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Artificial Intelligence Projection Model for Methane Emission from Livestock in Sarawak

(Unjuran Model Kecerdasan Buatan untuk Pelepasan Metana daripada Ternakan di Sarawak)

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ABSTRACT

Artificial Intelligence is a topical trend employed to solve engineering and industrial problems by virtue of its abilities to deal with data uncertainty such as methane emissions. Hard computing methods are not suitable for determining the optimal emission in a methane emission data set. Instead, soft computing solutions should be considered in an effort to obtain better optimal solutions for industrial problems. This paper utilized the Guidelines provided in the 2006 Intergovernmental Panel on Climate Change (IPCC) to calculate and project methane emissions from selected six livestock in Sarawak, Malaysia. A particle swarm optimization (PSO) model was developed to project future methane emission by using number of livestock as the input parameter. The total CH_4 inventory from the enteric fermentation of cattle, buffaloes, goats, sheep, swine and deer in Sarawak decreased from 1.860 to 1.856 Gg when calculation was carried out using the Tier 1 method. This decrease was due to population growth and the emission factors employed. Three statistical measures, root mean square error (RMSE), mean absolute error (MAE), and mean absolute percentage error (MAPE) were employed for evaluation. PSO has been shown to be able to give an accurate projection. The results of this study provide a benchmark information which can be used by the Sarawak government to develop appropriate policies and mitigation strategies to reduce future carbon footprint in the Sarawak livestock sector.

Keywords: Enteric fermentation; livestock; manure management; methane inventory; Tier 1

ABSTRAK

Kecerdasan Buatan adalah tren topikal yang digunakan untuk menyelesaikan masalah kejuruteraan dan perindustrian berdasarkan kemampuannya untuk menangani ketidakpastian data seperti pelepasan metana. Kaedah pengkomputeran keras tidak sesuai untuk menentukan pelepasan optimum dalam set data pelepasan metana. Sebaliknya, penyelesaian pengkomputeran lembut perlu dipertimbangkan dalam usaha untuk mendapatkan penyelesaian optimum yang lebih baik untuk masalah perindustrian. Kertas ini menggunakan Garis Panduan yang disediakan dalam Panel Antara Kerajaan tentang Perubahan Cuaca (IPCC) 2006 untuk menghitung dan mengunjurkan pelepasan metana daripada enam jenis ternakan terpilih di Sarawak, Malaysia. Model Particle Swarm Optimization *(PSO) telah dibangunkan untuk mengunjurkan pelepasan metana masa depan dengan menggunakan bilangan ternakan sebagai parameter input. Keseluruhan inventori CH_4 daripada penternakan lembu, kerbau, kambing, biri-biri, khinzir dan rusa di Sarawak menurun daripada 1.860 hingga 1.856 Gg apabila pengiraan dilakukan menggunakan kaedah Tier 1. Penurunan ini disebabkan oleh pertumbuhan penduduk dan faktor pelepasan yang digunakan. Tiga langkah statistik, iaitu kesilapan akar min kesilapan (RMSE), bermakna ralat mutlak (MAE), dan kesilapan peratusan mutlak (MAPE) digunakan untuk penilaian. PSO telah terbukti dapat memberikan unjuran yang tepat. Hasil kajian ini memberikan maklumat penanda aras yang boleh digunakan oleh kerajaan Sarawak untuk membangunkan dasar dan strategi mitigasi yang sesuai untuk mengurangkan jejak karbon pada masa hadapan dalam sektor ternakan di Sarawak.*

Kata kunci: Fermentasi enterik; inventori metana; pengurusan baja; ternakan; Tier 1

INTRODUCTION

Enteric methane (CH_4) makes up 17% of the world CH_4 emissions, and most of it is produced by ruminants such as livestock. Excretion of CH_4 by ruminant and non-ruminant livestock contributes 2% and 0.4% of the world CH_4 and GHG emissions, respectively (Knapp et al. 2014).

The typical digestion process in livestock results in the emission of methane. Enteric fermentation is defined as fermentation of food in the digestive system of a livestock by the organisms living in it. The process happens in the rumen of ruminant livestock such as cattle, buffaloes, sheep and goats and results in a huge methane emission per unit of food energy consumed. Methane emission via enteric fermentation of domesticated livestock contributes to greenhouse gases (GHG) inventories. In Malaysia, enteric methane emission from livestock contribute 2% of the total emitted methane in the country (Ministry of Natural Resources and Environment of Malaysia 2011).

