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Quantification of biogas potential from livestock waste in Vietnam

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Abstract. Quantification of biogas potential in Vietnam is highly needed to provide sufficient information for authorities properly support their future policy decisions. To achieve the aim of this investigation, two methods were applied: (i) the method for calculation of the amount of manure and its biogas potential from chosen livestock obtained from statistical data and (ii) the method for future forecast using middle scenario applications based on previous development of specific category, presuming homogenous continuation of growth. The total biogas energy potential in Vietnam was quantified to approximate 120,000 T Jy^{-1} in 2015 and has the potential of increasing to 127,000 TJ y^{-1} by 2020. However, when considering current manure management practices (including accessibility factor and collection efficiency) biogas potential was quantified to the values of almost 67,000 T Jy^{-1} in 2015 and over 71,000 T Jy^{-1} by 2020 if the current manure management practices remain unchanged. Biogas has the potential of generating renewable energy, while meeting requirements related to waste treatment and minimizing environmental impacts. This study shows that animal waste is a promising sustainable energy source in Vietnam which can be efficiently utilized for the generation of biogas energy as well as electricity. Furthermore, anaerobic digestion of livestock waste has the potential to play a vital role in farming systems by adding value to agricultural waste and livestock excreta, and reducing their presence in the environment therefore enhancing public health. There is a high development potential for the decentralized energy generation due to the exploitation of small-scale biogas plants in Vietnam. However, it is essential to realize that competition to other energy generating technologies is present.

Key words: biogas potential, quantification, biogas, Vietnam, livestock waste, anaerobic digestions, manure management

INTRODUCTION

The fast depleting supply of fossil fuels and growing environmental degradation by potent greenhouse gases is pushing the World´s economies towards the usage of alternate energy sources (IPCC, 2012). Constantly growing worldwide energy consumption and population expansion in developing countries increase stress and damage to the planet (Ahuja & Tatsutani, 2009). In the developing world, pollution and access to energy sources still represent a significant challenge, especially in connection with human and environmental health and with economic development (Ahuja & Tatsutani, 2009; Shane et al., 2015). Therefore, bioenergy production by fermentation reaction is gaining popularity due to its easy operation and a wide available selection of organic wastes feedstock (Priekulis et al. 2015; Ayhan, 2016; Thi et al., 2016). As rural areas in Asia are struggling to manage of vast quantities of manure (mainly from pigs, dairy and poultry) appropriate waste management systems are needed (Vu et al., 2015). By transforming of animal waste into energy, in the form of biogas, this would prevent these animals' slurry from being dumped directly into rivers and lakes, a common practice in parts of Asia that lack waste management infrastructure (Anenberg et al., 2013; Vu et al., 2015). This calls for appropriate manure management strategies with minimal impacts on the environment, simultaneously generating energy with little or no warming potential, such as biogas technology (Vu et al., 2015). Furthermore, global warming is one of the major concerns arisen in the natural environment of human beings and manure waste obtained from livestock sector is one of the main organic wastes which are hazardous if not managed suitably. Animal manure contains a high concentration of nitrogen (N) and phosphorus (P), which causes nutrient imbalance and pollution in environment (Abdeshahian et al., 2016). Livestock manure also contains residues of some harmful substances (as growth hormone, antibiotics and heavy metals) and also microorganisms in the animal manure could contaminate the environment resulting in an outbreak of human diseases (Nguyen 2011; Nguyen et al., 2012; Cu et al., 2015). Therefore, disposal of livestock manure may have significant polluting impact on the environment contaminating air, soil and water sources (Abdeshahian et al., 2016).

These days in Vietnam biogas technology is viewed as a method not only for solving environmental problems, but also for contributing to energy production and resolving economic and social issues (Chu, 2012; Cu et al., 2012; Cu et al., 2015; Roubík & Mazancová, 2016b). Having an abundance of organic waste, the country is being encouraged to further use 'Waste to Energy' technologies to properly address the treatment of waste materials (Surendra et al., 2014; Silva et al., 2016). The treatment of organic waste is necessary to keep the environment clean. Also, through the treatment of organic waste, such as livestock excreta, this allows to reintroduce materials into the material cycle (Nguyen et al., 2012).

