BIOGAS AS A PROMISING ENERGY SOURCE FOR SUMATRA (REVIEW)

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Abstract
As modern energy is seen as a key element to reduce poverty and enable human development, various international programmes currently focus on the distribution and implementation of appropriate ways of energy worldwide. Such technology may provide small-scale biogas plants; as they offer production of biogas via the anaerobic digestion of organic waste materials solving the waste management problems and simultaneously and digestate as a by-product. Interest of use of small-scale biogas technology in rural areas is increasing with numerous organisations promoting their use for both socio-economic and environmental reasons. Currently, biogas technology is not habitual in Sumatra; however this technology for rural areas of Sumatra has not only the potential to tackle the negative impact of livestock and increasing waste generation, but also to alleviate poverty by supporting agriculture (including the livestock sector), providing clean energy and fertilizer.

Key words: small-scale biogas technology, Indonesia, waste utilization, anaerobic digestion.

INTRODUCTION

Due to the factors as population growth, industrialization, urbanization and economic growth the rapid increase of waste generation is caused, especially in developing countries (DHOKHIKAH AND TRIHADINGRUM, 2012) such as Indonesia. The energy consumption is likely to grow faster than the population. In Indonesia (the fourth most populated nation) ranks as the 13th in the primary energy use which is about 893 Mboe (HASAN ET AL., 2013). Currently the final energy supply is dominated by non-renewable energy sources such as oil, gas and coal (contributing for 75 % of the final energy consumption) (MUJIYANTO AND TIESS, 2013; HASAN ET AL., 2013). Therefore, this situation makes the government and the energy society worry as the fossil energy resources and supply might be diminished in the near future (HASAN ET AL., 2013). Currently, is modern energy seen as a key element to reduce poverty and enable human development, various international programmes currently focus on the distribution (as well as implementation) of appropriate ways of energy worldwide (MARTÍ-HERRERO ET AL., 2015). One of such technologies and options are small-scale biogas plants; as they offer production of biogas via the anaerobic digestion of organic waste materials solving the waste management problems and simultaneously produces digestate as a by-product, which may serve as an organic fertiliser (ROUBÍK ET AL., 2016). Small-scale biogas plants have also great potential to contribute sustainable development by providing wide variety of socioeconomic benefits (MSHANDETE AND PARAWIRA, 2009) such as energy supply diversification, rural development opportunities enhancement and creation of employment opportunities.

The potential of biogas technology in rural areas of Indonesia is encouraging, as biogas produced from various types of excrements (mainly buffaloes, pigs and cow, but also human) can be found in all Indonesian provinces, though the quantities are different (IEO, 2006; HASAN ET AL., 2012; ANDRIANI ET AL., 2015). But the use of organic waste to produce biogas is not only limited to the excrements transformation (ANDRIANI ET AL., 2015) but Indonesia also offers possibility to produce biogas from oil palm waste and other agricultural wastes (CHAIKITKAEW ET AL., 2015). Biomass from residues of palm is; however, only scratching the surface of Indonesia's biomass capacities. It is estimated that Indonesia produces over 146.7 million tons of biomass per year (equivalent to about 470 $GJ \cdot y^{-1}$) comprising of agricultural residues, estate crops and forestry wastes.

Biomass has been used traditionally for household energy needs for cooking and water heating in Indonesia. Mainly two major biomass sources, wood and agricultural residues (wastes) were and still are used in rural areas (SINGH AND SETIAWAN, 2013). However, such a usage cannot be considered as sustainable. Furthermore, collecting of these fuels is not only physically challenging, but also time consuming and through its burning mainly women and children are exposed to the harmful indoor air pollution which may cause respiratory diseases and eye inflammation (HUBOYO ET AL., 2014). Therefore it is essential to realize that successful implementation of biogas projects which reduce greenhouse gas (GHG) emissions and substitute fossil fuels and mineral fertilizers can also attract funding under the Kyoto Protocol's Clean Development Mechanism and related funds (JURGENS ET AL., 2006). Furthermore, most of Indonesian people lives in rural areas and depends on the agricultural sector, however, on the other side, they still do not concern about the side products becoming often wastes from agricultural production (PURWONO ET AL., 2013). Nevertheless, these agricultural wastes (mainly livestock waste) may also become valuable energy sources.

