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Original Paper

Greenhouse Gas Emissions: Historical and Projected Methane Emissions from Rice Cultivation in Malaysia (1990-2030)

Shaidatul Azdawiyah A. Talib[1*], Mohd Fairuz M. Suptian[1], Mohammad Hariz A. Rahman[1], Nurul Ain A. Bakar[1], Fauzi J.[1], Azizi A. Azmin[2], Mardhati M.[2] & Mohamad Zabawi A. Ghani[1]

[1] Agrobiodiversity and Environment Research Centre, Serdang, Selangor, Malaysia

[2] Animal Science Research Centre, Serdang, Selangor, Malaysia

[*] Shaidatul Azdawiyah A. Talib, Agrobiodiversity and Environment Research Centre, Serdang, Selangor, Malaysia

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Abstract

Global warming and climate change has reached the alarming levels due to increase of greenhouse gas emissions into the atmosphere which includes carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Flooded rice (Oryza sativa L.) cultivation has been identified as one of the prominent global agricultural sources of anthropogenic CH_4 emissions. Moreover, it has been estimated that global rice production is responsible for 11% of total anthropogenic CH_4 emissions. The inventory of CH_4 emission from rice cultivation in Malaysia was estimated from 1990 to 2014 and was also used as basis for computing the projected emissions up to 2030 by using Auto-Regressive Integrated Moving Average (ARIMA) model. Results showed that CH_4 emissions is higher from granary area (continuously flooded) than non-granary area (rain-fed) due to different water management practices. Continuously flooded irrigation system which lead to anaerobic conditions emit almost (75%) higher CH_4 than rain-fed irrigation system. Emissions forecasted will be continuously increase from 2015 to 2030 within the confidence limits. Emissions were forecasted to increase up to 88 Gg by 2030 due to increase of country population which will lead to expansion of cultivation area in order to fulfil country needs.

Keywords

methane, greenhouse gas emissions, rice cultivation

1. Introduction

Global warming has a significant impact towards the world's climate. Global warming is actually the abnormally rapid rise in Earth's average surface temperature over the earlier century mainly due to the emissions greenhouse gases (GHG) into the atmosphere. The world is experiencing an unprecedented rise in surface temperature (Adhya et al., 2000). There is increase in global surface temperature by 0.74 ±0.18 °C between the beginning and the end of the 20th century and it is projected to increase by 1.1 to 6.4 °C in the 21st century (Baicich, 2013). This rise is attributed to the increased rate of GHG emissions into the atmosphere caused by the activities of human beings together with the anthropogenic nature of the problem. Over for the past 20 years, climate change which caused by human activities has emerged as a global concern (Shaidatul et al., 2015; Sarker, 2012).

Human population has grown up from 3.5 billion to more than 7 billion since 1970 up to 2010 and projected to increase up to 9.2 billion in 2040 (Franklin et al., 2014; Max & Esteban, 2017). Thus, it means that agricultural production will be more than doubled due to higher consumption together with the shift towards more animal-based products in the diet (FAOSTAT, 2014). At present, agricultural production and Land-Use Change (LUC) are responsible for almost 1/4 of total GHG emissions from human activities (Smith et al., 2014). This sector releases significant amounts of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) to the atmosphere (Smith et al., 2007). Compared to other sectors, agriculture contributes 10.3% out of world total GHG emissions in 2011 (FAOSTAT, 2014). Concentration of CH_4 had been increasing since last 20 years at average rate of 0.8% in a year causing it to be one of the major concern in GHG emissions (Smith et al., 2007). Atmospheric CH_4 is a potent GHG with high absorption potential for infrared radiation. Methane is present at about 1.8 ppmV in the atmosphere (IPCC, 1996). It was estimated that 50% of CH_4 emissions from global anthropogenic contribution were from agricultural activities (Smith et al., 2007).

