produce biogas for internal uses such as cooking and lighting. Those type of digesters are simple, easy to maintain and constructed with local production materials. Typically, there is not control in temperatures and usually operate in warmer climates with high water retention.

Biodigester can divided in different size varying from smalls scale household, farm biogas plants and communal (IRENA 2016).

2.11.2 Small scale digesters types use in developing countries

In Asia, a range amount of biodigester types have been introduced to manage the livestock manure. Importantly, many benefits have been addressed in terms of reducing odour, improving soil quality, and preventing diseases. In this type of biogas technology, due to the loss of biogas caused by blowing, the content of recycled nutrients is low (Bruun et al., 2014). The correct method must enable sustainable development and prevent methane loss. The main part of the biogas plant is the biodigester, a hermetic container which breakdown the organic waste through anaerobic digestion process.

According to the literature revised by Energypedia, 2015, there are different types of biodigesters specialized for rural households that according to the site and management are able to perform properly.

- **Fixed dome Plants:**

It is including a stable digester with a non-removable gas storage tank at the top of the digester. The slurry is moved through reward tank. Biogas plants are protected for physical damage while digester is protected from warm temperature and, not daylight fluctuation affect the bacteriolysis process. One of the main disadvantages is that the gas is less effective because the variations of gas pressure are large. One of the main types of fixed dome plants is Chinese fixed dome plants, Janata model and Camartec model.

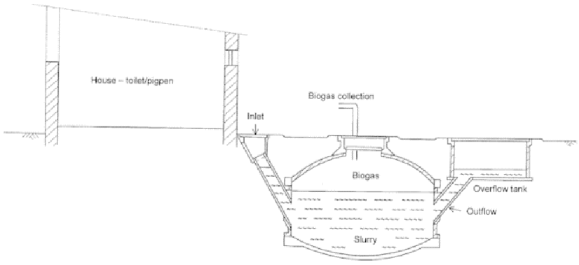

Fig 2. Chinese fixed dome biodigester plant (Hawdon 2014)

- **Floating Drum Plants:**

It consists of an underground dome digester, usually domed or cylindrical, with a removable gas storage tank. The fermentation of the slurry floats in the gas storage tank, and inside the gas storage cylinder the gas is storage. In order to produce biogas, the gas is rising and the consumer is decreasing.

The origin of this plant came from India and usually used animal and human faeces.

One of the main disadvantages is the expensive costs for maintenance. The lifetime is up to 15 years and for humid areas up to 5 years. One of the models used are Ganesh model and Pragati model.

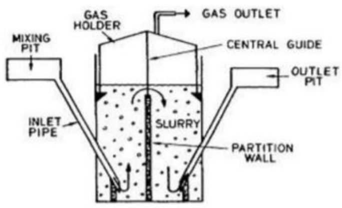

Fig 3. Floating drum biodigester (Ononogbo 2015)

- **Balloon Digester**

These types of biodigesters are used in Latin America and are housed in a plastic bag with a drain pipe attached to the end of the bag. These pipes function to add raw materials and eliminate mud. Biogas digesters are usually placed in ditches, and the depth of the ditches should be discharged into waste outlets to avoid damage. (IRENA 2016). One of the main benefits of these plants is low costs, simple construction, ideal for places with the high-water table and ideal for warmer climates. On the other hand, is not durable as compared with other digester types and the gas pressure is low (Energypedia, 2015).

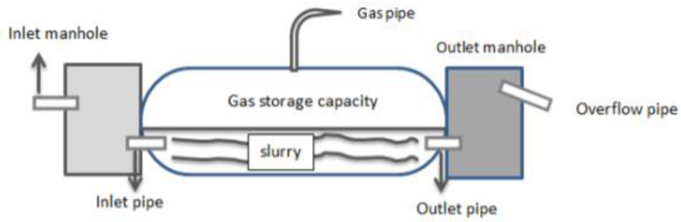

Fig 4. Diagram of Balloon digester (Puspawatiu. et al. 2019)

- **Horizontal Plants**

Usually, made of concrete or masonry, especially for shallow installation (groundwater and rock). One of the benefits of this type is the large slurry space. On the other hand, there is a problem of eliminating impurities and leaking gas. Disadvantages: It is difficult to eliminate the scum due to gas space leakage.

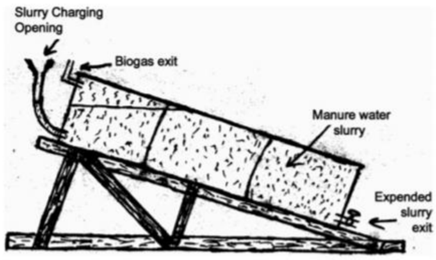

Fig 5. Diagram of Horizontal Biogas Plants (Forst 2002)

2.11.3 Farm Scale biogas plants

Those biogas plants use the feedstock substrate from the one farm on specific. Although its common produce methane rich substrates such as vegetable oils and fish oils mainly for increase the biogas yield production. A common practice it connects neighbourhood farms through via pipeline. The Digesters are classified in two types; horizontal or vertical with moving systems for mixing the substrate that avoid the risks of rotating deposits and sediment formation. The result biogas is used for generation of energy and heat production and the material digested is used as a fertilizer on the farm and the excess is sold to neighbourhood plants. The major disadvantages of those kind of plants it's the high operation costs, availability and land use (Allied Tech corp, 2020).

Fig 6. Example of farm biogas plant (Allied Tech corp, 2020)

2.11.4 Centralised co-digestion biogas plants

The biogas plants its localised in the manure collection area and the animal dropping its collected from different farms. The main goal for the privilege location is reduce costs, manpower and transport of biomass from biogas plants. Those type of plants are mainly got intensive animal farming and are extensively applied in Denmark. At the farm the animal waste its transported in special vacuum container trucks collected from the pre-storage tanks. At the biogas plants, manure is mixed with the others co-substrate inside the digester container. The main advantage of this plants is the integrated fertilisation plan that replace mineral fertilizers closing the carbon and nutrient recycling, economic benefits for farmers and the reduction of greenhouse gases emission among others as control of odours.

Fig 7. Example of centralized-co digest plants (Lemvig Biogas, 2013)

2.11.4 Industrial biogas plants

The main characteristic of biogas plants is the use of industrial residues to produce energy. The main typical substrate are residues from slaughterhouse, crop residues, fats, market waste, glycerol, industrial residues and waste for beverages industry. The plants are connected to an agriculture operation where liquid manure is the main basic substrate and it's delivered by trucks or pumped in the biogas plants at the same line industrial residues are bring to the plant. Because of environmental concern this type of technology have been increased among in industrial areas besides the energy production (Krieg & Fisher-Ingenieure GmbH, 2011)

.

Fig 8. Example of industrial biogas plants in Netherlands (Krieg & Fisher-Ingenieure GmbH, 2011)

2.12 Challenges presented for the installation of small – scale biogas plants in developing countries

There are several challenges that prevent the progress of biogas technology in developing countries and undermine the use of the technology and the benefits that offer to the small-scale households. A compilation of studies has been taken in account in order to compilate the challenges presented during the process of installation of small-scale biogas plants in developing countries summarize in table 4.

Table 4. Challenges of small scale biogas plants during the installation and maintenance process

Type of challenges	Description
Technical Issues	Improper expertise in the construction and maintained of biogas plants create difficulties in its use, especially in developing countries (Surendra et al. 2013). - According to Mittal et. al 2018, the inappropriate function of biogas mainly technical, infrastructural and informational barriers as a lack of user alertness and inaccessibility of cattle waste. -Lack of input materials as an availability of feedstock can be a problem in a proper development of biogas technology (Nevzorova & Kutrechov 2019).

Knowledge barriers	Lack of education in the use and benefits of biogas to reduce non-renewable energies and animal waste (Nevzorova & Kutrechov 2019). -Lack of research is a challenge in developing countries (Nevzorova & Kutrechov 2019). **-**Some farmers refuse to change and maintain the traditional practices (Nevzorova & Kutrechov 2019). -Social awareness and unfamiliarity with biogas technology. (Nevzorova & Kutrechov 2019).
Environmental barriers	-Level of groundwater that affect the construction of biodigesters, for example high water table causes a slowdown in the construction (Energypedia,2014). **-**High demand of water that can be a problem in dry seasons (Nevzorova & Kutrechov 2019). **-**Broken biogas can cause environmental problems such as gas scaping into the atmosphere contributing to pollution (Bensah et.al, 2011). Leakage of biogas due to poor design and construction of digester (Bensah et.al, 2011).

Economic Barriers	-Higher prices of biogas due to lower prices of fossil fuels (Nevzorova & Kutrechov, 2019). -Economic barriers reduce the interest of biogas projects because of financial support programs, lack of subsidies and instable loans (Chen & Lui 2017). -Maintaining and construction of biogas is expensive limit the commitment to use biogas (Chen et al. 2014). -Competition with electric vehicles and bioethanol could prevent biogas uses (Nevzorova & Kutrechov, 2019).

Social and Cultural Barriers	-Social and cultural barriers influenced in the concentration of clean renewables energies for example the woman status in rural communities are limited for making decisions (Mittal et al. 2018). -Stigmatization has an important impact in the spread use of biogas because is incompatible with the local beliefs (Nevzorova & Kutrechov 2019). Gender issue for example in India women that are responsible for cooking doesn't have authority to choose clean renewables energy (Nevzorova & Kutrechov, 2019).
Government challenges	- Lack of government support and attractive programs to promote biogas technology (Msibi & Korlenius 2017). -The biogas equipment doesn't fit in cooking techniques and fertilizing practice of the farmers, usually lack of government support at the time of repair broken down installation and the donor aid ends leading to a stop of the programme, because of the lack of monitoring (Bond & Templeton 2011). -According to a study made in the Rural Areas of Sumatra by Roubik and Mazancova (2020), biogas implementation faced several challenges for example lack of knowledge, and poor institutional backing to supports biogas technology. -Political instability in a huge problem on African countries (Nevzorova & Kutrechov, 2019).

Source: Own Author 2021

2.13 Historical context and current status of biogas in Cambodia

In Cambodia, the amount of greenhouse's gases emissions in 2013 was 51.67 million metric tons of carbon emissions correspond to 0.11 % of global emissions. The agricultural sector is the second largest source of emissions after land use change and forestry, and it contributes 36.4% to rice cultivation and livestock enteric fermentation (USAID 2017). Although the access to energy resources it's not extensively spread. For heating, especially lighting and other's energy appliances most families use fuelwood, charcoal, and agriculture residues from the forest and about 1.6 million to 2.3 householders depend on kerosene and car batteries (Energypedia, 2018a), sources of health problems and environmental as deforestation and pollution. Cambodia relies on the agriculture sector with 85 % of the population living in rural areas.
Currently, the government of Cambodia in cooperation with SNV Netherlands Development Organization during the period March 2006 to December 2018, constructed 27,000 biodigesters in 15 provinces. The MAFF (Ministry of Agriculture, Forestry and Fisheries) use the money generated from sale carbon credits and expand the programme. The projects have been generated several benefits, for example, reduction of air pollution to 88 %. Between March 2006 to December 2018, 27,231 biodigesters were constructed with 93.561 beneficiaries. Among this, the reduction of carbon emission was estimated with 759,000 tCO_2 on the reduction between May 2009 and December 2018. The number of woods saved were around 257,300 tonnes (National Biodigester Programme 2019).

