SELECTION OF CO$_2$ ADSORPTION TECHNOLOGY FOR SMALL SCALE LOW-PRESSURE BIOGAS FROM BACKYARD FARM SWINE INDUSTRY IN THE PHILIPPINES USING GEOGRAPHIC INFORMATION SYSTEM AND ANALYTIC HIERARCHY PROCESS

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ABSTRACT

In the Philippines, biogas has the potential to showcase sustainable energy resource for rural electrification owing to the dispersed characteristic of backyard farm swine industry as plotted using GIS. Barriers to promote backyard farm biogas plant were defined as the potential show-stopper of rapid biogas development in the countryside. Each barrier was discussed with corresponding perspectives to bridge the implied gaps where the study using AHP was utilized to address the issue on the poor quantity and quality of biogas production. Together with the results, criteria were identified and prioritized with the following relative weights: economical 40%, environmental 33%, social 19% and technical 8%. The alternatives used for the AHP process were also ranked with electrospun fibrous membrane at 30.4% as the highest rank presenting the viability of electrospun membrane purification technology for small scale low-pressured biogas plant. Very close second and third rank goes to polymeric membrane with 26.2% and pressure swing adsorption with 25.8% respectively. Last rank was amine absorption process with 17.6%. The electrospun fibrous membrane possess a great potential for promoting energy access in the Philippines where most rural areas out of more than 7,000 islands still use wood for cooking and candles for lighting.

KEYWORDS: CO$_2$ adsorption technology, renewable energy, biogas purification, porous fibers, analytic hierarchy process

1. INTRODUCTION

Fighting climate change has been evident for more than a quarter of a century since the treaty signing of Montreal Protocol [1-13]. From class discussions in every local university to international assemblies and conventions, climate change is simply global. Environmental issues such as climate change may win an election if we will account popularity votes from best colloquium topics to best searched subjects in the internet. Moreover, worries of environmentalists are now focused on fossil fuels – oil. Such energy resource is masked as the culprit for excessive CO$_2$ emission that leads to global warming then climate change.

Climate change is attributed with the global temperature rise caused by uncontrolled carbon dioxide emissions mainly from burning of fossil fuels to generate power. Much attention is given to exploit renewable resources to replace conventional energy that causes greenhouse gas effect and dramatic global temperature rise [14-27]. Dependence on conventional energy resource, with the possibility of depletion, somehow is an eye opener for the government, academe and industry [27-36]. Though the alarming climate change may be reduced with delivering innovative solutions on energy optimization [37-41] and energy conservation measures [42-46], same importance must be conveyed in renewable and other clean energy technologies [47-54]. And since the Philippine energy sector faces a great responsibility in providing more energy by adding capacity, it also possesses the ability to turn these challenges into opportunities.

Renewable energy and optimum mix of resources are included in creating a framework for energy security and energy planning [55-57]. Technology diffusion provides guidelines for strategic action to address barriers of renewable energy. Like solar, wind and bioenergy renewable resources, energy technology creates a venue to showcase such renewables closer to the rural development [58]. Apparently, biogas is a renewable energy resource that does not have the same fame of other renewable technologies although efforts have already been proposed for sustainable bioenergy [59]. While the large scale improvement in methane yield started in the 70s, not much research was published in biogas purification for small scale biogas plant. Biogas through anaerobic digester provides significant impact in rural electrification knowing the dispersed characteristic of backyard farm swine industry in the Philippines [60-62]. By adding more value to waste and converting it to a useful energy in remote areas and the countryside, biogas has great potentials in promoting renewable energy and capturing greenhouse gas methane.

However, the incombustible carbon dioxide content in biogas [63-68] could be a show-stopper in the production of a richer backyard farm biogas that could offset with the invested cost on a much higher rate of return. And since renewable energy technologies are very costly for small scale installation, it is imperative to study suitable biogas purification for backyard farms that would spur the development and promotion of clean energy in far rural areas that further leads to electrification in the countryside.

