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Climate Change

Prediction of methane (CH_4) emission based on paddy harvest area in Lampung Province, Indonesia

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Major ccontribution of greenhouse gas (GHG) emissions from agriculture sector comes from paddy cultivation system; flooded paddy field is the source of methane emissions. Several researches related to greenhouse gas emissions from agriculture (paddy field) by direct measurements have been done in plot scale. This research aimed to predict methane annual emissions from paddy field in regional scale (province) based on paddy harvest areas. Methods that used in this research were IPCC model to estimate the emission and time series method (ARIMA) to forecast the emission in next five years. The result of this research showed: (1) methane emissions from paddy field are predicted to decline in the next five years, the number will be 232.703 Gg (2013); 229.113 Gg (2014); 225.877 Gg (2015); 222.961 (2016) and 220.333 (2017) for methane emissions; (2) comparing the result from other country with similar area, it could be concluded that IPCC model could be applied to estimate methane emissions in Lampung; and (3) the amount of methane annual emissions from paddy field was effected by annual cultivated area/harvested area and cultivation period.

INTRODUCTION

Climate change as a result of global warming is a real earth problem that affects people life. The global average surface temperature of the Earth has increased by 0.6± 0.2 °C since 1900 and it is likely that the rate and duration of the warming are greater than at any time in the past 1000 years (1). Earth temperature rise because the longwave radiation emits by the earth surface is trapped by certain gasses known as greenhouse gasses. Global warming will affect climate processes and feedbacks and result in changes of mean temperature and precipitation distributions and is also expected to affect interannual and longer time-scale of precipitation (2). For instance, monsoon rainfall over South Asia has decreased during the last 5 to 6 decades according to several sets of observations (3). Global warming induces increased frequency or intensity of typhoons; for that reason, coastal zones and river sides are considered to be the residential areas that are most likely to be influenced by global warming (4)

Among all of atmospheric components, methane (CH_4) considered as a major greenhouse gas. IPCC declared that the warming forces of CH4 are 25-30 times higher than that of CO_2 per unit of weight based on 100-yr global warming potentials (5). The abundance of CH_4 in the atmosphere has increased by about a factor of 2.5 since the pre industrial era, it may give 15-20% additional radiative forcing of the atmosphere (6). Methane is produced in an anaerobic environment such as paddy fields, swamps, sludge digester, rumens and sediments (7, 8). Rice paddies have been identified as a major source of atmospheric CH_4. Global annual methane emission from rice fields were estimated to range from 25-100 Tg which contributed to 10-30% of global methane emission (8).

Various researches related to direct measurement of greenhouse gas emossion from paddy field have been done in plot scale such as in Japan, under the conditions of a single-cropping rice farming system typical of the region with five soil moisture treatments (9); in Southern China, the effects of tillage systems on methane (CH_4) and nitrous oxide (N_2O) emission in a double rice cropping system (5). Another plot scale research was done in Kedah Malaysia to quantify the methane emission from paddy fields with different irrigation methods and to study the potential of using the alternate flooding strategy in suppressing the methane emission (10). Most of plot measurement used closed chamber method which was placed over each pot with the bottom edge fitted right to the soil. Gas samples were collected at some intervals and gas samples were extracted through a plastic valve using a syringe. Then, gas concentrations were analyzed with a gas chromatograph. The next step should be to upscale the results to higher level, for example to city or regional scale. Since direct measurements might be complicated in this scale, models could be used for this purpose using data from direct measurements on the plot scale.

Model is a development of equations that describe the relationship between certain variable, parameters, management or control input and environment input (11). To predict methan gas emission of paddy field from a single measurement, IPCC (*International Panel for Climate Change*) has developed some mathematics models (12). Besides upscalling direct measurements to larger scales, it is also necessary to

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forecast the methane emission in the future years. There are two methods in forecasting: qualitative and quantitative; in quantitative there are causal/regresion method and time series methods. Time series method is used when the intention is only to forecast future results without analyzing the process. Box Jekins is time series method that could be the main alternative if inside the data exists some complicated data pattern (13). In Indonesia, Box Jenkin method for agriculture application has been done to forecast sugar cane production (14, 15); while in Climatology, Box Jenkin has been used to forecast rainfall anomaly based on monsoon index and El Nino event (16).