Agriculture is one of the important sector in Malaysia. Throughout for many years, this sector has been the backbone of country's economy by the production of agricultural products for domestic consumption, as the earner of foreign exchange. Moreover, agriculture sector also contributes to the national Gross Domestic Products (GDP). Agriculture sector continued to expand in 2015 with a contribution of 8.9% to Malaysia's GDP. Oil palm was a major contributor to the GDP of agriculture sector at 46.9% followed by other agriculture (17.7%), livestock (10.7%), fishing (10.7%), and rubber (7.2%) as well as forestry & logging (6.9%) in 2015 (Department of Statistics of Malaysia, 2017). According to Malaysia's Second National Communication (NC2), agriculture sector contributed 3% of the total GHG emissions for the year 2000 compared to industrial processes sector (IP) with 6%, waste sector with 12%, land use, land-use change and forestry (LULUCF) with 13% and energy sector with 66% (Ministry of Natural Resources and Environment of Malaysia, 2011). Contribution of agriculture sector (Figure 1) as reported in the Malaysia's First Biennial Update Report (BUR1) increased up to 5% of the total GHG emissions for the year 2011 (Ministry of Natural Resources and Environment of Malaysia, 2015).

Rice (*Oryza sativa* L.) is the major food crop for people living in Asia, where about 80% of rice is grown under irrigated wetland conditions (Watanabe & Roger, 1984). Furthermore, the world's annual rice production must increase from 518 million tons in 1990 to 760 million tons by 2020 for the purpose of food security (Guerra et al., 1998). Rice fields have been one of the major concern by scientists worldwide as a part of the three most persuasive and long-lived GHG in the atmosphere, due to CO_2, CH_4, and N_2O are emitted from rice fields (Noppol & Nathsuda, 2017). Rice fields are one of the major atmospheric sources of CH_4 as most of the world's rice is grown on flooded fields (Karthik, 2011; USEPA, 2006; Wassman et al., 2009; Winiwarter et al., 2009). Flooded rice fields emit CH_4 due to a methanogenesis process which occurs in anaerobic conditions, during the decomposition of organic matter (Noppol & Nathsuda, 2017; Jain et al., 2004). Rice cultivation has been specifically identified as one of the leading global agricultural sources of anthropogenic CH_4 emissions, accounting for approximately 22% of the total global agriculturally related CH_4 emissions (Smith et al., 2007). Moreover, it has been estimated that global rice production is responsible for 11% of total anthropogenic CH_4 emissions (Max & Esteban, 2017; USEPA, 2006).

