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Non-CO_2 Greenhouse Gas Emissions from Field Burning of Crop Residues in the Philippines: 1990-2015

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ABSTRACT

About 32% of the Philippine land area is devoted for agriculture. Given this, the agriculture sector is expected to increasingly generate significant emissions of non-carbon dioxide (CO_2) greenhouse gases (GHG) and their precursors such as methane (CH_4), carbon monoxide (CO), nitrous oxide (N_2O) and nitrogen oxide (NO_x) from open burning of biomass residues from rice, corn and sugarcane farming. This study was undertaken to generate an updated yet specific inventory of contributions of provinces and regions to the total emissions of such radiative gases. Biomass residues from rice, corn and sugarcane were purposively sampled from the field and subjected to laboratory analyses to determine carbon fraction as well as carbon-nitrogen ratio values. Secondary data on annual crop production were obtained from the PSA while default values of emission factors were secured from the IPCC. Inventory of such non-CO_2 GHwG emissions covering all provinces of the Philippines were undertaken using the IPCC Tier 1 approach. Thematic maps were then generated through simple geographic information system. The study showed an average annual total emissions of 21 Gg, 550 Gg, 0.4 Gg and 15 Gg, respectively for CH_4, CO, N_2O and NO_x from 1990 to 2015 with CO constituting 94% of the emissions. Western Visayas was the top "hotspot" region with about ⅓ of the total emissions. Other "hotspot" regions include Central Luzon, Northern Mindanao and Cagayan Valley. Apart from providing technical and financial support to entice farmers to recycle crop residues, heightened monitoring and implementation of applicable environmental regulations must also be pursued to deter farmers from burning crop residues. Tax and non-tax incentives may be offered likewise to attract investors to put up processing plants utilizing crop residues primarily for power generation.

Keywords: crop residue, open burning, non-CO_2 emissions, inventory, philippines

INTRODUCTION

The total land area of the Philippines is about 30 million hectares (M ha) owwf which 9.67 M ha or about 32% is utilized for agriculture purposes (PSA, 2014). Of this, 51% and 44% were arable and permanent croplands, respectively. In 2014, palay production reached 18.97 million metric tons (MT) from a harvest area of 4.74 M ha (PSA, 2014). Significant production growths were noted in Central Luzon, Cagayan Valley, MIMAROPA, Northern Mindanao and Davao Region. In the same year, corn production reached 7.77 M MT from a harvest area of 2.61 M ha. The regions that contributed significant increment in production were Cagayan Valley, Western Visayas, ARMM, Davao Region and Northern Mindanao. On the other hand, sugarcane produced in 2013 was about 24.6 M MT harvested from an area of approximately 0.44 M ha. Expansion in harvested areas in the provinces of Kalinga, Isabela, Capiz, Cebu, Leyte and Bukidnon were observed also in 2013. Given this, the country's agriculture sector is expectedly generating every year significant amount of wastes called crop residues foremost of which are derived from rice, corn and sugarcane farming. Crop residues are the biomass left in the field after removing the economically important components such as grains and canes. It includes both the stubble left standing during the harvest process and the leaves and stems left over after threshing.

Based on estimates of Strehler and Stützle (1987), global annual crop residue production reached about 3.1 billion tons in which 60% originates from the developing world and the remaining 40% from the developed world. Specifically, sugar cane residues constitute about 11% of the world's

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agricultural waste (Crutzen & Andreae, 1990). In the Philippines, wetland rice cultivated under a moderate level of management produces 0.6 to 0.9 ton of straw per ton of grain (Ponnamperuma, 1984) while corn plantations generate 4,731.92 kg ha^{-1} of potential biomass residues (DAP, n.d.).

For various reasons, these crop residues are openly burnt in fields, which has long been a wide practice among farmers in the Philippines. Rice straw burning for one is not only a cost-effective method but it acts as an effective pest control procedure (Kadam et al., 2000; Dobermann & Fairhurst, 2002). It is also seen as a way of preparing the soil for the next crop as well as releasing nutrients contained in the residue for the next crop cycle (Gadde, et al., 2009). For sugarcane, Mendoza (2015) reported that non-burned canes slows down harvesting work by 40%. Farmers burn sugarcane trash (leaves and tops) to make harvesting easier and to prevent the trash from obstructing succeeding land operations. Besides, weedy fields are associated with the presence of snakes (Mendoza & Samson, 1999). On the other hand, post-harvest burning primarily get rid of remaining trash and tops that obstruct ratoon crop establishment or in preparing the land for new cane establishment.

Meanwhile, similar to that of rice, corn stovers are normally left in the field to dry up and decompose naturally while corn cobs are normally piled up outside processing plants after shelling for use as fuel and for other minor purposes. Only a few farmers practice burning of corn residues and it is difficult to measure how much of the corn residues are burned as no agency monitors this kind of activity. However, an estimated 489,000 tons of cobs are recoverable per year (Mendoza, 2006). The inadequacy of substitute uses for crop residues and the absence of suitable mechanization to manage increasing amounts of residue also led Asian farmers to burn crop residues more and more as a mode of disposal (Yadvinder-Singh et al., 2005 as cited in Bijay-Singh et al., 2008).

In Asia, it is estimated that 730 teragrams (Tg) are burned in a year of which 34% or 250 Tg originate from crop residue burning (Streets et al., 2003). Hao and Liu (1994) reported that the typical annual amounts of biomass burned in the Philippines is about 7.1 Tg. Based on estimates by the Industrial Technology Development Institute [ITDI, n.d.] of DOST, 250 kg of rice straw and 100 kg of rice hull are burned per ton of rice produced. This comes to a total of 5,073,880 tons of rice straw and rice hull burned every year. In terms of land area, 76% and 64% of rice and sugarcane lands, respectively are still burned (Launio et al., 2013; Mendoza & Samson, 2000).

However, the practice of field burning crop residues is usually manifested by uncontrolled and incomplete combustion of such residues which leads to the production of large amounts of greenhouse gases (GHG) such as carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O) and nitrogen oxide (NO_x). CO_2 would not pose a serious concern though because the carbon (C) emitted into the atmosphere is re-sequestered by the vegetation during the succeeding growing season through photosynthesis. Hence, crop residue burning is not a net source of CO_2 (IPCC, 2006) and therefore need not be reported. Crop residue burning is, however, a net source of non-CO_2 and their precursors such as CH_4, N_2O, CO, and NO_x, which are released during combustion (Levine, 1995; IPCC, 2006). In fact, Romasanta et al. (2017) reported that burning of rice straw containing 10% moisture content emits 4.51 g of CH_4 and 0.069 g N_2O kg^{-1} dry weight of straw. This is equivalent to 10.04 kg of CH_4 ha^{-1} and 0.154 kg of N_2O ha^{-1} as averages for both dry and wet cropping seasons. Gadde et al. (2009) estimated that the burning of rice straw contributed 0.05%, 0.18%, and 0.56% of the total amount of greenhouse gas emissions in India, Thailand and the Philippines, respectively.