2.13.1 Background of Livestock production in Cambodia

Livestock production in Cambodia play an important role in the farmers lives. Mainly, cattle and buffalos are used as a draft power, while pigs are use of cash generation and home consumption.

Farmer consume lower number of livestock. Chicken is commonly slaughter for special events, furthermore the chicken produces lower protein requirement for farmers. In the case of Buffalos, cattle and pigs are sold to slaughterhouses and the meat it's rare for farmers consumption. The bigger demand of domestic meat its purchase by urban centres where the major population its concentrated, particularly Phom Phen, likewise the trade flow from meat come from Phom Phen.

The majority of livestock are rise in the traditional rice production system. In the major centres of populations Battambang and Phnom Pah, predominant egg production-poultry and pig production (Macklean, 1998).

Animal production in Cambodia is increasing, a dietary change has a greater impact on meat consumption. According to data presented for the Ministry of Agriculture, Forestry and Fisheries 2016-2017, report 40.3 million heads in 2015 with an increase of 42.18 million in a year, being buffalos with 41 %, swine 7.07 % and poultry 3.52%. The average annual meat consumption per capita is 16.13 kg (The Phnom Penh Post 2018).
In a study conducted in six districts of Battambang province, was analysed the important role of livestock for the livelihood of the rural sector in Cambodia. For example, generate income for families, generates labour work (the case of cattle), provide organic fertilizer and advantages for human and environment. Livestock rearing, is an important occupation at the same time they are unable to produce livestock systems with higher productivity (Darith et al. 2017).

2.13.2 Benefits of using biogas technology in Cambodia

The important benefits of using biogas in Cambodia as a resource for biological waste management are summarized below (ISAT & GTZ 1999):

- Reduction of pathogenic content of waste through anaerobic digestion of animal waste
- Health benefits associated with the changed of the use of traditional cooking fuel, improvement health wellbeing of the householders
- Fill the electricity gap

- Generate carbon credits through reduction of greenhouse gases as a methane and carbon dioxide, nitrous oxide being an economic benefit for householders
- Time saving for collected firewood
- Reduce the cost of fertilizer, improve the crop yield and prevent soil erosion
- Reduce disease transmission as a schistosomiasis, ancylostomiasis, dysentery and parasites caused by the faecal matter from direct liquid manure
- Reduce air pollution and odours caused by the application of manure direct to the soil
- Generate local regional jobs
- Time to attended schools, reducing the hours taken to gather the fuel.

2.13.3 Status of energy availability in Cambodia

The total available energy supply for Cambodia indicates 4.8 million tons of oil in 2015. Oil and petroleum have an equivalent of 38.5 %, coal for 10.7 %, fuel wood and biomass for 44.4 %, hydropower for 3.6 %, and electricity buy and in for 2.8 %. Regarding to the use of fossil fuels, 40 % of biomass is useful for heating and cooking, 15 % for industries and the remaining 40 % to produce charcoal, one of the main energy sources for householders (ADB 2018). The households, relying on wood, car batteries and other traditional energy sources, about 5 million Cambodians receive less electricity from the grid. Divided by 5% charcoal, 31% liquefied petroleum gas, 62 firewood and 2% electricity consumption. Nearly 5 million Cambodians cannot access to the grid, because of the higher prices of electricity.

According to (Energy progress report 2018), total energy consumption of Cambodia was accounted for 65 % in 2015, attributed to 15 % from new biomass methods as a biogas produced for animal and human waste,46 % for traditional biomass as a fuel, charcoal, wood and dung and 3 % hydropower. Cambodia has limited no large renewables energies, it represents around 30 megawatts, involving biomass (sugar cane, bagasse), solar home systems, risk husk biomass trough gasification mainly administrated by Cambodia national electricity utility.

The country has experienced economic growth with and increased in electricity demand. Experienced a growth of 18 % between 2011 to 2015.The economic growth and energy prediction by 2030 is predicted to rise to 18,000 GWh. Biogas technology come to bring a solution for the increased demand of energy in Cambodia to fulfil the lack of energy for the small-scale householders.

2.14 Description of methods to calculate greenhouse gas emissions from livestock manure

In order to ensure the benefits of biogas technology, one of the main benefits among others is the significantly reduction of greenhouse gas emissions. Different methods for calculating greenhouse gas reductions have been developed, and this study will focus on two characterized for the simplicity and acquired in their calculations.

2.14.1 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories IPCC Greenhouses emissions guidelines

IPCC (2019) has developed the National Greenhouse Gas Inventory Guidelines, which defines the method for calculating greenhouse gas emissions. The gas emissions from different industries arising from enteric fermentation and manure management, and the emissions from animal husbandry will take into account the estimation of the amount of CH_4 and nitrous oxide N_2O directly produced by livestock and poultry manure. In the method of estimating CH_4 and N_2O, livestock sub-categories and annual population are important influencing factors and feed intake characterization.

The calculation of manure includes dung and urine (solids and liquids) produced for livestock. Different factors affect the CH_4 emissions from uncontrolled methane emission include portion of the manure that discomposed anaerobically, and amount of manure produced. The primary livestock produced in Cambodia are cattle/Buffalo, pigs and poultry. According to the literature review there are three Tier methods to estimate CH_4 for livestock manure and the selection of the method is according to the information provide for every country.

General Description for each Tier method:

Methane Emissions from Enteric Fermentation and manure management

Tier 1: Is a simplified method that requires animal population data divided in species and categories based on climate region and temperature, to estimate the emissions is important the IPCC default emission factors collected in previous studies and the most appropriate for each country.

For the case of manure management is required estimate the average annual temperature related with the locations where dung was managed depends of the emissions.

For Nitrous Oxide (N_2O) emissions is required the total amount of nitrogen from livestock species in every management system and use IPCC default for nitrogen excretion data and manure management system.

Tier 2: The animal population is disaggregated in categories and used for calculate emissions factors as an opposed to default values. The most important features of this method are the development of emissions factors and activity data.

In the case of manure management is a complex method that can be used where a particular livestock species represents an important part of country emissions. Although, required characteristics and manure management practices that will be use to developed emissions factors.

For calculation of Nitrous oxide (N_2O) use the country-specific data, for example the nitrogen excretion rates for livestock category

Tier 3: This approach incorporates additional country specific information and employ sophisticated models that consider seasonal variation in animal population or feed quality and availability, die composition more in detail, mitigation strategies and where the country has more data available.

Nitrous Oxide (N_2O) calculation use alternatives estimation trials including like mass balance approach, a process based and its should be well documented.

For this study Tier 1 methods are suitable for Cambodia because emissions factors for Cambodia have been calculated in other studies reflected on IPCC (Intergovernmental Panel on Climate Change).

2.14.2 Agriculture model (AG) of the State inventory tool developed by EPA (United States Environmental Protection Agency)

EPA's State Inventory Tool (SIT) is a collaborative database model designed to support states to calculate their greenhouses gases inventory emission per country to provide an update of an inventory realized before or make a new inventory.

The inventory tool calculates GHG emission based on 11 estimation models and give users the option of using default data or use their own data. The default data are collected from federal agencies and others sources as a fossil fuels, agriculture, forestry, waste management and industry. All modules study direct GHG emissions, except the electricity module that estimate indirect GHG emissions.

The State inventory tool was settled together with EPAs Emission Inventory Improvement Programme (EIIP). Previous EPA, developed the state workbook for estimate greenhouses gases emission in 1998 and updating on 2020.

The following formulas are taken in account for calculated the CO_2, CH_4, and N_2O emissions from livestock manure.

Equation for calculating of CH_4 from Enteric Fermentation. To calculate the carbon emission, its required multiplied for 25 that is the global warming potential

Formula Emissions (MMTCO2E) = Animal Population (per head) x Emission Factor (kg CH4/head) × 25 (GWP) divided in 1,000,000,000 (kg/$MMTCO_2E$)

Formula CH_4 manure management vs produced cattle, excluding claves= Animal Population (‘000 head) × 1,000 × VS (kg/head/yr.)

VS (volatile solids) for cattle, excluding calves= Animal Population (‘000 head) × 1,000 x VS (kg/head/yr.)

Produced Calves and all other livestock = Animal Population (‘000 head) × TAM (Typical animal mass) × VS (kg/1,000 kg animal mass/day) × 365 (days/yr.)

Formula Emissions ($MMTCO_2E$) = $\underline{\text{VS Produced (kg)} \times B^0 \text{ (m}^3\text{ o } CH_4\text{/kg VS)} \times \text{MCF (Mass conversion factor)} \times 0.678 \text{ kg/m}^3 \times 25 \text{ (GWP)}}$ divided in 1,000,000,000 ($MMTCO_2E$)

Formula Emissions ($MMTCO_2E$) = K-Nitrogen Excreted × Emission Factor (liquid or dry) × 298 (GWP) divided in 1,000,000,000 (kg/$MMTCO_2E$)

Calculation of emissions factors for Direct N_2O Manure Management

K-Nitrogen Excreted Cattle, excluding calves = Animal Population (‘000 head) × 1000 × K-Nitrogen (kg/head/day)

K-Nitrogen Excreted Calves and all other livestock = Animal Population (‘000 head)

The method provided clear data and consisted for emission estimates at national level, for the requiring of this work the calculation of nitrogen manure, methane emission, carbon emissions is taking in account for the use of this guideline.

This detailed methodology was appreciated by states with the capacity to devote considerable time and resources to the development of emission inventories. For other states, the EIIP (EPA’s Emissions Inventory Improvement Program) guidance was overwhelming and impractical for them to follow (EPA, 1998).

2.15 Methods to Calculate Biogas Potential from Livestock Manure

2.15.1 IRENA methodology for calculate biogas production

A methodology developed in 2016 for IRENA, that helps energy calculator to measure and estimate the production and capacity of biogas plants used for small-scale householders, communal or farm, focus on data collection mainly for the feedstock that are useful and removed.

The purpose of the guide is support countries in the biogas data report at internationally format, produced by capacity building programme at Renewable Energy Agency (IRENA).