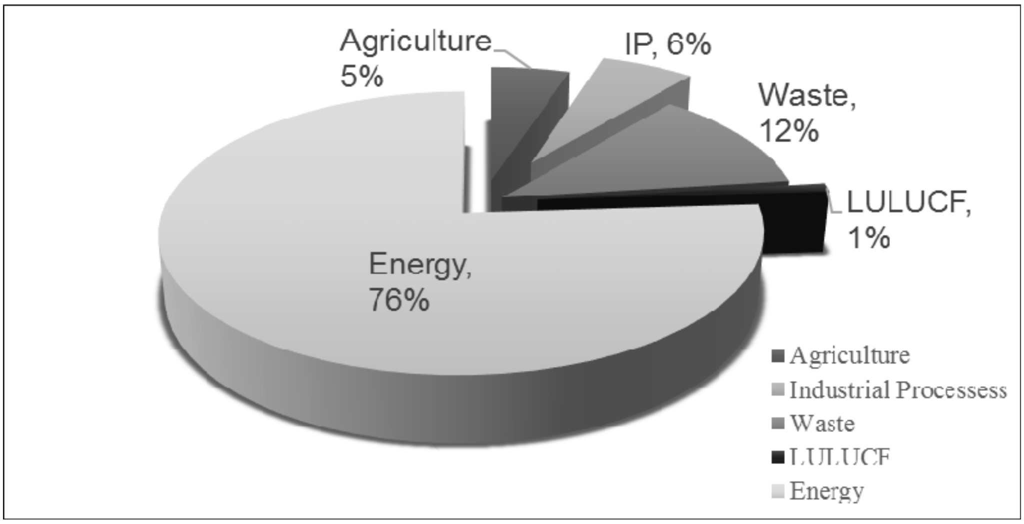

Figure 1. Percentages of Greenhouse Gas Emissions by Sector in 2011

Rice is the third most widely planted crop in Malaysia after oil palm and rubber. In 2014, approximately 679,239 ha were planted with rice (wetland and dryland paddy) including those that are planted twice a year (Department of Agriculture of Malaysia, 2015). There are 2 planting seasons in Malaysia, main season where rice is grown without depending wholly on any irrigation system and off-season (dry period) where normally rice cultivation depends on an irrigation system. Total area of rice cultivation in Malaysia can be classified into three categories which are granary areas (irrigated), non-granary areas (rain-fed) and upland (Table 1). Granary areas refer to major irrigation schemes (areas greater than 4,000 ha) and recognized by the government in the National Agricultural Policy (NAP) as the main rice producing areas. Previously, there are 8 granary areas in Malaysia, namely

MADA, KADA, IADA KERIAN, IADA Barat Laut Selangor, IADA Pulau Pinang, IADA Seberang Perak, IADA KETARA and IADA Kemasin Semerak. Other rice cultivation areas which are less than 4,000 ha are classified as non-granary area or rain-fed area (Department of Agriculture of Malaysia, 2015).

Table 1. Rice Area Planted (Hectares)

Area Classification	1990	2005	2010	2011	2012	2013	2014
Granary	373,588	383,201	387,160	389,544	381,553	369,273	400,733
Non-Granary	217,171	208,654	221,777	227,484	232,248	234,631	214,974
Upland	89,888	80,932	68,947	70,912	70,744	67,775	63,532
Total	680,647	672,787	677,884	687,940	684,545	671,679	679,239

Water management system under which rice is grown is one of the most important factors affecting CH_4 emissions besides fertilization practices, soil temperature, soil type, rice variety, and cultivation practices. The main water management practice applied in Malaysia is continuous flooding with 2 planting seasons in a year (double cropping). When the fields are flooded, aerobic decomposition of organic matter gradually depletes most of the oxygen (O_2) present in the soil, causing anaerobic soil conditions. Once the environment becomes anaerobic, CH_4 is produced through anaerobic decomposition of soil organic matter by methanogenic bacteria (Wassman et al., 2009). Upland rice fields are not flooded, thus are believed not emitting CH_4.

Approximately 60-90% of the CH_4 produced is oxidized by aerobic methanotrophic bacteria in the soil (some O_2 remains at the interfaces of soil and water, and soil and root system) (IPCC, 1996). Some of the CH_4 is also leached away as dissolved CH_4 in floodwater that percolates from the field. The remaining un-oxidized CH_4 is transported from the submerged soil to the atmosphere primarily by diffusive transport through the rice plants. Minor amounts of CH_4 also escape from the soil via diffusion and bubbling through floodwaters (Environmental Protection Agency of United State, 2014). The pathways of CH_4 emissions from a flooded rice field are shown schematically in Figure 2. As the CH_4 approaches the soil-water interface or the plant roots, it enters a region of oxidizing conditions where aerobic micro-organisms convert some of the CH_4 to CO_2. This is either released via the water to the atmosphere or is used by the plant.