During anaerobic digestion process, not only biogas, methane-rich gas with net calorific value of 20–25 MJ m^3 that can be used in many appliances including biogas lamps, biogas cookers or generators and engines, is produced (Cundr & Haladová, 2014; Roubík & Mazancová, 2016a). Also a product of fermentation called digestate is generated (Chu, 2012; Kouřimská et al., 2012). Digestate as a by-product can also be used as a fertilizer (Chu, 2012; Kouřimská et al., 2012; Roubík et al., 2016) or for other energy purposes (Brunerová et al., 2016).

Anaerobic digestion technologies have been utilized in Vietnam over 30 years (Silva et al., 2016) with thousands of small-scale biogas plants in usage (Roubík et al., 2016). Small-scale biogas plants were applied as an optimal livestock waste treatment as well as biogas supply for cooking and lighting demand for small-scale farmers in Vietnam (Roubík et al., 2016). Although the biogas technology was introduced nearly 30 years ago, the number of the constructed biogas plants is still limited (Nguyen, 2011; Chu, 2012; Nguyen et al., 2012; Roubík & Mazancová, 2016b).

Following a decade of expansion aided by heavy government and foreign organizations investment (over 725,000 people in Vietnam benefit ~~by~~ from the implementation of biogas technology) (BPAHS, 2016), biogas development in rural

Vietnam is currently at its crossroad. However, emerging problems call into question whether small-scale biogas technology is still able to meet the increasing energy needs of rural households (Roubík et al., 2016). Also, it is questioned by government how to make subsidies for funding this technology in a more cost-effective way (Roubík & Mazancová, 2016b). Another challenge lies in technology financial performance (York et al., 2016), which directly influences technology owners' satisfaction level (Roubík & Mazancová, 2016b). Rapid economic development and urbanization across the Vietnam is bringing also major changes to rural settings and therefore impacting small-scale biogas production (Vu et al., 2015). Migration to cities means less labour to operate biogas technology. Other difficulties include inadequate technical services for post-installation maintenance and repair It is also essential to realize that these combined factors may result in many small-scale biogas plants either functioning below their full potential or being out of use altogether (Bruun et al., 2014).

Therefore, quantification of biogas potential in Vietnam is highly needed to provide sufficient information for authorities to have their future policy decisions well supported.

MATERIALS AND METHODS

To achieve the aim of the investigation, two methods were applied: (1) the method for calculation of the amount of manure and its biogas potential from chosen livestock obtained from statistical data and (2) the method for future forecast using middle scenario applications based on previous development of a specific category, presuming homogenous continuation of growth. The second method is reflecting the continuation of past development trend assuming no significant changes and constraints within each specific category. Furthermore, the second method involves accessibility factor and collection efficiency in order to reflect current manure management practices.

Target area, data collection methods and SWOT analysis

In order to verify current situation, field visits were carried out in central Vietnam in August and September 2016. Based on those visits SWOT analysis of biogas potential as a complex method of strategic analysis (considering internal and external factors) was elaborated. SWOT analysis is a strategic planning tool, which is helping identify internal factors (strengths and weaknesses) and external factors (opportunities and threats) in order to determine the future heading. By capitalizing on strengths and eliminating or correcting weaknesses there is higher possibility to be able to take advantage of opportunities as they emerge and cope with threats before they become reality. By investigating and assessing both internal and external factors affecting the performance, a clearer vision of success and failure possibilities is achieved. The SWOT analysis, in this study, is developed based on such facts, and obtained through a series of face-to-face meetings with all concerned stakeholders from the biogas sector in the central Vietnam, including but not limited to biogas owners, local facilitators of biogas plants and experts from the local university. Then an analysis of the notes from these meetings was conducted and results were compiled to establish the strengths, weaknesses, opportunities and threats.

Biogas yield calculations

Biogas potential from various available excrements was calculated according to typical biogas yield per kg in mesophilic conditions, i.e. 20–45 °C.