In the Second National Communication to the UNFCC, field burning of agricultural residues was reported to generate 24.42 Gg of CH_4, 512.74 Gg of CO, 0.6 Gg of N_2O and 21.56 Gg of NO_x during the year 2000 Philippine GHG inventory (DENR, n.d.; UNDP, 2011). This translates to a total of 699 Gg CO_{2e} and accounts two percent of the total agriculture GHG emissions. The year 2000 inventory would appear to have increased by 16% from the 1994 inventory, which reported a total of 581 Gg of CO_{2e} from field residue burning (DENR, 1999).

Little work has been done on the emission inventories and emission allocations of non-CO_2 GHG and their precursors from the burning of major agricultural crop residues from rice, corn, and sugarcane crops in the Philippines. In addition, these inventories were all national in scope which means that specific contributions of provinces and regions to the total national emissions were not assessed in details. Considering that its economy heavily relies on agriculture coupled with a growing population, the country needs to progressively increase agricultural productivity. As such, it is expected to increasingly generate large quantities of agricultural wastes especially from rice, corn and sugarcane farms. This would in turn result to an increase in GHG emissions. Although the Philippines contributes only a small fraction (0.27%) of the global GHG emissions (IPCC, 2007), it is still important to find ways on how to reduce emissions. Undertaking an updated and detailed

Figure 1. Field collection of rice straw samples for laboratory analysis

inventory of non-CO_2 GHG and their precursors at the regional and provincial levels could be used particularly by policymakers in national agencies like the Department of Environment and Natural Resources (DENR) and the Department of Agriculture (DA) as well as at the provincial and municipal/city government levels as basis in setting research, policy and development directions.

This study was undertaken to generate a national, regional and province-wise data on the amount of non-CO_2 GHG emissions generated from field burning of rice, corn and sugarcane residues. Specifically, this study intended to: (1) determine the "hot spot" regions and provinces in the Philippines in terms of crop residue burning, (2) propose practical measures or options to "cool" these identified hot spots and to recommend policy options to address the environmental impacts and implications resulting from the nagging practice of open burning of crop residues among farmers in the country.

METHODOLOGY

Sources of Data

This study heavily utilized secondary data from various sources. Data on region-wise annual crop production from 1990-2015 for rice and corn, and from 1990-2014 for sugarcane were obtained from the database of the Philippine Statistics Authority (PSA). Due to the unavailability of country-specific factors, other necessary data including default values of emission factors were secured from the 1996 IPCC guidelines. These consisted of values fro the following: residue to crop ratio, dry matter fraction, fraction burned in fields, fraction oxidized, and emission ration.

However, carbon fraction as well as carbon-nitrogen ratio of various crop residues were obtained through actual laboratory analysis. Seven samples per crop residue type of rice, corn and sugarcane were taken from 21 purposively selected farms (Figure 1). For practical reasons, only farms in Bukidnon were considered for sampling, which was done from November 2015 to April 2016. These samples were then brought to the laboratory at Soil and Plant Analysis Laboratory in Central Mindanao University (CMU), Musuan, Bukidnon for analysis.

Calculating Non-CO_2 Emissions from Crop Residue Field Burning

Inventory of non-CO_2 GHG emissions (such as CH_4, CO, N_2O and NO_x) covering all regions of the Philippines were undertaken using the IPCC Tier 1 method. The Tier 2 approach or higher could not be used as the Philippines has not developed yet its own country-specific default emission factors for crop residues that are openly burnt. The method involved first the estimation of total carbon released using the following equation:

$$\text{Total carbon released (tonnes of carbon)} =$$
$$\sum_{\text{all crop types}} \text{annual production (tonnes of biomass per year),}$$
$$x \text{ the ratio of residue to crop product (fraction),}$$
$$x \text{ the average dry matter fraction of residue (tonnes of dry matter per tonne of biomass),}$$
$$x \text{ the fraction actually burned in the field,}$$
$$x \text{ the fraction oxidized,}$$
$$x \text{ the carbon fraction (tonnes of carbon per tonne of dry matter)}$$

Values on total carbon released were then used to estimate the following:

CH_4 emissions = (carbon released)x (emission ratio)x16/12
CO emissions = (carbon released)x(emission ratio)x28/12
N_2O emissions = (carbon released)x(N/C ratio)x(emission ratio)x 44/28
NO_x emissions = (carbon released)x(N/C ratio)x(emission ratio)x 46/14

The coefficients used in the inventory as well as

Table 1. Coefficients used in the inventory.

Crop	Residue to Crop Ratio[a]	Dry Matter Fraction[a]	Fraction Burned in Fields[a]	Fraction Oxidized[a]	Carbon Fraction[b]	Nitrogen-Carbon Ratio[b]	Emission Ratio[a]
Dry Season Rice	1.4	0.4	0.59	0.9	0.433	0.11	0.004 for CH_4; 0.06 for CO; 0.007 for N_2O; and 0.121 for NO
Wet Season Rice	1.4	0.83	0.12	0.7	0.433	0.11	
Corn	1.0	0.4	0.25	0.9	0.5264	0.12	
Sugarcane	0.8	0.9	0.25	0.9	0.5224	0.007	

[a]Source: IPCC, 1996; [b]Primary data

primary data gathered in the conduct of the study are presented in Table 1.

GIS Map Generation

Data on regional and provincial emissions of non-CO_2 GHG emissions were utilized in generating geographic information system (GIS)-based maps. The process required the utilization of GIS application software with base maps sourced from PhilGIS. ArcMap ver. 10.1 was used to generate the final spatial maps. Such maps were used to identify the so-called "hotspot" regions and provinces in the country. The term "hotspots" here refers to the Top 5 and 10 regions and provinces, respectively, in terms of computed mean annual emissions of non-CO_2 greenhouse gases.

Statistical Analysis

All data generated in this study were analyzed using descriptive statistics. This included

Table 2. Region-wise estimated annual amounts of agricultural crop residue and those burned in the field, 1990-2015.

