A Differentiation of Estimated Methane Emissions from Domestic Wastewater Handling using Different IPCC Guidelines

S. Nairum[1,2] and S. Towprayoon[1,2,*]

[1]The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Bangkok, Thailand
[2]Center for Energy Technology and Environment, Ministry of Education, Thailand
*Corresponding author: sirin@jgsee.kmutt.ac.th

Abstract: This study was conducted to estimate methane emissions from domestic wastewater handling in Thailand during 1990-2008 by comparing the revised 1996 IPCC guidelines with the 2006 IPCC guidelines using results from activity data, assumptions and major parameters. The results using the revised 1996 IPCC guidelines showed that the methane emissions from domestic wastewater handling were higher than when using 2006 IPCC guidelines by about 1.49-1.64 times. These were due to the different parameters used and their assumptions including the fraction of population income group and the degree of utilization of treatment or discharge for each income group used in the 2006 IPCC guidelines. The differences in this study are due to the assumption of data of income fraction which is based on gross provincial product (GPP). Methane emissions from this study were higher than estimates reported elsewhere. The results were due to different BOD loads and different assumptions of urban and rural populations.

Keyword: methane, domestic wastewater, IPCC guidelines.

1. Introduction

Global warming has become a major environmental problem due to increases in greenhouse gases (GHG) as a result of human activity. The three main greenhouse gases are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These gases are emitted continually from various anthropogenic sources [1]. CH_4 is one of the most important greenhouse gases because of its high global warming potential. Emissions of methane can occur both in the agricultural and waste sectors of society. These two sectors are the key emission sources of CH_4, particular in developing countries such as Thailand. Thailand's GHG emissions are from the energy sector (69.6%), agriculture (22.6%), waste production (4.1%), and industrial process (7.2%) [2]. Especially notable were the increases in emissions from the waste sector during 2000-2004 of 7 percent per year which is in the second highest increasing sector in the country in terms of emissions. Emissions from the waste sector are related to population size and human activities. Reduction of GHG in the waste sector would not only help abate global warming but also would bring benefits to human health. Proper waste management can also lead to sustainable development and poverty eradication. Reduction of GHG in the waste sector is potentially become National Appropriate Mitigation Actions (NAMAs) in many developing country due to its win-win co-benefits. In addition, the measuring, reporting and verification (MRV) of these activities need to be clarified. The easiest method is to follow the IPCC national inventory guidelines. However, there were new parameters introduced in the 2006 IPCC guidelines [3], particularly on domestic wastewater emission methodology, that are different from the revised 1996 guidelines [4-6]. The implementation of these two methodologies is interesting in terms of discrepancies of emissions output. In Thailand, the domestic wastewater handling system produced 2.301 Gg CH_4 emissions in 1990 [7] and 1.77 Gg in 2000 [8] using 1996 IPCC revised guidelines. This study estimated greenhouse gas emissions from domestic wastewater handling categories by using the revised 1996 IPCC guidelines [6-8] and the 2006 IPCC guidelines [3] in order to reveal and discuss the gap in activity data, assumption of parameters, emission factors used as well as the final output of emission volume for national greenhouse gas inventories. Besides, the result of current estimations will bring the increasing of greenhouse gas emissions from domestic wastewater to the concern of relevant government organizations. It also has the advantage of assisting in domestic wastewater management such as a wastewater management plan, and can be used to develop potential NAMAs and to clarify the MRV system.

2. Experimental

2.1 Estimation of Methane Emissions using the Revised 1996 IPCC Guidelines

Domestic wastewater emissions are calculated by the equation:

$$WM = \sum_i (TOW_i \times EF_i - MR_i) \quad (1)$$

Where:
- WM = Total methane emissions from wastewater ($kgCH_4$)
- TOW_i = Total organic waste for wastewater type i (kgDC/yr)
- EF_i = Emission factor for wastewater type i ($kgCH_4$/kgDC)
- MR_i = Total amount of methane recovered or flared from wastewater type i ($kgCH_4$)