Table 5. Volume type of biodigester

Type of Biodigester	Formula
Fixed domed plant (hemisphere design)	$V_d = \frac{2}{3\pi\left(\frac{D}{2}\right)^3}$ Where V_d is equal to digester volume and D is equal to diameter.
Fixed domed plant (Chinese design)	$V_p = \frac{D^3}{2.2368}$ Where V_p is equal to total plant volume and D is equal to diameter.
Balloon digester	V_p: $\pi \left(\frac{D}{2}\right) 2L$ V_p is equal to total plant volume, D is equal to diameter and K is equal to length of the biodigester.
Floating drum plant	$V_p = \pi \left(\frac{D}{2}\right)^2 H$ $V_g = \frac{30}{70} \text{ x } V_d$ $V_p = V_d + V_g$ V_p is equal to total plant volume, V_d is equal to digester volume, D is equal to diameter and H is equal to Height of the digester.

Source: IRENA 2016

The parameters of biogas calculation are temperature, total feedstock volume, feedstock properties; feedstock retention time and plant capacity.

Biogas production is measure in cubic meter done a period of time, but it's necessary to convert in energy units. The conversion in methane production into energy has to be in

Megajoules (Mj). The content of methane should be around 65 % and 1 m^3 of methane is equivalent of 34 Mj of energy then 1 m^3 of biogas should contain 22 Mj of energy.
The following formulas are development for calculation of biogas production:
This methodology is based in amount and type of feedstocks utilized in the digesters, for that its necessary collect data in digestor size, feedstock use, technology and the level of assume gas production. To measure the digester volume is used to calculate biogas production, likewise its necessary volume and weight of different feedstock every day, for that is required a survey to get the data for the householders.

$$G = \frac{\text{YxVdxS}}{1000}$$

G= is equal to biogas production, V_d equivalent to volume of biodigester and Y is yield factor based on the retention time and temperature, S is equivalent to initial concentration of volatile solids.

2.15.2 Theoretical biogas potential for Buswell formula ,1976

The biogas potential formula analyses and characterized biogas feedstock, the formula allows calculating methane and biogas yield with the amount of water and biogas quantity and composition. It's important to know the content of proteins, lipids, and carbohydrates of the biogas substrate. Another way to be determined is using animal feed method's analysis. The following formula developed by Buswell and Hatfiel (1936),

$$C_n\,H_a\,O_b + \left(n - \frac{a}{4} - \frac{b}{2}\right) H_2O \rightarrow \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4}\right)CH_4 + \left(\frac{n}{2} - \frac{a}{8} + \frac{b}{4}\right)CO_2$$

The biogas potential of the following composition is produced. Fats and carbohydrates of animal origin account for approximately 80% of the biogas potential; fats and carbohydrates from plants account for approximately 50-70%, and biogas potential from proteins account for approximately 70% or more.

2.16 Comparation of methods to calculate greenhouse gases emissions and biogas potential

Table 6. Methods to calculate greenhouse gas emissions and biogas production

	Biogas Potential	
Methods	**Advantages**	**Disadvantages**
Theoretical biogas potential from Buswell formula.1976	It allows to compare materials based on their composition. The estimation of methane potential prediction provides suitable information because is not needed a broader number of feedstocks, if the user has the data for the analysis of composition of Hydrogen, Carbon, Oxygen Nitrogen and Sulphur. Experimental procedures to make the results more comparable and be able to focus in real cases (Achinas & Euverink 2015).	Without sufficient data it's not possible run the calculations.
Feedstock use developed for IRENA, 2016	It's not required assumption of capacity utilization and its most suitable for householder's energy surveys, and the calculation are based of feedstock use. Errors in the calculation are	To produce results, require complex calculations and the estimation of feedstock input it's not 100 % acquire, require complex set of questionnaires.

	lower than the other methods (IRENA 2006).	
Methods	**Reduction of Greenhouse gases emissions**	
	Advantages	**Disadvantages**
2019 Refinement of IPCC 2006 Guidelines of Greenhouse gases emissions	Provide acquire methods to obtain emissions and updated resources available for the greenhouse gases inventories.	Uncertain in the default emissions factors. Estimation of carbon dioxide emission it's not takes in account because is considered zero in annual net.
EPA Guidelines, 2020	The estimation of CO_2 emissions is calculated; among of this easy to manage and simple. Default data is provided for countries that have lack of information to run the calculations of greenhouses gases emissions.	It's not suitable for all world regions.

Source: Own Author 2021

3. Aims of the thesis

The general goal of the thesis is the quantification of the biogas potential from livestock manure (cattle, pig and chicken), and the number of emissions (methane, and carbon dioxide) reduced that will determine its climate contribution to climate change.

Specific goals

1. Estimation of the biogas potential from livestock waste
2. Estimation of methane, carbon dioxide emissions from manure and enteric fermentation specifically poultry, pigs' buffalos and cattle without using biogas technology
3. Estimation of the reduction of methane, carbon dioxide and nitrous oxide using biogas technology

The study will answer the following questions:

- What will be the amount of methane, nitrous oxide and carbon dioxide reduced through biogas technology?

-How biogas potential will contribute to climate change mitigation?

To answer the following questions the estimations of reduced greenhouse gases emission will calculated using the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories IPCC Greenhouses emissions guidelines Tier 1.

For the calculation of the biogas production, the formula provide for IRENA Methodology 2016 will take in account for estimate the biogas production to determine the energy potential.

In this research the following hypothesis will be accepted or rejected according to the calculation of greenhouses gases emission and biogas potential.

Ha. Management of livestock manure through biogas technology in Cambodia has a biogas potential to reduce the greenhouses gases emission likewise contribute of climate change mitigation

Ho. Management of livestock manure through biogas technology in Cambodia has a biogas potential to reduce the greenhouses gases emission, likewise contribute of climate change mitigation. Without biogas, the increase of greenhouses gases emissions will accelerate.

4. Methods

4.1 Secondary data from the Census of Agriculture in Cambodia, 2013 from (National Institute of National Statistics, Cambodia 2013).

Due to the travel restrictions, wasn't possible to travel and do the data verification for the emission factors country for that reason, secondary data was used through a deep online search. For that reason, data on numbers of livestock were used from the National Census of Cambodia, 2013. The emission factors by country, weather is described in 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories IPCC Greenhouses emissions guidelines Tier 1. Although a questionnaire was made in google forms to collect information that could be used to calculate emission factors and to know the current status of manure management practices and biogas Technology in Cambodia, unfortunately not information was received from key informants for 3 months due to the corona crisis situation.

4.2 Calculation of Methane emissions from enteric fermentation and methane, nitrous oxide from manure

The amount of methane emissions from methane from enteric fermentation and manure management and nitrous oxide from manure management and poultry were calculated using the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories IPCC Greenhouses emissions guidelines Tier 1. The emission factor used, the IPCC default emission factors from geographical region, type of weather.

The following formulas are applied for the calculation of GHG emissions.

Formula 1. Methane emissions from enteric fermentation

$$\text{Emissions} = \Sigma EF_{(t,P)} \cdot \left(\frac{N_{(t,P)}}{10^6}\right)$$

ET = methane emissions from Enteric Fermentation in animal category T, Gg CH_4 yr-1

(T P)

EF = emission factor for the defined livestock population T and the productivity system P, in kg CH_4 head-1 yr-1 (T P,)

N = the number of head of livestock species / category T in the country classified as productivity system P.

T = species/category of livestock P = productivity system, either high or low productivity for use in advanced Tier 1a – omitted if using Tier 1 approach

To quantify the methane emissions from enteric fermentation and manure management, its necessary country emission factor. The 2019 refinement to the 2006 IPCC Guidelines for National Greenhouses gases inventories.

Table 7. Emission factor, based on the regional characteristics for the table 10.10 from the 2019 refinement to the 2006 IPCC Guidelines for National Greenhouse gas inventories

	Emission factor in Kg CH_4 head $^{-1}$ year^{-1}		
Regional Characteristics	Swine	Buffalo	Non-Dairy Cattle (Other's cattle)
Asia	1	76	54

Source: IPCC 2019

Formula 2. Methane emissions from manure management

- $CH_{4manure}=\sum(N_{T,P}.VS_{T,P}.AWMS_{T,S,P}.EF_{T,S,P}\ /1000$

$CH_{4\ (mm)}$ = CH_4 emissions from Manure Management in the country, kg CH_4 yr-1
$N_{(T,P)}$= Number of head of livestock species/category T in the country, for productivity system P, when applicable
$VS_{(T,P)}$ = Annual average VS excretion per head of species/category T, for productivity system P, when applicable in kg VS animal-1 yr-1 (Table 10.13a calculated by Equation 10.22a)
$AWMS_{(T,S,P)}$ = Fraction of total annual VS for each livestock species/category T that is managed in manure management system S in the country, for productivity system P, when applicable; dimensionless, default regionally specific AWMS fractions are found in Tables 10A.6.

$EF_{(T,S,P)}$ = Emission factor for direct CH_4 emissions from manure management system S, by animal species/category T, in manure management system S, for productivity system P, when applicable (Table 10.14) g CH_4 kg VS-1

S = manure management system

T = species/category of livestock

P = high productivity system or low productivity system

Formula 3, calculate the Annual Volatile Solids for livestock category

$$VS_{T,P} = \left(VS\,rate\ (T,P)x\frac{TAM(T,P)}{1000}\right).365$$

$VS_{(T,P,)}$ = annual VS excretion for livestock category T, for productivity system P (when applicable), kg VS animal-1 yr-1

$VSrate_{(T\,P)}$ = default VS excretion rate, for productivity system P (when applicable), kg VS (1000 kg animal mass)-1 day-1 (see Table 10.13a)

$TAM_{(T\,P)}$ = typical animal mass for livestock category T, for productivity system P (when applicable), kg animal-1

Table 8. Amount of methane emission factor by animal category, manure management system and climate zone (GCH_4 Kg Vs $^{-1}$) from table 10.14

Animal	Productivity class	Manure storage system	Warm
Non-Dairy Cattle	Low Productivity	Daily spread	0.9
Buffalos	Low Productivity	Daily spread	0
Swine	Low Productivity	Daily spread	1.9
Poultry	Low productivity	All Systems	2.4

Source: IPCC 2019

Formula 4. Direct N_2O manure emissions

$$N_20_D=\sum[\sum(N_{(T)}.Nex_{(T)}.MS_{(TS)})].EF_{3(S)}].\frac{44}{28}$$

N_2O_D (mm) = Direct N_2O emissions from Manure Management, kg N_2O yr^{-1};

N(T) = Number of head of livestock species/category T;

$Nex_{(T)}$ =Excretion per head of species/category T in kg N $animal^{-1}$ yr^{-1};

$MS_{(T, S)}$ = Fraction of total annual nitrogen excretion for each livestock species

S =Manure management system; T = Species/category of livestock; 44/28 =Conversion of (N_2O-N) (mm) emissions to N_2O(mm) emissions.

44/28 =Conversion of (N_2O-N) (mm) emissions to N_2O(mm) emissions.