The Indonesian Domestic Biogas Programme (BIRU) in Indonesia is not only focused on the technology of small-scale biogas plants (BGPs), but also on its community potential (one biogas plant, depending on its capacity, can supply energy for multiple households or community purposes). However, according to the SINGH AND SETIVAN (2013) majority of households is not adequately interested in using and implementing the biogas technology due to the relatively low prices of kerosene and subsidised LPG bottles.

Interest in use of small-scale biogas technology in rural areas with aim to solve waste management problems and simultaneously produce biogas and digestate is increasing, especially with numerous organizations promoting their use (both for socioeconomic and environmental reasons). Therefore, biogas potential from agricultural waste of small-scale biogas plants in case of Sumatra, especially in connection with livestock waste should be considered. This paper is composed mainly from secondary sources and will serve as a pilot for terrain research design.

Review of small-scale biogas technology in Indonesia and Sumatra

For the production of biogas, various organic material can be used, as it is placed along with water into an anaerobic (oxygen free) conditions. This can be executed by usage of a digester in form of a tank or a plastic membrane.

Biogas is mainly composed of methane, a combustible gas, and carbon dioxide (Tab. 1). Due to containing incombustible components (like CO_2) the calorific value of biogas (produced from manure) is lower (4800-6700 $kcal{\cdot}m^{-3}$) than that of pure methane (8900 $kcal{\cdot}m^{-3}$). In addition, there might be present other substances (not involved in Tab. 1 as they are not always part of biogas) as chlorine and fluorine (combustion of these compounds produces aggressive products such as: SO_2, SO_3, HCl or HF and consequentially it can have negative effects on the equipment and fittings, such as biogas cookers). The energy content of biogas is higher than energy content of traditional biomass (such as fuelwood, charcoal and cow dung) (LAM AND HEEGDE, 2012). The energy content of biogas is lower in comparison to fossil fuels, however it is cleaner and sustainable (WAHYUDI ET AL., 2015). Due to its characteristics it is an adequate substitute to fossil fuels and biomass usually used for cooking, heating and electricity generation (MAITHEL, 2009; WAHYUDI ET AL., 2015).

Tab. 1. – Composition of biogas in small-scale biogas plants

Compound	**Symbol**	**Content (%)**
Methane	CH_4	50-75
Carbon dioxide	CO_2	25-45
Water vapour	H_2O	2 (20 °C)
Oxygen	O_2	<2
Nitrogen	N_2	<2
Ammonia	NH_3	<1
Hydrogen	H_2	<1
Hydrogen sulphide	H_2S	<1

MAITHEL, 2009; BOND AND TEMPLETON, 2011; WAHYUDI ET AL., 2015

In general, all organic materials can be digested, however, only homogenous and liquid substrates can be considered for simple biogas plants (OLUGASA ET AL., 2014; ROUBÍK ET AL., 2016). Therefore, it is also necessary to dilute the organic material (waste) with adequate quantity of liquid (OLUGASA ET AL., 2014). In case of manure the water/manure ratio should be around 3-6:1 as was described for case of central Vietnam (ROUBÍK ET AL., 2016). The maximum of gas production from a given amount of raw material depends on the type of a substrate. For example, pig liquid manure produces 300 m^3 of methane per a ton of ODM (Organic Dry Matter) and 30 m^3 biogas/m^{-3} liquid, cattle manure produces 200 m^3 methane/t ODM and 20 m^3 biogas/m^{-3} liquid (OLUGASA ET AL., 2014). About the heat retention time it varies in case of different wastes and in the temperature in the digester. As in the case of Indonesia, mesophilic temperature range (20-40 °C) is considered. Therefore the following approximate hydraulic retention time (HRT) can be applied (WERNER ET AL., 1999; OLUGASA ET AL., 2014):

- Liquid pig manure (15 – 25 days);
- Liquid cow manure (20 – 30 days);
- Animal manure mixture with plant material (50 – 80 days).

It is essential to keep HRT because when HRT is too short, the bacteria in the digester are "washed out" faster than they can reproduce, so the fermentation can comes out to a standstill (OLUGASA ET AL., 2014). Furthermore, HRT is important for proper pathogens removal or preventing pathogen spread, therefore is recommended to keep HRT at least 45 days (HUONG ET AL., 2014). These days, in Indonesia all from the main four types can be found (WAHYUDI ET AL., 2015):

- Plastic tubular biogas plant;
- Floating drum;
- Fibreglass;
- Fixed dome.