The total organic wastewater is calculated by using the equation:

$$TOW_{dow} = P \times D_{dom} \times (1-DS_{dom}) \quad (2)$$

Where:
- TOW_{dow} = Total domestic organic waste-water in kgBOD/yr
- P = Population per 1,000 people
- D_{dom} = Domestic degradable organic component in kgBOD/1,000 persons/yr
- DS_{dom} = Fraction of domestic/ comercial degradable organic component removed as sludge

Emission Factors (EFs) resulting from the multiplication of maximum methane producing capacity (B_o) and methane conversion factor (MCF) which differs from the technologies used. It can be calculated by equation below:

$$EF = B_o \times \text{Weighted Average of MCFs} \quad (3)$$

Where:
- EF = Emission factor
- B_o = Maximum methane producing capacity ($kgCH_4$/kgBOD)
- MCF = Methane conversion factor (Fraction)

2.2 Estimation of Methane Emissions by using 2006 IPCC Guideline

Step 1: The estimated total degradable organic carbon in wastewater (TOW) is calculated by using equation (4) below:

$$TOW = P \times BOD \times 0.001 \times I \times 365 \quad (4)$$

Where:

TOW = Total organic compounds in wastewater in the inventory year (kgBOD/yr)
P = Country population in the inventory year
BOD = Country-specific per capita BOD in the inventory year (g/person/day)
0.001 = Conversion from grams BOD to kgBOD
I = Correction factor for additional industrial BOD discharged into sewers

Step 2: Estimations of the emission factor for each domestic wastewater treatment/discharge pathway or system was calculated by using equation (5) below:

$$EF_i = B_o \times MCF_i \quad (5)$$

Where:

EF_j = Emission factor for each treatment/discharge pathway or system ($kgCH_4$/kgBOD)
B_o = Maximum methane producing capacity ($kgCH_4$/kgBOD)
MCF = Methane conversion factor (Fraction)

Step 3: Methane emissions adjusted for possible sludge removal and/or methane recovery, and a total of the results for each pathway/system were calculated by using equation (6) below:

$$CH_4 \text{ emissions} = [\sum(U_i \bullet T_{i,j} \bullet EF_j)](TOW - S) - R \quad (6)$$

Where:

CH_4 emissions = CH_4 emissions in the inventory year ($kgCH_4$/yr)
TOW = Total organics in wastewater in the inventory year (kgBOD/yr)
S = Organic component removed as sludge in the inventory year (kgBOD/yr)
U_i = Fraction of population in income group i in the inventory year
$T_{i,j}$ = Degree of utilisation of treatment/discharge pathway or system j, for each income group fraction i in the inventory year
I = Income group: rural, urban high income and urban low income
J = Each treatment/discharge pathway or system
EF_j = Emission factor ($kgCH_4$/kgBOD)
R = Amount of CH_4 recovered in the inventory year ($kgCH_4$/yr)

3. Activity Data

3.1 Population size

The population data was collected from the Department of Provincial Administration for 1990-2008 [9]. According to the classification of the local administration organizations in Thailand, the country was divided into five categories, namely the Bangkok Metropolitan Administration, Patthaya city, the Provincial Administration Organization, the Municipality, and the Sub-District Administrative Organization. In terms of the Municipalities, they can be classified into three types namely: Nakorn, Muang and Tambol Municipality according to its population size. Likewise the Sub-District Administrative Organization was categorized into large, medium and small sizes. In this study, the population was divided into two areas; urban community areas and rural community areas. This was due to the differences in their respective wastewater pathways or systems. It was assumed that in urban community areas without a centralized wastewater treatment plant, wastewater would be treated by a septic tank system. In contrast, in rural community areas, it was treated in latrines or discharged directly into the river or environment. The population in urban community areas included the population in the Bangkok Metropolitan Administration, Patthaya, the Municipality, and large Sub-District Administrative Organizations while other areas were considered to be rural communities. The data for population of the Municipalities, Patthaya and Bangkok areas were collected from online information of Department of Provincial Administration [9].