Because rice is the main staple food in Indonesia while methane emission is crucial related to global warming, it is necessary to forecast its future emission using a suitable model based on paddy harvest area in Lampung Province, Indonesia. The objectives of this research was to forecast annual methane emission in five years period (2013-2017) in Lampung Province based on paddy field area in the last 20 years (1993-2012). From this research it was expected that methane emission in this province could be quantified that agriculture project plan should also consider mitigation efforts and techniques.

METHODS

Data

This research used existing data which are: (1) direct observation of methane emission in Lampung Province from Nugroho *et al.* (1994) (2) data of paddy field harvest in Lampung from Indonesia Statistical Bureau (17)

Methods

1. Estimation of annual methane emission

Methane emission from paddy field was calculated based on mathematical model released by IPCC (2006). This model has been applied by some researchers such as (18) and (19). In this research different ecosystem of the paddy field was ignored since the observation data came from an experiment in one paddy field area, so it was assumed having the same ecosystem.

$$CH_4 Rice = \sum_{i,j,k} \left(EF_{i,j,k} \, x \, t_{i,j,k} \, x \, A_{i,j,k} \, x 10^{-6} \right) \quad (1)$$

where

CH_4 Rice = annual methan emission from from rice cultivation, Gg CH_4 yr^{-1}

EF$_{ijk}$ = a daily emission factor for i, j, and k conditions, kg CH_4 ha^{-1} day^{-1}

t$_{ijk}$ = cultivation period of rice for i, j, and k conditions, day

A$_{ijk}$ = annual harvested area of rice for i, j, and k conditions, ha yr^{-1}

i, j, and*k* = represent different ecosystems, water regimes, type and amount of organic amendments, and other conditions under which CH_4 emissions from rice may vary

2. Forecasting annual emission

Paddy field area in Lampung was applied on mathematical model in order to get annual methane emission in Lampung Province. Data from the estimation would be used as data base to forecast methane emission for next 5 years period using Box-Jekins method (ARIMA model).

Box-Jekins method (ARIMA model) was developed through identification and estimation steps (13). In identification, model was tentatively categorized; from this stage data could be identified whether it was random, stationer or seasonal and whether there was AR (*auto regressive*), MA (*moving average*), or both ARMA (*auto regressive moving average*) processes. Next step was estimating parameters of the tentative model. This step included non linier estimation, parameter test and model fitness. With those approaching the best ARIMA model for the forecasting could be achieved. Eventually, this research would come up with graphs showed the tendency of the methane emission from paddy field area in Lampung Province by 2017.

RESULTS AND DISCUSSIONS

Direct observation of methane emission from paddy field had been done in Lampung (20, 21) and the result was presented in Table 1. The result of applying Equation 1 to direct observation of methane emission and paddy harvest area was presented in Table 2 and Figure 1. Next step is to calculate autocorrelation and partial autocorrelation; and the results were presented in Figure 2 and 3. Both graphs could be indicators whether the data was random, stationer or seasonal or having AR, MA, or ARMA processes. The stricked dotted line showed the upper and lower border of the coefficient values.

Determination of random pattern

Data was considered random when the coeficient value was inside the borders. The ACF, showed r_1 = 0.579 bigger than 0.438 (the upper border). It meant autocorrelation coefficient when k = 1 was significantly different from zero. When k>1, all autocorrelation coefficients did not significantly different from zero. The same result was showed by the PACF, when k = 1, r = 0.579 bigger than 0.438. It meant autocorrelation coefficient when k = 1 was significantly different from zero. When k>1, all autocorrelation coefficients did not significantly different from zero. Therefore, it could be concluded that the data series were random.

Determination of stationary

The ACF did not show a diagonal trend from left to right as the time lags increases (Figure 2); this proved that the data was stationer; therefore, no data differentiation was necessary. Stationer data had constant mean and variant, there was no up and down pattern. With this result prediction of methane emission the ordo was 0 (d = 0) since no data differentiation was needed.

Determination of seasonal trend

The autocorrelation on the ACF did not show a repetition; it meant on the ACF no identification that the coefficient on two or three time lags were significantly different from zero; therefore, it could be concluded that no seasonal influence on the data series.