2. Integration of biogas technology into the farm unit

Lack of access to the basic energy call for the need to integrate the biogas technology into the farm unit to meet energy challenges of rural households and farm units. The raw material for BGPs must be conveniently available on a daily basis. Tab. 2 shows quantity of organic material needed for BGPs. If the daily access is not assured, the technology will not be viable. The integration of biogas technology into the farm unit may reduce the use of fuelwood for cooking and reduce the involvement of farmers in charcoal production. It is therefore imperative for the government and other relevant stakeholders to support and encourage the integration of biogas technology into the farm units in Sumatra.

The design of the BGP should have suitable inlets and outlets to allow the introduction of organic waste and the use of digestate without a large input of labour. The digester should be positioned to minimise transport labour; the biogas pipe line is easily to be extended, whereas the transport of feedstock can be labour exigent. The digesters should be positioned close to a ready flow of wastewater (which should be used in a preference against fresh potable water).

Tab. 2. – Quantity of organic material needed according to the volume of the biogas digester

	Volume of biogas plant (m^3)*				
	4	6	8	10	12
Required heads of animals / quantity of excrements (kg/day)					
Buffaloes	3/25-30	4-5/30-45	6/45-60	7-8/60-75	9/75-90
Pigs	7/15-20	10/20-30	13/30-40	17/40-50	20/50-60
Poultry	600/56	900/84	1200/112	1500/140	1800/168
Biogas production (m^3day)	1-2	1.5-3	2-4	2.5-5	3-6
Equivalent biogas production (hours of cooking)	4	6	8	10	12

Based on: SA PPLPP, 2009; BIRU, 2014

*Volumes are taken according to the most commonly installed volumes by National Biogas Programme BIRU

When considering the feedstock for BGP feeding, the C: N ration and pH of the matter must be followed. Both (C: N ration and pH) can be adjusted by selecting an appropriate mixture of feedstocks. Different feedstocks have different gas yield potentials (Tab. 3). In general, materials with high C: N ratios (such as waste wheat and bread), typically have a higher biogas yields than materials with a low C: N ratio (such as cattle and pig manure). Therefore, co-digestion can be used to selectively improve the biological and nutrient environment in the digester, while increasing available biogas and nutrients and improving waste management.

Tab. 3. – Calculation of typical biogas yields of different feedstocks

Substrate	**Daily production (kg/animal)**	**Content of dry matter (%)**	**Biogas yield (m^3/kg dry matter)**	**Biogas yields (m^3/animal/day)**	**References**
Pig manure	2	17	0.25-0.50 0.66 0.47	1.43	Steffen et al., 1998 An and Preston, 1999 Maithel, 2009
Cow manure	8	16	0.2-0.3 0.3	0.32	Bond and Templeton, 2011 Steffen et al., 1998 Maithel, 2009
Chicken excrements	0.08	25	0.35-0.8 0.35-0.6 0.5	0.01	Templeton, 2011 Steffen et al., 1998 Maithel, 2009
Human faeces	0.5	20	0.35-0.5 0.49	0.04	Templeton, 2011 SEAI, 2015
Straw, grass	-	80	0.35-0.4 0.35-0.55	-	Templeton, 2011 Steffen et al., 1998
Water hyacinth (EcengGondok, *Eichhorniacrassipes*)	-	7	0.17-0.25	-	Bond and Templeton, 2011
Corn	-	20	0.25-0.40 0.20	-	Bond and Templeton, 2011 KWS, 2015
Barley	-	25	0.62-0.86	-	Bond and Templeton, 2011
Hemp	-	28	0.25-0.27	-	Bond and Templeton, 2011
Rice straw	-	87	0.18	-	Bond and Templeton, 2011
Rice husk	-	86	0.014-0.018	-	Bond and Templeton, 2011
Waste green biomass (leaves)	-	80	0.06 0.1-0.3	-	Bond and Templeton, 2011 Steffen et al., 1998
Food remains	-	10	0.5-0.6		Steffen et al., 1998

Based on Steffen et al., 1998; An and Preston, 1999; Maithel, 2009; Bond and Templeton 2011; KWS, 2015; SEAI, 2015

There is an adequate and popular on-farm use of biogas as fuel for engine-generator to produce electricity for farm site use (OLUGASA ET AL., 2014) or as fuel for irrigation pumps, engine driven refrigeration compressors etc. Biogas treatment to prevent corrosion from H_2S is usually not necessary if proper maintenance procedures are followed, however H_2S filter for device (biogas cooker) life extension is recommended.