3.2 Degradable organic material in wastewater

Degradable organic materials that are expressed as biochemical oxygen demand (BOD) were not available for each area of the city. The population equivalent (BOD/person) was proposed by the Office of Environmental Policy and Planning (1995) [10]. It was defined as the organic material that was measured in terms of BOD from human daily activity, and could be estimated by the multiplying of BOD in domestic wastewater (g/l), and the volume of wastewater generation (l/capita/day). These values were reported every 5 years. Therefore, interpolation and extrapolation techniques were used for calculating the value of the population equivalent (BOD/person). For determining the BOD/person, the interpolation was expressed in equation (7), and extrapolation was equation (8).

$$Y_t = Y_{start} + \frac{(T_t - T_{start})}{(T_{end} - T_{start})} * (Y_{end} - Y_{start}) \quad (7)$$

$$Y_t = Y_{t-1} + (Y_{t-1} - Y_{t-2}) \quad (8)$$

Y=BOD (g/l)
T=year

The population equivalent (BOD/person) gradually increased every year. This has led to an increase of wastewater and BOD load. Comparing the values in regions of Thailand as seen in Table 1, the values of the Central regions are the highest at 38.0-43.8 gBOD/capita/day, followed by the South (36.8-42.8), the North (32.4-36.4) and the Northeast (32.4-36.4).

Table 1. Population equivalent in term of gBOD/capita-day used in this study.

Year	Population equivalent (gBOD/capita-day)			
	Nothern	Northeastern	Central	Southern
2000	32.4	32.4	38.0	36.8
2001	33.2	33.2	39.0	37.4
2002	34.0	34.0	40.0	38.0
2003	34.4	34.4	40.6	38.8
2004	34.8	34.8	41.2	39.6
2005	35.2	35.2	41.8	40.4
2006	35.6	35.6	42.4	41.2
2007	36.0	36.0	43.0	42.0
2008	36.4	36.4	43.8	42.8

3.3 Domestic sludge

Domestic sludge is a by-product of domestic wastewater treatment plants. The disposal of sludge by an anaerobic system may generate greenhouse gases, such as CH_4. In the Bangkok area, sludge is treated by composting and used as fertilizer. Data on sludge management at the provincial level are not available and therefore were assumed to be treated by land application and the emissions from domestic sludge were not included in this study.

3.4 Fraction of population income group

Wastewater treatment systems or pathways were different in each area especially in developing countries. The 2006 IPCC Guidelines [3] outlined the methodology for estimating CH_4 emissions from domestic wastewater, by using the fraction of population in three income groups: rural, urban high income and urban low income. In Thailand, the income groups were not classified this way, however, the population was divided into two areas, rural and urban, which was similar to the 1996 IPCC guidelines. The rural community covered all the people living outside the Municipality and large Sub-District Administrative Organization areas. Because the data of income in each area is not available, we use gross provincial products (GPP) to categorize the type of population income group in urban areas. For values of GPP which were higher than average were categorized as urban high income while those below average GPP value are classified as urban low income. Distribution of population incomes is shown in Figure 1.

The classification of urban high income or low income by using mean GPP indicated that the GPP in almost all the provinces of Thailand was lower than the average GPP. It indicated that almost every province of Thailand was classified as urban low income. However, these data were not available for all time series and all municipalities, districts or sub-districts. Hence,the ration of urban high and low income in rural and urban areas in 2008 were used to calculate CH_4 emissions from domestic wastewater for the whole time series.

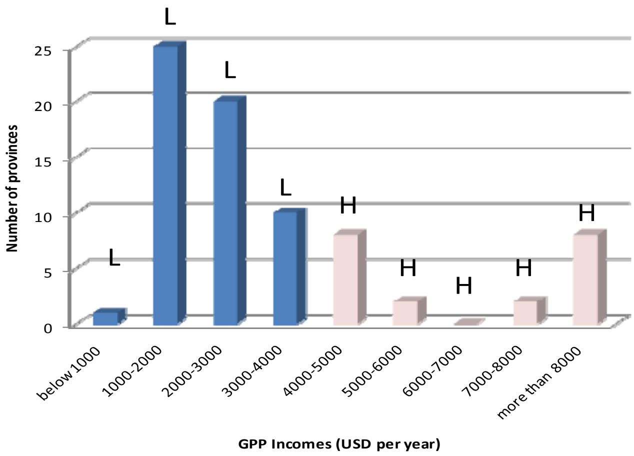

Figure 1. Distribution of GPP incomes by province.