EF_3 = Emission factor for direct N_2O emissions from manure management system S in the country, kg N_2O-N/kg N in manure management system S

Formula 5 Amount of Nitrogen excretion per head of species/ category T in kg N N_2O yr^{-1} (Nex $_{(T)}$

$$Nex = N_{rate}\ _{(T)} . \frac{TAM}{1000} .365$$

$Nex_{(T)}$ = annual N excretion for livestock category T, kg N $animal^{-1}$ yr^{-1}

N $rate_{(T)}$ = default N excretion rate, kg N (1000 kg animal mass)$^{-1}$ day^{-1} (see Table 10.19)

$TAM_{(T)}$ = typical animal mass for livestock category T, kg $animal^{-1}$

Table 9. Animal Waste Management System (updated) from the table 10 A.8. 10 A9.0 from 2019 Refinement of the 2006 IPCC Guidelines for Greenhouse gas Inventories.

Region	Animal category			
	Non - Dairy Cattle (daily spread)	Buffalos (daily spread)	Swine (solid storage)	Chicken layers (liquid slurry)
Asia	0	0	0.18	0.04

Source: IPCC 2019

4.3 Biogas Production from IRENA Methodology for feedstocks, 2016

Formula 6. Biogas production

The plant volume is based on the values provided by the paper of (Himen and Bailys, 2013).

$$G = \frac{\text{YxVdxS}}{1000}$$

G= is equal to biogas production, V_d equivalent to volume of biodigester and Y is yield factor based on the retention time and temperature, S is equivalent to initial concentration of volatile solids.

Table 10. References values of feedstock retention time according to different average temperature based on the table 5.0 from IRENA Methodology. It assumes that the retention time is 35 days.

Feedstock retention time in days	Temperature					
	16-18	19-21	21-24	25-272	28-30	31-33
31-35	5.41	7.98	10.83	13.59	15.91	18.33

Source: IRENA 2016

The following formulas is use to calculated the amount of CO_2 emissions from methane of enteric fermentation and NO_2, CH_4 from manure management from EPA,2020, since The 2019 refinement to the 2006 IPCC Guidelines for National Greenhouses gases inventories its doesn't calculated Carbon dioxide emissions and its assumed as zero.

Formula 7, Emissions of Carbon dioxide from enteric fermentation

Formula 8, Emissions ($MMTCO_2E$) = Animal Population (per head) x Emission Factor (kg CH4/head) × 25 (GWP) divided in 1,000,000,000 (kg/$MMTCO_2E$)

Formula 9, Emissions ($MMTCO_2E$) = VS Produced (kg) × B^0 (m^3 o CH_4/kg VS) × MCF (Mass conversion factor) × 0.678 kg/m^3 × 25 (GWP)

Formula 10, Emission of Carbon Dioxide from direct N_2O emissions of manure management

Emissions ($MMTCO_2E$) = K-Nitrogen Excreted × Emission Factor (liquid or dry) × 298 (GWP) .

Table 11. According to the table 10.16 the B^0 (maximum methane production capacity), from low productivity system is described below. According to the table 10.17 the values of MCFs were extracted. The VS produced were calculated in previous step through the formula 3.0

Category of Animal	VS produced (Kg)	Nex(T) kg N_2O yr^-	B^0 m^3 CH_4 Kg^{-1} VS) Low productivity system	Mass conversion factor based on the climatic zone, warm and daily spread
Non -Dairy Cattle	1872.45	44.24	0.13	1.00 %
Buffalos	1141.063	61.02	0.10	1.00 %
Swine	59.28	6.23	0.29	1.00 %
Chicken	4.91	0.48	0.24	1.00 %

Source: Own Author 2021

4.4 Calculation of greenhouse gases emissions reduced from biogas technology

Two scenarios are taking into account starting for the emissions emitted without any management systems and the emission reduced using biogas technology.

Scenario 1 described the amount of greenhouse gases emissions as a methane, carbon dioxide, nitrous oxide without any management.

Scenario 2 described the amount of greenhouses gases emissions reduced when a biogas technology its implemented and the benefits for the households in the provision of a renewable's energy.

To determine the greenhouse gases emitted from the biogas that will determine the greenhouse gases reduction as a CO_2, CH_4, N_2O using biogas technology; standards value for the content of fuels (lower heating value) and GHG emissions during combustion of different fuels for household stove will be considered based in the academic paper of Bruun et al. 2014.

Table 12. Energy content of fuels (lower heating value) and GHG emissions during combustion of different fuels in ordinary households' stoves used in developing countries for each type of fuel

Energy content of fuel		Gas emission per Mj delivered energy			
	(Mj Kg-1)	gCO_2	Mg CH_4	gCO	Mg N_20
Biogas	17.7	81.5	57	0.11	5.4
Coal	24.9	682	1300	26.2	1.4
LPG	45.8	139	8.9	0.82	6.0
Wood		532	600	14	4.3
Dung		885	7100	39	270

Source: Bruun et al. 2014

4.4 Limitations of the research

An application for a mobility was submitted. The trip was planned for January 2020 when the corona paralyzed the world. Currently Cambodia required a 2000 insurance and 10 days of quarantine and only works trip. A questionnaire was developed in google form to collect country emissions factor, to have more updated results and its was send to a partner university in Battambang, since the situation got worse for 3 months, we didn't receive any responses. Since for me it's not possible to extend the period of my studies. I have to take action and use the secondary data available.

Furthermore, there is lack of study for Cambodia and Asian countries referring to quantification of greenhouse gases emissions, methane from enteric fermentation and manure management, it needed a furthers and updated studies.

5. Results and Discussions

The following chapter include the secondary data from the Census of Agriculture in Cambodia 2013. The results of the greenhouse gas emissions (methane) from enteric fermentation, nitrous oxide and methane from manure management were based on the 2019 Refinement of IPCC 2006 Guidelines of Greenhouse gases emissions. The calculation of carbon dioxide emissions was based on EPA, 2020 Guidelines. The second part include the biogas production potential from livestock manure using the IRENA, 2016 methodology based on feedstocks use.

As its shows in the table below, the Cambodia Zone has the highest reporting livestock, with a total of 51,155,894 with the highest owners of chicken, following non-dairy cattle, swine and buffalos. The second province with the highest number of livestock was Plain Zone with 23,366,709 with the highest reporting of chicken. The lowest value of livestock reporting was in the province of Pailin, in total 18,541 livestock reported of swine, chicken and non-dairy Cattle.

The table 13 was use as a main reference for the quantification of greenhouse gas emissions based in the livestock population of Cambodia.

Table 13. Amount of total reporting animals in Cambodia for 26 zones/ provinces, according to the Census of Agriculture in Cambodia, 201

	Number of Livestock			
Provinces	**Swine**	**Buffalos**	**Chicken**	**Non-Dairy Cattle**
Cambodia	2,220,811	519,083	45,167,583	3,248,417
Plain Zone	1,085,189	213,188	20,724,045	1,344,287
Kampong Cham	127,574	20,699	3,070,979	208,456
Kandal	138,108	4,527	2,238,030	172,382
Phnom Penh	42,664	745	834,95	43, 146
Prey Veng	220,496	45,068	4,097,906	310,596
Svay Rieng	171,475	175,791	2,910,632	175,791
Takeo	306,986	6,511	4,875,245	335,728
Battambang	65,321	3,487	3,154,476	167, 912
Kampong Thom	90,637	52,368	2,731,156	225,124
Pailin	3,709		7,416	7,416
Kampot	144,748	11,622	3,442,825	229, 818
Stung Treng	20,421	40,528	258,218	34,106
Siemreap	127,566	16,359	2,500,735	201, 077
Preah Sihanouk	22,813	1800	490,341	12,150
Ratanak Kiri	38,927	8,343	294,42	29,650
Oddar Meanchey	31,071	1,454	806,694	32,033
Kratie	33,199	2,516	693,382	106,164
Coastal Zone	199,991	31,751	4,444,991	267,866
Kandal	138,108	4,527	2,238,030	172, 382
Koh Kong	23,237	12,748	313,216	11,475
Plateau and Mountanious Zone	427,171	9,337	5,102,696	697,838
Pursat	42,088	60,551	2,109,559	86, 465
Kep	9,193	1,185	198,609	14,423
Kampong Speu	259,563	2,412	3,039,735	364,446
Tonle Sap Lake Zone	508,459	180,775	14,895,849	938, 427

Source: National Statistics Cambodia 2013

Table 14. CH_4 emissions from buffalos and non-dairy cattle from enteric fermentation

Provinces	**Number of Livestock**		**Amount of CH_4 from Enteric Fermentation in animal category T, Gg CH_4 yr-1**	
	Buffalos	Non- Dairy Cattle	CH_4 enteric fermentation Buffalos	CH_4 enteric fermentation Non-dairy cattle
Cambodia	519,083	3,248,417	39.45	175.41
Plain Zone	213,188	1,344,287	16.20	72.60
Kampong Cham	20,699	208,456	1.57	11.26
Kandal	4,527	172,382	0.34	9.31
Phnom Penh	745	43, 146	0.05	2.33
Prey Veng	45,068	310,596	3.42	16.77
Svay Rieng	171,475	175,791	13.03	9.49
Takeo	6,511	335,728	0.49	18.12
Battambang	3,487	167, 912	0.27	9.06
Kampong Thom	52,368	225,124	3.98	12.16
Pailin		7,416		0.40
Kampot	11,622	229, 818	0.88	12.41
Stung Treng	40,528	34,106	3.08	1.84

Siemreap	16,359	201, 077	1.24	10.86
Preah Sihanouk	1800	12,150	0.13	0.66
Ratanak Kiri	8,343	29,650	0.63	1.60
Oddar Meanchey	1,454	32,033	0.11	1.73
Kratie	2,516	106,164	0.19	5.73
Coastal Zone	31,751	267,866	2.41	14.46
Kandal	4,527	172, 382	0.34	9.30
Koh Kong	12,748	11,475	0.97	0.61
Plateau and Mountainous Zone	9,337	697,838	0.71	37.68
Pursat	60,551	86, 465	4.60	4.66
Kep	1,185	14,423	0.09	0.78
Kampong Speu	2,412	364,446	0.18	19.68
Tonle Sap Lake Zone	180,775	938, 427	13.74	50.67

Source: Own Author 2021

According to the National Census of Agriculture of Cambodia, 2013, the total CH_4 emissions from enteric fermentation from buffalos was 108.1 Gg CH_4 yr-1 and 509.58 Gg CH_4 yr-^{1}. The total emissions from buffalos and non-dairy cattle were 617.58 Gg CH_4 yr^{-1}. According to the Cambodia's Second National Communication, 2015 the amount of methane emissions from enteric fermentation using national inventories from 2000, was accounted as 163.82 Gg CH_4 yr-1. The results from methane emissions from enteric fermentation based on livestock population from the National Census, Cambodia 2013 shows a significant increase in methane emissions from enteric fermentation through over 13 years. Around one third of the methane emissions from livestock come from Asian countries (World Resource Institute, 1994). The Enteric methane has a live span of 12 years which stay in the atmosphere for hundred to thousand years, this gas trapped 84 times more heat than CO_2 after is released into the air (FAO, 2014).

