Chapter 1
Estimating Greenhouse Gas Emissions in the Pacific Island Countries

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Abstract A national Greenhouse Gas Inventory (GHGI) outlines estimates of emissions of greenhouse gases (GHGs) from various sectors of a country such as energy, agriculture, forestry and other land use (AFOLU), waste and industrial processes and product use (IPPU). The accuracy and consistency of the inventory is a basic requirement to ensure reliability of the estimates so that opportunities for potential reductions could be realized that would eventually lead to the development of low emission scenarios to achieve near zero emissions by 2050. An analysis of the second national communications of Pacific Island Countries (PICs) to UNFCCC shows that most of the emissions from PICs are from the energy sector and probably explains why Fiji's NDC Roadmap focuses on 30% emission reduction in the energy sector by 2030. This chapter discusses the IPCC 2006 guidelines to estimate emissions of CO_2 and other non-CO_2 greenhouse gases from different sectors. The uncertainties in emission estimates are discussed with more focus on data availability in the PICs. Research needed to derive country specific emission factors are also highlighted for certain sectors.

Keywords Greenhouse gas (GHG) · GHG inventory (GHGI) · Paris agreement · IPCC guidelines · Pacific Island countries (PICs) · Fiji NDC implementation roadmap

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1.1   Introduction

Estimating greenhouse gas emissions or developing a national greenhouse gas inventory is crucial in implementing mitigation policies and strategies to achieve climate goals. To execute an effective and feasible mitigation strategy it is critical to obtain robust emissions data before and after the implementation of the strategy to calculate the reduction of CO_2 equivalent achieved (Bi et al. 2011). The accuracy of the emission calculations depends on the consistency of the methodology applied, the robustness of the input data such as emission factors and other activity data required in the model (Kennedy et al. 2009).

The UNFCCC Article 4 – Commitments simply states "All Parties, taking into account their common but differentiated responsibilities and their specific national and regional development priorities, objectives and circumstances, shall:

- Develop, periodically update, publish and make available to the Conference of the Parties, in accordance with Article 12, national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies to be agreed upon by the Conference of the Parties.

It is known that not all emissions can be measured. However, they can be estimated using credible methodologies that are generally accepted by the Conference of the Parties. To this end, the IPCC developed IPCC National Greenhouse Gas Inventory 1996 guidelines and good practice guidelines (GPG) 1996 which was then revised to IPCC National Greenhouse Gas Inventory 2006 guidelines and GPG2003. Currently a special Task Force is set up to refine the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, and the final draft of this new methodology report titled "2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories" will be considered by the IPCC for adoption/acceptance at its Plenary Session in May 2019. The development of such methodologies provide the much needed consistency in reporting emissions and providing comparable data to monitor progress in achieving reduction target set by international agreements.

The IPCC methodology is based on a simple inventory method highlighted in Fig. 1.1.

The complexity of the reporting methodologies depends on the extent of the availability of the activity data and the country specific emission factor. There are

Fig. 1.1 The basis of calculating greenhouse gas emissions from activity data and emission factor

three tiers in the methodology defined by IPCC 2006 namely, Tier 1, Tier 2 and Tier 3.

- *Tier 1* is a simple method that uses default emission factors and to some extent uses guided principles to estimate activity data and consequently has a large uncertainty associated with the estimates derived from such methodology.
- *Tier* 2 is similar to tier 1 methodology except that country specific emission factors and other nationally available activity data are used in the calculation.
- *Tier 3* is a more complex method involving process based models with detailed, geographically specific data. Such methods provide robust and accurate estimate but requires thorough uncertainty assessments via means of detailed documentation procedures to ensure consistency and comparability between countries (Lokupitiya and Paustian 2006).

The greenhouse gases for which emissions are reported are those GHG that are regulated by the mandate of the Kyoto protocol and includes the following; Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and nitrogen trifluoride (NF_3) (Michael and Hsu 2008). The 2006 IPCC Guidelines for Greenhouse Gas Inventories, IPCC Good Practice Guidance (GPG) 2000 and 2003 takes a sectoral approach in estimating national greenhouse gas emissions and the following sectors (given below) are covered which are relevant for the PICs:

- Energy Sector
- Industrial Processes and Product Use (IPPU)
- Agriculture, Forestry and Other Land Use (AFOLU)
- Waste

The PICs have used the mentioned IPCC guidelines to prepare their national greenhouse gas inventories that were reported to the UNFCCC. Table 1.1 below gives sectoral emissions (CO_2eq in Gg/year) overview of the PICs as reported in their Second National Communication to UNFCCC.

It is apparent from the table that the energy sector is the major contributor in the PICs except in Tonga and Vanuatu. This is very obvious and is aligned with global scenario whereby cities in developed countries contribute over 67% to the global GHG emissions from fossil fuel use (Bi et al. 2011). In Vanuatu, the agriculture sector, particularly emissions from enteric fermentation in ruminants, was the dominant sector while land use changes in Tonga was the major emission source. The compiled data demonstrates the strength of each sector and clearly highlights which sector needs serious mitigation efforts in order to reduce the emissions in an effort to realize the objectives of the Paris agreement. Hence it is important that PICs develop capacity in generating valid and robust national greenhouse gas inventories using the IPCC guidelines for identification of opportunities for emission reduction. A classic example is Fiji's Nationally Determined Contributions (NDC) Roadmap which highlights 30% reduction in the energy sector by 2030 as the energy sector provides opportunities and feasible emission reductions.