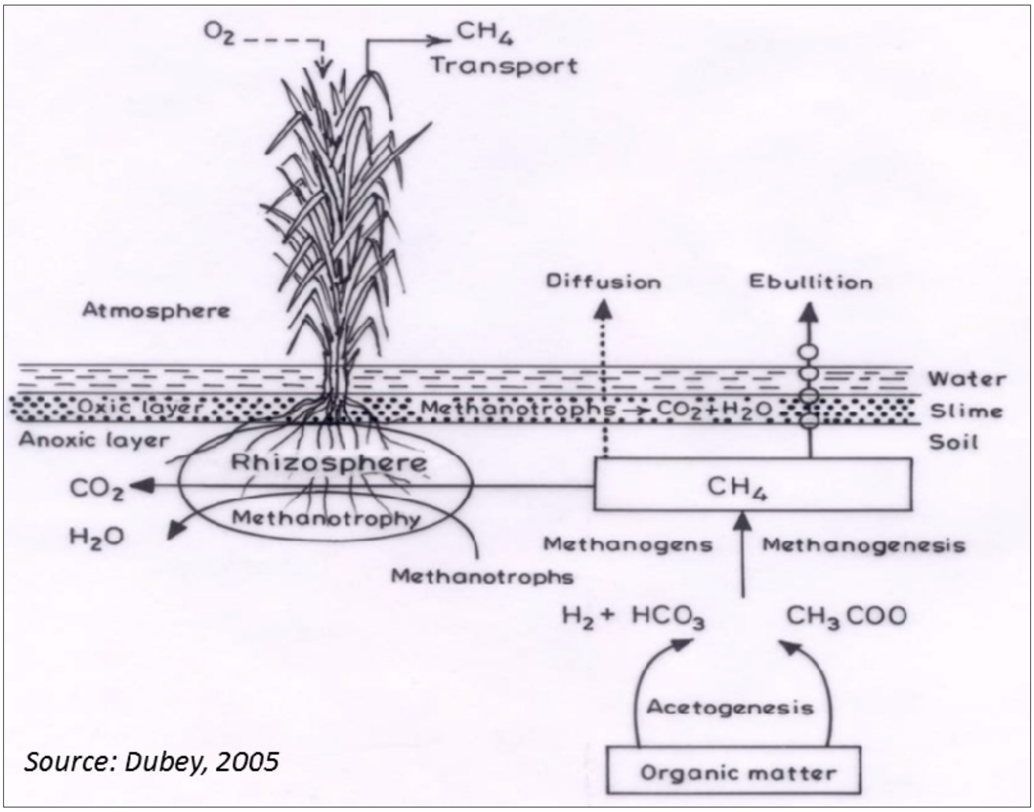

Figure 2. Schematic Diagram of Methane Production, Oxidation and Emission from Rice Field

Inventories in Malaysia from 1990-2014 were prepared to determine the contribution of CH_4 emissions from rice cultivation. An emission inventory is used to assess the impact of specific human activities and the main sources responsible for such emissions besides to develop and assess the results of specific mitigation strategies (Winiwarter et al., 2009).

2. Method

2.1 Activity Data Collection

Activity data (1990-2014) were primarily based on planted area statistics, which are available from a national statistics agency as well as complementary information on cultivation period and agronomic practices. Those activity data were broken down by regional differences in rice cropping practices or water regime. Planted area estimates corresponding to different conditions obtained on a countrywide basis through accepted methods of reporting. Only planted area data were used to estimate the emission. Activity data were obtained from Paddy Statistics of Malaysia by Department of Agriculture.

2.2 Emission Calculations from Inventory

The emission calculations were based on the guidelines given by the Intergovernmental Panel on Climate Change (IPCC) on how to conduct national GHGs inventories. Methane emissions were estimated by multiplying daily Emission Factor (EF) by cultivation period of rice and annual harvested areas. In its most simple form, this equation, Eq. (1) was implemented using national activity data such as national average cultivation period of rice and area harvested and a single EF (IPCC, 2008).

$$CH_{4\ Rice} = \sum_{i,j,k} (EF_{i,j,k} * t_{i,j,k} * A_{i,j,k} * 10^{-6}) \quad (1)$$

Where;

$CH_{4\ Rice}$ = annual methane emissions from rice cultivations (Gg CH_4 yr^{-1})