3.5 Degree of utilization of treatment or discharge pathway or system (T)

The degree of utilization of treatment or discharge pathway or system (T) for each income group was determined by the proportion of the population that was served by each wastewater treatment systems. These systems were classified as sewer, septic tank, and latrine. The values T of sewer was found from the fraction of population that wastewater treatment plant served in urban area. The septic tank was used to treat domestic wastewater onsite. The T value of the septic tank was calculated from the fraction of population in urban areas that the wastewater treatment plant cannot serve. For rural areas, some part of the wastewater was treated onsite by latrine. However, the fraction of population treated by this handling system in rural areas was not available. Hence, we assumed that in rural areas wastewater was treated by latrine.

3.6 Correction factors for additional industrial BOD discharge into sewers (I)

This is the value expressed for BOD from industries that was co-discharged with domestic wastewater. The factor I may not be available in some countries. The default suggested by the IPCC for collected wastewater is 1.25, and for uncollected is 1.00.

4. Emission Factors

The CH_4 emissions from wastewater were estimated based on activity data and emission factors. The activity data were described previously. Emission factors for domestic wastewater were calculated for each wastewater and sludge type. A weighted average of CH_4 conversion factor was calculated using estimates of wastewater managed by each wastewater handling method. The emission factors were calculated by multiplying the average MCF and the maximum methane producing capacity (B_o).

4.1 Maximum methane producing capacity (B_o)

The maximum methane producing capacity (B_o) is expressed in terms of $kgCH_4/kgBOD$ or $kgCH_4/kgCOD$. A default value of 0.6 $kgCH_4/kgBOD$.

4.2 Methane conversion factor (MCF)

The MCF is an estimate of the fraction of BOD or COD that will ultimately degrade in an anaerobic process. In general, the MCF depends on the technology used. There were many types of technology used in Thailand and the value of MCF was not available. Figure 2 showed various type of municipal wastewater treatment plant of Thailand.

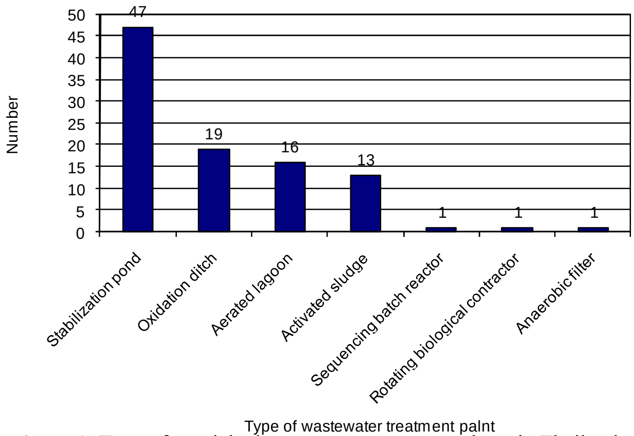

Figure 2. Type of municipal wastewater treatment plants in Thailand.

The IPCC suggested that expert judgments can be used for obtaining suitable MCF values. Questionnaires were designed and then sent to wastewater experts and the replies analyzed. Table 2 shows the MCF values for different technologies, compared

Table 2. The methane conversion factor for wastewater treatment and discharge pathway

Type of treatment and discharge pathway	Evaluated Value	IPCC default value	Used MCF value
Stabilization pond	0.22±0.15	0.80	0.22
Oxidation ditch	0.08±0.08	0.00	0.10
Aerated lagoon	0.06±0.06	0.00	0.05
Activated sludge	0.03±0.05	0.00	0.00
Contact stabilization activated Sludge	0.04±0.07	0.00	0.00
Two-stage activated sludge process	0.03±0.05	0.00	0.00
Combination of fixed activated sludge	0.08±0.07	0.00	0.10
Rotating biological contractor	0.12±0.06	0.00	0.12
Constructed wetland	0.20±0.11	0.20	0.20
Anaerobic filter	0.69±0.17	0.80	0.69
Septic tank	0.57±0.16	0.50	0.30
Latrine	0.10±0.00	0.10	0.10