Table 1.1 PICs emissions (Gg/year of CO_2 eq) from different sectors reported as Second National Communication to UNFCCC

	Cook Islands	Fiji	Kiribati	Marshalls	Nauru	Samoa	Solomons	Tonga	Tuvalu	Vanuatu
Energy	54.5	1570	64.0	85.0	13.3	174.4	350.6	94.9	11.2	122.4
AFOLU	0.08	977	0.84	NE	1.61	135.4	76.39	150.8	4.61	587.4
Waste	2.94	84	101.1	37.5	4.55	32.8	191.6	29.1	2.63	10.8
IPPU	0.59	NE	NE	NE	NE	9.51	NE	NE	NE	NE

Many developed cities have reported their carbon footprints using both GHG protocols and taking into account the Life Cycle Assessment (LCA) approach. The GHG protocol is based on the IPCC Guidelines whereas the LCA approach takes into account emissions from the initial stages to final stages of a product or service and is termed "cradle to grave" when considered from the resource extraction stage to the waste disposal stage (Reijnders 2012). In addition to GHG emissions, LCA offers the benefit of assessing other environmental impacts of products or services. It is becoming a widespread practice recently in greenhouse gas emission estimate that the IPCC guidelines are combined with the LCA approach to provide a more holistic estimate if a particular mitigation strategy is actually an emission reduction strategy (Ramaswami et al. 2008). The life cycle assessment of wind and solar energy, which are strong mitigating options in the energy sector, shows that they are not entirely emission free technologies. A comprehensive study involving published literature concludes that the LCA approach shows that the wind energy emits an average of 34.11 g CO_2eq/kWh and solar energy emits an average of 49.91 g CO_2eq/kWh (Nugent and Sovacool 2014).

1.2 Energy Sector

The energy sector emits GHGs mainly through the combustion of fossil fuels and Volume 2 of IPCC 2006 guidelines states that the key source categories in the energy sector are fuel combustion activities (stationary combustion), fugitive emissions from the oil refineries and carbon dioxide transport and storage. For PICs, stationary combustion is the only relevant key source category (See Fig. 1.2) as the advanced technologies in exploration and exploitation of fossil fuel and injection and storage of CO_2 underground are not available. The major greenhouse gas emitted by the energy sector is CO_2 although there are very minimal emissions of CH_4 and N_2O as well.

1.2.1 Estimating Emissions from the Energy Sector

1.2.1.1 Stationary Combustion Sub-Sector

The emissions from the stationary combustion sub-sector mainly included the sum of emissions from main producers of electricity generation, on-site use of fuel to generate its own electricity such as in generators in commercial and institutional buildings, manufacturing and construction industries, mining and quarrying industries, agricultural industries and most importantly all emissions from fuel combustion in households such as use of kerosene or natural gas for cooking.
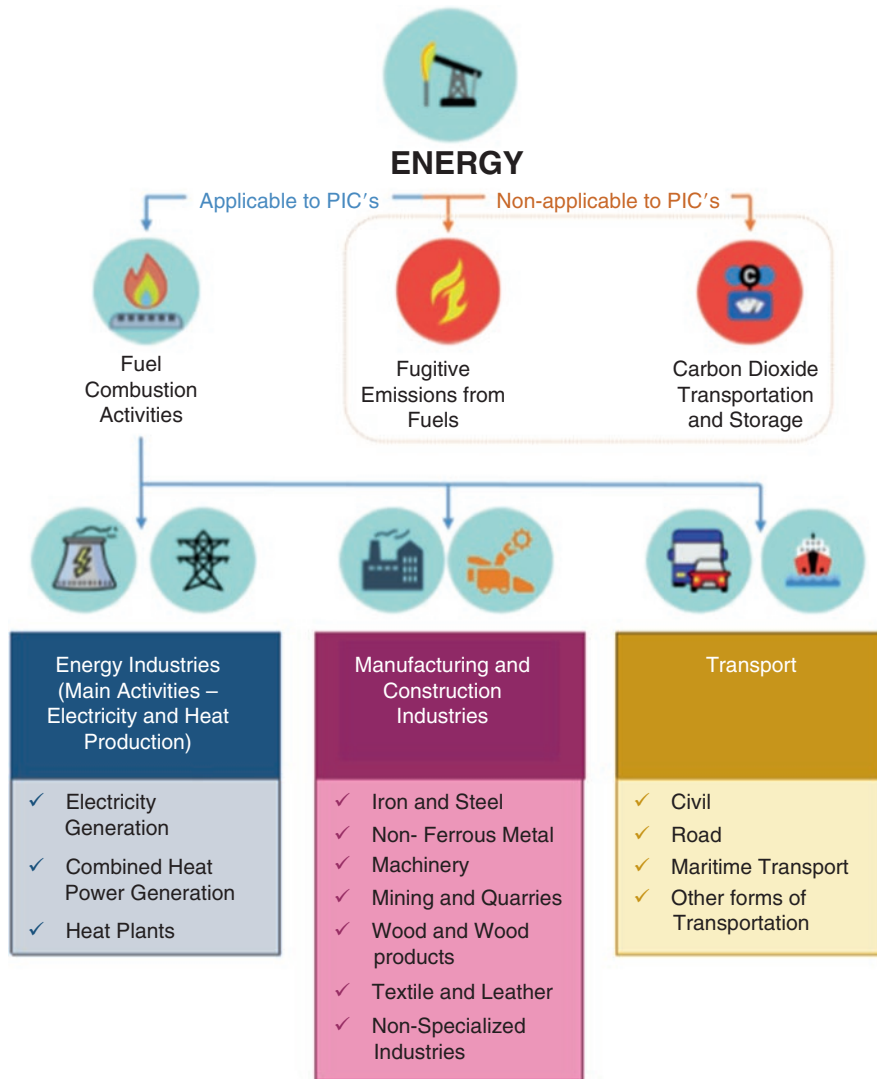
Fig. 1.2 The key source categories in the energy sector and the only relevant source category for PICs are fuel combustion activities