Identification of AR (*autoregressive*) processes

The ACF showed autocorrelation values which decreased exponentially (r_1 = 0.579 >r_2 = 0.346 >r_3 = 0.266 >r_4 = 0.069 >r_5 = 0.036), until reached zero after 2 and 3 time lags; that showed the existence of AR process. The ordo of AR processes could be determined from the numbers of partial coefficients in PACF that was significantly different from zero, in this study the ordo was one p = 1. The existence of AR process showed that the last data had a correlation with the previous data series and the correlation decreased with further time lags.

Identification of MA (*moving average*) processes

MA processes could be identified from the value of partial autocorrelation in PACF that decreased exponentially. Since there was no indicator of that pattern in this data series; it could be concluded that

Table 1 Methane emission from paddy field measurement in Lampung Province

Season	Month	week	Emission (mg CH_4 $m^{-2}h^{-1}$)
Rain (wet)	December	4	10
	January	1 2 3 4	18 25 22 25
	February	1 2 3 4	20 25 19 18
	March	1 2	9 7
Dry Season	May	1 2 3 4	15 30 18 24
	June	1 2 3 4	40 42 20 27
	July	1 2	17 19

Table 2 Paddy harvest area and estimated methane emission in Lampung Province, Indonesia

Year	Area (ha)	Methane emissions Gg/year	Year	Area (ha)	Methane emissions Gg/year
1993	433,078	163,703	2003	472,635	178,656
1994	425,940	161,005	2004	495,519	187,306
1995	514,363	194,429	2005	496,538	187,691
1996	515,192	171,645	2006	494,102	186,771
1997	454,087	197,155	2007	524,955	198,433
1998	521,575	180,268	2008	506,547	191,475
1999	476,899	187,820	2009	570,417	215,618
2000	496,879	189,423	2010	590,608	223,250
2001	501,119	179,724	2011	606,973	229.436
2002	475,461	178,656	2012	626,158	236,688

Source of paddy harvest area: Badan Pusat Statistik/ Indonesian Statistic Bureau (2012)