This release has several impacts in in Asian countries; for example, according to IPCC (2007) a decline of fresh availability of water mainly in South, East and Southeast Asia affecting the crop production, high temperature decline rice yield, recurrences of heat stress affecting the livestock production. Since agriculture in Cambodia is highly dependent on livestock for incomes since they sell the buffalos and non-dairy cattle that are the significant emitters to the slaughterhouses. Because of that there are several mitigation measures to prevent the release of methane emissions from enteric fermentation. According to Llonch et al. 2017 the diets have important impact for ruminants, for example addition of fatty acids decrease the enteric methane emissions by changing the microbial population of the rumen. Furthermore, the nutrient efficiency is a key to increase the diet digestibility and reduce the methane emissions per unit of output (Gerbert et al. 2011).

The results show the higher values of non-dairy cattle from the Zone of Cambodia with 175.41 Gg CH_4 yr-1, in comparison of buffalos with 39.45 Gg CH_4 yr-1. According to FAO, 2021 Globally, cattle account for 77 % of all methane emissions from ruminant livestock around 2.5 Gt, following by buffalos for 13 % (0.43 Gt) and small ruminants with 0.31 Gt. It reflects that the thesis results coincide with the global emissions cattle is the higher emitter of methane from enteric fermentation that through the years has been increase in Cambodia. The province with the lowest methane emissions from enteric fermentation, was Phnom Penh with 0.05 Gg CH_4 yr-1 from buffalos and Pailin with 0.40

Gg CH_4 yr-1. from non-dairy cattle. Its results in the lower number of reported animals in this province. The population in Cambodia is still growing and at the same time the numbers of animals, for that reason is important to apply mitigation measures to reduce the methane emissions from enteric fermentation, then to reduce the consequent impact of climate change for Cambodia.

The following graph described the methane emissions from enteric fermentation of buffalos and non-dairy cattle for 13 Zone/ Province of Cambodia, Where its reflected non-dairy cattle as a higher emitter and Cambodia Zone with the higher CH_4 emissions from enteric fermentation.

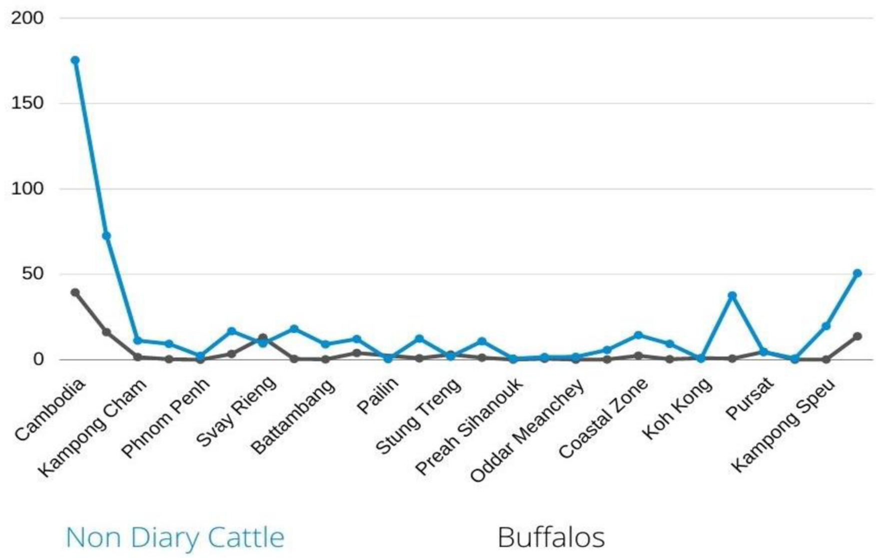

Figure 9. Methane Emissions from enteric fermentation of buffalos and non-dairy cattle (Own Author, 2021)

Table 15. CH_4 emissions from Manure Management Values of AWMS taken from the table 10A.5, 10A.6, 10 A.7, 10A.8, 10A.9 for the section daily excrete and the emission factor for direct CH_4 emissions from manure management system from table 10.14, pasture range and paddock (0.6 G CH_4 kg VS^{-1})

Provinces	CH_4 emissions from manure management in kg CH_4 $yr.^{-1}$			
	Buffalos	**Swine**	**Non- Dairy Cattle**	**Poultry**
Cambodia	0	473938.83	463701720.8	638705.75
Plain Zone	0	231588.01	440387328.7	19009.29
Kampong Cham	0	27225.31	68290016.19	2947.73
Kandal	0	29473.35	56472203.11	4265.83
Phnom Penh	0	9104.83	14134594.54	1180.68
Prey Veng	0	47055.61	101750997.2	57947.67
Svay Rieng	0	36594.13	57588988.73	41158.66
Takeo	0	65513.27	109984220	68939.86
Battambang	0	13940.02	55007834.74	44606.81
Kampong Thom	0	19342.66	73750439.44	38620.73
Pailin	0	791.53	2429475.57	104.87
Kampot	0	2480.22	75288190.03	48684.30
Stung Treng	0	8648.99	11173097.88	3651.41

Siemreap	0	3491.14	65872661.78	35362.40
Preah Sihanouk	0	4868.48	3980330.126	6933.81
Ratanak Kiri	0	8307.33	9713315.90	416.33
Oddar Meanchey	0	6630.80	10493984.77	11407.30
Kratie	0	7084.93	34779240.12	9804.98
Coastal Zone	0	42679.67	87752683.91	62855.73
Kandal	0	29473.35	56472203.11	31647.53
Koh Kong	0	4958.97	3759200.67	4429.12
Plateau and Mountainous Zone	0	91161.70	228611161.7	72156.20
Pursat	0	8981.91	28325863.73	29830.85
Kep	0	1961.85	4724963.078	29830.85
Kampong Speu	0	55392.82	119392213.4	42984.28
Tonle Sap Lake Zone	0	108509.21	307427922.5	210639.22

Source: Own Author 2021

Table 16. Amount of nitrogen excretion for livestock category per year, according to the values used in 2019 Refinement of the 2006 IPCC Guidelines for Greenhouse gas Inventories from the table 10 A-5, 10 A-6, 10 A-7 calculated from formula 3 to calculate the CH_4 emissions from manure management

Animal	**Default values for volatile solids excretion rates**	**TAM (Typical animal mass for livestock category T, Kg)**	**VS Kg/Year**
Buffalo	13.5	380	1872.45
Non-Dairy Cattle	9.8	319	1141.063
Swine	5.8	28	59.28
Chicken	11.2	1.2 (Taken from Table A.5)	4.91

Source: Own author 2021

The total amount of CH_4 emissions from manure management include the three livestock types (non-dairy cattle, swine and poultry) was 2494.12 Gg CH_4 yr. $^{-1}$. The methane emissions from non-dairy cattle were 2491.26 Gg CH_4 yr. $^{-1}$, for swine was 1.33 Gg CH_4 yr. $^{-1}$, for poultry was 1.51 Gg CH_4 yr. $^{-1}$, described in table 17.

In comparison with the information found in the Cambodia's Second National Communication, 2015, the methane emissions from manure management were 22.37 Gg CH_4 yr. $^{-1}$, according to the 2000 National Statistics, it shows the continuously increase on emissions from 2000 to 2013, the animal population increased dramatically. The livestock sector is dominated for small families that usually have pigs and chicken, while families with a higher income has draught animals and breeding cattle. In Cambodia the pig manure management is dumped to the environment around 46 %, while 18 % is sold and give away and 31 % is use as a fertilizer for rice production and 7 % of cattle manure is dumped to the environment (Strom et al. 2017). More than 46% of household don't believe that zoonic disease could be spread between humans and animals (Strom et al. 2017), and they don't wash their hands with soup and water after handling animal manure, since they are not aware, its crucial to apply manure management practice to reduce the risk of zoonic diseases that are spread for unproper manure treatment. According to the

Vietnam Second National Communication in 2010, that use National GHG emissions in 2000, the amount of CH_4 emissions from manure management was 79.69 Gg. In comparison with Cambodia that has higher methane emissions of 2494.12 Gg CH_4 $yr.^{-1}$.

Its was explained by the Hanoi City reporting on Vietnam that were 1.8 million pigs, 136,000 cattle, 23,500 buffaloes, 21.8 million chickens, and 6.2 million waterfowls (Hanoi Statistics, 2019) in Hanoi city as we see that the Greenhouse gas emissions are higher since the livestock population of chickens, buffalos, non-dairy cattle and swine are higher in Cambodia.

Table 17. Direct N_2O Manure management emissions. The Ms values will take in account the table 14A referent to the fraction of nitrogen manure from Ms slurry applied to soil, by animal category and IPCC area focus in Asia.

Provinces	Number of Animals Swine	Number of Animals Chicken	Direct N_2O Manure emissions in kg N_2O yr^{-1} Swine	Direct N_2O Manure emissions in kg N_2O yr^{-1} Chicken
Cambodia	2,220,811	45,167,583	39135.13	6813.85
Plain Zone	1,085,189	20,724,045	19123.20	3126.37
Kampong Cham	127,574	3,070,979	2248.10	463.28
Kandal	138,108	2,238,030	2433.74	337.62
Phnom Penh	42,664	834,95	751.82	12.59
Prey Veng	220,496	4,097,906	3885.58	618.19
Svay Rieng	171,475	2,910,632	3021.73	439.08
Takeo	306,986	4,875,245	5409.70	735.46
Battambang	65,321	3,154,476	1151.08	475.87

Kampong Thom	90,637	2,731,156	1597.20	412.01
Pailin	3,709	7,416	65.36	1.11
Kampot	144,748	3,442,825	2550.75	519.37
Stung Treng	20,421	258,218	359.85	38.95
Siemreap	127,566	2,500,735	2247.97	377.25
Preah Sihanouk	22,813	490,341	402.01	73.97
Ratanak Kiri	38,927	294,42	685.97	4.44
Oddar Meanchey	31,071	806,694	547.53	121.69
Kratie	33,199	693,382	585.03	104.60
Coast Zone	199,991	4,444,991	3524.24	670.55
Kandal	138,108	2,238,030	2433.73	337.62
Koh Kong	23,237	313,216	409.48	47.25
Plateau and Mountainous Zone	427,171	5,102,696	7527.60	769.77

Pursat	42,088	2,109,559	741.67	318.24
Kep	9,193	198,609	161.99	29.96
Kampong Speu	259,563	3,039,735	4574.01	458.56
Tonle Sap Lake Zone	508,459	14,895,849	8960.06	2247.14

Source: Own Author 2021

Table 18. Excretion per head of species/category T in kg N animal^{-1} yr^{-1}. The values from the EF3 (Emission factor for direct N_2O emissions from manure management system S in the country, kg N_2O-N/kg N in manure management system S) from the table 10.21

Category Animal	Default nitrogen excretion rate (table 10.19)	EF3 (kg N_2O-N/kg N) Solid storage	TAM	Nex(T) kg N_2O yr^{-1}
		Asia		
Non Dairy-cattle (Others Cattle)	0.38	0 (daily spread)	319	44.24
Buffalo	0.44	0 (daily spread)	380	61.02
Swine	0.61	0.01 (solid storage covered/compacted)	28	6.23
Chicken (poultry)	1.10	0.005 (liquid/ slurry cover)	1.2	0.48

Source: Own Author 2021 adopted from IPCC, 2019

According to (Prusty et al. 2014) the nitrous oxide (N_2O), is released during the nitrification-denitrification of nitrogen contained in the livestock waste. Cattles and feedlots are responsible of 26 % of N_2O emissions from anthropogenic sources (IPCC, 2001). The emission of nitrous oxide is related to the application of manure as fertilizer and manure management. In total nitrous oxide is responsible of the 5 % of greenhouse gas effect (Prusty et al. 2014).