Issues associated with use of small-scale biogas plants in Sumatra

Despite the obvious benefits of the small-scale biogas technology, possible negative impacts shall be also mentioned. Majority of them can be found in next chapters (Technical and Policy issues, Socio-Economic issues and Environmental issues). It is essential to identify factors influencing the demand for biogas technology. It is presented by the following section Biogas technology potential in Indonesia (3.1.-3.4.).

Biogas technology potential in Indonesia – Policy issues

Energy policy development in Indonesia has been generally slow and the role of renewable energy has been overshadowed by other energy sources. However, today, the issue of energy situation in Indonesia is still more and more discussed topic. According to the Indonesian Presidential Regulation No. 5/2006 (dated January 25th), Indonesia established to diversify the use of energy sources by 2025 in the following proportion: coal 33 %, natural gas 30 %, crude oil 20 %, and renewable energy 17 % (MUJIYANTO AND TIESS, 2013).

In the study of ROSYIDI ET AL. (2014) was concluded that two proposed energy programs should be implemented for better dissemination of biogas technology in Indonesia: i) Biogas Energy Package (BGEP) for cooking purposes (because cooking represents a high portion of energy used in rural areas) and ii) Biogas Energy Package (BGEP) for local entrepreneurs (meaning the complete low-cost biogas installation with capacity of 5-10 cows for local farm units).

Currently Indonesian Domestic Biogas Programme – known as Biogas Rumah (BIRU) is running. BIRU is programme implemented by the Dutch NGO Hivos in cooperation with construction partner organizations. It started in May 2009 and by the 2012 it disseminated over 8,000 BGPs (BIRU, 2014) and by the 2015 over 16,000 BGPs. Programme is currently working in ten provinces: Lampung, West Java, Banten, Central Java, DI Yogyakarta, East Java, South Sulawesi, Bali, West Nusa Tenggara and East Nusa Tenggara. HHs benefiting from BIRU programme has above average income and level of education (compared to the average for their region in Indonesia). Biogas users receive subsidy of 2 000 000 IDR (194 USD) per plant. In the case of the most common volume (6 m^3) it is around ¼ of the total price.

Biogas technology potential in Indonesia – Technical issues

It is essential to realize, that with spreading of small-scale biogas plants is bringing also various technical problems, which may harm the further technology dissemination potential. Therefore it is essential to identify the problems and minimize them. Strictly technical issues can be various in nature as obvious in study ROUBÍK ET AL. (2016) where failure criteria were descripted in 5 main technical subsystems where problem can occur: structural components (*i.e.* problems with inlet and outlet system), piping system (*i.e.* leakages and blockages in the piping system), biogas utilization equipment (*i.e.* malfunction of biogas cookers and biogas lamps), digestate disposal system (*i.e.* lack of OM in digestate), anaerobic digestion process and biogas production (*i.e.* leakages in reactor, poor quality biogas and its smell, breakdown of the AD process). Furthermore, feedstock for the BGP needs to be conveniently available on the daily basis.

Biogas technology potential in Indonesia - Socio-Economic issues

As described in MWIRIGI ET AL. (2014) there are some key socio-economic characteristics, which impact the decision of a household to adopt biogas technology. Therefore we tried to set up the costs and benefits associated with biogas technology at the household level (summarized in Tab. 4).

Tab. 4. – Financial costs and benefits associated with biogas technology

Costs	**Benefits**
Costs of a biogas technology	Cooking and lightening fuel savings
Repair and maintenance costs	Time saving due to the biogas technology
Costs of extra time consumed due to the BGP installation	Saving in households health related expenditures
	Income effects of improved health

However, there are many socio-economic constraints for adoption as well. While implementing the biogas technology in larger scope, challenges of adoption mentioned studies from Asian and African countries shall be taken into consideration also in Indonesia. The most influential socio-economic factors are demonstrated in Tab. 5 which are affecting the adoption process in other regions, however there are applicable for Indonesia. Therefore there is a need to address country specifics for widespread adoption of biogas technology. Costs and subsidies are also an important factor that can positively influence adoption process within the region. As for renewable energy projects (including biogas technology) their economic competitiveness is much lower without subsidies when compared with their alternatives (*i.e.* fossil fuels) (WANG ET AL., 2016). Also awareness about the technology needs to be addressed, using various methods of dissemination, for end users to realize value of the technology.