Ratio	Annual volume of Production, Gg			Annual Volume of Agricultural Crop Residue, Gg			Annual Agricultural Crop Residue Burned in the Field, Gg		
	Rice	Corn	Sugarcane	Rice	Corn	Sugarcane	Rice	Corn	Sugarcane
CAR	309.1	115.9	11.7	173.1	46.3	8.4	102.1	11.6	2.1
Ilocos Region	1284.1	251.9	20.4	719.1	100.8	14.7	424.3	25.2	3.7
Cagayan Valley	1736.9	1043.4	218.7	972.7	417.4	157.4	573.9	104.3	39.4
Central Luzon	2414.5	131.0	1358.6	1352.1	52.4	978.2	797.7	13.1	244.6
CALABARZON	396.6	64.6	1953.0	222.1	25.8	1406.1	131.0	6.5	351.5
MIMAROPA	778.1	77.2	0	435.7	30.9	0	257.1	7.7	0
Bicol Region	865.0	145.1	243.0	484.4	58.0	174.9	285.8	14.5	43.7
Western Visayas	1698.9	172.3	12751.2	951.4	68.9	9180.9	561.3	17.2	2295.2
Central Visayas	242.5	176.5	2170.5	135.8	70.6	1562.8	80.1	17.6	390.7
Eastern Visayas	676.9	84.0	556.7	379.1	33.6	400.9	223.7	8.4	100.2
Zamboanga Peninsula	474.2	192.5	0.4	265.5	77.0	0.3	156.7	19.2	0.1
Northern Mindanao	514.2	911.5	2494.3	287.9	364.6	1795.9	169.9	91.2	449.0
Davao Region	415.9	215.0	430.9	232.9	86.0	310.2	137.4	21.5	77.6
SOCCKSARGEN	1002.6	1178.0	639.2	561.5	471.2	460.3	331.3	117.8	115.1
CARAGA	363.4	84.0	0	203.5	33.6	0.0	120.1	8.4	0.0
ARRM	421.0	668.8	55.2	235.7	267.5	39.7	139.1	66.9	9.9
TOTAL	13593.8	5511.8	22753.5	7612.5	2204.7	16382.5	4491.4	551.2	4095.6

Source: Philippine Statistics Authority
1 gigagram (Gg) = 1,000 metric tons

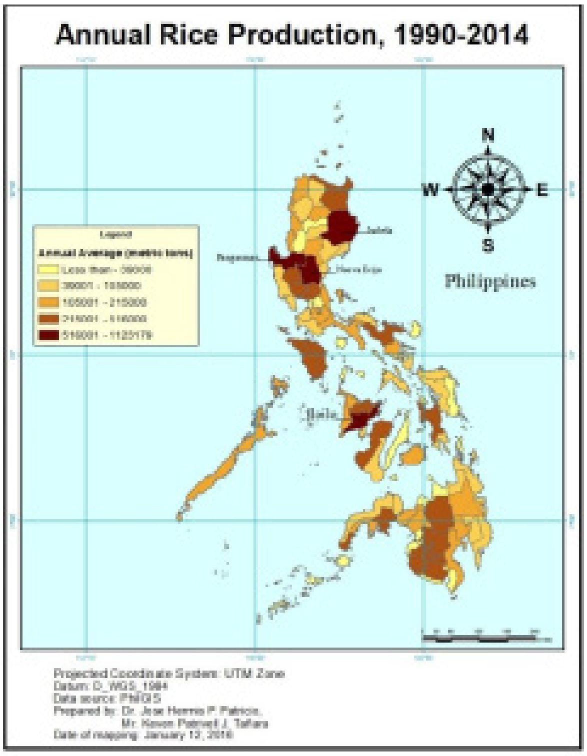

Figure 2. Mean annual rice production in the Philippines Data sources: PSA, 2016 & PhilGIS, nd

trend analysis of regional variations of emissions of non-CO_2 GHG in the country.

RESULTS AND DISCUSSION

The Volume of Crop Production, and Residue Generation and Burned in the Field

The volume of rice production in the Philippines posted an annual mean of about 13.6 M MT (13,600 Gg) from 1990 to 2015 with Central Luzon, Cagayan Valley and Western Visayas regions topping the list (Table 2). Production of this crop yielded a 94.8% increase during this 25-year period. The most notable increases in yield are recorded in the provinces of Isabela, Pangasinan, Nueva Ecija, and Iloilo (Figure 2). This is primarily attributed to expansion in production areas, utilization of high yielding varieties, availability of irrigation water, and improved fertilizer and pest management (PSA, 2016).

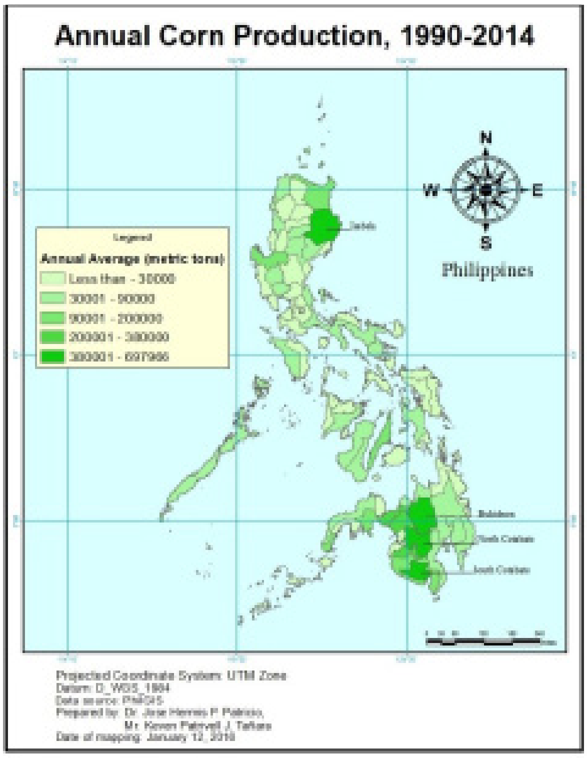

Figure 3. Mean annual corn production in the Philippines. Data sources: PSA, 2016 & PhilGIS, nd

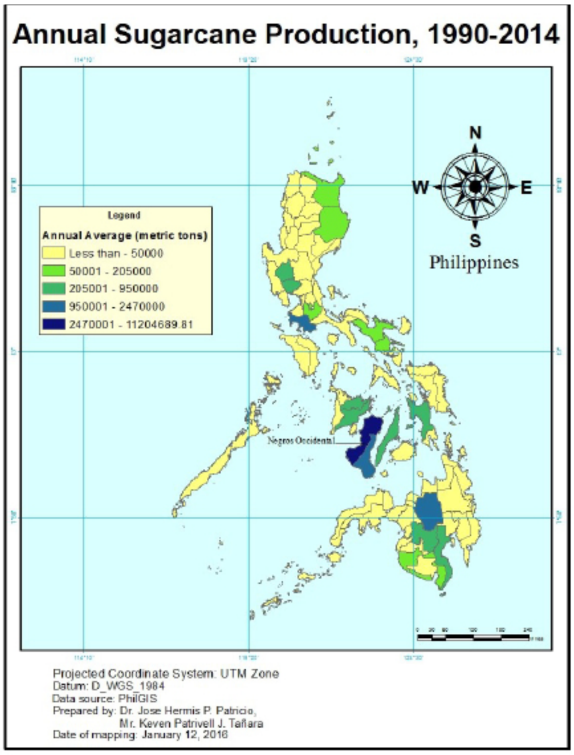

Figure 4. Mean annual sugarcane production in the Philippines.
Data sources: PSA, 2016 & PhilGIS, nd

Corn production at around 7,500 Gg in 2015 was higher by 35.4% as compared to 1990. Annually, the corn subsector yielded about 5,500 Gg. The corn-producing regions include SOCCSKSARGEN, Cagayan Valley and Northern Mindanao especially in the provinces of North and South Cotabato, Isabela, and Bukidnon as shown in Figure 3. PSA (2016) reported that increase in corn harvests was associated to sustained use of hybrid and open pollinated varieties of seeds, and favorable weather condition.