In this study, it was found that, the total amount of N_2O emissions from manure management of Cambodia for the case of swine is 89859.72 kg N_2O yr^{-1}, is equivalent to 0.08 Gg N_2O yr $^{-1}$. For the case of chicken results on 15683.87 kg N_2O yr^{-1} that is equivalent to 0.015 Gg N_2O yr^{-1}. The manure management system from swine and chicken was selected as solid storage before spread as a fertilizer since past studies like the by Strom et al. 2017 have been found that in the case of swine the manure is storage. For the case of cattle and buffalos was assumed that is daily spread. According to a study made in Cambodia by Strom et al. 2017, it was found that 68 % of households stored the manure before sold or dumped to the environment, while the manure of cattle and buffalos is used as a fertilizer, taken into account this study, it needed an adequate manure treatment, where through the process of anaerobic digestion the manure is convert to energy, being a solution to reduce methane emissions and pollution from an improper manure treatment. Livestock manure increase the possibility of spreading disease because of the high content of nutrients, especially nitrate, which can cause health hazards to adult drinking water and reduce the body function of livestock (Kumar et al. 2013). This will lead to a reduction of pollution and spread of diseases between householders.

The results show that Cambodia Zone has the higher emissions from swine of N_2O from manure management, 39135.13 kg N_2O yr^{-1} that is equivalent to 0.03 Gg N_2O yr^{-1}. The second province higher emitter from swine was Plain Zone with 19123.20 kg N_2O yr^{-1} equivalent to 0.019 Gg N_2O yr^{-1}.

According to the Cambodia's Second National Communication of Cambodia, 2015, the amount of N_2O emissions from manure management was 1.11 Gg N_2O yr^{-1} in 2000, its shows that the N_2O emissions reduced sharply through the years, probably the manure management improved in Cambodia. At the same time still is needed to apply mitigation measures to reduce the N_2O emissions from manure management. Please noted that for the lack of data the N_2O emissions from manure management was calculated based on the emission factor provided by the 2019 Refinement of the 2006 IPCC Guidelines for Greenhouse gas Inventories. In comparison with the neighbour country Indonesia, didn't report direct nitrous emissions from livestock manure, according to the Greenhouse Gas National Inventories, this means that there is lack of updated data among Asian countries. On the other hand, India report emissions of nitrous oxide from manure management of 0.0004 Gg N_2O from pigs, 0.0301 Gg from buffalos and 0.0315 from indigenous breed (Second National Communication, 2012). It is showing the higher nitrous emissions from manure management from Cambodia that emitted 0.08 Gg N_2O yr^{-1}.in comparison with India.

Biogas production potential for Cambodia, according to the numbers of animals of livestock manure.

The biogas production was calculated from livestock manure based in the IRENA, Methodology. Several assumptions will be used regarding certain parameters such as plant volume, daily manure production.

. The volatile solids were calculated through formula 3.0 referent to annual average VS excretion per head of species/category T, for productivity system P, when applicable in kg VS animal^{-1} yr^{-1}

Table 19. Amount of biogas production

Animal	Total production Kg/year	Volatile solids Kg/ year	Yield factor	Plant Volume (m^3)	Biogas Production (m^3)	Energy value/Mj	kwh
Non-Dairy Cattle	2905954425	1872.45	15.91	15	447.57	9846.54	2735.15
Buffalos	481670900	1141.063	15.91	15	272.31	5990.82	1664.11
Swine	181986700	59.28	15.91	15	14.14	311.08	86.41
Chicken	153272022	4.91	15.91	15	1.17	25.74	7.15

Source: Own Author 2021

The average calorific value of biogas is 22 Mj/m^3

According to the value provided from the Cambodia National Census, 2013, the biogas production was calculated for each type of livestock.

The total annual biogas production potential was 935.19 m^3/year. The results indicate that Cambodia has higher biogas potential threating the livestock manure from non-dairy cattle resulted in a significant energy value of 9846.54 Mj. Secondly, buffalos produced the second higher resulting in 5990.82 Mj, following by swine with 311,08 Mj and chicken with 25.74 Mj. The amount of biogas produced depends on the quantity of volatile solids excreted. This will threat the livestock manure and reduce greenhouse gases emissions produced from the unpropped manure management that usually is spread in the soil without any treatment leading to environmental problems. According to Parthiba et al. 2006, the livestockmanure without management leads to sources of pollution such as prevalence of bacteria, parasites, viruses, poultry contain arsenic that is used for feed control and promote growth, cooper, iron which applicate direct to the soil leads to a pollution.

According to CIPS, 2004 they found that 14 % of the household had access to electricity, while 16 % battery lighting and 64 % kerosene. The results show the biogas potential as a renewable energy source for Cambodia, and at the same time the improving of the energy system and the importance of the continuity in the maintenance of small-scale biogas plants to provide electricity and at the same time reducing greenhouse gas emissions.

In comparison of Indonesia that analysis the opportunities to turn animal waste on energy calculated the biogas production of 9597.44 m^3/year could be used to generate 1.7×10^6 kwh/year (Khalil et al. 2019), showing as well a higher potential.

Table 20. CO_2 emissions from methane of enteric fermentation and NO_2, CH_4 from manure management.

Livestock	Number of Livestock	CH_4 emission factor	CO_2 Emissions from CH_4 manure management (kg)	CO_2 Emissions from CH_4 enteric fermentation (Gg)	CO_2 Emission from N_2O manure management (kg)
Swine	6499525	1	0.29	162.48	9.28
Chicken	129625285	2.4	0.19	7777.51	0.71
Non-Dairy Cattle	9437575	54	41.25	12740	65.91
Buffalos	1427375	76	28.52	2712.01	90.91

Source: Own Author 2021

The results show the amount of carbon emissions from enteric fermentation and methane and nitrous oxide from manure management. The results were transformed in Gg, following the conversion of 1 Gg equivalent to 1000000 Kg.

The total amount of Greenhouse gases emissions of CO_2 from CH_4 enteric fermentation is 23392 Gg CO_2 eq. According to Gerber et al. 2013 in total livestock contribute around 7.1 Gg CO_2eyr^{-1} to the global anthropogenic greenhouse gas emissions that is equivalent to 14.5 % of total GHGs emissions.

According to the Second National Communication, 2015 from 2000 National Statistics of Cambodia, the total of CO_2 emissions from enteric fermentation in domestic livestock, was 3440.31 GgCO_2, as we see from 2000 to 2013, an increase of carbon dioxide from CH_4 enteric fermentation is higher visible and apply technologies that reduced the methane emissions are essential. In the case of India, the higher emitter for buffalos account for 1155 kg CO_2 CH_4 head, following from cattle with 672Kg CO_2 CH_4 head and the less emitter sheeps and goats with 105 kg CO_2 CH_4 (Kimur et al. 2016).

The higher amount of carbon dioxide emissions relies in non-dairy cattle with 12740 Gg CO_2 methane from enteric fermentation, following surprisal by chicken with 7777.51 Gg CO_2. In Cambodia the consumption of chicken is increasing linking to the raising in chicken production that leads to an increase in carbon dioxide emissions.

The total amount of CO_2 from CH_4 manure management is 70.25 KgCO_2, the higher emitter is non-dairy cattle with 41.25 KgCO_2. The total amount of CO_2 from N_2O manure management is 166.81 Kg N_2O. The higher emitter of CO_2 from N_2O manure management is buffalos with 90.91 Kg N_2O following by non-dairy cattle. According to the Cambodian National Second Communication (2015) from the 2000 National Inventories the CO_2 emissions from N_2O manure management was 343.11 Gg CO_2 eq. As we see in 2013 the amount of carbon dioxide emissions reduces.

According to the paper of Bruun et al. 2014, shows the different energy content of fuel, where biogas has the lower emission from Mj delivered energy compared with others fuel as for exam dung, coal, wood that are the highest emittors of CH_4, CO_2, N_2O. As we see using biogas will significantly reduce the Greenhouses gases emissions that are produced without giving adequate tretament tot the manure. To introduce biogas technology and the continuation will ensure a significant change in the Cambodia household.

6. Conclusion

This work shows the higher biogas potential of Cambodia with 935.19 m^3/year, following the results its estimated that will converted on 4492.82 kwh/year of electricity. Its is shows that the utilization of livestock manure has enormous benefits for the Cambodian householders since they don't give a proper manure treatment.

The total annual of CH_4 emissions produced from enteric fermentation is 617.68 Gg CH_4 yr^{-1} in Which non-dairy cattle is the higher contributor to the global warming that will lead to an increase of impact in the climate affecting mainly the agriculture sector among others in Cambodia, for that reason is important to apply mitigation measures to reduce the impacts of methane from enteric fermentations.

The total annual amount of CH_4 emissions from manure management is 2494.12 Gg CH_4 yr. $^{-1}$ and the total amount of N_2O from manure management is 0.095 Gg N_2O yr^{-1}. It results shows a remarkable potential to solve manure problems and pollution to water, health problems that are related to animal manure. At the same time using agriculture waste provide an extra income to farmers. Biogas comes as a solution to solve climate change problems, treat livestock manure and provide electricity to the Cambodian householders. At the same time help to decrease greenhouse gas emissions such as methane, nitrous oxide and carbon dioxide that leads to the global warming.

The total amount of greenhouse gas emissions of CO_2 from CH_4 enteric fermentation is 23392 Gg CO_2, 70.25 KgCO_2 from manure management and 166.81 Kg N_2O. There is a need to apply mitigation measures to reduce the methane, carbon dioxide and nitrous oxide emissions, where biogas seems a potential source that mitigate to reduce the emissions for Cambodia.

Biogas has the lower carbon dioxide, methane and nitrous oxide in comparison with dung and wood, showing the potential of biogas to climate change mitigation.

Cambodia has a higher biogas potential to close the gap of electricity that mostly rely in wood and charcoal. Biogas comes as a solution to treat livestock manure that is usually spread or storage as a solid pile leading to environmental problems and pollution.