$EF_{i,j,k}$ = a daily emission factor for i, j, k 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 i, j and k conditions (ha yr^{-1})

i, j and k = represent different ecosystem, water regimes, type and other conditions under which CH_4 emissions from rice may vary

Table 2. Emission Factor and Other Factors for Emissions Estimation

	Value
Emission Factor (kg CH_4 ha^{-1} day^{-1})	1.6
Scaling Factor for Water regime (SF_W): Upland	0.0
Scaling Factor for Water regime (SF_W): Irrigated-Continuously flooded	1.0
Scaling Factor for Water regime (SF_W): Rain-fed	0.27
Water regime prior to rice cultivation (SF_p): Non flooded pre-season <180 day	1.0
Organic amendment (CFOA): Straw incorporated shortly (<30 days) before cultivation	1.0

Due to close proximity, Thailand rice CH_4 EF of 1.6 kg CH_4 ha^{-1} day^{-1} was used as Malaysia not yet developed country specific EF at present (IPCC, 1996). Scaling factors water regimes during the cultivation period relative to continuously flooded field and the default CH_4 emissions scaling factor for water regimes before the cultivation period (non-flooded pre-season < 180 days) were based on IPCC default values as in Table 2.

2.3 Emission Forecasting

The forecasting of methane emission from 2015 to 2030 was carried out using the Auto-Regressive Integrated Moving Average (ARIMA), which is one of the general classes of models used for forecasting time series. Differencing and lagging are the transformations used to fix the model. In the forecasting equation "auto-regressive" terms are used to describe lags of the differenced series that appear in the equation, the "moving average" terms describe lags of the forecast errors, and an "integrated" version of a stationary series is used for a time series requiring differencing to become stationary. The model classification of a non-seasonal ARIMA model is as an "ARIMA (p, d, q)", where p represents the autoregressive terms, d represents the non-seasonal differences, and q represents the lagged forecast errors that appear in the prediction equation (moving average). This time interval was chosen because the models give accurate forecast over short time periods (Rafiu et al., 2012; Winiwarter et al., 2009).

3. Result

Results of the calculated CH_4 emissions estimation from 1990-2014 are presented in Figure 3. Based on Figure 3, we can conclude that CH_4 emissions is higher from granary area (continuously flooded) than non-granary area (rain-fed) due to different water management practices. Moreover, statistical analysis using Statistical Analysis System (SAS) Version 9.3 showed that there is a positive correlation between annual rice planted in granary area (irrigated) and CH_4 emissions (Table 3) with $r = 0.9380$, $p < 0.01$. Therefore, bigger granary area will lead to higher emissions of CH_4. Figure 4 showed the observed and forecasted methane emission from 1980-2014 and 2015-2030.

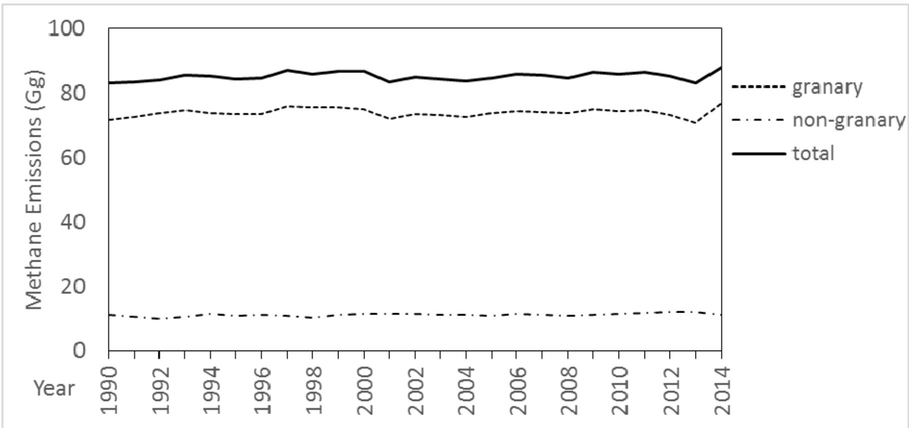

Figure 3. Methane Emissions Estimation from Rice Cultivation since 1990-2014 (Gg)