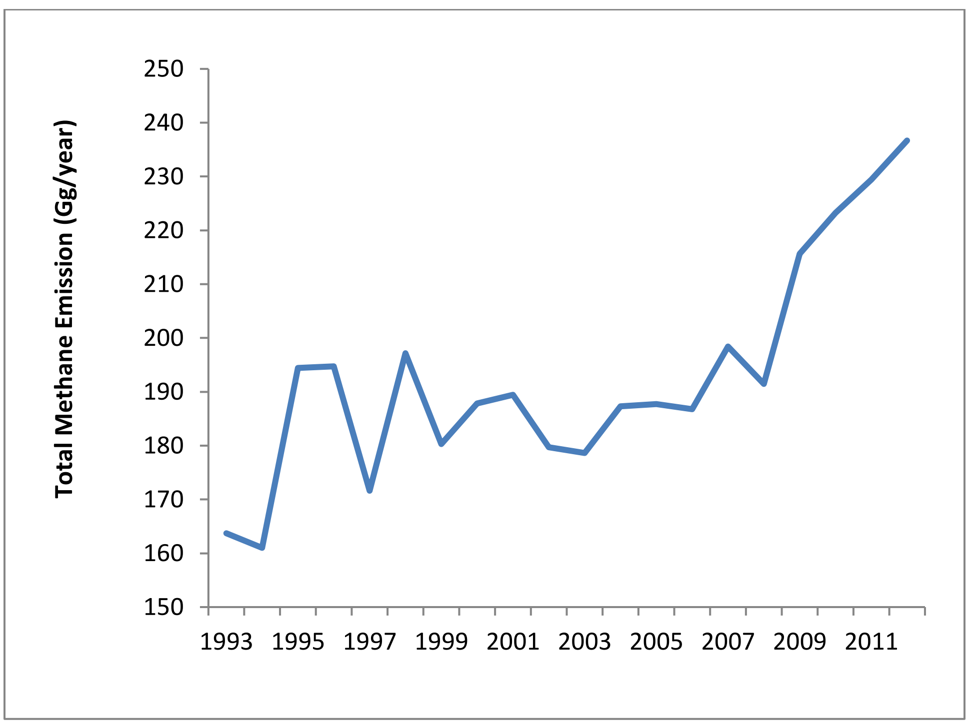
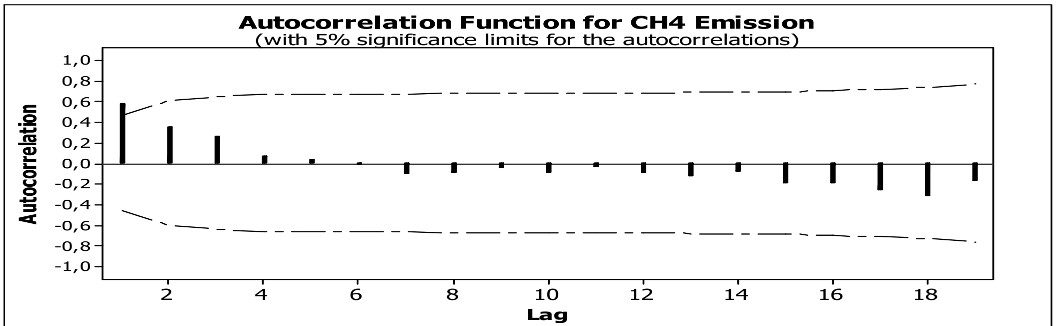
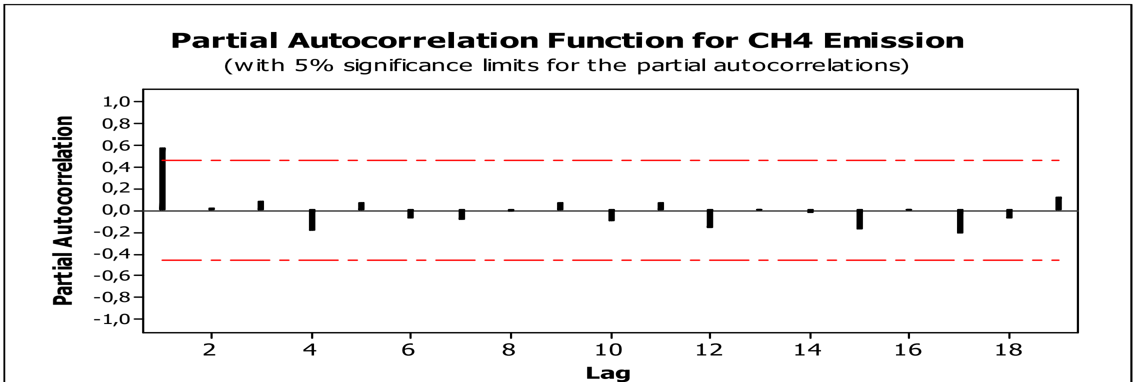


Figure 1 Estimated methane emission based on paddy field area in Lampung Province, Indonesia (1993-2012)



Lag	ACF	T	Lag	ACF	T	Lag	ACF	T	Lag	ACF	T
1	0,57	2,59	6	-0,01	-0,03	11	-0,03	-0,10	16	-0,19	-0,57
2	0,34	1,20	7	-0,10	-0,32	12	-0,08	-0,27	17	-0,25	-0,75
3	0,26	0,86	8	-0,09	-0,30	13	-0,12	-0,39	18	-0,31	-0,91
4	0,06	0,22	9	-0,04	-0,13	14	-0,07	-0,24	19	-0,16	-0,45
5	0,03	0,11	10	-0,08	-0,28	15	-0,19	-0,58			

Figure 2 Autocorrelation function (ACF) of estimated methane emission from paddy field Lampung Province from 1993 to 2012



Lag	PACF	T	Lag	PACF	T	Lag	PACF	T	Lag	PACF	T
1	0,57	2,59	6	-0,06	-0,31	11	0,07	0,32	16	0,00	0,02
2	0,01	0,07	7	-0,07	-0,34	12	-0,15	-0,69	17	-0,21	-0,96
3	0,08	0,40	8	-0,00	-0,02	13	0,00	0,00	18	-0,06	-0,28
4	-0,18	-0,82	9	0,06	0,31	14	-0,01	-0,08	19	0,12	0,56
5	0,07	0,32	10	-0,09	-0,42	15	-0,17	-0,78			

Figure 3 Partial autocorrelation function (PACF) of estimated methane emission from paddy field Lampung Province from 1993 to 2012