On the other hand, sugarcane production in the country rose by 22.8% from 1990 to 2015 at an annual rate of about 22,700 Gg as shown also in Table 2. The Western Visayas region had the greatest particularly the provinces of Negros Occidental and Negros Oriental (Figure 4). Other provinces like Bukidnon and Batangas also showed remarkable increases. Increase in production areas and efficient usage of fertilizer were among the reasons cited by PSA (2016).

Because of increased volume of production of these three primary agricultural crops, volume of crop residue generated and burnt consequently increased. Based on estimates of Strehler and Stützle (1987), global annual crop residue production reached about 3.1 billion tons in which 60% originates from the developing world and the remaining 40% from the developed world. This is out of the 140 billion MT of biomass that is generated globally every year from agriculture (UNEP, 2009). Annually, 7.1 Tg of crop residue is burned openly in the Philippines as reported by Streets et al. (2003).

Specifically, sugarcane residues constitute about 11% of the world's agricultural waste (Crutzen & Andreae, 1990). In the Philippines, it is estimated that about 64% of the sugarcane fields are burned before or after harvesting (Mendoza & Samson, 1999). Traditional sugarcane farmers openly burn large volumes of the crop's trash consisting of leaves and tops to hasten harvesting and the succeeding land operations. As shown in Table 2 earlier and Figure 5, sugarcane residue generation and burned in fields in the Philippines is about 16,400 Gg and 4,100 Gg, respectively or a contribution of 63% of the total in the 1990-2015 period. In terms of area planted, sugarcane is listed in the top five agricultural crops. In fact, its production area surged by 79.1%, that is, from 235,269 ha in 1990 to 421,312 in 2015 (PSA, 2016). Production is mainly focused in Western Visayas, Northern Mindanao, Southern Tagalog, and Central Luzon.

Rice is the second greatest residue-generating crop at 29%. For the assessment period, rice residue generated is on the average of about 7,600 Gg while the one burned is around 4,500 Gg. Malaysia produced around 8,750 Gg of rice straw in 2007 (John, 2013). Large volumes of straw are mostly burned during the dry season except in the northern parts of the Philippines where it

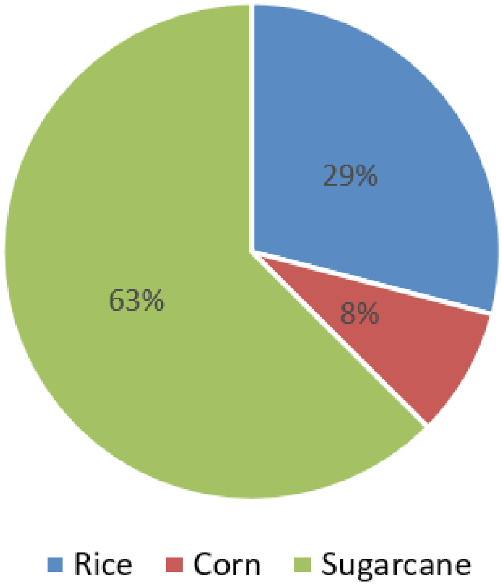

Figure 5. Contribution of different agricultural crops in residue generation.

is utilized as chief feed source for animals and as mulching material for vegetable crops (Villarin, et al. 1999). Rice as a residue source is expected to continuously surge given that the area utilized in growing this crop globally is predicted to rise by 4.5% by 2030 (FAO, 2003). In the Philippines, wetland rice cultivated under a moderate level of management produced between 0.6 and 0.9 tonnes of straw per tonne of grain (Ponnamperuma, 1984). Mendoza and Samson (1999) estimated that about 90% of Filipino rice farmers simply burn their rice straw. Globally, emissions from rice production and burning of biomass were heavily concentrated in the group of developing countries, with 97% and 92% of world totals, respectively (Smith et al., 2007). Street et al. (2003) reported that in Asia, around 730 Tg of biomass are burned per year from both anthropogenic and natural sources.

Meanwhile, DAP (n.d.) reported that the Philippines produces 4,731.92 kg ha^{-1} of potential biomass residues from corn plantation. In this present study, corn residues in the form of stovers and cobs generated the least amount at 8% of the total volume of crop residues generated in the country annually from 1990-2015. On the average, about 2,200 Gg of corn residues were generated and 550 Gg were burned during this period. Villarin *et al.* (1999) reported that only a few farmers practice burning of corn residues which come mostly from white and yellow corn varieties. Instead of burning, most farmers just normally leave the stovers in the field to naturally decompose while corn cobs are usually piled up outside the milling plants after shelling for use primarily as fuel (Ramat, 2007).

Emissions of Non-CO_2 Greenhouse Gases

Crop residue burning is assumed to be a non-net source of CO_2 because when this gas is

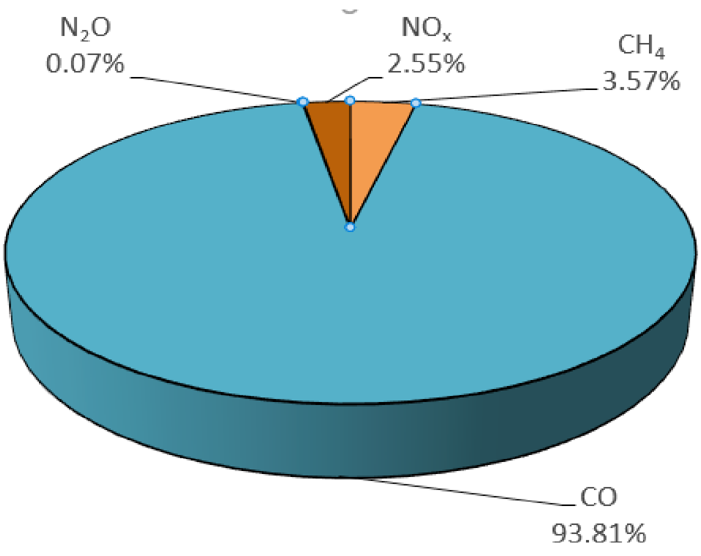

Figure 6. Percentage distribution of non-CO_2 emissions from crop residue burning

Table 3. Mean annual emissions of non-CO_2 greenhouse gases from various regions in the Philippines, 1990-2015.