The theoretical biogas potential from animal dung was determined using equation (1) (Shane et al., 2015):

$$BEP = \frac{N \cdot VS \cdot B_0 \cdot D \cdot CV}{10^6} \qquad (1)$$

Where BEP (Fig. 1) is the theoretical biogas energy potential in TJ y^{-1}, N is the population of animal category, VS is the volatile solids in $kg \cdot d^{-1}$, B_0 is the methane potential $m^3\ kg^{-1}$ VS, D is the number of days in year and CV is the calorific value of biogas at 60% of methane in MJ m^{-3}. Statistical and prediction data were used for livestock production in Vietnam to determine the theoretical biogas potential from animal waste. Data about B_0 and VS were extracted from IPCC (2006) for Vietnam. Data about the population of animal category (2008–2015) were extracted from Vietnamese statistics (2015) and data about population of animal categories 2015–2020 were based on own calculations.

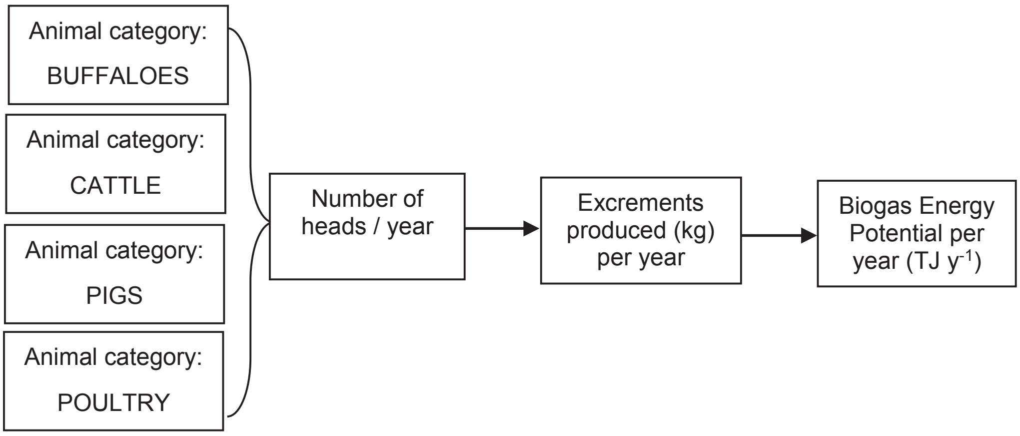

Figure 1. Simplified design of theoretical calculations.

Furthermore, there was applied the estimated accessibility factor and collection efficiency (Table 1) to the final quantifications in order to reflect current manure practices for livestock in Vietnam. These two factors were set up after field visits, which were carried out in central Vietnam August and September 2016 and after face-to-face meetings with all concerned stakeholders from the biogas sector in the central Vietnam. These factors are estimated according to the local production conditions.

Table 1. Estimated accessibility factor and collection efficiency for different livestock manure

	Accessibility factor	Collection efficiency
BUFFALOES MANURE	0.40	0.80
CATTLE MANURE	0.80	0.80
PIGS MANURE	0.80	0.95
POULTRY MANURE	0.60	0.80

(Thornton, 2010), which was based on the previous development of the specific category, presuming the homogenous continuation of population growth. Coefficient of determination between the data points and the estimated values were analysed by the R-squared value (result values are shown in Table 3, where higher R-squared value indicates higher probability of predictions to be exact – providing a measure of how well observed outcomes are replicated by the model, based on the proportion of total variation of outcomes explained by the model).

RESULTS AND DISCUSSION

Livestock production in Vietnam with taking into account manure accessibility and collection efficiency

Livestock production in Vietnam is primarily undertaken on rural household farms (where usually crops and other agricultural products are also produced). More than 92% of producers in 2003 used only household labour in livestock production sector (Nin et al., 2003) and this situation is still valid. The domestic market easily absorbs majority of livestock production in Vietnam (Nga et al., 2015). Livestock is an important source of income for the majority of Vietnamese farmers, particularly those in upland areas where poverty rates are highest, so that its development carries important implications for poverty reduction and income distribution. Livestock raising costs are dominated by feed costs, which account for an average of over 75% of total costs. Feed costs are still the dominant cost component even when household labour is valued at full cost. Poor producers use mainly grazing systems while larger households use more cut and carry grasses and complete feed systems.