A large percentage of the methane emissions from this sector originated from ruminants such as cattle, buffaloes, sheep and goats. Methane emission from other ruminants, such as swine and horses, is generally low (Yusuf et al. 2012).

Pratt et al. (2015) stated that manure management is one of the main sources of agricultural GHG, while O'Mara (2011) estimated that around 10% of the emission is from on-farm emissions. Methane from manure is produced during anaerobic decomposition of the organic matter present in faecal matter and bedding material. These organic compounds are degraded into several compounds. Methane is then generated by methane producing microbes in the presence of volatile acids. Anaerobic condition is a prerequisite for the production of CH_4 as bacteria metabolizes the organic material in livestock manure (Chadwick et al. 2011).

Tauseef et al. (2013) stated that livestock manure continues to release methane due to the anaerobic decomposition of organic material present in the manure by the bacteria that is expelled along with the manure (Chhabra et al. 2009). The manure deposited on the fields and pastures also produces a significant amount of methane. Manure lagoons and holding tanks, which are commonly used in larger dairy and swine operations, release a large quantity of methane (Aneja et al. 2009). In Malaysia, however, livestock is governed by individual state authorities, and since Malaysia is a developing country, there is no requirement for greenhouse gas emission to be reported (United Nations Framework Convention on Climate Change 2017). Nevertheless, the Prime Minister of Malaysia has announced a voluntary reduction target during the 2009 Copenhagen Summit (United Nations Climate Change Conference 2009). The reason for adoption of Tier 1 method is due to lack of specific data on emission rates. Ogle et al. (2013) pointed out that incomplete activity data and insufficient documentation are among the challenges faced by developing nations.

In this study, methane emission from the livestock sector in Sarawak is quantified for the period from 1998 to 2009. Estimation of future emission is then made using particle swarm optimization (PSO). Only a specific period is chosen due do the difficulty in obtaining the most recent analysis and information due to the scarce and irregular survey of the livestock production systems in the state.

Materials and Methods

This study adopted method stated in Volume 4 of the 2006 IPCC Guidelines while raw data used was obtained from the published Sarawak Facts and Figures between year 1998 and 2010. According to the 2006 IPCC Guidelines, emission factors are grouped into three temperature classes, <15°C, 15°C–25°C, and>25°C. Since Malaysia does not have a seasonal change in climate, the study adopted the temperature class of higher than 25°C.

Methane Emission from Enteric Fermentation

The amount of CH_4 emission from enteric fermentation is given in (1).

$$\text{Emissions} = EF \cdot [(N/10^{\wedge}6)] \tag{1}$$

where emission is the emitted methane, (Gg CH_4/yr); EF is livestock population' emission factor (kg CH_4 head^{-1}yr^{-1}); and N is the number of livestock.

Methane Emission from Manure Management

Emission of CH_4 from manure management was determined using (2).

$$CH_{4Manure} = \Sigma [(EF \cdot N)/(10^{\wedge}6)] \tag{2}$$

where $CH_{4Manure}$ is the emitted CH_4, (Gg CH_4 yr^{-1}); EF is livestock population' emission factor, (kg CH_4 head^{-1} yr^{-1}); and N is number of livestock.

The emission factors for sheep, goat and deer are for the class of > 25 since the temperature does not change drastically as Sarawak. One of the new challenges faced by researchers is predicting GHG. Chairul Saleh et al. (2016) proposed a support vector machine (SVM) to predict the expenditure of carbon dioxide (CO_2) emission from the consumption of electrical energy and coal burning. However, SVM has a high algorithmic complexity and a large memory requirements. Ming et al. (2014) employed GM (Grey Model) to predict CO_2 emissions from energy usage in China, and found that GM is not effective when used for large sample size. Tang and Zhang (2011) combined Genetic Algorithm (GA) into GM with backpropagation neural network (BPNN) and used it to predict energy load. They concluded that BPNN is a gradient based algorithm that has the possibility of being stuck in local minimum, slow convergence, high dependence on parameter settings, and generates complex error surfaces with a multiple local minimum.

Particle Swarm Optimization (PSO) Algorithm

In PSO, every particle keeps tracks of its best fitness position in hyperspace known as pbest or personal best. The overall best value obtained by any particle is known as gbest or global best. In each iteration, each particle moves towards its own pbest in the direction of gbest. Position of gbest is achieved by obtaining new velocity value for all particle.