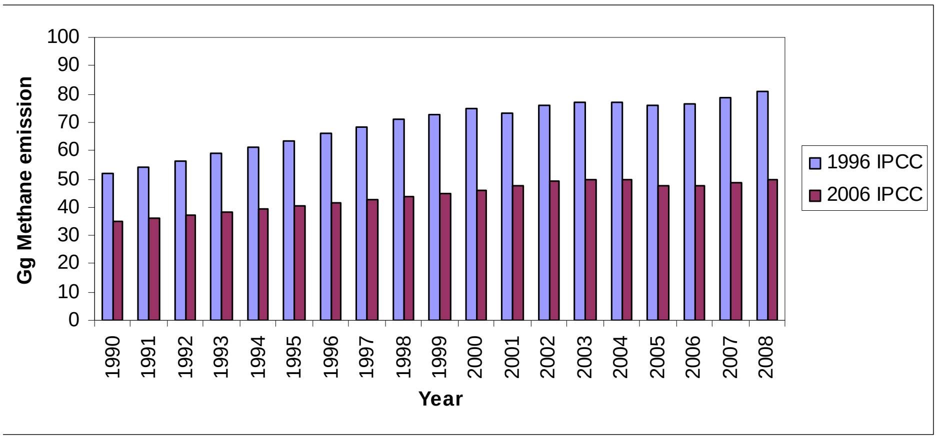

Figure 3. Time series of methane emission from wastewater handlings categories using 1996 IPCC Guidelines and 2006 IPCC Guidelines.

with the values from IPCC guidelines. The MCF from the expert judgments are different from the default values of the IPCC with both higher and lower values. The higher MCF values are from oxidation ditches, aerated lagoons, and a combination of fixed activated sludge and rotating biological contractors. For all of these higher MCF values, the IPCC default value recommended is zero. Lower MCF values than the IPCC default are from stabilization ponds, anaerobic filters, septic tanks and latrines. These expert judgments of MCF were used in the calculations of methane emission in this study.

5. Results and Discussion

5.1 Emission estimate

The results of CH_4 emissions from domestic wastewater handling using the revised 1996 IPCC guidelines for 1990-2008 are shown in Figure 3. It can be seen that the CH_4 emissions gradually increased from 1990-2000, ranging from 51.72 Gg to 74.75 Gg. Subsequently, emissions from 2001-2008 were quite stable with slight variations. It was found that the pattern of emissions estimated using the 2006 IPCC Guidelines was the same but the amount of total emissions was lower with a range of 34.72 Gg to 49.98 Gg for 1990-2000. However, the emissions from 2000 onward were quite stable around 49.53 Gg to 49.55 Gg. The difference between the former guidelines and the new guidelines fell within 0.49-1.64 times from 1990-2008. An increase in CH_4 emissions depended on several factors including population growth, the expansion of the urban areas in the country and an increase of BOD/person. The adoption of wastewater treatment plants also affected CH_4 emissions for all regions. However, we used the same factors mentioned above in both methodologies. Therefore discrepancies are due to the assumption of fraction of population income group and degree of utilization of technology that is belong to IPCC 2006 GL.

5.2 Domestic wastewater pathway

The main activity data for estimating the total organic matter contained in wastewater were the population and the BOD. In the 1996 IPCC methodology, the population are categorized according to national administrative organization, namely; Metropolitan (Bangkok), Municipalities, and Sub-districts. In addition, Municipalities and Sub-districts are further divided into three levels according to their population and its density. Domestic wastewater treatment technologies in each administrative level were varied. In the metropolis, some municipalities and large sub-districts, wastewater treatment plants were available. There are 98 wastewater treatment plants currently in operation. However, their technology was mostly aerobic treatments which were sometimes incomplete. Therefore, MCF estimated for methane emission by experts were used in this study. Parts of the population without wastewater treatment plants are facilitated by septic tanks. Populations in small and medium sub-districts were classified as using latrine for their wastewater treatment. Wastewater in rural areas were treated by latrine while wastewater generated from urban areas without wastewater treatment plant, were treated by septic tank. Actually, part of the wastewater was discharged directly into the environment, or into a sewer that was not connected to the wastewater treatment plant Figure 4 shows the decision tree of methane emission sources in this study.