Region	Emissions, Gg yr^{-1}			
	CH_4	CO	N_2O	NO_x
CAR	0.2	6.5	0.01	0.2
Ilocos Region	1.0	25.0	0.02	0.9
Cagayan Valley	1.6	40.8	0.04	1.4
Central Luzon	2.3	60.4	0.05	1.8
CALABARZON	1.2	30.7	0.02	0.7
MIMAROPA	0.6	14.5	0.01	0.5
Bicol Region	0.7	19.4	0.02	0.6
Western Visayas	6.9	182.6	0.11	4.1
Central Visayas	1.2	31.2	0.02	0.7
Eastern Visayas	0.7	19.3	0.02	0.6
Zamboanga Peninsula	0.4	9.8	0.01	0.3
Northern Mindanao	1.7	44.8	0.03	1.1
Davao Region	0.5	14.0	0.01	0.4
SOCCSKSARGEN	1.3	33.4	0.03	1.0
CARAGA	0.3	7.1	0.01	0.2
ARRM	0.5	12.7	0.01	0.4
TOTAL	20.9	550.4	0.41	15.0

released into the atmosphere, it is reabsorbed in the following crop growing season. Nevertheless, burning process does not only emit CO_2 but other gases or precursors of greenhouse gases as well that arise from partial combustion of the fuel. Such farming practice therefore is an important source of carbon monoxide (CO), methane (CH_4), and nitrogen (e.g., N_2O, NO_x) species (Levine, 1994). The present study revealed that around 94% of the total amount of non-CO_2 greenhouse gases emitted through crop residue burning in the Philippines is CO (Figure 6). The remaining six percent consists of CH_4, NO_x, and N_2O emissions.

Annually, around 550 Gg of CO, 21 Gg of CH_4, 15 Gg of NOx, and 0.4 Gg of N_2O are produced in the country due to crop residue burning (Table 3). This is comparable to the amount of emissions generated for the year 2000 wherein the Philippines emitted 512.74, 24.42, 21.56 and 0.60 Gg of CH_4,

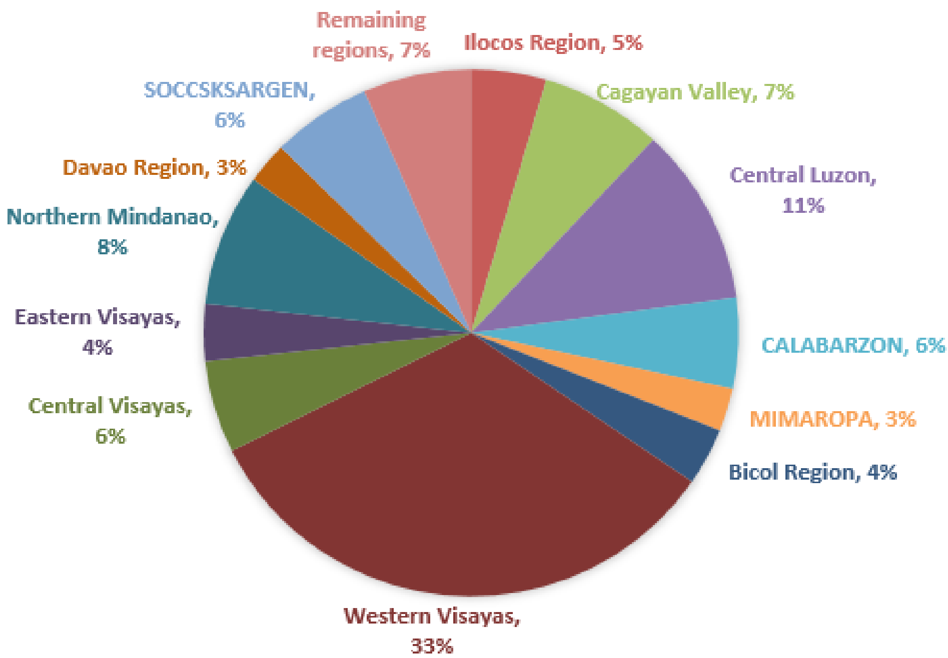

Figure 7. Regional percentage contribution to non-CO_2 emissions from crop residue burning, 1990-2015.

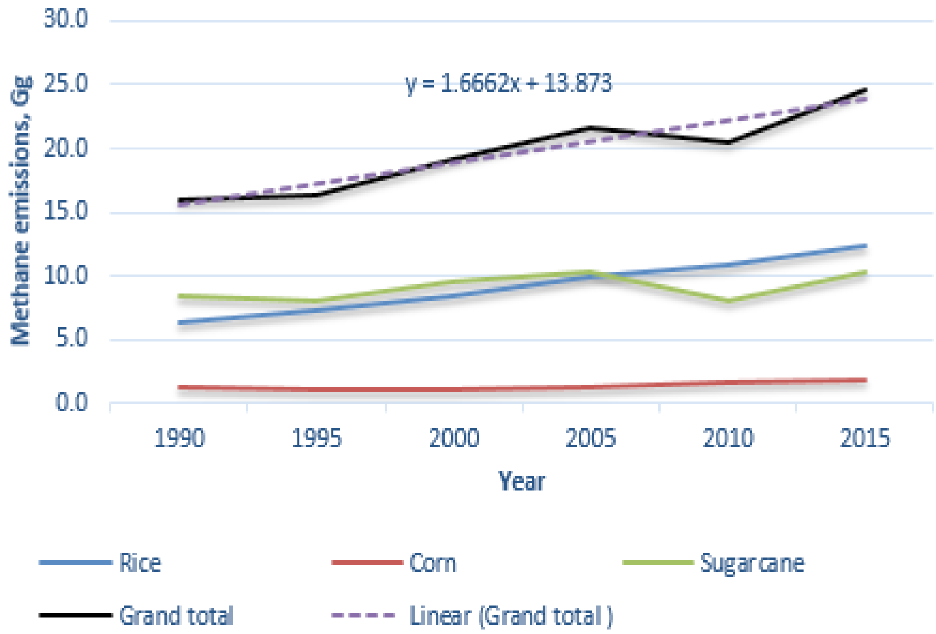

Figure 8. Methane (CH_4) emissions from crop residue burning, 1990-2015.

CO, N_2O, and NO_x, respectively (UNDP, 2011). One-third of the emissions originate from the Western Visayas region followed by Central Luzon (11%) and Northern Mindanao (8%) as presented in Figure 7. CAR, CARAGA, ARRM, and Zamboanga Peninsula are the regions with the least emissions from crop residue burning. Gadde et al., (2009) estimated that the burning of rice straw alone contributed 0.05%, 0.18%, and 0.56% of the total amount of greenhouse gas emissions in India, Thailand and the Philippines, respectively.