Two main equations are used in PSO to update the velocity and position of each particle. Equation (3) is used to update velocity and (4) is used to update the position of each particle.

$$V_n = w * V_n + C_1 * \text{rand}()*(g_{\text{best}, n} - X_n) + C_2 * \text{rand}()*(p_{\text{best}, n} - X_n) \tag{3}$$

where w is inertia weight; V_n is the current velocity of a particle; rand() is any random number from zero to one; $g_{best, n}$ is the best global position for each particle; C_1 and C_2 are cognitive and social parameters; respectively, and X_n is the current position of a particle.

$$X_n = X_n + V_n \quad (4)$$

where X_n is the current position of a particle; and V_n is the current velocity of a particle.

The major PSO parameters used in this study and their respective values are given in Table 1.

RESULTS AND DISCUSSION

CALCULATED EMISSION USING THE 2006 IPCC AND PSO PROJECTED EMISSION

Comparison of methane emitted by cattle, buffalo, goat, sheep, swine and deer, via manual calculation and PSO projection are shown in Figures 1 to 4.

TABLE 1. PSO parameters and their values

Description	Value used
Number of particles, N	50
Acceleration constants for gbest (C_1)	0.2
Acceleration constants for pbest (C_2)	0.2
Dimension of particles, D	1
Inertia weight, w	0.4
Maximum number of iterations (T) for stopping condition	500

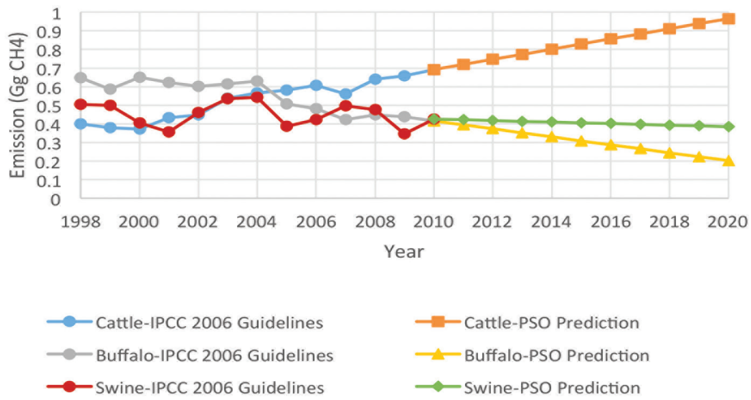

FIGURE 1. Comparisons of methane emission between enteric fermentation of cattle, buffalo and swine

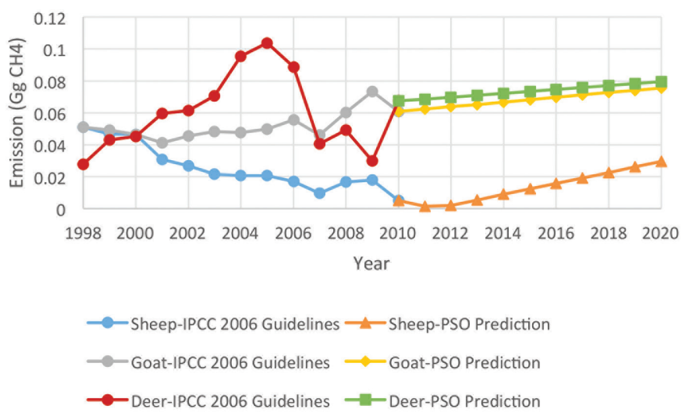

FIGURE 2. Comparisons of methane emission between enteric fermentation of sheep, goat and deer

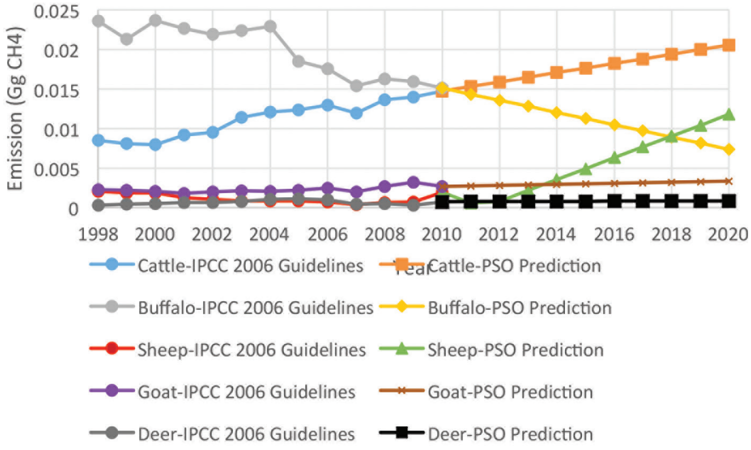

FIGURE 3. Comparisons of methane emission between manure management of cattle, buffalo, sheep, goat and deer