The native buffalo is a traditional animal in Vietnam and is usually raised for rice culture and meat (Nha et al., 2008) and it gains important role due to the increasing demands for its meat with growing population. Even though raising buffaloes without shelter is currently habitual for farmers in Vietnam as they are fed by natural grasses (Nha et al., 2008) they were also added to the final quantifications of biogas potential. As there is potential with move towards other buffalo raising practices (such as keeping buffaloes in shelters or using manure from their sleeping shelters), however, in the current state of circumstances the estimated accessibility and collection factors were set up for buffaloes 0.4 reflecting difficult manure accessibility during the day and 0.8 respectively for relatively ease use of manure into the biogas plant when accessed.

Cattle production also plays a very important role in farming systems and Vietnamese life as the demand for beef is increasing, mainly in major urban centres (Parsons et al., 2013; Dung et al., 2013). Dairy cattle are mainly raised in smallholder farms (approximately 96%), therefore accessibility factor was set up for 0.8, reflecting relatively good accessibility of cattle manure and collection efficiency of 0.8 for relatively ease use of manure into the biogas plant when accessed. The percentages of farms falling into smallholder farms with meat cattle are around 78%. Local breeds are dominant in the smallholder farms. Cattle production in Vietnam has increased significantly during the last decade, with annual cattle population growth from 6 to 11% (MARD, 2014; Vietnamese statistics, 2015). The reasons are both tourism and increasing income of the local population and their growing purchasing power. The major constraints perceived in a study by Parsons et al. (2013) were including lack of capital, breed, feeding, labour availability, diseases and lack of knowledge. Such constraints if not managed may lead to number reductions of the animal sector.

The pig sector consistently contributes up to 80% of total meat production in Vietnam (Nga et al., 2013) and provides a livelihood for over 4.1 million small-scale farms in the country (Nga et al., 2015). Rising income is one of the driving factors of pork demand (Nga et al., 2015). At present, the smallholders provide at least 80% of total pork for domestic consumption that is mainly distributed in traditional wet markets where food production processes are not traceable and food quality remains a big concern (Nga et al., 2015). Vietnam's swine production is composed of mostly backyard/household operations or small farms. In 2006, about 85% to 90% of swine were raised in backyard/household operations, while the remainder were raised at larger, commercial farms. In Vietnam, farms are considered commercial if they have more than 20 sows. While small farms account for 85% to 90% of the total pig population, they produce only about 75% to 80% of the pork supply. Crossbred pigs are the dominant type of pig, with the proportion of crossbred and exotic pigs increasing with farm size. Local pigs are predominantly fed using only roughage; crossbred pigs are mostly fed on roughage and concentrates while for exotic pigs a diet of complete feed is used. Accessibility factor was set up for 0.8, as reflecting good accessibility in case of current way of rising pigs and collection efficiency of 0.95 as pigs' manure is currently extensively used by farmers.

Poultry production in Vietnam is also characterized by small-scale farms, where the birds are mainly fed by farm-produced grain combined with scavenging (Tung & Rasmussen, 2005). However, also middle farms are common. At present, there are 11 national poultry breeding centres with 3,000 pure breeds and 18,000 grandparent chickens. There are 106 local poultry breeding farms The characteristics of poultry intensive production system are high investment, good management and a short husbandry period. In Vietnam, there are two main poultry production systems: i) semi-subsistence (where small flock of local breeds are left to scavenge in backyards and garden area and fed with locally available feeds) ii) semi-commercial poultry systems (larger flock size with local or improved breeds and supplementary feeding with either grain or concentrate feeds or both). Poultry also plays an important role in providing food and income for small-scale households (Tung & Rasmussen, 2005). As the current poultry production in Vietnam is still mainly in the hands of small-scale farmers, where during the day, birds are often in the open area without any concrete floor accessibility factor was set up for 0.6 and collection efficiency when already applied, is generally quite sufficient for 0.8.

As shown in Table 2, where numbers of livestock of chosen categories (buffaloes, cattle, pigs and poultry) are provided, the numbers are differing in nature. Such as in the case of buffaloes, there is slow decrease in numbers (almost 2.9 million in 2008 to the approximately 2.52 million in 2014). In the case of cattle, there is also an obvious trend of slight decrease in numbers (with over 6.33 million in 2008 to the 5.23 million in 2014). In case of pigs, there are very stable numbers with over 26.7 million in 2008 to the almost 26.8 million in 2014. The poultry category has experienced significant increase in numbers from 248.3 million in 2008 to almost 328 million in 2014.