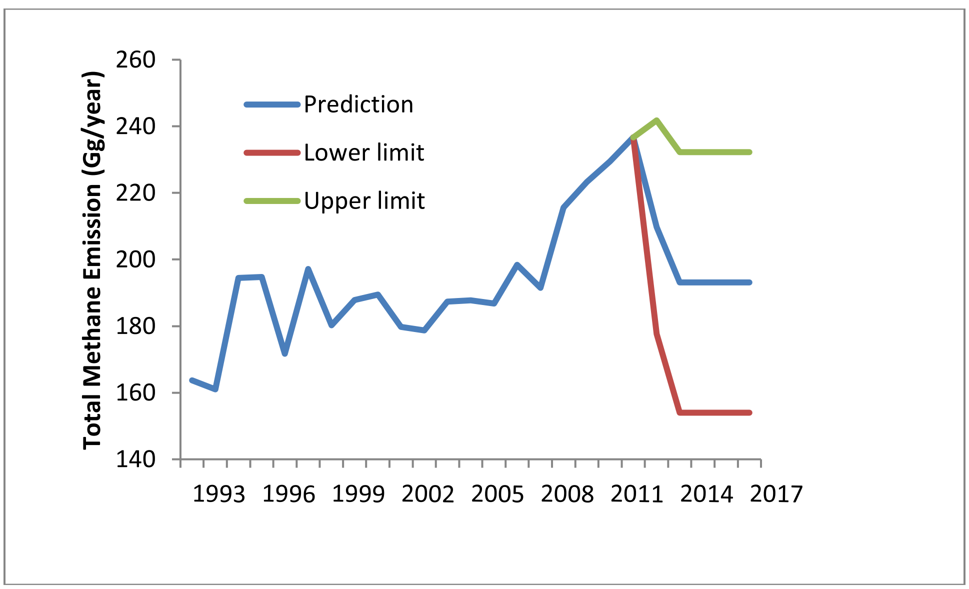


Figure 4 Forecasting of methane emission using ARIMA (0,0,1) model

Table 3 Statistic analysis model ARIMA (0,0,1) and ARIMA (1,0,0)

Type	Coef	SE Coef	T	p	MSE
MA 1	-0,6985	0,1671	-4,18	0,001	267.68
AR 1	0,9012	0,1773	5,08	0,000	195,91

Table 4 Level of MSE and model equations

Model	MSE (mean square error)	Equation
ARIMA (0,0,1)	267,68	$X_t = \mu + e_t - \theta_1 e_{t-1}$
ARIMA (1,0,0)	195,91	$X_t = \mu + \Phi_1 X_{t-1} + e_t$

Tabel 5 Forecasting of methane emission in 5 years near future based on ARIMA (1,0,0) model

Period	Methane emission	Lower border	Upper border
21	232,703	205,264	260,143
22	229,113	192,175	266,050
23	225,877	182,739	269,015
24	222,961	175,378	270,544
25	220,333	169,425	271,241