1.1 Biogas as renewable energy

Biogas is a renewable energy resource that has been in existence for a very long time. In the past, biogas is mainly used for cooking and lighting. Biogas is considered to be a biofuel that is a by-product of the decomposition of organic wastes from industrial, municipal and agricultural in an anaerobic environment. Biogas production from anaerobic digestion holds several significances aside from biogas production as renewable energy resource. Biogas from biomass is a potentially reliable and renewable energy resource [69] because of its availability as agricultural waste, sewage sludge, animal manure and industrial waste. In 2012, the Bureau of Resources and Energy Economics published the Australian Energy Technology Assessment 2012. Based on the report, biogas and biomass electricity generation technologies in 2012 are some of the most cost competitive forms of electricity generation and are projected to remain cost competitive out to 2050 [70]. It was also highlighted in the study that between 2012 and 2020, except for biogas, most renewable
technologies have higher LCOE than the lowest cost non-renewable technologies. According to Frank and Smith in 1993 on their paper “Methane from biomass: Science and Technology; Feedstock Development” [71], environmental issues could become more important and the lower carbon dioxide emissions, cleaner technology and reduced waste streams would be advantageous. Waste treatment is one process that works alongside the methane production. Since biogas production mostly occurred in waste treatment facility, it only shows how sustainable this renewable energy resource compared to other renewable technologies. Biogas produced from biomass and wastes represent a large potential energy resource that is renewable on a sustained basis [72-73].

Alcohol distilleries are one of the most polluting industries due to enormous amount of waste water. Anaerobic treatment is the most attractive primary treatment due to over 80% biochemical oxygen demand (BOD) removal combined with energy recovery in the form of biogas [74]. With number of studies and research growing in the determination of bio-methane potentials of solid organic substrates, some protocols [75] and guidelines in defining ultimate methane potentials is of particular importance which advises, to a certain extent, both design and economic details of a biogas plant. Bioenergy from industrial and agricultural wastes are promising research field. Anaerobic digestion of industrial and agricultural wastewater to methane is a mature process that is being used within full-scale facilities worldwide [76] that leads to paradigm shift from disposing waste to strategically utilizing it. Aside from waste treatment, production of organic acids and hydrogen were also studied with the effects of pH control in anaerobic acid reactor [77-78]. Reviews were also performed by researcher in the field of bioenergy potentials from palm oil [79-80]. Bioenergy produced from energy crops is well known topic in research symposia. Several reports were presented in international conferences to further improve bioenergy development [81-85]. Bio resources present a promising biofuels production that can be improved using catalytic processes. Also, evaluations of biogas production from different substrate were well studied [86-88] such as the research that lemon grass demonstrated less volume but better quality biogas than cow dung and poultry droppings [89].

Biogas is dependent on the type of organic waste used during anaerobic digestion. Anaerobic digestion is an application of biological methanogenesis which is an anaerobic process responsible for degradation of much of the carbonaceous matter in natural environments where organic accumulation results in depletion of oxygen for aerobic metabolism [90]. Production of methane via anaerobic digestion of energy crops and organic wastes would benefit society by providing a clean fuel from renewable feedstock. This would replace fossil fuel derived energy and reduce environmental impacts including global warming and acid rain. In 2000-2010 time frames, the contribution of energy from biomass and wastes to primary energy consumption was expected to increase to 4.2-4.5% of the total energy supplied to the U.S. economy and anaerobic digestion would begin to contribute to energy supply [91]. Aside from anaerobic digestion process, most bioresources feedstock may be utilized to produce bioethanol [92]. While bioethanol production is mainly dependent in fermentation process, biogas from different feedstock is produced without the aid or presence of oxygen.

Different types of anaerobic digesters and equipment were also studied for bioenergy improvements such as an up-flow anaerobic sludge blanket where in the substrate competition, methanogens are generally destined to win the competition over acetogens during the degradation of methanol in the reactor if either the methanol concentration in the effluent, inorganic carbon content, or the cobalt concentration is low [93]. An up-flow anaerobic sludge-fixed film is a hybrid reactor with an up-flow fixed film part over an up-flow anaerobic sludge blanket section [94]. Meanwhile, in an expanded granular sludge bed reactor, the calculation results of mass transfer parameters and parametric sensitivity analysis results showed that the intra-granule mass transfer would lead to a more influencing effect than the external mass transfer on the overall substrate removal rate in expanded granular sludge bed reactor [95].