Table 2. Number of livestock in Vietnam (2008–2014)

	2008	2009	2010	2011	2012	2013	2014
BUFFALOES	2,897,700	2,886,600	2,877,000	2,712,000	2,627,800	2,559,500	2,521,400
CATTLE	6,337,700	6,103,300	5,808,300	5,436,600	5,194,200	5,156,700	5,234,300
PIGS	26,701,600	27,627,700	27,373,300	27,056,000	26,494,000	26,264,400	26,761,400
POULTRY*	248.3	280.2	300.5	322.6	308.5	317.7	327.7

*Poultry is in million heads. Source: Vietnamese general statistics office (2015).

With the application of middle scenario based on the previous development of each category, presuming the homogenous continuation of growth, there are probable predictions of development demonstrated in Table 3.

Table 3. Prediction of number of livestock in Vietnam (2015–2020) based on previous development of animal categories

	R^2	2015	2016	2017	2018	2019	2020
BUFFALOES	0.94	2,491,926	2,419,344	2,346,762	2,274,180	2,201,598	2,129,016
CATTLE	0.92	4,545,624	4,337,856	4,130,088	3,922,320	3,714,552	3,506,784
PIGS*	0.30	26.95	27.02	28. 90	28.78	28.65	29.53
POULTRY*	0.78	346.6	358.14	369.61	381.08	392.55	404.02

*Poultry and pigs are in million heads.

Table 3 provides predictions of the development of various animal categories, however the future evolution of livestock production systems is greatly related to the major constraints faced by most producers in the region. Those constraints may be those mentioned by Hanh et al. (2013) such as dependence on purchased feed, the increase of the price of animal feed, threats from animal infectious epidemics, and the environmental pollution. Other relevant factors include the economic purchasing power of consumers and policy issues. As obvious from Table 3, R-squared values are relatively high for buffaloes, cattle and poultry, indicating exact predictions for those three categories. However, quite low for pigs, showing potential higher errors between the data points and the estimated values in the case of pigs, indicating less exact predictions.

Quantification of biogas potential

It is also important to realize that livestock manure keeps releasing methane due to the anaerobic decomposition of organic material contained in the manure by bacteria exited along with the manure from the animal (Chhabra et al., 2009). Therefore, proper quantifications are relevant to be able to keep such challenges. As calculated by Tauseef et al. (2013) livestock manure contributes globally about 240 million metric tons of carbon dioxide equivalent of methane to the atmosphere and represents one of the biggest anthropogenic sources of methane. Considering that methane is the second biggest contributor to global warming, after carbon dioxide, it is imperative that ways and means are developed to capture as much of the anthropogenic methane as possible. There is a major associated advantage of methane capture: its use as a source of energy which is comparable in 'cleanness' to natural gas.

Livestock waste is composed of the organic matter that can be treated as the potential raw substance for the production of bioenergy (Abdeshahian et al., 2016). The livestock manure is one of the cost-effective and renewable substrates for biogas production and therefore the treatment of livestock manure through anaerobic digestion is an appropriate manure management method decreasing polluting effect on the environment and simultaneously producing biogas and converting manure into organic fertilizer (digestate). The biogas potential in Vietnam is large in numbers, as the livestock population is continuously growing with the higher demand for meat products. However, a major problem for biogas utilization may be the lack of large-scale farms (mainly for pigs or poultry as potential sources). The livestock sector is mainly kept in small-scale household farms. However, such small-scale farms and households are appropriate for small-scale biogas plants.

Table 4a shows quantification of biogas potential from the livestock sector based on statistical data up to 2014 Obviously, the biogas produced from the livestock waste is affected by the various factors, such as feeding regime, animal type, animal body weight, the proportion of total solids and the waste availability, therefore those numbers should be considered as a rough estimations of biogas potential considering middle scenario for country such as Vietnam.