Is important that the government contribute to the promote biogas technology, supporting the small-scale farmers in all the process starting for installation and maintenance, training, to ensure that the technology prevalence in the country since there are notable benefits in the treatment of livestock manure. Since, the electricity in Cambodia is high, biogas will be a solution to increase the accessibility within smalls small scale household that usually rely on n wood, charcoal and battery lighting. This thesis should be helping the policy makers to be aware the potential of biogas and giving support to the technology.

7. References

- ADB. 2003.Key Indicators 2003.Available on https://www.adb.org/node/30966 (accessed from March 2020)
- Al Seadi T, Rutz D, Prassl H, Köttner M, Finsterwalder T 2008.Biogas Handbook. University of Southern Denmark
- Allied Tech Corp.2020.Biogas. Available on https://alliedtechcorp.com/renewable-energy/biogas/ (Accesed from March 2020)
- Battini F, Agostini A, Boulamanti A. K, Giuntoli J and Amaducci S.2014.Mitigating the environmental impacts of milk production via anaerobic digestion of manure: case study of a dairy farm in the Po Valley.Science Total Environment 481. doi:10.1016/j.scitotenv.2014.02.038
- Bond T. and Templeton M.2011. History and Future of Domestic Biogas Plants in the Developing World. Energy for Sustainable Development 15
- Bhattachrya S.C, Thomas M. J, Salam A. 1997.Greenhouse gas emissions and the mitigation potential of using animal waste in Asia. Energy 11 https://doi.org/10.1016/S0360-5442(97)00039-X
- Bruun S, Stoumann L, Thi V and Sommer S. 2014. Small-scale household biogas digesters: An option for global warming mitigation or a potential climate bomb?. Renewable and Sustainable Energy Reviews 33 DOI: 10.1016/j.rser.2014.02.033
- Britannica. 2021. Manure. Available on https://www.britannica.com/topic/manure (accessed on July, 2021)
- Chen, J. L., Ortiz R., Steele, T. and Stuckey, D. C. 2014. Toxicants inhibiting anaerobic digestion: A review. Biotechnology Advances, 32. doi: 10.1016/j.biotechadv.2014.10.005
- ClimateLinks. 2017.GreenHouse Gases Emission Fact Sheet: Cambodia. Available on https://www.climatelinks.org/resources/greenhouse-gas-emissions-factsheet-cambodia (accessed from February 2021)
- CIPS, 2004. Cambodia Inter-Censal Population Survey 2004. National Institute of Statistics, Ministry of Planning. Phnom Penh.
- Darith S, Shiwei X, Wen Y, Abdul-Gafar A, Kennvidy S, Ratanak O, Mukeba E. 2017.Potentials and Constraints of Small-Scale Livestock Productions in

Cambodia. World Engineering and Technology 5. DOI: 10.4236/wjet.2017.52B002 J

- Dessler A. 2016.Introduction to Modern Climate Change-Second edition. Cambridge University Press
- Energypedia. 2018.Cambodia Energy Situation. Available from https://energypedia.info/wiki/Cambodia_ Energy_ Situation (accessed December 2019)
- EPA 2014. Available on https://www.epa.gov/ghgemissions/understanding-global-warming-potentials (accessed from February 2020)
- EPA 2019. User's Guide for estimating carbon dioxide, methane, and nitrous oxide emissions from agriculture using the state inventory tool. Available on https://www.epa.gov/sites/production/files/2017-12/documents/ag_module_users_guide.pdf (accessed from march 2020)
- Ersahin M, Ozgun H, Dereli L and Oztkurt I. 2011.Anaerobic Treatment of Industrial Effluents: An Overview of Applications. Waste Water-Treatment and Reutilization.DOI:10.5772/16032
- Energypedia. 2015.Types of Biogas Digester plants. Available on https://energypedia.info/wiki/Types_of_Biogas_Digesters_and_Plants (accessed from March 2020)
- Emerald Enterprises India. 2018.Ferro Cement Biogas Plant. Available on http://emeraldenterprisesindia.com/commercial-biogas-eb/ (accessed from March 2020)
- Fournel S, Pelletier S and Feddes J. 2012.Greenhouse Gas Emissions from Three Cage Layer Housing Systems.Animals 2.DOI: 10.3390/ani2010001
- FAO. 2017.The State of Food and Agriculture. Available on http://www.fao.org////3/a-i7658e.pdf (accessed from February 2020)
- FAO. 2004. Review of the Livestock Sectors in the Mekong countries. Available on http://www.fao.org/docs/eims/upload/153492/lsr_mekong.pdf (accessed from March 2020)
- FAO. 2014. Reducing Enteric Methane for improving food security and livelihoods. Available on http://www.fao.org/in-action/enteric-

methane/background/why-is-enteric-methane-important/en/ (accessed from July, 2021)

- FAO. 2021. Reducing Enteric Methane for improving food security and livelihoods. Available on http://www.fao.org/in-action/enteric-methane/background/why-is-enteric-methane-important/en/ (accessed from July. 2021)
- Llonch P, Haskell MJ, Dewhurst RJ, Turner SP. 2017. Current available strategies to mitigate greenhouse gas emissions in livestock systems: an animal welfare perspective. Animal 11 https://doi.org/10.1017/S1751731116001440
- Gerber P, Opio C and Vellinga TH. Productivity gains and greenhouse gas emissions intensity in dairy systems. Livestock Science 139
- Gautam R, Baral S and Herat S. Biogas as a sustainable energy source in Nepal: Present status and future challenges. Renewable and Sustainable Energy Reviews 13 DOI: 10.1016/j.rser.2007.07.006
- Grainger C, Beauchemin K.A. Can enteric methane emissions from ruminants be lowered without lowering their production. Animal Feed Science Technology 166.https://doi.org/10.1016/j.livsci.2011.03.012
https://doi.org/10.1016/j.anifeedsci.2011.04.021
- Gomez, Claudius. 2013. Biogas as an energy option: an overview. The Biogas Handbook. 10.1533/9780857097415.1
- Grossi G, Goglio P, Vitali A, Williams A. Livestock and climate change: impact of livestock on climate and mitigation strategies. Animal Frontiers 9. https://doi.org/10.1093/af/vfy034
- Hawdon J.2014.Controlling Soil-Transmitted Helminths: Time to Think Inside the Box?.Journal of Parasitology 100.DOI:10.1645/13-412.1
- Harvey D.1993.A Guide to Global Warming Potentials (GWPs). Energy Policy 21. DOI: 10.1016/0301-4215(93)90205-T
- Hanoi Statistics Office. 2019. Hanoi Statistical Yearbook 2018
- IPCC Fourth Assessment Report. 2007.Climate Change, The Physical Sciences. Available from https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/faq-1-3.html (accessed from February, 2020)

- IPCC.2007. Climate Change Impacts, Adaptation and Vulnerability. Available from https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf (accessed from July, 2021)
- IPCC.2014.AR5 Climate Change: Impacts, Adaptation and Vulnerability. Available from https://www.ipcc.ch/report/ar5/wg2/ (accessed from February 2020)
- IPCC. 2006.Chapter 10: Emissions from Livestock and Manure Management. Available from https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf (accessed from February 2020)
- IPELC 2019. Manure production and Characteristics. Available from https://lpelc.org/manure-production-and-characteristics/ (accessed from March 2020
- IPTTS Associates.2020. Biogas Plants – An Introduction to The Advantages of Anaerobic Digestion. Available from https://ipptsassociates.co.uk/biogas-plants/ (Accessed from March 2020)
- IRENA. Measuring small scale biogas capacity and production. 2016.Available from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_Statistics_Measuring_small-scale_biogas_2016.pdf (accessed from January 2020)
- IEA, IRENA, UNSD, WB, WHO. 2019. Tracking SDG 7: The Energy Progress Report. Available from https://sustainabledevelopment.un.org/content/documents/2019_Tracking_SDG7_Report.pdf (accessed from March 2020)
- ISAT and GTZ. 1999. Biogas Digest Volume III-Biogas Costs and Benefits and Biogas-Programme Implementation. Available from https://www.pseau.org/outils/ouvrages/giz_biogas_digest_volume_iii_biogas_costs_and_benefits_and_biogas_programme_implementation_1999.pdf (accessed from March 2020)
- Kumar A, Mandal B and Sherma A.2015.Advancement in Biogas Digester. Energy Sustainable through Green Energy 201.DOI: 10.1007/978-81-322-2337-5_14

- Kumari S, Fagodiya RK , Hiloidhari M, Dahiya RP, Kumar A Methane production and estimation from livestock husbandry: A mechanistic understanding and emerging mitigation options. Science Total Environment 709. https://doi.org/10.1016/j.scitotenv.2019.136135
- Kutilek Miroslav and Nielsen R. Donal. 2019.Facts about Global Warming.Geoecology Essay.Schweizerbart Sciences Publication,Stuggard Germany
- Kumar R, Park B, Cho J.2013.Application and Environmental Risks of Livestock Manure.Journal of the Korean Society for Applied Biological Chemistry 56.DOI: 10.1007/s13765-013-3184-8
- Krieg & Fisher-Ingenieure GmbH.2011.Description of a digestion plant for biowaste and kitchen waste.Available on https://www.kriegfischer.de/en/biogas-plants/about-biogas/types-of-biogas-plants/digestion-plant-for-biowaste-and-kitchen-waste/ (accesed from March 2020)
- Mc Allister TA, Newbold CJ. 2008. Redirecting Rumen fermentation to reduce methanogenesis. Australian Journal Experimental Agriculture 48. https://doi.org/10.1071/EA07218
- Merino P, Ramirez-Fanlo E, Arriaga H, del Hierro O, Artetxe A, Viguria M.2011 Regional inventory of methane and nitrous oxide emission from ruminant livestock in the Basque Country. Animal Feed Science and Technology 166. DOI: 10.1016/j.anifeedsci.2011.04.081
- Mittal S, Ahlgren E and Shukla P.2017.Barriers to biogas Dissemination in India: A review.Energy Policy 112.DOI: 10.1016/j.enpol.2017.10.027
- Msibi S and Kornelius G.2017.Potential for Domestic Biogas as householder's energy supply in South Africa.Journal Energy Southern Africa 28 doi: 10.1016/j.biotechadv.2014.10.005
- Mohankumar S, Miniwarter W and Amon B. 2017.Greenhouse Gas and Ammonia Emissions from Different Stages of Liquid Manure Management Chains: Abatement Options and Emission Interactions.Journal of Environmental Quality 47. DOI: 10.2134/jeq2017.05.0199
- Macklean M.1998.Livestock in Cambodian rice farming systems. Phnom Penh: Cambodia-IRRI-Australia Project (CIAP)