Several organic wastes are used as feedstock for anaerobic digestion. These feed stocks were biomass from organic waste from different industries. Biomass includes trees, crops, plants, agricultural and forest residue, wastes from food and beverage manufacturing effluents, sludge from wastewater treatment plants and the organic fraction of domestic waste [96]. Meanwhile, alkaline hydrolysis pre-treatment and co-digestion with kitchen waste were beneficial to enhance the methane production from barley waste [97]. The production of methane from sugar beet silage was also well studied by researchers exploring the possibilities of other feedstock for biogas production [98].

The anaerobic batch digestion of solid potato wastes are also well-studied [99]. Researchers further combined potato waste with sugar beet leaves and profile hydrolases on two-stage mesophilic anaerobic digestion. Also, different animal wastes possess biogas production in anaerobic digestion. Even the metabolic activities of pathogenic bacteria during semi-continuous anaerobic digestion were studied with different substrate such as beef cattle slurry [100]. Meanwhile, combination of biomass and animal waste for biogas production were also explored such as maize and dairy cattle manure [101] where it was found that maximum methane yield is achieved from digestion of whole maize crops. Digesting corn cob mix, corns only or maize without corn and cob gives 43–70% less methane yield per hectare.

1.2 Biogas purification

In 2006, Ezekoye and Okeke studied the design, construction and performance evaluation of plastic biodigester. The rationale was the increasing cost of conventional fuel in urban areas and wastes are abundant especially in rural areas of Nigeria. The study confirms that biogas can be produced from plant wastes as a substitute for fossil fuels [102]. However, biogas produced could be more cost-effective if incombustible carbon dioxide is reduced. Some mechanisms to improve the quality of biogas from anaerobic digestion are cited in this study. Methane is the fuel produced from anaerobic digestion of organic wastes. It is the combustible component of biogas that has been used for power generation and heating. Hence, the characteristic of
the biogas must be in good quality. Measurements of biogas production may be validated according to DIN 38 414 standards [103]. On the average, the study measured composition of biogas as 62.1 % methane and 32.3 % carbon dioxide. The biggest differences in biogas quality occur in the first week of the digestion and then the gas content is more or less stable.

Biogas is produced from anaerobic digestion of organic wastes. Naturally occurring in anaerobic system, biogas is combustible with the presence of methane. However, it is also composed of carbon dioxide which reduces the heating value. The composition of carbon dioxide from biogas ranges from 30 to 45 vol. % [104]. Biogas purification has been reported by several publications and the use of membrane for gas separation has been included in the book of Baker in 2004 [105]. In the second edition of the book, Membrane Technology and Applications, carbon dioxide separation from natural gas is part of the major group of application under developing processes. The technology of membrane and the potentials of its applications were enormous for commercial scale. The unpopularity of small scale application could be same as the “to be developed” membrane processes which has a very large market but the fraction that membranes will ultimately capture is unknown.

Improvements in membrane performance focused on reliability and cost to compete with existing gas separation technologies. High performing membranes for gas separations became a venue for various researchers in the field. In order to achieve this, polymeric membranes [106-110], inorganic membranes [111-119] and mixed matrix membrane [120-124] have been explored by recent studies and reviews.

Several studies, applications and reviews on current practice of large-scale biogas purification technologies were already published such as amine absorption [125], pressure swing adsorption [126] and polymeric membranes [127]. Moreover, electrospun fibrous membrane [128] possesses the potential to be applied for small-scale low-pressured biogas purification. Electrospun fiber, thinner compared to other membrane, could solve the thickness problems of existing membranes. It also entails higher permeability of CO$_2$ since cross-flow gas separation occurs in a single fiber structure. Moreover, smaller diameter means that more fiber can handle a dead-end flow gas separation setup. The porous fibrous mixed matrix membrane characteristics enable better CO$_2$ adsorption. The development of fibers produced a multiple pore system for gas separation: (a) pores between fibers, (b) pores on fiber surface and (c) pores on zeolite.