Table 4a. Quantification of total biogas energy potential from various livestock waste in Vietnam (TJ y^{-1}) in the period 2008–2014

	2008	2009	2010	2011	2012	2013	2014
BUFFALOES	15,843	15,782	15,730	14,828	14,367	13,994	13,786
CATTLE	20,436	19,680	18,728	17,530	16,748	16,627	16,878
PIGS	32,568	33,697	33,387	33,000	32,314	32,034	32,641
POULTRY	42,329	47,768	51,228	54,996	52,592	54,161	55,865
TOTAL	111,178	116,929	119,076	120,356	116,024	116,818	119,171

Table 4b then shows the prediction of biogas potential from livestock sector from 2015 up to 2020. As obvious, livestock manure is notified as the potential feedstock for sustainable generation of biogas through the anaerobic digestion process.

Table 4b. Estimation of total biogas energy potential from various livestock waste in Vietnam (TJ y^{-1}) in the period 2015–2020*

	2015	2016	2017	2018	2019	2020
BUFFALOES	13,625	13,228	12,831	12,434	12,037	11,640
CATTLE	14,657	13,987	13,317	12,647	11,977	11,307
PIGS	32,872	32,957	35,247	35,098	34,949	36,019
POULTRY	59,099	61,054	63,010	64,966	66,921	68,877
TOTAL	120,254	121,228	124,407	125,147	125,886	127,846

*Data are based on authors´ predictions of development of each animal category.

Figure shows the total biogas potential from livestock manure in the period 2008–2020. The potential has growing trend as has the livestock population of Vietnam responding to the increasing demands for the animal products resulting huge amounts of organic waste to be handled. As demonstrated in Fig. 2, the total biogas energy potential arises from over 111,000 TJ y^{-1} in 2008 to over 120,000 TJ y^{-1} in 2015 and can with continuous trend go up to 127,000 TJ y^{-1} in 2020. In this view, it is also desirable to consider the electricity potential to be generated from the potential biogas. Furthermore, within this context, it is required for the continued development of anaerobic digestion in terms to get clean energy, which is less costly than comparable renewable technologies and thus have a great potential for a country such Vietnam.

In order to make our quantifications more precise, there were used specific accessibility factors and collection efficiency for each of the categories showing us the adjusted result of quantifications (Table 5a and 5b). As obvious in Fig. 2, where biogas energy potential in the period 2008–2020 (TJy^{-1}) from livestock manure adjusted by accessibility factors and collection efficiency is shown, the growing trend is still present and showing very high biogas potential. The potential in 2008 is over 63,000 TJy^{-1}, in 2014 already almost 67,000 TJy^{-1} and with predicted values of over 67,000 TJy^{-1} in 2015 and over 71,000 TJy^{-1} by 2020.

Table 5a. Quantification of total biogas energy potential from various livestock waste in Vietnam (TJ y^{-1}) in the period 2008–2014 adjusted by accessibility factors and collection efficiency

	2008	2009	2010	2011	2012	2013	2014
BUFFALOES	5,069	5,050	5,033	4,745	4,597	4,478	4,411
CATTLE	13,079	12,595	11,986	11,219	10,719	10,641	10,801
PIGS	24,751	25,610	25,374	25,080	24,559	24,346	24,807
POULTRY	20,318	22,928	24,589	26,398	25,244	25,997	26,815
TOTAL	63,219	66,185	66,985	67,443	65,121	65,464	66,836

Table 5b. Estimation of total biogas energy potential from various livestock waste in Vietnam (TJ y^{-1}) in the period 2015–2020* adjusted by accessibility factors and collection efficiency

	2015	2016	2017	2018	2019	2020
BUFFALOES	4,360	4,233	4,106	3,979	3,852	3,725
CATTLE	9,380	8,952	8,523	8,094	7,665	7,236
PIGS	24,983	25,047	26,788	26,674	26,561	27,375
POULTRY	28,367	29,306	30,245	31,183	32,122	33,061
TOTAL	67,092	67,539	69,663	69,932	70,202	71,398

*Data are based on authors´ predictions of development of each animal category.