CH_4 is one of the most potent greenhouse gases with a global warming potential (GWP) 21 times greater than that of CO_2. In 2005, it was estimated that the agriculture sector contributed 33 $GtCO_{2e}$ of CH_4 per year (Smith et al., 2007). Agriculture accounts around 50% of this gas of

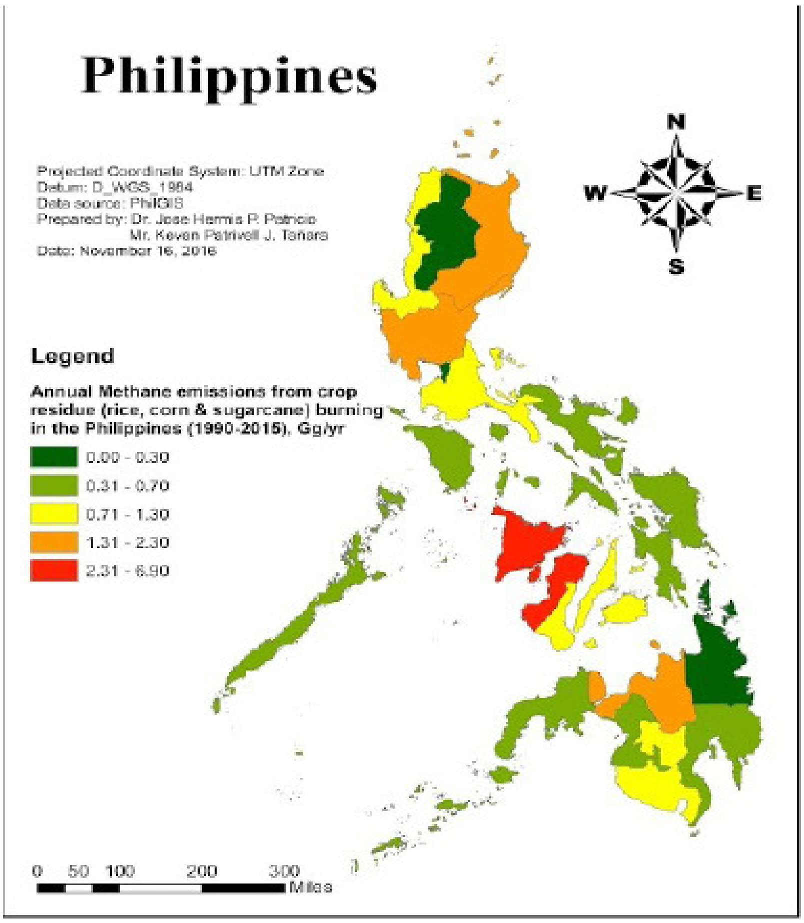

Figure 9. Provincial distribution of methane emissions from crop residue burning, 1990-2015 (Gg yr-1).

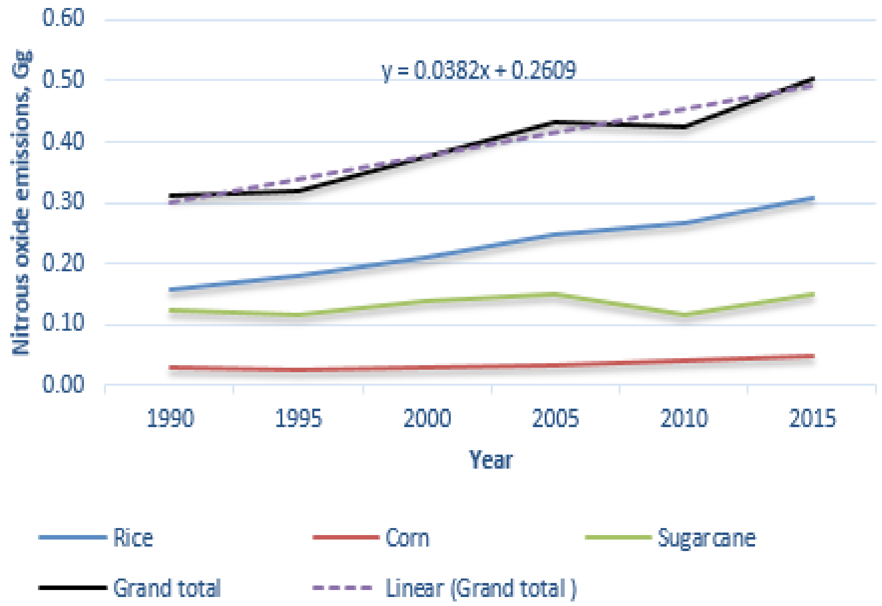

Figure 10. Carbon monoxide (CO) emissions from crop residue burning, 1990-2015.

the global anthropogenic emissions in 2005. In this study, CH_4 emissions in the country indicates an increasing trend (y = 1.6662x + 13.873). In fact, it surged by about 54% between 1990 (16 Gg) and 2015 (24.6 Gg) as shown in Figure 8. Rice and sugarcane are the greatest contributors to CH_4 emissions in 2015 at 12.4 Gg and 10.32 Gg, respectively. Considered "hotspot" areas are the provinces of Western Visayas primarily Negros Occidental and Iloilo (Figure 9). This is primarily associated with the high volume of sugarcane production in the area.

Like CH_4, CO emissions from crop residue burning in the Philippines is moving on an upward trend (y = 43.785x + 364.57) as shown in Figure 10. CO in itself is not a greenhouse gas but a precursor in the formation of CO_2 which is the most abundant

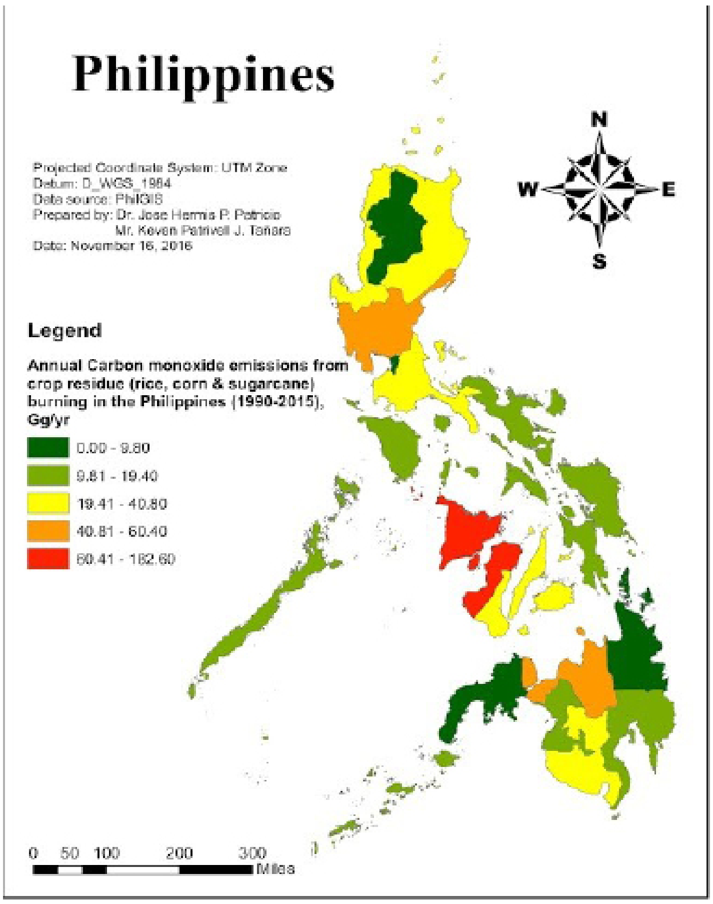

Figure 11. Provincial distribution of carbon monoxide emissions from crop residue burning, 1990-2015 (Gg yr^{-1}).