1.3 Analytic hierarchy process

In any existing small scale low-pressured biogas plant without any purification technology, it is a complex problem to decide what purification technology is applicable with the highest benefit and lowest cost involved. With the aid of decision making tools, complex decision can be made and evaluated by determining the relative importance of a set of activities or criteria [129]. The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. AHP was developed by Thomas L. Saaty in the 1970’s and has been extensively studied and refined since then. AHP doesn’t provide correct decision but rather assist the decision maker to synthesize the problem and identify the best alternatives according to their defined criteria and pair-wise comparisons.

AHP is well-used in energy sector such as reviews of sustainable energy strategies in Thailand for improved cooking stove and small biogas digester [130], selection of the most appropriate Solar Home System for rural electrification in Bangladesh [131] and selection of renewable energy sources for sustainable development of electricity generation system in Malaysia [132] where it employs four main criteria; technical, economical, social and environmental aspects, and twelve sub-criteria.

AHP provides insights on developing the goal for decision makers. The structure of criteria and alternatives are important in making the decision. Structuring AHP is cost-friendly in nature compared to straightforward field test which only validate the capability of technology such as actual field test of membrane modules for the separation of carbon dioxide from low-quality natural gas [133]. Actual field test provides significant inputs in gas purification through correlation studies and computer simulations; however, defining criteria and sorting other technologies and alternatives were commonly not included in most studies.

Technological trade-offs and opportunities of renewable system were necessary in achieving sustainability. The output of AHP could provide such analysis on the opportunities and constraints of the different biogas applications. It could also provide the basis for policies for the development of biogas plants and for the adjustment of the scale of biogas development to match local requirements. Based on the characteristics of different biogas plants and geographic regions, fuzzy analytic hierarchy process (fuzzy-AHP) model could provide a suitability evaluation for development of the regional biogas industry.

In this paper, the perspective on low quality biogas as the show-stopper for the rapid promotion of biogas development in the countryside was used as the rationale. To assist in addressing this barrier, different biogas purification technologies were compared with the aid of AHP. Known large scale purification technologies were identified such as amine absorption, pressure swing adsorption, membrane purification. These technologies were compared and ranked with electrospun porous fibrous mixed matrix membrane to check the prioritization of criteria and alternatives for low-pressured small scale backyard farm biogas purification. Consistency checks were performed for each ranking of criteria and alternatives to check consistency and reliability of acquired data while trade-offs between identified purification technologies were presented in pair-wise comparison matrix.

2. METHODOLOGY

In this paper, backyard farm swine data from Bureau of Animal Industry were used to map the dispersion quality of backyard farm swine industry in the Philippines. These data were utilized and characterized using geographic information system (GIS). The map rendered was presented to the decision maker along with the discussion on the barriers of biogas digester rapid development. The perspectives acquired were then used to identify the
criteria that must be used to rapidly promote and develop backyard farm biogas digesters. These criteria were technical, economical, social and environmental. Descriptions for each criterion were discussed to the decision maker to aid during the pair-wise comparison of each criterion.

| Table 1 Criteria and description for small-scale carbon separation and capture |
|----------------------------------|----------------------------------|----------------------------------|
| Criteria                        | Symbols | Description                                      | Remarks                          |
| Technical                       | $C_1$   | Maturity of technology depicted by commercial availability and ease of operation | From Ahmad and Tahar in 2014 |
| Economical                      | $C_2$   | Cost involved during purchasing and installation Also pertains to operational expenses including service life |                                |
| Social                           | $C_3$   | Acceptability of the technology Job generation on both technology supply and demand |                                |
| Environmental                    | $C_4$   | $CO_2$ emission reduction Impact on environment |                                |

Pairwise comparison of criteria was performed where the relative importance between each criterion was measured using important scale. Fractional values were acquired for the pairwise comparison of each criterion. The fractional values during the pairwise comparison were transformed to decimal for matrix manipulation. Consistency checks were then performed for each ranking of criteria. Meanwhile, the alternatives were provided and discussed to the decision maker and the main goal was identified. Based on the result of criteria comparison and consistency checks, ranking of criteria was established. The relative weights of the criteria with respect to the goal were then evaluated. Pairwise comparison was performed for each alternative based on the ranked criteria and synthesis was performed.