Forecasted CH_4 emissions had been done using ARIMA Model (0, 2, 2). Table 4 shows the model fit statistics where the value of the coefficient of determination (R2) was 0.8888 which indicated that less than 11% of the total variations were not explained by the model. These R2 values are indications of good model fits. Generally, it was noted that there were no seasonal patterns in the trends, hence there was no need to transform the data to stabilize the variance. The model was then used to fit the emission of methane from these sources.

Table 3. Correlations Table

		Granary area (irrigated)	Non-granary area (rain-fed)	Methane emissions
Granary area (irrigated)	Pearson Correlation	1	-.329	.938**
	Sig. (2-tailed)		.108	.000
	N	25	25	25
Non-granary area (rain-fed)	Pearson Correlation	-.329	1	.019
	Sig. (2-tailed)	.108		.928
	N	25	25	25

Methane emissions	Pearson Correlation	.938**	.019	1
	Sig. (2-tailed)	.000	.928	
	N	25	25	25

** Correlation is significant at the 0.01 level (2-tailed).

Table 4. Model Fit Statistics

Model	R^2	RMSE	MAPE	MAE	MaxAPE	MaxAE	Normalized BIC	No. of Outliers
Rice	0.8888	0.8975	0.7478	0.6392	2.0805	1.7557	0.4653	0

Note. BIC: Bayesian information criterion; RMSE: Root mean square error; MAPE: Mean absolute percentage error; MaxAPE: Maximum absolute percentage error; MAE: Mean absolute error; MaxAE: Maximum absolute error.

Table 5. Ljung-Box Q Statistics for Model Validation

Source	Statistics	DF	Sig. *(p)*
Rice	25.472	16	.062

Table 5 also shows the Ljung-Box Q statistics for model validation. It indicated that the models were correctly specified because the p values above 0.05 which implied that all structures in the observed series had been accounted for. It has been used to validate the correctness of the fitted models. Based on the correctness of the fitted model, it was used to predict methane emissions from 2015 to 2030. Figure 4 showed that emissions forecasted will continuously increase from 2015 to 2030 within the confidence limits. Emissions were forecasted to increase up to 88 Gg by 2030.

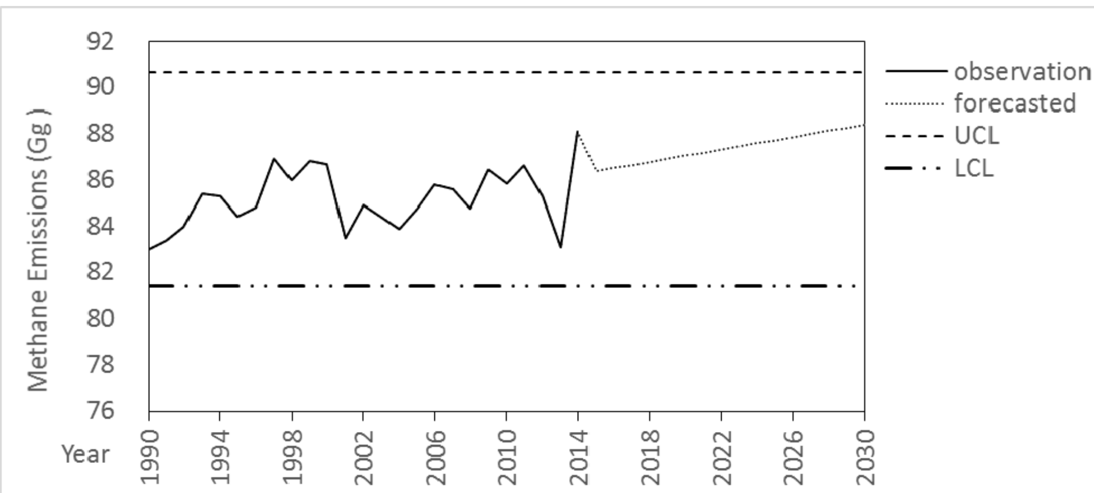

Figure 4. The Observed and Forecasted Methane Emissions Estimation from 1990-2030 (Gg)