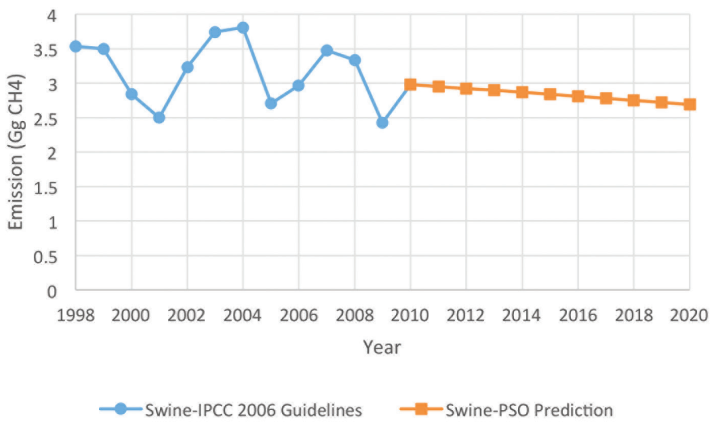

FIGURE 4. Comparisons of methane emission between manure management of swine

PREDICTED EMISSION USING PSO

The measures of PSO performance is shown in Tables 2 and 3, respectively.

DISCUSSION FOR EMISSIONS FROM ENTERIC FERMENTATION

Cattle Emission of enteric fermentation increases steadily from 0.81 Gg CH_4/year in 2007 to 0.95 Gg CH_4/year in 2009. We believe portion of dietary fibre and type of carbohydrate have significant impact on ruminant's fermentation, thus, affecting methane generated. Incorporating lipids in diet has proven to mitigate methane (Grainger & Beauchemin 2011; Martin et al. 2010). Another appropriate mitigation measure would be to capture the biogas or methane from beef feedlots and dairy farms by using suitable facilities. Emission can be reduced once the methane or biogas has been captured (Ministry of Natural Resources and Environment of Malaysia 2011).

Buffalo Even though there is a slight increase in methane emission from 0.63 Gg CH_4/year in 2002 to 0.42 Gg CH_4/year in 2007, a marked increase in emission was recorded in 2004 where the amount of methane emission is 0.65 Gg CH_4/year. The initial high amount methane emission is probably due to the fact that buffaloes are categorized as ruminant livestock, as well as relationship between body weight and rumen volume due to kinetics of ruminal feed particles. In other words, when livestock with different body weight consuming the same amount of diet, different amount of fermented feed is presented. Such difference of ruminal kinetics would affect methane emitted (Moraes et al. 2014).

Yusuf et al. (2012) proposed feeding buffaloes with high quality grasses to reduce the emission from enteric fermentation. Grainger and Beauchemin (2011) pointed out that high quality grass with high concentration of water-soluble carbohydrates, forage legumes containing secondary metabolites (tannings) and fruits/plants containing saponins have been found to reduce methane emission.

Goat The amount of methane emission decreased from 0.055 Gg CH_4/year in 2006 to 0.046 Gg CH_4/year in 2007. This value increased abruptly from 0.046 Gg CH_4/year in 2007 to 0.07 Gg CH_4/year in 2009. The prediction for the years after 2009 shows a slight increase in emission

TABLE 2. Performance measure of PSO for enteric fermentation

Livestock	MAE	MAPE	RMSE
Cattle	3.17E-06	0.00063	3.58E-06
Buffalo	3.33E-06	0.00063	4.08E-06
Sheep	0	0	0
Goat	0	0	0
Swine	2.33E-06	0.00056	2.77E-06
Deer	0	0	0

TABLE 3. Performance measure of PSO for manure management

Livestock	MAE	MAPE	RMSE
Cattle	0	0	0
Buffalo	0	0	0
Sheep	0	0	0
Goat	2.5E-08	0.0012	2.89E-08
Swine	2.73E-05	0.086	3.03E-05
Deer	5E-09	0.00045	1.29E-08

most probably caused by differences in temperature and geographic location. Livestock from arid and semi-arid regions produced lesser methane contrast to livestock in temperate region (Pragna et al. 2018).