| Table 2 Alternatives and description for small-scale carbon separation and capture |
|----------------------------------|----------------------------------|----------------------------------|
| Alternatives                     | Symbols | Description                                      | Remarks                          |
| Amine absorption process         | $A_1$   | Using methanolamine (MEA) as absorbent with which $CO_2$ is absorbed when in contact in MEA solution acting as a scrubber | From Yang et al. in 2008 |
| Pressure swing adsorption        | $A_2$   | Using activated carbon as adsorbent operating in pressure swing mode; high-pressure for adsorption and low-pressure for desorption | From Yin et al. in 2013 |
| Polymeric membrane               | $A_3$   | Three types of processes can be considered depending on the membrane structure and permeation mechanism: Knudsen’s diffusion through microporous barriers, molecular sieving with ultra-microporous membranes and diffusion through non-porous, dense membranes based on solubility-diffusion mechanism. | From Harasimowicz et al. in 2007 |
| Electrospun fibrous membrane     | $A_4$   | Using electrospun zeolite-filled porous fibrous membrane as adsorbent operating in low-pressure. Three pore system was applied; inter-fiber pores, fiber surface pores and pores on zeolite | From Calderon et al. in 2014 |

Matrix of the pairwise elements, fractional values of pairwise and decimal transformed matrix were presented in Fig. 2-4. Transformation of fractional values to decimal is necessary for further matrix manipulation.

| Table 3 Summary of important scale and random index |
|----------------------------------|----------------------------------|----------------------------------|
| Important Scale ($n$ for RI)     | Definition | Random Index (RI) |
| 1                                | Equal importance | 0.00                           |
| 2                                | Intermediate values | 0.00                           |
| 3                                | Somewhat more important | 0.58                           |
| 4                                | Intermediate values | 0.90                           |
| 5                                | Much more important | 1.12                           |
| 6                                | Intermediate values | 1.24                           |
| 7                                | Very much more important | 1.32                           |
| 8                                | Intermediate values | 1.41                           |
| 9                                | Absolutely more important | 1.45                           |

Figure 1 Horizontal hierarchy of proposed AHP

Presented above in Fig. 1 is the horizontal hierarchy representation of proposed AHP. Pairwise comparison of each element at the corresponding level by assigning a numerical value or the intensity of importance was performed using the important scale developed by Saaty in 1970’s. To transform qualitative data into quantitative data, the 9-point important scale were used as presented in Table 1 below while the random index uses the important scale as number of factors $n$ as reference.

| Criteria | Symbols | Description                                      | Remarks                          |
|----------------------------------|----------------------------------|----------------------------------|
| Technical                        | $C_1$   | Maturity of technology depicted by commercial availability and ease of operation | From Ahmad and Tahar in 2014 |
| Economical                       | $C_2$   | Cost involved during purchasing and installation Also pertains to operational expenses including service life |                                |
| Social                            | $C_3$   | Acceptability of the technology Job generation on both technology supply and demand |                                |
| Environmental                     | $C_4$   | $CO_2$ emission reduction Impact on environment |                                |

Figure 2 Matrix of pairwise elements
matrix.

Sum of values in each column of pairwise matrix was shown in Eq. (1) where $C_{ij}$ is the element of row $i$ and column $j$ of the matrix.

$$C_{ij} = \sum_{n=1}^{C} C_{ij}$$  

To generate a normalized matrix, each element in the matrix was divided by its column total as presented in Eq. (2) below where $X_{ij}$ is the normalized pairwise matrix. Normalized matrix was shown in Fig. 5 below.

$$X_{ij} = \frac{c_{ij}}{\sum_{j=1}^{n} c_{ij}}$$  

To generate weighted matrix, the sum of the normalized column of matrix was divided by the number of criteria $n$ as presented in Eq. 3 below.