4. Discussion

There was a rapid increase of CH_4 emissions from 83.06 Gg in 2013 to 88.08 Gg in 2014. This may due to new granary area gazette by the government of Malaysia in 2014 which is IADA Pekan with 4,940 ha and IADA Rompin with 2,920 ha as there is a positive correlation between annual rice planted in granary area (irrigated) and CH_4 emissions (Department of Agriculture of Malaysia, 2015). Emissions were forecasted to increase up to 88 Gg by 2030. Department of Statistics of Malaysia in 2015 reported that Malaysia's population are projected to increase from 28.6 million in 2010 up to 41.5 million by 2040. As it is known, rice is one of the most important crops in Malaysia as rice is the staple food for the country (Shaidatul Adawiyah et al., 2016). Hence, with the growth of population numbers, demand for rice will also increase. In order to fulfil those demand, rice production should be boosted to ensure food security. This can be done mostly through expansion of rice cultivation area besides producing high yield rice variety or five seasons of cultivation in two years' time interval.

Both expansion of rice cultivation area and five seasons of cultivation in two years' time interval will increase CH_4 emissions as there is a positive correlations between planted area and CH_4 emissions. In 2014, two new granary area, IADA Pekan and IADA Rompin had been gazette by the government causing addition of emissions by 6% in 2014. Moreover, under Barrio Rice Industry Development project, two new granary areas which is 5,000 ha in Kota Belud, Sabah and 5,100 ha in Batang Lupar, Sarawak will be established by the year 2020 (National Key Economic Area, 2011). This is in line with the forecasted emissions which will continuously increase up to 2030.

Water management has been recognized as one of the most important practices that affect CH_4 emissions from rice fields (Hadi et al., 2010). Irrigated rice field area release higher amount of CH_4 emissions than rain-fed rice field area, due to longer period of flooding (Noppol & Nathsuda, 2017). Development of efficient irrigation water management practices such as alternate cycles of wetting and drying could reduce more CH_4 emissions than continuously flooded fields besides saving more water (Noppol & Nathsuda, 2017; Adhya et al., 2000). Moreover, due to the scarcity of freshwater resources available for irrigated agriculture and escalating food demand around the world in the future, it will be necessary to produce more food with minimum water usage (Oliver et al., 2008).

The investigation has provided an historical analysis of methane emission from 1990 to 2014 and made projections from 2015-2030. Methane emissions projected to increase up to 2030 due to the expansion of rice cultivation area in order to fulfil the demands as the country population also projected to increase by 41.5 million in 2040 (Department of Statistics of Malaysia, 2017). Methane has a shorter atmospheric life span of 12-17 years and its reduction will have a much more immediate impact on climate (Smith et al., 2007). Results showed that CH_4 emissions from granary area (irrigated field) was 74% higher than non-granary area (rain-fed field). Earlier study in China indicated that there was no significant difference on the rice yield between flooded rice field and water saving irrigation rice field which proven that non-flooded fields can also promise good harvest besides reducing CH_4 emissions and water wastage (Lo et al., 2016; Oyewole, 2012). Moreover, previous study done in Kedah, Malaysia showed that CH_4 emission rate from non-flooded area with the water saving irrigation method was found relatively low compared to the flooded area (Lo et al., 2016). This calls for further investigation on the effects of water management practices towards rice yield as climate condition in Malaysia may differ due to geographical location.

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