Tab. 5. – Social and economic factors affecting biogas purchasing and adoption

Category	Factors	References
Social		
	Education	Mwirigi et al., 2009;, Alonbami et al., 2001; Mwakaje, 2008; Omer and Fadalla, 2003; Roubík and Mazancová, 2014
	Awareness about technology	Mwirigi et al., 2009; Alonbami et al., 2001; Mwakaje, 2008; Omer and Fadalla, 2003; Roubík et al., 2016
	Age and sex of households head	Mwirigi et al., 2009; Roubík et al., 2014
Economic		
	Costs and ability to pay	Mwirigi et al., 2009
	Family income	Mwirigi et al., 2009
	Size of farm	Mwirigi et al., 2009; Walekhwa et al., 2009
	Construction costs	Akinbami et al., 2001; Mwakaje, 2008; Omer and Fadalla, 2003; Roubík et al., 2016
	Costs of traditional fuels	Walekhwa et al., 2009; Omer and Fadalla, 2003
	Availability of feedstock	Mwirigi et al., 2009; Mwakaje et al., 2009; Roubík et al., 2016
	Number of dairy cattle	Mwirigi et al., 2009; Akinbami et al., 2001; Walekhwa et al., 2009
	Average costs of a dairy cow	Mwirigi et al., 2009

Biogas technology potential in Indonesia – Environmental issues

Anaerobic digestion utilization is an appropriate solution to environmental problems and can play a fundamental role in conditions improvement. The extensive use of fuelwood for energy purposes in developing countries has fundamental effect on local forests (SURENDRA ET AL., 2014). Deforestation is responsible for up to 25 % of all anthropogenic GHG emissions (STRASSBURG ET AL., 2009) and has also impact on soil erosion and land degradation (GAUTAM ET AL., 2009). In study done by KATUWAL AND BOHARA (2009) it was estimated that annually a small-scale biogas plant spares the direct burning of around 3 metric tons of firewood and 576 kg of dung, subsequently eliminating around 4.5 metric tons of CO_2 emissions to the atmosphere. Furthermore, biogas technology installations reduce pathogenic content of substrate materials (HUONG ET AL., 2014) and also improve health of users. Especially through reduction of indoor smoke coming from solid fuels (traditional biomass), which is widely used by the farmers in developing countries, as well as in Indonesia. Majority of victims of exposure to the indoor air pollution are women and children, mainly from low-income homes in rural areas (LOHANI, 2011; SURENDRA ET AL., 2014). Furthermore, the biogas production does not come with the environmental pollution of degradation; instead it comes with clean energy as a main product and fertilizer as a by-product.

However, biogas plants also produce a significant number of problems and complications regarding their operation (ROUBÍK ET AL., 2016), thereby reducing the benefits of this technology. Afterwards, environmental benefits of biogas technology may not be as great as it initially appears, because the digesters may release methane (CH_4) through leaks as well as from the inlets and outlets (BRUUN ET AL., 2014; ROUBÍK ET AL., 2016). In study done by BRUUN ET AL. (2014) calculations showed that CH_4 emissions from the biogas plants (from leaks and intentional releases), are likely to be substantial because of poor maintenance and poor biogas handling. Furthermore, inappropriate handling with digestate or its uncontrolled disposal may cause environmental contamination.

Small-scale biogas plants can be a very useful tool for energy creation and for waste management, if managed properly. Otherwise benefits of this technology may be compromised.

Recommendations

The following recommendations are drawn for consideration for optimal integration of biogas technology as an energy source in Sumatra:

- There is need for creation of adequate loan system, improving possibility of farmers to increase their livestock capacity and improve stables and pig-pens;
- Exemptions of tax on material made purposely for biogas plants (biogas cookers, generators running on biogas) should be considered;
- Subsidies for farmers who wants to integrate a biogas technology into the farm unit;
- Identification of the suitable institution serving as disseminator;
- Facilitators (extension agents) should be trained to improve integration of biogas technology into the farm units and its adoption;

and

- Systematic empirical studies in case of Indonesia are a high priority for further research

CONCLUSIONS

With the increasing demand for the farm animal products it is coming a growing trend of livestock population resulting in the production of plenty of the organic waste. Such a waste can be used within the biogas technology in Sumatra. Whereas abundant potential for widespread of the biogas technology as it offers significant advantages, especially in regard to energy, the environmental and economic development. However, this development might be compromised and slowed by the lack of technical and policy implications, socio-economical obstacles and by the lack of institutional support. Therefore, these challenges have to be adequately addressed. Biogas technology has not only the potential to tackle the negative impact of livestock and increasing waste generation, but also to alleviate poverty by supporting agriculture (including the livestock sector), it can provide clean energy in form of biogas and fertilizer as a by-product.

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