$$\text{TOTAL} = \frac{1}{n}$$

### Table 4: Pairwise comparison matrix with priority vector, consistency index and ratio

<table>
<thead>
<tr>
<th>Criteria Matrix</th>
<th>$C_1$</th>
<th>$C_2$</th>
<th>$C_3$</th>
<th>$C_4$</th>
<th>Sum</th>
<th>Weighted Priority Value ($W_i$)</th>
<th>Consistency Value ($\lambda_{max}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$</td>
<td>0.083</td>
<td>0.083</td>
<td>0.056</td>
<td>0.100</td>
<td>0.322</td>
<td>0.081</td>
<td>4.137</td>
</tr>
<tr>
<td>$C_2$</td>
<td>0.417</td>
<td>0.417</td>
<td>0.278</td>
<td>0.500</td>
<td>1.611</td>
<td><strong>0.403</strong></td>
<td>4.137</td>
</tr>
<tr>
<td>$C_3$</td>
<td>0.250</td>
<td>0.250</td>
<td>0.167</td>
<td>0.100</td>
<td>0.767</td>
<td>0.192</td>
<td>4.086</td>
</tr>
<tr>
<td>$C_4$</td>
<td>0.250</td>
<td>0.250</td>
<td>0.500</td>
<td>0.300</td>
<td>1.300</td>
<td>0.325</td>
<td>4.256</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 5: Weighted priority value of alternatives based on criteria

<table>
<thead>
<tr>
<th>Decision Matrix</th>
<th>$C_1$</th>
<th>$C_2$</th>
<th>$C_3$</th>
<th>$C_4$</th>
<th>Criteria Priority Value</th>
<th>Alternative Priority Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_1$</td>
<td>0.407</td>
<td>0.095</td>
<td>0.126</td>
<td>0.248</td>
<td>0.081</td>
<td>0.176</td>
</tr>
<tr>
<td>$A_2$</td>
<td>0.098</td>
<td>0.286</td>
<td>0.393</td>
<td>0.183</td>
<td><strong>0.403</strong></td>
<td>0.258</td>
</tr>
<tr>
<td>$A_3$</td>
<td>0.133</td>
<td>0.349</td>
<td>0.206</td>
<td>0.220</td>
<td>0.192</td>
<td>0.262</td>
</tr>
<tr>
<td>$A_4$</td>
<td>0.363</td>
<td>0.269</td>
<td>0.275</td>
<td>0.350</td>
<td>0.325</td>
<td><strong>0.304</strong></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

$$\text{MEAN } \lambda_{max} = \frac{\sum_{i=1}^{n} \lambda_{cij}}{n}$$  

$$CI = \frac{(\text{Mean } \lambda_{max} - n)}{(n - 1)}$$  

$$CR = \frac{CI}{RI}$$

Summarized values of pairwise comparison of criteria, weighted priority values, consistency values, **MEAN $\lambda_{max}$**, and the results of consistency checks were presented in Table 4. Based on the criteria matrix, $C_2$ – economical, is the most valuable with 0.403 weighted priority value, followed by environmental 0.325, social 0.192 and technical 0.081 respectively. For the consistency check, random consistency index used was 0.90 based on Table 3. From the calculated matrix of criteria weight priority, the decision-maker prioritized economic and environmental aspect over social and technical aspect. With the aid of descriptions of these criteria and explanation of criteria details, the hierarchy for...
these criteria has been plotted. The resulted consistency index was 0.051 with the consistency ratio (CR) of 0.057 setting the judgments for criteria to be consistent and reliable since the evaluation can depend on the consistency ratio of less than 0.1 as recommended.

3. RESULTS AND DISCUSSION
3.1 Swine industry in the Philippines using GIS
In 2014, the total number of swine in the Philippines is 11.8 million heads. Close to 65% are from backyard farms with 7.7 million heads and 35% are being raised by commercial farms with 4.1 million heads. Per region, the highest number of total swine can be found in Region III CENTRAL LUZON with 1.9 million heads followed by Region IV CALABARZON with 1.6 million heads and Region VI WESTERN VISAYAS with 1.3 million heads. For backyard farm swine, highest count is in WESTERN VISAYAS with 1.2 million heads and the lowest count is in ARMM with 69 thousand heads. Out of the total backyard head count, it was computed that average per region was 480 thousand heads except NCR which doesn’t have any backyard farm swine. Data for provincial level was used to further synthesize the backyard farm swine in the Philippines. This dispersed characteristic of backyard farm swine in the Philippines per province was used to generate GIS map as presented in Fig. 6 below.