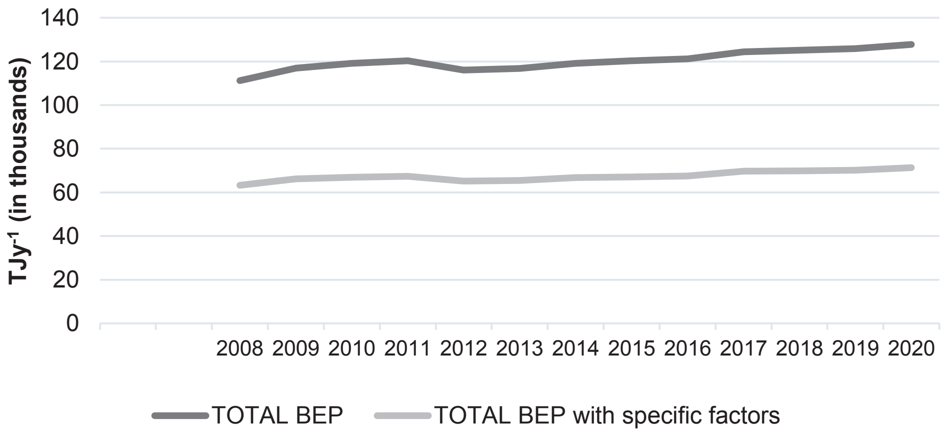

Figure 2. Comparison of total biogas energy potential in the period 2008–2020 (TJ y^{-1}) from livestock manure and biogas energy potential from livestock manure adjusted by accessibility factor and collection efficiency.

Apparently, as obvious in Table 6 where SWOT analysis of biogas potential in Vietnam is showed, strengths and opportunities are more when compared to the weakness and threats which can be easily overcome through different operation mechanisms.

Table 6. SWOT analysis of biogas potential in Vietnam

STRENGTHS	It is renewable energy and it has been supported by foreign NGOs and the Vietnamese government.
	Biogas production is a technology to reduce waste and it offers solutions for organic waste disposal.
	The combustion of methane has very low exhaust emissions (NOx, CO, Particulate Matter) compared to fossil fuels.
	Biogas can be produced in a decentralized way.
	Use of biogas prevents deforestation.
	Generated biogas may be used for cooking, lighting & electricity production.
	The digestate obtained from biogas plant has got a higher nutritive value as compared to that of ordinary farmyard manure.
	In the case of small-scale biogas plants, it is generally onetime investment.
	There is no or little maintenance in case of small-scale biogas plants needed.
WEAKNESSES	When methane escapes from biogas plant through leakages (in the case of small-scale biogas plants), it is a contributor to the greenhouse effect.
	In case of some livestock waste, due to the current stabling, a collection of feedstock for biogas plants may be difficult.
OPPORTUNITIES	Biogas may replace Liquefied Petroleum Gas (LPG) or fossil fuels.
	Biogas technology offers environmental improvement.
	There is a need for changes in government policy or regulations and legislation.
THREATS	When the organic waste is not continuously fed or overfed into the biogas plant it can lead to less or no generation of biogas.
	Subsidized low costs of LPG making biogas technology not competitive.

CONCLUSIONS

This study shows that animal waste is a promising low-cost and sustainable energy source in Vietnam which could be efficiently utilized for the generation of biogas energy as well as electricity. Furthermore, anaerobic digestion of livestock waste has potential to play a vital role in farming systems by adding value to agricultural waste and livestock excreta and may reduce their negative impacts on the environment by enhancing public health. The biogas potential has growing trend as has the livestock population of Vietnam responding to the increasing demands for the animal products resulting huge amounts of organic waste to be handled. The total biogas energy potential in Vietnam from livestock was quantified to over 120,000 TJ y^{-1} in 2015 and can with continuous trend go up to 127,000 TJ y^{-1} in 2020. However, when considered current manure management practices biogas energy potential was quantified to the values of over 67,000 TJ y^{-1} in 2015 and expected to be over 71,000 TJ y^{-1} in 2020 if the current manure management practices sustain unchanged. There is a high development potential for the decentralized energy generation due to the exploitation of small-scale biogas plants in Vietnam. However, it is essential to realize that competition to other energy generating technologies is present. Future research should focus on determining electricity potential from largescale farms and on biogas potential in fellow developing countries in Southeast Asia.

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