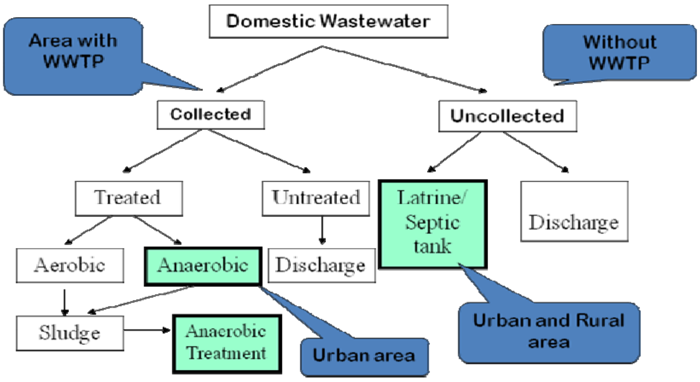

Figure 4. Decision tree indicated emission sources of methane emission estimate for wastewater handlings subsector in Thailand.

5.3 Factor affecting the difference.

In general, the principle methodology of the two guidelines is similar. Both methodologies can follow the decision tree represented in the IPCC 2000 [11] good practice guidance and uncertainty management. However the differences between revised 1996 IPCC guidelines [4-6] and 2006 IPCC guidelines [3] are the fraction of population income group (U) and degree of utilization of treatment (T). These two parameters are the key factors in estimation.

In 2006 methodology, rural and urban income group were mentioned and utilization of treatments depends on the income group particularly urban high incomes and urban low income. Therefore in the 2006 methodology, Metropolitans, Municipality and large Sub-districts were identified as urban areas while medium and small sub districts were identified as rural area. In order to clarify the high income and low income in each level of local administrative organization, we used the gross provincial product (GPP) to separate low and high incomes. Provinces with theirs GPP higher than the average value of GPP will be identified as high income and vice versa for the low incomes.

The assumption of fraction of population income (U) and degree of utilization of treatment (T) showed less impact in the capital city. Figure 5 indicates that using both methods showed similar emissions in the Bangkok metropolitan area. This is due to the assumption used in the 2006 guidelines that the part of the population not connected to treatment plants are identified as high income and most wastewater treatment plants are septic tanks. On the other hand, Figure 6 showed that when introducing U and T to the estimation, emissions from north and northeast regions are higher than estimated by the 1996 guidelines. The discrepancy is due to the assumption of using gross provincial product (GPP) that leads to differences between high income and low income urban area in the 2006 guidelines and city and sub-district area in the 1996 guidelines.

Using aggregated activity data lead to more accurate estimations but need more data such as the technology used and treatment plant services. We found that when using the population served by wastewater treatment technologies to calculate the degree of utilization for treatment pathway (T) can lead to over or under estimations depended on the data collection system and the assumptions made. The emissions in this study were calculated by the multiplying of total organic content and summation of the fraction of population income-U (using the assumption of provincial GPP), the degree of treatment method-T (using assumption of septic tank and discharge to waterway) and emission factors (TOWx∑(UxTxEF)). The results obtained were different from previous calculations using the IPCC 1996 guidelines.

According to CH_4 emission calculations from previous studies for 1990, 1994 and 1995, following IPCC guidelines, emissions from domestic wastewater handling were included in the waste sector. In 1990, total CH_4 emissions from domestic wastewater was approximately 2.301 Gg, as reported in Thailand's national greenhouse gas inventory 1990 report [7]. The emissions slightly decreased to 1.77 Gg in 1994 [8]. In addition, Sripetpun (2002) [12] estimated CH_4 emissions from domestic wastewater for 1995. They were about 8.476 Gg higher than the 1994 inventory. Whereas, in the current calculations, the CH_4 emissions were gauged by using two different methodologies (the revised 1996 IPCC guidelines and the 2006 IPCC [3-6] guidelines) for 1990-2008. The result from using the revised 1996 IPCC methodology showed that CH_4 emissions from domestic wastewater were 51.72 Gg in 1990, 61.29 Gg in 1994 and 63.64 Gg in 1995. Using the 2006 IPCC guidelines, the CH_4 emissions were 34.72 Gg in 1990, 39.25 Gg in 1994 and 40.38 Gg in 1995. These results indicate that CH_4 emissions from wastewater in the current study were generally higher than the previous study. The difference, as discussed above, was due to the choice of activity data and emission factors used and most importantly the assumptions of the parameters used.