- NEEDS Project – National Economic, Environment and Development Study for Climate Change. Options for Mitigation of Greenhouse Gas Emissions in Costa Rica: Towards Carbon Neutrality in 2021.Available from https://unfccc.int/files/cooperation_and_support/financial_mechanism/application/pdf/costa_rica_eng_needs_report_final.pdf (Accessed from March 2020)
- National Biodigester Programme Cambodia.2015 Available from http://nbp.org.kh/Slurry.aspx (accessed from December 2019).
- Nevzorova T and Kutcherov V.2019. Barriers to the wider implementation of biogas as a source of energy: A state-of-the-art review. Energy Strategy Reviews 26. https://doi.org/10.1016/j.esr.2019.100414
- National Biodigester Programme Cambodia.2015. Available from http://nbp.org.kh/Slurry.aspx (accessed from December 2019).
- Nicks B and Philippe F. 2015Review on greenhouse gas emissions from pig houses: Production of carbon dioxide, methane and nitrous oxide by animals and manure. Agriculture, Ecosystems and Environment 199. http://dx.doi.org/10.1016/j.agee.2014.08.015
- Linderholm .2006. Growing Season Changes in the Last Century. Agriculture and Forestry Meteorology 37. DOI: 10.1016/j.agrformet.2006.03.006
- Lemvig Biogas. 2013. An example of successful centralized co-digestion in Denmark. Available from https://www.ieabioenergy.com/wp-content/uploads/2018/01/success_story_denmark_lemvik2013.pdf (accessed from March 2020)
- Owen J.and, Whendee L. Greenhouse gas emissions from dairy manure management: a review of field-based studies. Global Change Biology 2021. https://doi.org/10.1111/gcb.12687
- Ogbuewu I,Odoemenam V, Omede A, Durunna C,Emenalom O, Uchegbu M, Okoli I and Jloeje M.2012.Livestock waste and its impact on the environment. Scientific Journal of Review 1 (2). DOI:10.14196/sjr. v1i2.184
- Ononogbo C.2015.An innovative approach to construction and operation of biodigesters: a consideration of floating drum biogas plant. TLEP International Journal of Mechanical Engineering Research 1

- Pen State Extension 2015.Reducing Risks from Animals and Manure. Available from https://extension.psu.edu/reducing-risks-from-animals-and-manure (accessed from April 2020)
- Pedersen S, Blanes-Vidal V, Joergensen H, Chwalibog A, Haeussermann A, Heetkamp and Aarnink A. Carbon Dioxide Production in Animal Houses: A literature review. Agricultural Engineering International: CIGR Ejournal. https://cigrjournal.org/index.php/Ejounral/article/view/1205/1132
- Palma Carolina. 2019.Review Methods for the Treatment of Cattle Manure—A Review.Journal of Carbon Research 5. doi:10.3390/c5020027
- Niu Q., Li Y.-Y. Recycling of Solid Waste for Biofuels and Bio-Chemicals. Springer; Singapore: 2016. Recycling of Livestock Manure into Bioenergy; pp. 165–186
- Prevention Web-The knowledge Platform for disaster risk reduction. 2006.National Adaptation Programme of action to Climate Change. Available on https://www.preventionweb.net/english/policies/v.php?id=8504&cid=29 (accessed from February 2020)
- Puspawati S, Budhi T and Soemantojo R.2019.An overview of biogas utilization from tempeh wastewater.IOP Conference Series Earth and Environmental Science 306.DOI: 10.1088/1755-1315/306/1/012019
- Prusty S, Sontakke UB, Kundu SS. 2014. Methane and nitrous oxide emission from livestock manure. African Journal of Biotechnology 44. DOI: 10.5897/AJB2014.14073
- Roubík H and Mazancová. Suitability of small-scale biogas systems based on livestock manure for the rural areas of Sumatra. Environmental Development 33. https://doi.org/10.1016/j.envdev.2020.100505
- SARE. 2012.Using Fertilizers and Amendments. Available from https://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition/Text-Version/Nutrient-Management-An-Introduction/Using-Fertilizers-and-Amendments (Accessed from March 2020)

- Ström G, Albihn A, Jinnerot T, Boqvist S, Djurfeldt A, Sokerya S, Osbjer K, San S, Davun H and Magnusson U.2017.Manure management and public health: Sanitary and socio-economic aspects among urban livestock-keepers in

Cambodia. Science of The Total Environment 621.https://doi.org/10.1016/j.scitotenv.2017.11.254

- Santibañez C and Bustamante M.2011. Residual Glycerol from Biodiesel Manufacturing, Waste or Potential Source of Bioenergy: A Review. Chilean Journal of Agriculture Research 71.DOI: 10.4067/S0718-58392011000300019
- Scarlat N, Dallemand F and Fahan F.2018.Biogas: Developments and perspectives in Europe. Renewable Energy 129.https://doi.org/10.1016/j.renene.2018.03.006Get rights and content
- UNFCCC. 2012. Second National Communication, India. Available on https://unfccc.int/resource/docs/natc/indnc2.pdf (accessed from July 2021).
- UNFCCC. National Communication Vietnam. Available on https://unfccc.int/resource/docs/natc/vnmnc02.pdf (accessed from July 2021)
- OSU. 2014. Biogas Cleaning and Upgrading Technologies. Available from https://ohioline.osu.edu/factsheet/AEX-653.1-14 (accessed from February 2020)
- The Phnom Penh.2018. Rising Cambodia's livestock sector a lifeline for farmers' prosperity. Available from https://www.phnompenhpost.com/post-focus/rising-cambodias-livestock-sector-lifeline-farmers-prosperity (accessed from March 2020)
- Achinas S, Gerrit J W,Euverink. 2016Theoretical analysis of biogas potential prediction from agricultural waste. Resource-Efficient Technologies 2.DOI: 10.1016/j.reffit.2016.08.001
- UNFCCC.2020. Clean Development Mechanism (CDM). Available from https://cdm.unfccc.int/ (Accessed from February 2020)
- https://unfccc.int/files/national_reports/non-annex_i_natcom/submitted_natcom/application/pdf/indonesia_snc.pdf
- UNFCC. 2015.Nationally Appropriate Mitigation Actions (NAMAS). Available on https://unfccc.int/topics/mitigation/workstreams/nationally-appropriate-mitigation-actions#eq-2 (Accessed from March 2020)
- USAID, Climate Links. 2017.Greenhouse Gas Emissions Factsheet: Cambodia. Available from https://www.climatelinks.org/resources/greenhouse-gas-emissions-factsheet-cambodia (accessed January 2020)

- World Resources Institute. 1994. Available on https://files.wri.org/d8/s3fs-public/pdf/worldresources1994-95_bw.pdf (accessed July 2021)
- World Bionergy Association. 2019.Gobal potential of biogas. Available from https://www.worldbiogasassociation.org/global-potential-of-biogas/ (accessed from March 2020)
- World Bank. 2019.The Power of Dung. Lessons learned from on-farm biodigester programs in Africa. Available from http://documents1.worldbank.org/curated/en/468451557843529960/pdf/The-Power-of-Dung-Lessons-Learned-from-On-Farm-Biodigester-Programs-in-Africa.pdf (accessed from May 2020)
- Wellinger A, Murphy J, Baxter D.2013The Biogas Handbook. Science Production and Applications. Wood Head Publishing series in Energy
- WHO. 2016.Climate Change and Human Health. Available from https://www.who.int/globalchange/mediacentre/news/cop23-23-key-messages/en/ (Accessed from February 2020) Prevention Web-The knowledge Platform for disaster risk reduction. 2006.National Adaptation Programme of action to Climate Change. Available from https://www.preventionweb.net/english/policies/v.php?id=8504&cid=29 (Accessed from February 2020)
- Zhou, DM, Hao, X-Z, Wang YJ, Hua D C, Long C. 2005. Copper and Zn uptake by radish and pakchoi as affected by application of livestock and poultry manures. Chemosphere. 59.DOI: 10.1016/j.chemosphere.2004.11.008
- World Resour. Inst. 1994. World Resources 1994-95: A Guide to the Global Environment. New York: Oxford Univ. Press. 400 pp

Appendices

List of the Appendices:

Anex 1.0

Questionnarie-Current status of manure management practices and biogas Technology in Cambodia

Livestock manure used as a fertilizer directly to the soil can cause enormous environmental problems as an increase of pathogens, odours, contamination of watercourses, pollution. A solution to prevent those effects is anaerobic digestion process where microorganisms decomposed the organic matter in the absence of air producing methane for heat generation and carbon dioxide.
Biogas plays an important role in the mitigation of climate change; replacement fossils fuel as oil and coal for clean energy reducing the greenhouses gases emissions; being used as a fuel and fertilizer for correct manure management.
Please answers all the questions with the more acquire information. The purpose of the questionnarie is to have an overview of the manure management practices in your community and the current situation of biogas technology .
Deadline: 14 May, 2021

* Required

Family name, first name *

Your answer

Family name, first name *

Your answer

Age *

Your answer

Gender

◯ Female

◯ Male

District *

Your answer

Name of the village *

Your answer

Occupation *

Your answer

How you describe your region *

- crop producion region
- Livestock production region
- Other, specify

Next

Please, specify the number of animals per year and kg head for the category swine if was your choice *

Long answer text

Please, specify the number of animals per year and kg head for the category dairy cattle if was your choice *

Short answer text

Please, specify the number of animals per year and kg head for the category buffalos if was your choice *

Short answer text

Please, specify the number of animals per year and kg head for the category chicken if was your choice *

Short answer text

Please, specify the number of animals per year and kg head for the category ducks if was your choice *

Short answer text

Please, specify the number of animals per year and kg head for the category others cattle if was your choice *

Short answer text

What do you do with the animal waste *

Long answer text

What is the common type of housing for livestock in your community *
Cows, buffalos

- ◯ No housing
- ◯ Semi-covered
- ◯ concrete
- ◯ woods

Please, specify the number of animals per year and kg head for the category others cattle if was your choice *

Short answer text

Please explain the main goals and usage of animals in your community. *

Long answer text

What do you do with the animal waste *

Long answer text

What is the common type of housing for livestock in your community Cows, buffalos *

- No housing
- Semi-covered
- concrete
- woods

What is the common type of housing for livestock in your community Swine *

- No housing
- Semi-covered
- concrete

What is the common type of housing for livestock in your community Chicken, ducks *

- No housing
- Semi-covered
- concrete
- woods

How do you store manure? *

- Liquid storage
- Solid storage
- composting

What is the most critical concern regarding the manure? *

Short answer text

Can you recall any manure management practices in your community? *

Long answer text

What are the main problems with manure disposal? *

Short answer text

What are the main energy sources in your community? *

Short answer text

Is biogas widely use in your community? *

Long answer text

How satisfied are the community with the biogas technology? *

Long answer text

Other comments

0 responses

Accepting responses

Waiting for responses

Anex 2.0 Corona situation in Cambodia

Time to revert disastrous Covid situation: officials

The Covid-19 situation in Cambodia is heading towards further large-scale community transmission as the total number of confirmed cases is nearing 61,000 and the death toll passed 900 on July 10, senior health officials warned. Ministry of Health spokeswoman Or Vandine expressed concern that the country was going