Figure 6 Dispersion of backyard farm swine industry in the Philippines

3.2 Gaps and perspective in biogas implementation
Anaerobic digester is a known technology. It is not an emerging technology that needs attentive study and research. However, the difficulty of realizing the positively potential impacts of this technology is the reason of defining the gaps in the rapid development of anaerobic digester. The summary of arguments for the development of small scale backyard farm biogas (swine waste) was established. To summarize, there were two (2) main gaps that encompass the difficulty of rapid development of backyard farm biogas digester. First is investment perspective where financing and incentives mechanism were found to be lacking for small scale renewable projects. Also, owners of backyard farm swine opted to invest more on swine production without understanding the biogas potential if prioritized. Second is technical perspective where biological treatment and animal wastewater technology were defined as new and relatively unknown technology for most rural areas.

Methane capture as greenhouse gas was far from the realization of stakeholders compared to known predominant technology for piggery wastewater treatment which is a lagoon-based system.

3.2 Ranking of purification technology using AHP
Due to prevailing practice of existing anaerobic digestion systems, ranking for purification technology for backyard farm biogas plant was established using AHP. This ranking addresses the barriers of installed backyard farm biogas digesters that possess low efficiency system owing to high CO₂ composition that leads to low biogas quality. High content of carbon dioxide in a biogas system prevent the combustible methane to be fully utilized. This became the main reason of backyard farm owners not to develop their own biogas system since the payback period is very long compared to investments on swine production improvements.

Pairwise comparison was conducted for each alternative based on criteria C₁, C₂, C₃ and C₄. Based on the decision criteria C₁ – technical, the most preferred alternative is A₁ with 0.407 weighted priority value, followed by A₄ 0.363, A₂ 0.133 and A₃ 0.098 respectively. For decision criteria C₂ – economical, the most preferred alternative is A₁ with 0.349 weighted priority value, followed by A₄ 0.286, A₂ 0.269 and A₃ 0.095 respectively. For decision criteria C₃ – social, the most preferred alternative is A₂ with 0.393 weighted priority value, followed by A₄ 0.275, A₁ 0.206 and A₃ 0.126 respectively. For decision criteria C₄ – environmental, the most preferred alternative is A₂ with 0.350 weighted priority value, followed by A₄ 0.248, A₁ 0.220 and A₃ 0.183 respectively.

![Figure 7 The relative weights of criteria with respect to goal](image)

![Figure 8 Ranking of alternatives with respect to the relative weights of the criteria](image)

The resulted consistency index were 0.028, 0.065, 0.040 and 0.060 with the consistency ratio (CR) of 0.031, 0.072, 0.044 and 0.066 for C₁, C₂, C₃ and C₄ respectively, setting the judgments for criteria to be consistent and reliable since the evaluation can depend on the consistency ratio of about 10% or less for acceptable overall consistency according to Saaty [128]. The relative weights of criteria with respect to goal can be evaluated from the pie chart presented in Fig. 7 below. It can be seen that the two highest weight of criteria belongs to C₂ – economical having 40% weight and C₁ – environmental having 33% weight respectively. Far behind is C₃ – social with 19% and the least priority is C₄ – technical with only 8%. It was synthesized that the cost involved in biogas
purification system during material purchasing and cost involved during installation weighs with the highest priority. The ranking of criteria also characterize high concerns on the economics of operational expenses including service life. Meanwhile, the ranking of alternatives with respect to the relative weights of the criteria were presented in Fig. 8 below. The decision maker ranked the purification technologies with electrospun fibrous membrane at 30.4% as the highest rank. Very close second and third rank goes to polymeric membrane with 26.2% and pressure swing adsorption with 25.8% respectively. Last rank was amine absorption process with 17.6%.

4. CONCLUSION

Being archipelagic in nature, the Philippines with more than 7,000 islands has dispersed characteristics of backyard farm swine industry which can be utilized for rural electrification and energy access for all. However, barriers were identified in the rapid promotion of such technology in the countryside. Based on these perceived barriers, recommendations were identified to promote small scale backyard farm digester.

1. The government should further promote the technology through demonstrations and deployment. Pilot design in areas with potential resources of swine industry must be collaborated with the government and investors since the commercial viability of backyard swine industry is sustainable in nature. Historically, swine industry in the Philippines for the past decade shows stable quantity for backyard farm swine. Moreover, these programs must reach far rural areas where such resources are available.