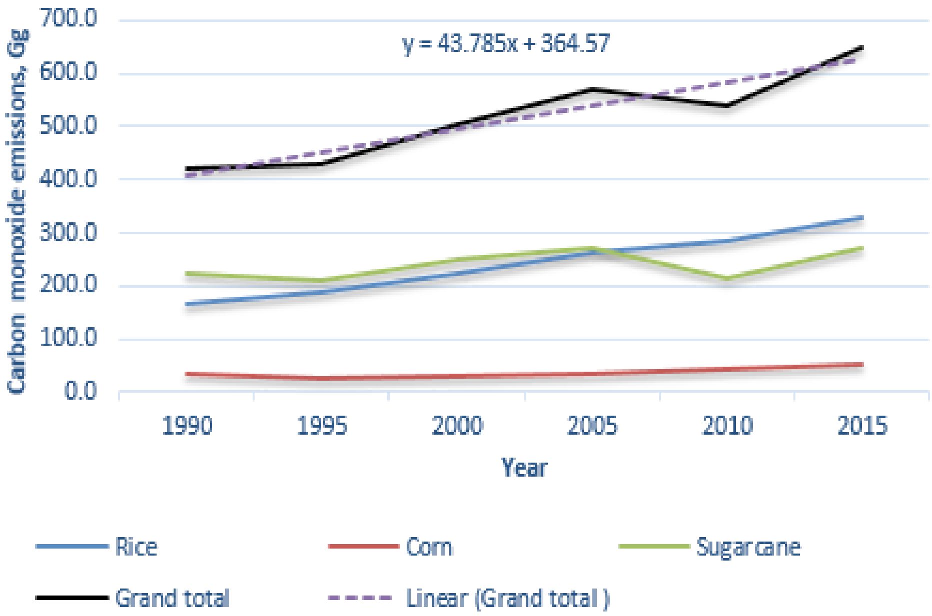

Figure 12. Nitrous oxide (N_2O) emissions from crop residue burning, 1990-2015.

heat-trapping gas in the atmosphere causing global warming. Gupta et al. (2004) reported that a tonne of rice straw burned would produce 60 kg of CO. In this present study, CO emissions posted an increase of 54% between 1990-2015 at an average of 550 Gg yr^{-1}. Similar to CH_4, emissions of this gas are concentrated as well in the Western Visayas region at a range of 60-183 Gg yr^{-1} (Figure 11).

Meanwhile, N_2O is a long-lasting, powerful GHG with GWP of 310 times to that of CO_2. Like CH_4, N_2O emissions from crop residue burning are greatly lower than CO_2. Nevertheless, the very large GWP makes N_2O a chief contributor to climate change. In this study, total N_2O emissions from crop residue burning in the country recorded an increase of 67% from 1990 to 2015 (Figure 12). With an average of 0.41 Gg yr^{-1}, most of the N_2O emissions came from burning of rice straws and sugarcane

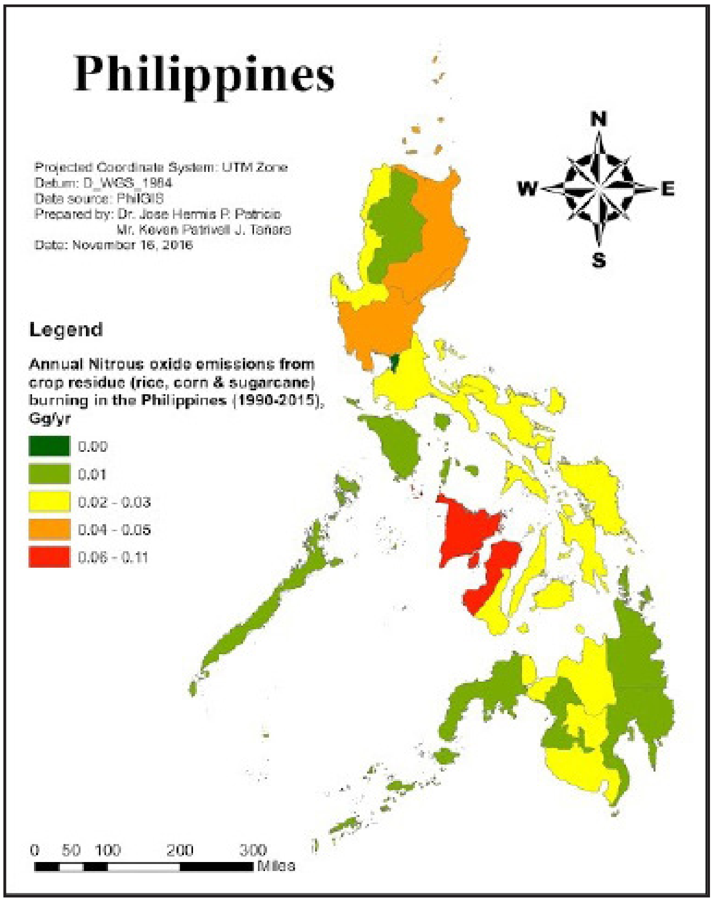

Figure 13. Provincial distribution of nitrous oxide emissions from crop residue burning, 1990-2015 (Gg yr-1).

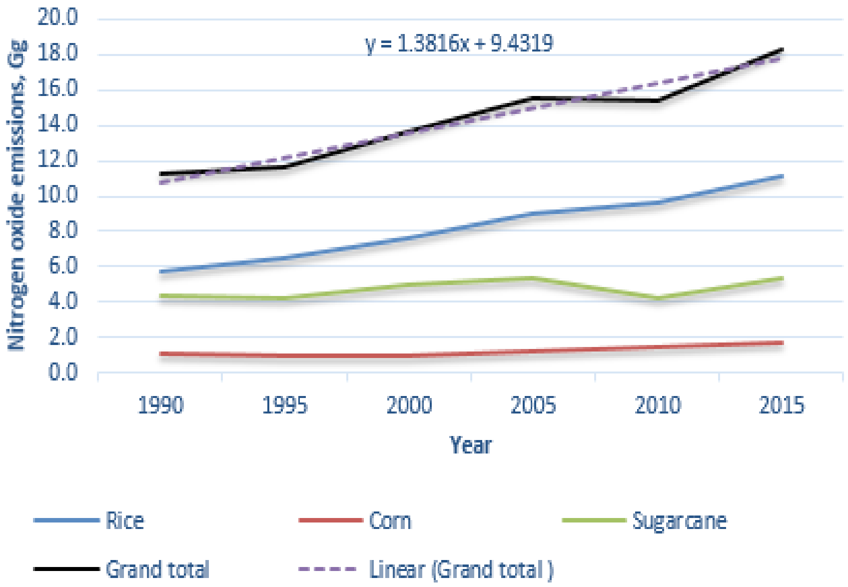

Figure 14. Nitrogen oxide (NO_x) emissions from crop residue burning, 1990-2015.