6. Conclusions

This study aims to differentiate estimations of greenhouse gas emissions from domestic wastewater treatment in Thailand using the revised 1996 IPCC and 2006 IPCC guidelines [3-6]. The estimating results were comparable, in terms of emission amounts, data input, assumptions and suitability of data used. CH_4 emissions from domestic wastewater were gauged by the using revised 1996 IPCC guideline and 2006 IPCC methodologies for 1990-2008. Emission factors used were evaluated by many wastewater experts. In comparison of emissions using both methods, it was found that the estimation of CH_4 emissions were different. The use of the revised 1996 IPCC guidelines gave higher values than the results of 2006 IPCC guidelines. This was due to the assumption in different parameters including population incomes (U) and degree of utilization of wastewater technology (T) used in urban and rural area. Higher emissions of CH_4 than previous studies are the result of different BOD loads and different assumptions for urban and rural populations.

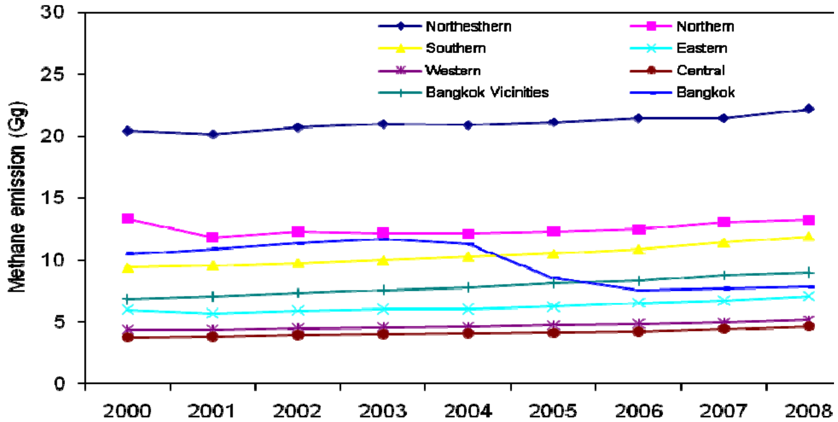

Figure 5. Methane emissions from domestic wastewater using revised 1996 IPCC guideline methodology for 2000-2008 in different regions.

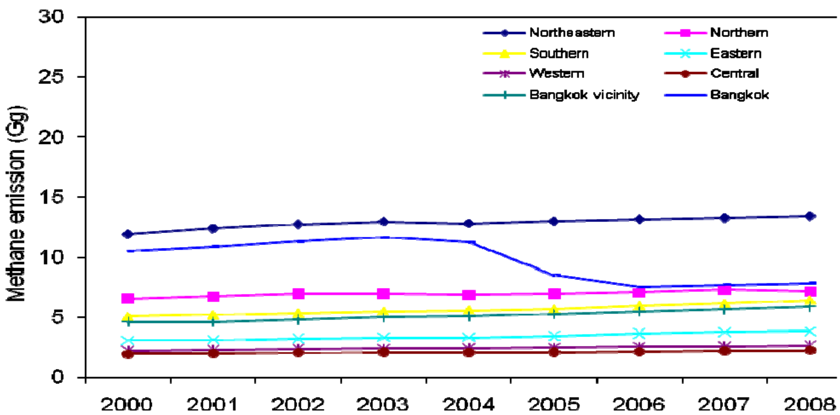

Figure 6. Methane emissions from domestic wastewater, using 2006 IPCC guideline methodology for 2000-2008, in different regions.

The differences of estimates using the 1996 guideline and 2006 guideline depended solely on the use of 'U' and 'T' in the equation. In general, the guidelines are designed to facilitate estimation with common and basic data collection. However, the basic assumption and availability of degree of income (urban low income, urban high income) are difficult to access. Therefore guidance on how to implement the degree of income is essential and needs to be clarified in the guidelines. Our results indicated that assumptions by gross provincial product (GPP) can be one parameter that can be used to distinguish the degree of income. However, in some areas where common differences of provincial activity were high such as in tourist provinces or, agricultural provinces where major incomes are from minor activities, then an underestimation of emissions could occur.

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