Sheep There is a slight increase in methane emission from 0.009 Gg CH_4/year in 2007 to 0.018 Gg CH_4/year in 2009. Bell et al. (2016) discovered adding more cereal grain in the diet leads to reduction in yielded methane. Other effective method for preventing an increase in methane emission is by composting manure, which could also be a means for farmers to earn extra income. Hence this method is strongly recommended in an effort to reduce CH_4 emission.

Swine The amount of emission from swine fluctuates from 0.3 to 0.5 Gg CH_4/year during the period 1998 to 2009. The amount of methane emitted from swine is very dependent on its fermentative capacity as well as its physiological stage. Female swine tends to exhibit higher methane emission compared to male swine. Also, an adult swine tends to produce a higher amount of methane (Le Goff et al. 2002).

Deer An increase in emission from 0.03 Gg CH_4/year in 1998 to 2005 0.10 Gg CH_4/year in 2005 was observed, and the trend of emission decreased from 2006 to 2007 and show a further reduction from 2008 to 2009. Crutzen et al. (1986) explained methane production from wild ruminants such as deer and moose is difficult to estimate since there are insufficient data on populations and feed intake.

In summary, the trend of emission from enteric fermentation of cattle, goat and deer show gain in emission compared to buffalo, sheep and swine. Amongst the factors influencing methane generation by livestock are amount of feed intake, digestibility of the feed and environmental living conditions of the livestock.

DISCUSSION ON METHANE EMISSIONS FROM MANURE MANAGEMENT

Cattle There is an increase in the amount of methane emitted from cattle from 1998 to 2009 mainly arising from activity of cattle that increases from morning to late afternoon when livestock wake and begin to eat, drink, ruminate and urinate. Gain in CH_4 emissions is expected as these activities increase (Leytem et al. 2010). Future emission from the livestock sector was predicted to increase due to the government's plan to increase cattle livestock production from the present 15 percent to 40 percent self-sufficiency or an increase of about 1.5 million cattle (Ministry of Natural Resources and Environment of Malaysia 2011).

Buffalo Emission from buffaloes' ranges from 0.015 to 0.024 Gg CH_4/year for the period from 1998 to 2009. This trend is predicted to decrease after 2009 with reduction in buffalo population. There are two (2) fundamental components influencing the amount of methane released from manure management practices, type of treatment or storage facility and ambient climate (Yusuf et al. 2012). Storage and treatment of manure in liquid systems, such as lagoons, ponds or pits cause build-up of anaerobic condition that results in the release of methane. Production of methane is also influenced by moisture content and ambient temperature.

Goat The predicted emission by PSO after 2009 fluctuates from 0.002 to 0.004 Gg CH_4/year, due to extreme hot, dry weather in the state of Sarawak. Marino et al. (2016) pointed out that climate change will affect the health and production of ruminant. Under extreme conditions, ruminants tend to travel further when grazing to search for pastures. In the long term, the heat stress they experience will have an adverse effect on their health in terms of blood metabolites, hormone secretion, enzymatic reactions, mineral balance, energy alteration, metabolic disturbance and feed intake depression (Marai et al. 2007). On the other hand, Sevi and Caroprese (2012) reported that appropriate management, such as appropriate nutritional strategies, afternoon feeding time, providing shade, and proper ventilation regime can restore the ruminant's health. This should be complemented with ensuring improved immunological functions and udder health of small ruminants.

Sheep PSO projected decreasing trend in methane emission from sheep after 2009. This reduction is driven by decreased population and production of mutton. Jha et al. (2011) found out when livestock manure is stored under aerobic conditions, or when manure is turned regularly, there is lowered methane emission from manure management. Alternative method to cut off the methane emitted from manure management is to compost the manure. Composted manure that are used in agricultural soils are both useful and beneficial to soil microbes. Such simple method will increase the content of the soil's organic matter, thereby increasing its fertility while simultaneously minimizing GHG emission from manure decomposition (Ministry of Natural Resources and Environment of Malaysia 2011).

Swine The methane emission from swine is between 2.4 and 3.8 Gg CH_4/year. The data showed a decreasing trend from 1998 to 2001, followed by an increase from 2002 to 2004 which then decreased in 2005, and increased again in 2007 before decreasing slightly until 2009. Since huge portion of swine's manure management is in the form of liquid, higher CH_4 emission is observed from swine (Moeletsi &Tongwane 2015). Also, regional characteristics is believed to have a strong influence in the huge fluctuations of methane emission from swine management after 2009. This is due to the different methane emission factors used for the different regions across the globe. This can be clearly seen when the Tier 1 method was applied. The same emission factor was used for all livestock regardless of livestock's body weight, feed intake and other factors. This is consistent with the findings made by Ogle et al. (2013) who reported that the default factors are not precise and accurate for application in certain countries or areas due to the unique conditions that are not always represented by the default factors. Philippe et al. (2015) contended that microbe activity could also result in methane production; additionally, a C/N ratio of between 15 and 30, low redox potential, high moisture content, higher amount of degradable organic matter, higher temperature and the absence of oxygen could increase the amount of methane generated (Amon et al. 2006).