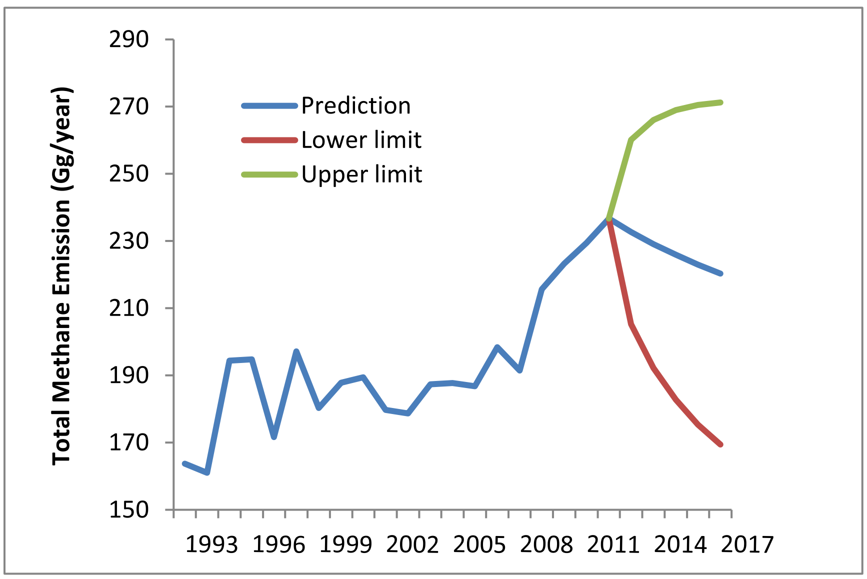


Figure 5 Forecasting methane emission using ARIMA (1,0,0) model

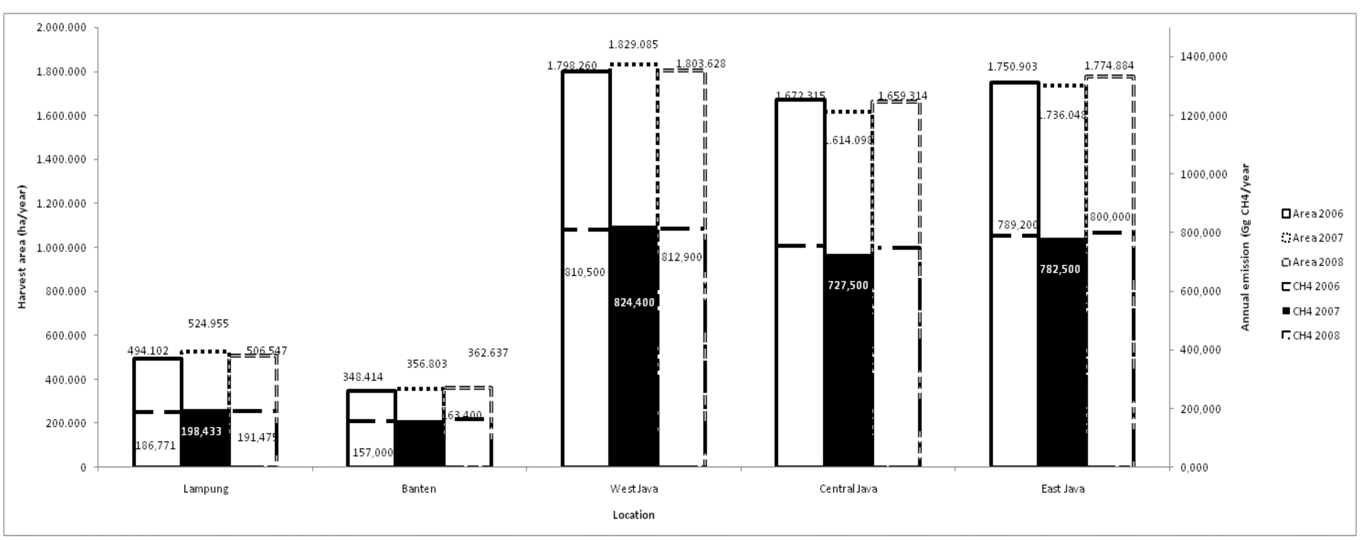


Figure 6 Methane emission from paddy field in provinces of Java Island, Indonesia (BPPT, 2009)