2. As for the academe, the inclusion of technology assessment of renewable energy, particularly biogas, as an elective for engineering courses will translate to early adaption of technology and innovation. An academe-industry linkage program for biogas experimentations must kicked-off. These programs will yield optimization and characterization of the parameters to arrive at the maximum amount of biogas possible with the best quality. Also, technical experts will build up for both academe and industry not to mention how these programs build capacity for researchers in the industry. These activities bridge the knowledge gaps on biogas digesters.

3. While operational cost depends on the system at work, capital cost is hard to swallow. The initial cost needed to install small scale biogas plant for backyard farming is still unbearable. Investment cost is equally important as payback period. The uptake on quality and quantity of biogas produced may be resolved with technology assessment to yield optimum system. Inclusion of cost down scheme, like value engineering, to further reduce the initial cost must be a pre-construction requirement.

Based on the recognized perspectives on the barriers of rapid biogas development, AHP was performed to rank the purification technology for backyard farm biogas plant to addresses the barrier of backyard farm biogas digesters that possess low efficiency system owing to high incombustible CO₂ composition. It can be seen that the highest weight of criteria belongs to C2 — economical having 40% weight. The cost involved in biogas purification system during material purchasing and cost involved during installation weighs with the highest priority. The ranking of criteria also characterize high concerns on environmental impacts of greenhouse gas. Meanwhile, the prioritization of alternatives with respect to the relative weights of the criteria found that electrospun porous fibrous membrane at 30.4% as the highest rank for backyard farm biogas purification technology. This may be attributed to the simplicity of this novel CO₂/CH₄ low-pressure small scale gas separation technology which doesn’t need highly technical engineers to operate and monitor the system. Ultimately, it doesn’t consume energy to compress and purify biogas to yield higher methane.

REFERENCES


methodology for criticality analysis in symbiotic energy production: a literature review and research, inc., menlo park, california, 2004

m. a. abdel-hadi, a simple apparatus for biogas quality determination, misterj. agr. eng., vol. 25 (no.3), pp. 1055-1066, 2008

c-y liang, p. uychtli, r. petrychkovych, y-c lai, k. friess, m. splek, m. m. reddy and s-y suen, a comparison on gas separation between pes (polyethersulfone) / mmt (na-montmorillonite) and pes-p20 mixed matrix membranes, separation and purification technology, vol. 92, pp. 57-63, 2012.

t. d. kusworo, budiyono, a. f. ismail, n. i. widiasa, s. johari and sunarso. co2 removal from biogas using carbon nanotubes mixed matrix membranes, international journal of science and engineering, vol. 1 (no.1), pp. 1-6, university of diponegoro, semarang, indonesia, 2010.

p.v. rao, s. s. baral, r. dey and s. mutruli, biogas generation potential by anaerobic digestion for sustainable energy development in india, renewable and sustainable energy reviews, vol. 14 (no.7), pp. 2086-2094, 2010.


j. r. frank and w. h. smith, methane from biomass - science and technology 1. feedstock development, guest editorial, biomass and bioenergy, vol. 5 (no.1), pp. 1-2, 1993.

c-y liang, p. uychtli, r. petrychkovych, y-c lai, k. friess, m. splek, m. m. reddy and s-y suen, a comparison on gas separation between pes (polyethersulfone) / mmt (na-montmorillonite) and pes-p20 mixed matrix membranes, separation and purification technology, vol. 92, pp. 57-63, 2012.

t. d. kusworo, budiyono, a. f. ismail, n. i. widiasa, s. johari and sunarso. co2 removal from biogas using carbon nanotubes mixed matrix membranes, international journal of science and engineering, vol. 1 (no.1), pp. 1-6, university of diponegoro, semarang, indonesia, 2010.

p.v. rao, s. s. baral, r. dey and s. mutruli, biogas generation potential by anaerobic digestion for sustainable energy development in india, renewable and sustainable energy reviews, vol. 14 (no.7), pp. 2086-2094, 2010.


j. r. frank and w. h. smith, methane from biomass - science and technology 1. feedstock development, guest editorial, biomass and bioenergy, vol. 5 (no.1), pp. 1-2, 1993.