Deer The methane emission from deer ranges from 0.0003 to 0.001 Gg CH_4/year for the period 1998 to 2009. Projected emission after 2009 is similar to emissions of previous years since the deer population is expected to remain the same. Methane emission from manure management of cattle, goat and deer demonstrate high methane emission rate. The difference in emission from buffalo and swine are smaller as compared to sheep which illustrated abrupt reduction in emission. Due to difference in the practices adopted by farmers in Sarawak, the emission released from livestock in the state differs from those in other locations. CH_4 emissions data from manure management would be improved if specific emission factors were determined via in-depth studies that integrate temperature, storage duration and method, and mass flow with methane emission in different regions.

DISCUSSION ON PROJECTED EMISSION AND PERFORMANCE MEASURE OF PSO

The mean absolute error (MAE) does not indicate underperformance or over-performance of a model and hence was introduced to validate the accuracy of projection made using PSO. It shows the degree of error that can be expected from the projection. The performance of the PSO model has both error value (MAE) of zero and close to zero for livestock, as shown in Tables 2 and 3. Those values showed little difference between actual and projected value. Thus, PSO model is great at prediction.

Mean Absolute Percentage Error (MAPE) is a measure frequently applied in projection to compare how far PSO's projections are off from their corresponding output on average. A smaller MAPE indicates better projection. In the study, the MAPE values provide clear interpretation for the projected emission from enteric fermentation and manure management since values of 0 - 0.086 generated point to good projective ability of PSO.

Meanwhile, the Root Mean Square Error (RMSE) is commonly applied measure of difference between projected values by a model and the values actually obtained. It is useful for showing a greater deviation and helps to give a complete picture of the error distribution. The values of RMSE from Tables 2 and 3 are small enough to prove that the error distributions for PSO are significantly small. When PSO demonstrated small error distributions, it means the projected values are reliable. Another RMSE usage is in evaluating model accuracy. A particular model is categorized as an excellent model if the RMSE is zero. In the present study, PSO is an excellent model by virtue of zero and close-to-zero values for the livestock.

To ensure the projected values are accurate and precise, RMSE and MAE are employed to analyse whether the projection contains large but infrequent errors. In other words, the larger the difference between RMSE and MAE, the more inconsistent will be the error size. As can be seen from Tables 2 and 3, the differences between RMSE and MAE values are very small for all livestock. For projected methane emission from enteric fermentation, RMSE and MAE values of sheep, goat and deer are zero while RMSE and MAE are 3.58E-06 & 3.17E-06, 4.08E-06 & 3.33E-06, and 2.77E-06 & 2.33E-06 for cattle, buffalo and swine, respectively. For projected methane emission from manure management, the RMSE, MAE and MAPE values for cattle, buffalo and sheep are zero while RMSE and MAE are also close to zero, i.e. 2.89E-08 & 2.5E-08, 3.03E-05 & 2.73E-05, and 1.29E-08 & 5E-09 for goat, swine and deer, respectively. Values prove that the PSO model can yield high accuracy of projection.

CONCLUSION

The study has estimated the methane emissions from livestock in Sarawak during the period from 1998 to 2009. The inventory development and the changes in the amount of methane emissions indicate that there is a need for all parties in the livestock sector, from small stakeholders to commercial farmers, to improve their practices in the livestock farming. The enteric emissions of CH_4 has decreased from 1.860 Gg/year in 1998 to 1.856 Gg/year in 2009 while the reduction for manure management is from 3.825 Gg/year in 1998 to 2.877 Gg/year in 2009. The decrease in the amount of emission is due to the slower growth of livestock population as well as the default emission factors (EFs) used in the study (Tier 1 in IPCC).

In order to reduce emission, there is a need to make major changes in the manure management systems. The utilization of proper facilities and technologies for capturing biogas or methane is crucial. This is especially true in Malaysia as the captured methane can be used as alternative energy source, thus further reducing emissions from fossil fuel generated energy.