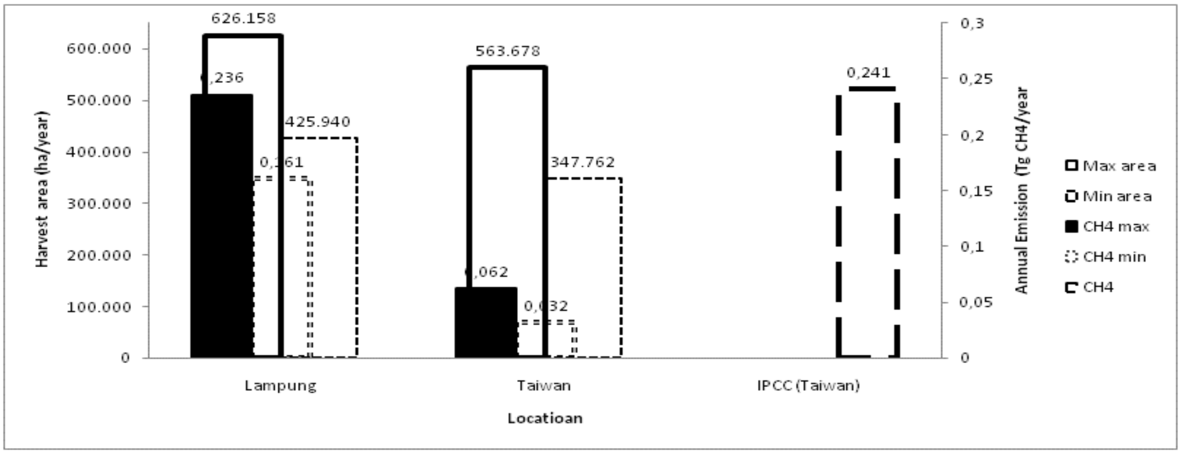


Figure 7 Comparison of methane emission from paddy field in Lampung and Taiwan (8)

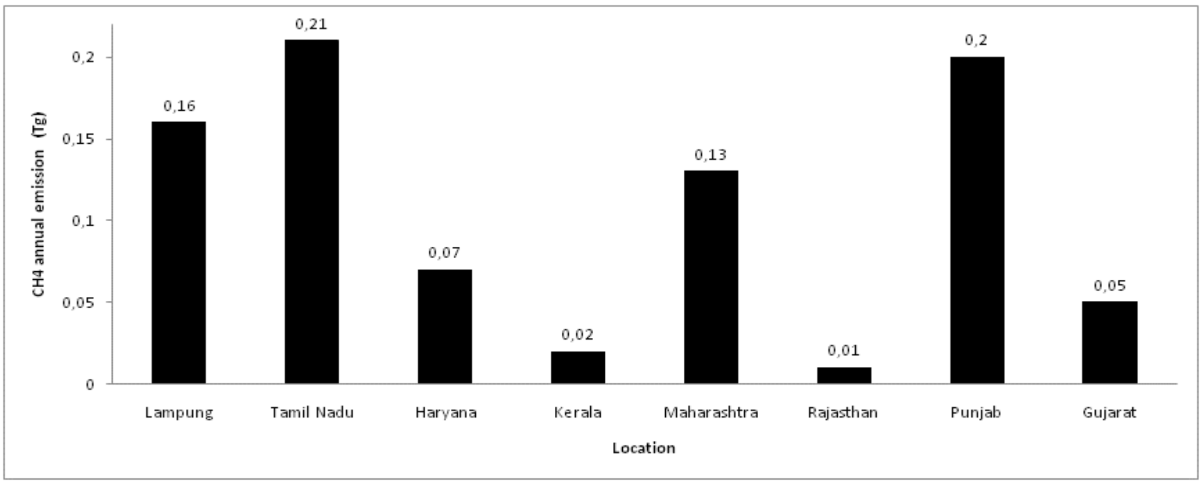


Figure 8 Comparison of methane emission of Lampung and some areas in India (18)

MA processes did not exist, or the ordo was zero ($q = 0$). Moving average existed when data had connection with previous data in short time (having short memory).

From those identification steps eventually the ARIMA model found tentatively suitable for the data series was ARIMA (1,0,0) model. However to determine the ordo for that model, besides the identification steps, it was also necessary to do the "trial and error" steps to obtain ordo comparisons in order to achieve better model. In this study ARIMA (0,0,1) model was chosen as the alternative model, then parameter estimation would be done for those two tentative models. The model analysis for ARIMA (0,0,1) and ARIMA (1,0,0) were presented in Table 3. For $\alpha = 0.05$; $| t |$ value for MA (1) parameter (4,18) was higher than $t_{0.025(24)} = 2.064$. This showed that parameter estimation value of those models were significantly different from zero (reject H_0). Value of p parameter of MA (1) was 0,001; much lower than significant level 0.05; meant reject H_0. Therefore, the MA (1) model could be accepted.

For $\alpha = 0.05$; $| t |$ value for AR(1) parameter (5.08) was higher than $t_{0.025(24)} = 2.064$. This showed that parameter estimation value of this model were significantly different from zero (reject H_0). Value of p parameter of AR (1) was 0.000; much lower than significant level 0.05; meant reject H_0. Therefore, the AR (1) model could also be accepted. Both models could be used for methane emission forecasting, the results are shown in Figure 4 and 5, however, the most suitable model should be chosen. The criterias for choosing the model were: 1) should have less means square error (MSE) and 2) should have more simple equation (see Table 4). Based on those criterias ARIMA (1,0,0) model was chosen to forecast methane emission from paddy harvest area in Lampung Province in near 5 years future (Figure 5, Table 5). In general from the data series could be concluded that paddy harvest area in Lampung Province was stationer, non seasonal and had a strong correlation with the previous area data.