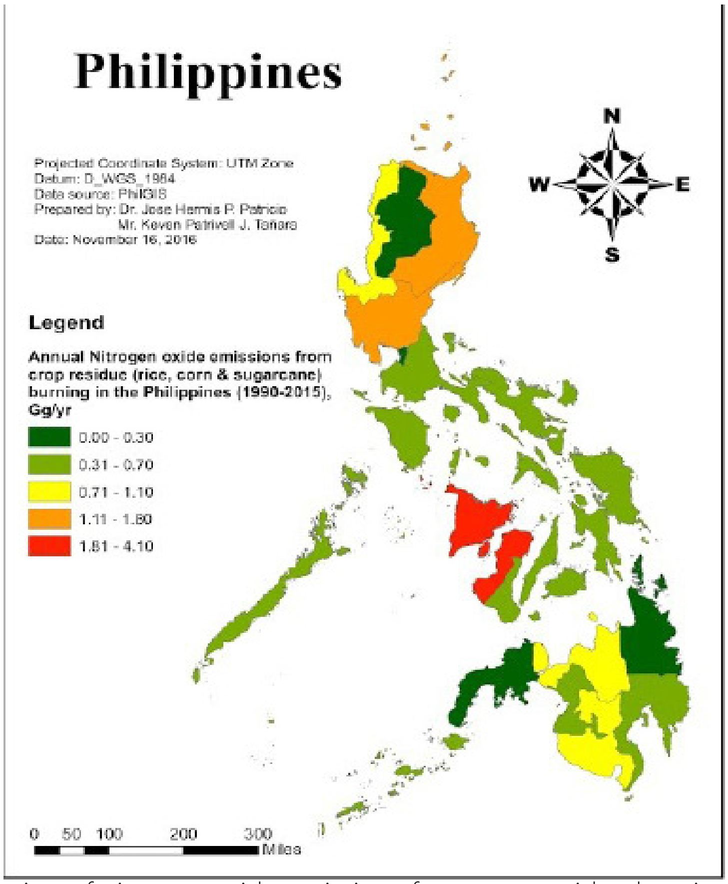

Figure 15. Provincial distribution of nitrogen oxide emissions from crop residue burning, 1990-2015 (Gg yr^{-1}).

particularly from Western Visayas, Central Luzon and Cagayan Valley regions as presented in Figure 13. The Western Visayas provinces generated an annual mean 0.6-0.11 Gg of N_2O.

Finally, emissions of NO_x in the country during the assessment period rose by more than 60% from 1990-2015, that is from 11.2 to 18.2 Gg per year (Figure 14). Similar to other gases, NO_x are emitted mostly from the following hotspot regions: Western Visayas, Central Luzon, Cagayan Valley, Northern Mindanao, SOCCSKSARGEN and the Ilocos Region (Figure 15). NO_x is also an important greenhouse gas that lasts 166 years in the atmosphere with a GWP of 296 times compared to CO_2 (IPCC, 2006).

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the study, the following conclusions are drawn:

1. There is an upward trend in the volume of crop residue generated and burned in the Philippines from

1990 to 2015 due to increased volume of production of rice, sugarcane and corn which is attributed to expansion in production areas, utilization of high yielding varieties, availability of irrigation water, and improved fertilizer and pest management;

2. Sugarcane generated about 63% of the total volume of crop residue produced annually while rice and corn contributed 29% and 8%, respectively;

3. There is likewise an observed upward trend in the mean annual emissions of GHG in the Philippines from crop residue burning from 1990 to 2015 which are estimated at 21 Gg CH_4, 550 Gg CO, 0.4 Gg N_2O and 15 Gg NO_x, with CO constituting 94% of the total emissions; and

4. There is likewise an observed upward trend in the mean annual emissions of CH_4, CO, N_2O and NO_x in the Philippines from crop residue burning from 1990 to 2015 which are estimated at 21 Gg, 550 Gg, 0.4 Gg and 15 Gg, respectively with CO constituting 94% of the total emissions; and

5. Western Visayas, Central Luzon, Ilocos Region, Northern Mindanao and Cagayan Valley are considered "hotspot" regions particularly the provinces of Negros Occidental and Iloilo. However, the provinces of Isabela, Pangasinan, Nueva Ecija, North and South Cotabato, Tarlac, Cagayan, Leyte, Camarines Sur and Bukidnon are becoming "hotspot" areas as well based on 2015 data.

Based on the foregoing, the following recommendations are forwarded:

1. Future local and international research networking and collaboration need to be established to find much better sustainable technologies and overcoming logistical constraints in harnessing potential renewable energy from crop biomass residues such as production of biofuel which is the conversion of biomass to liquid fuel or as source of biopower which involves the conversion of biomass to electricity;

2. The government should consider creating investment opportunities such as provision of tax and non-tax incentives to locals and foreigners who wish to invest in processing plants that utilize crop residues particularly for power generation. This is in consonance with Republic Act 9136 (Electric Power Industry Reform Act of 2001) and Republic Act 9367 (Biofules Act of 2006). Tax incentives may include among others income tax holiday for a certain period of operation of the processing plant, and reasonable tax and duties exemptions on equipment, accessories, spare parts, and machinery. Non tax incentives may come in the form of simplified procedures in the equipment import and hiring of foreign nationals particularly for highly technical positions;

3. In tandem with industry leaders, chief executives in provinces located in "hotspot" regions such as in Western Visayas should encourage and provide the necessary policy, technical and financial support to sugarcane farmers to engage in ecological sugarcane farming where residues are conserved in the field and allowed to decompose, and where biological nitrogen-fixing sugarcane cultivars are utilized;

4. The DENR, DA and concerned local government units must pursue aggressive information, education and communication campaigns targeting farming communities to heighten their awareness on the negative environmental and health impacts associated with open burning crop residues. This should be pursued together with heightened monitoring and implementation of environmental regulations prohibiting open residue burning; and

5. There is a need to come up with more precise estimates on non-CO_2 greenhouse gas emissions from crop residue burning using the Tiers 2 and 3 methodologies of IPCC.

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