It can be concluded that low RMSE values will be obtained when accuracy of the projection model is high. Projection with high accuracy can provide information regarding CH_4 emissions. The PSO developed in this study has been proven to be capable of projecting future emissions accurately for the selected six livestock. It should be noted that similar results can only be obtained if the same agricultural practices, namely machinery, type of feed and condition of farm, are retained. In conclusion, emissions of methane in agricultural production, particularly livestock enteric and manure methane, are often a major contributor to methane emission in developing countries. It is hoped that the projected emission will facilitate the formulation of appropriate mitigation measures, thus reducing the total greenhouse gas footprint in Sarawak.

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REFERENCES

Al-Sulttani, A.O., Ahsan, A., Hanoon, A.N., Rahman, A., Daud, N.N.N. & Idrus, S. 2017. Hourly yield prediction of a double-slope solar still hybrid with rubber scrapers in low-latitude areas based on the particle swarm optimization technique. *Applied Energy* 203: 280-303.

Alwee, R., Shamsuddin, S.M., Aziz, F.A., Chey, K.H. & Hameed, H.N.A. 2009. The impact of social network structure in particle swarm optimization for classification problems. *International Journal of Soft Computing* 4(4): 151-156.

Amon, B., Kryvoruchko, V., Amon, T. & Zechmeister-Boltenstern, S. 2006. Methane: Nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment. *Agriculture, Ecosystems & Environment* 112(2-3): 153-162.

Aneja, V.P., Schlesinger, W.H. & Erisman, J.W. 2009. Effects of agriculture upon the air quality and climate: Research, policy and regulations. *Environmental Science & Technology* 43(12): 4234-4240.

Bell, M., Eckard, R., Moate, P.J. & Yan, T. 2016. Modelling the effect of diet composition on enteric methane emissions across sheep, beef cattle and dairy cows. *Animals* 6(9): 1-16.

Chadwick, D., Sommer, S., Thorman, R., Fangueiro, D., Cardenas, L., Amon, B. & Misselbrook, T. 2011. Manure management: Implications for greenhouse gas emissions. *Animal Feed Science and Technology* 166-167: 514-531.

Chairul, S., Dzakiyullah, N.R. & Nugroho, J.B. 2016. *Carbon Dioxide Emission Prediction using Support Vector Machine*. IOP Conference Series: Materials Science and Enginering. United Kingdom: IOPscience. pp. 1-8.

Chhabra, A., Manjunath, K., Panigrahy, S. & Parihar, J. 2009. Spatial pattern of methane emissions from Indian livestock. *Current Science* 96: 683-689.

Clark, H., Brookes, I. & Walcroft, A. 2003. *Enteric Methane Emissions from New Zealand Ruminants 1999-2001 Calculated using an IPCC Tier 2 Approach*. New Zealand: Ministry of Agriculture and Forestry.

Crutzen, P.J., Aselmann, I. & Seiler, W. 1986. Methane production by domestic animals, wild ruminants, other herbivorous fauna, and humans. *Tellus B: Chemical and Physical Meteorology* 38(3-4): 271-284.

Grainger, C. & Beauchemin, K.A. 2011. Can enteric methane emissions from ruminants be lowered without lowering their production? *Animal Feed Science and Technology* 166-167: 308-320.

Intergovernmental Panel on Climate Change (IPCC). 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Volume 4. Japan: Institute for Global Environmental Strategies.

Jha, A.K., Singh, K., Sharma, C., Singh, S.K. & Gupta, P.K. 2011. Assessment of methane and nitrous oxide emissions from livestock in India. *Journal of Earth Science & Climatic Change* 2(1): 1-12.

Johnson, K., Huyler, M., Westberg, H., Lamb, B. & Zimmerman, P. 1994. Measurement of methane emissions from ruminant livestock using a SF6 Tracer technique. *Environmental Science and Technology* 28(2): 359-362.

Knapp, J.R., Laur, G.L., Vadas, P.A., Weiss, W.P. & Tricarico, J.M. 2014. Invited Review: Enteric methane in dairy cattle production: Quantifying the opportunities and impact of reducing emissions. *Journal of Dairy Science* 97(6): 3231-3261.

Le Goff, G., Dubois, S., Van Milgen, J. & Noblet, J. 2002. Influence of dietary fibre level on digestive and metabolic utilisation of energy in growing and finishing pigs. *Animal Research* 51(3): 245-259.