The tabel showed the forecasting in 5 years of methane emission range from paddy harvest area in Lampung Province. The upper border might be reached if the harvest area and the planting intensity increased which was possible since Lampung province is one potential center of rice paddy production in Indonesia. For comparison, research of methane emission from paddy field in other province in Java Island, Indonesia from 2006-2008 had been done (19), (See Figure 6).

Comparing the ratio of the area and methane emission in those provinces in general it was 1:2000. In Lampung in 2007 methane emission was 198,433 Gg and the area was 524.955 ha (1:2.645), while in Banten the emission was 160,800 Gg with harvest area 356.803 ha (1:2.219). From the ratio, it can be concluded that the result from IPCC model in this study was fairly close to those direct measurements.

Figure 7 showed comparison of the results on this study with similar study conducted in Taiwan (22). In Lampung, the methane emission was about 0.161- 0.236 Tg/year with paddy field area was about 425.940-626.158 ha; while in Taiwan the emission was 0.032-0.062 Tg/year with the paddy area was 182.807-277.498 ha (8). Similar results has also found from researches in several locations in India (18), (see Figure 8).

This study showed the possibility of decreasing methane emission in Lampung Province due to decreasing paddy field area. Decreasing paddy field area could happen because of exchanging land use. Some factors influence exchanging land use in farmers level were (1) 97.5% because of no irrigation facilities, (2) 92.5% because the prize of other substitute commodities were higher, (3) 43,4% because of low rice prize, (4) 52.5% because planting paddy did not economically beneficial, (5) 32.5% because of labor scarcity (23).

However, even with decreasing possibility of methane emission in Lampung Province, the emission itself was considered high. With long life stay in the atmosphere, increasing rate of methane emission will significantly effect the climate change processes.

Based on data from Indonesian Statistic Bureau (17) paddy field area in Lampung Province did not always increase. In general, average increasing rate of paddy field area in Lampung Province from 2001 to 2009 was 1.57% per year or about 2.626 ha per year (23). On national scale, in 2010 Indonesian government budgeted to develop 62.000 ha new paddy field and 100.000 ha in 2012 and planned to develop 100. 000 ha every year (24). Badan Pusat Statistik (BPS, Indonesia Statistic Bureau) predicted rice production in 2015 increased 6.64 percent or 75.55 million tons compared to the previous year; and this would be the highest in last 10 years; while the need was only 28 million tons. Recent census of agriculture by Indonesian Statistic Bureau stated that paddy field area was 638.090 ha (2013), 648.731 ha (2014) and 707.266 ha (2015) so the methane emission production based on IPCC formula should be 241.98 Gg, 245.220 Gg and 267.347 Gg, respectively, which was still in the range of emission border (see Table 5). Even though the need for rice decreased, rice is still be Indonesian staple food, therefore, mitigation techniques in paddy cultivation is important. Some of the possible techniques are: using paddy varieties with low emission, shorter growth time, drought tolerant; moderate fertilizer application and manage the paddy field water regime.

CONCLUSIONS

Applying those models, methane emission from paddy planting area in Lampung Province, Indonesia on the period of 2013-2014 were 232,703 Gg and 229,113 Gg. ARIMA model predicted the emission were 225,877 Gg (2015); 222,961 Gg (2016); and 220,333 Gg (2017). This study has some limitations because data of direct methane emission was collected weekly; no daily observation was available. However, since the IPCC model was an emission model broadly used in many countries and the ARIMA model is a statistic model known in forecasting future data based on previous time series data, the results from this study was still valuable for mitigation recommendation.

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Author contribution
First author: developed the main idea, searched the literatures, with the second author checked the results, and wrote the manuscript
Second author: collected the data, calculated the emission from the IPCC equations, prepared the results (tables and figures)
Third author: predicted the emission with time series methods (ARIMA)

Disclosures about potential conflict of interests
We declare that there will be no conflict of interest

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