Leytem, A.B., Dungan, R.S., Bjorneberg, D.L. & Koehn, A.C. 2010. Emissions of ammonia, methane, carbon dioxide, and nitrous oxide from dairy cattle housing and manure management systems. *Journal of Environmental Quality* 39: 1-12.

Marai, I.F.M., El-Darawany, A.A., Fadiel, A. & Abdel-Hafez, M.A.M. 2007. Physiological traits as affected by heat stress in sheep - A review. *Small Ruminant Research* 71(1-3): 1-12.

Marino, R., Atzori, A.S., D'Andrea, M., Lovane, G., Trabalza-Marinucci, M. & Rinaldi, L. 2016. Climate change: Production performance, health issues, greenhouse gas emissions and mitigation strategies in sheep and goat farming. *Small Ruminant Research* 135: 50-59.

Martin, C., Morgavi, D.P. & Doreau, M. 2010. Methane mitigation in ruminants: From microbe to the farm scale. *Animal* 4: 3141-3150.

Ming, M, Niu, D. & Shang, W. 2014. A small-sample hybrid model for forecasting energy-related CO_2 emissions. *Energy* 64: 673-677.

Malaysia's Second National Communication (NC2) to the UNFCCC. http://unfccc.int/resource/docs/natc/malnc2.pdf. Accessed on 18 August 2016.

Moeletsi, M.E. & Tongwane, M.I. 2015. 2004 methane and nitrous oxide emissions from manure management in South Africa. *Animals* 5: 193-205.

Moraes, L.E., Strathe, A.B., Fadel, J.G., Casper, D.P. & Kebreab, E. 2014. Prediction of methane emission from cattle. *Global Change Biology* 20: 2140-2148.

O'Mara, F.P. 2011. The significance of livestock as a contributor to global greenhouse gas emissions today and in the near future. *Animal Feed Science and Technology* 166-167: 7-15.

Ogle, S.M., Buendia, L., Butterbach-Bahl, K., Breidt, F.J., Hartman, M., Yagi, K., Nayamuth, R., Spencer, S., Wirth, T. & Smith, P. 2013. Advancing national greenhouse gas inventories for agriculture in developing countries: Improving activity data, emission factors and software technology. *Environmental Research Letters* 8: 1-8.

Philippe, F.X. & Nicks, B. 2015. Review on greenhouse gas emissions from pig houses: Production of carbon dioxide, methane and nitrous oxide by animals and manure. *Agriculture, Ecosystems & Environment* 199: 10-25.

Pragna, P., Chauhan, S.S., Sejian, V., Leury, B.J. & Dunshea, F.R. 2018. Climate change and goat production: Enteric methane emission and its mitigation. *Animals* 8(12): 1-17.

Pratt, C., Redding, M., Hill, J. & Jensen, P. 2015. Does manure management affect the latent greenhouse gas emitting potential of livestock manures? *Waste Management* 46: 568-576.

Sevi, A. & Caroprese, M. 2012. Impact of heat stress on milk production, immunity and udder health in sheep: A critical review. *Small Ruminant Research* 107(1): 1-7.

Sneath, R.W., Phillips, V.R., Demmers, G.M., Burgess, L.R., Short, J.L. 1997. *Long Term Measurements of Greenhouse Gas Emissions from UK Livestock Buildings*. Livestock Environment: Proceedings of the Fifth International Symposium, Bloomington MN, May 29-31. Wrest Park, Silsoe, Bedford: Silsoe Research Institute.

Tang, N. & Zhang, D.J. 2011. Application of a load forecasting model based on improved grey neural network in the smart grid. *Energy Procedia* 12: 180-184.

Tauseef, S.M., Premalatha, M., Abbasi, T. & Abbasi, S.A. 2013. Review: Methane capture from livestock manure. *Journal of Environmental Management* 117: 187-207.

United Nations Climate Change Conference, 15th Conference of Parties (COP 15). https://www.najibrazak.com/en/speeches/u-n-climate-change-conference-2009-15th-conference-of-parties-cop-15/. Accessed on 26 November 2016.

United Nations Framework Convention on Climate Change, List of Non-Annex I Parties to the Convention http://unfccc.int/parties_and_observers/parties/non_annex_i/items/2833.php. Accessed on 20 December 2017.

Yusuf, R.O., Noor, Z.Z., Abba, A.H., Hassan, M.A. & Din, M.F. 2012. Methane emission by sectors: A comprehensive review of emission sources and mitigation methods. *Renewable and Sustainable Energy Reviews* 16(7): 5059-5070.

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