The Tier 1 approach requires data on the amount of fuel combusted in the source category and the default emission factor (See Table 1.2) as shown in the equation below:

$$\text{Emissions}_{GHG, fuel} = \text{Fuel Consumption}_{fuel} * \text{Emission Factor}_{GHG, fuel}$$

Table 1.2 Emission factors for different GHG and fuel type typically used in the Pacific Islands

Fuel Type		CO_2 (kg-CO_2/TJ)	CH_4 (kg-CO_2/TJ)	N_2O (kg-CO_2/TJ)
Crude Oil		73 300	3	0.6
Natural Gas Liquids		64 200	3	0.6
Gasoline	Motor Gasoline	69 300	3	0.6
	Aviation Gasoline	70 000	3	0.6
	Jet Gasoline	70 000	3	0.6
Jet Kerosene		71 500	3	0.6
Other Kerosene		71 900	3	0.6
Gas/Diesel Oil		74 100	3	0.6
Liquefied Petroleum Gases		63 100	1	0.1
Ethane		61 600	3	0.6
Coal		94 600	1	1.5
Coke		107 000	3	1.5
Residual Fuel Oil		77 400	3	0.6

Where;

- Emissions$_{GHG, fuel}$ = emissions of a given GHG by type of fuel (kg GHG)
- Fuel Consumption$_{fuel}$ = amount of fuel combusted (TJ)
- Emission factor$_{GHG, fuel}$ = default emission factor of a given GHG by type of fuel (kg gas/TJ). Refer to Table 1.2.

It should be noted that to use the above equation to calculate the emissions, the fuel consumption data in mass or volume units must be converted into the energy content of these fuels in terajoules (TJ). Tier 2 approach is used when a country specific emission factor for the source category and fuel for each gas is available. Tier 3 takes a more complex approach where different technologies to combust fuels are taken into account as some technologies maybe more fuel efficient and may influence emissions.

There have been some documented evidences on research into country specific emission factors to generate a more reliable estimate of GHG emissions from combustion sources. A study conducted on obtaining country specific emission factors for energy sector in Mauritius clearly demonstrated that emissions calculated with the experimentally derived country specific emission factors showed that the emission reported under the Third National Communication (TNC) was overestimated by 10% in the power subsector (Ramphull and Surroop 2017). Similarly in China the estimates from fossil fuel combustion were revised using two sets of comprehensive new measurements of emission factors as the fuel composition in China is known to vary widely from year to year especially for coal (Liu et al. 2015). The new revised emission estimate was lower than what was reported in the inventory earlier which was the consequence of the emission factor for Chinese coal being on average 40% lower than the IPCC recommended values (Liu et al. 2015).

1.2.1.2 Mobile Combustion Sub Sector

The greenhouse gas emissions from mobile combustion are due to major transport activity, i.e., road, off-road, air, railways, and maritime transport. The major greenhouse gas emitted is CO_2 with minute emissions of CH_4 (2%) and N_2O (1%). The following equation is used to calculate CO_2 emissions from the transport sector:

$$\text{Emission} = \Sigma \left(\text{fuel type} \times EF \right)$$

Where:

Emission = Emissions of CO_2 (kg)
Fuel = fuel sold (TJ)
EF = emission factor (kg/TJ)

The activity data needed to estimate emissions is the amount of fuel sold and to engage in higher tier approach than further classification is required in terms of amount of fuel sold to a particular type of vehicle with known emission control technologies such as catalytic converters. The aviation source category takes into account the emissions associated with the international bunkers and should be prepared as part of the national inventory but excluded from the national total and reported separately. It should be cautioned when considering emissions from biofuels used in vehicles. Only the CO_2 emissions from the fossil fuel component is accounted for whereas CO_2 emissions from the combustion of biogenic carbon is accounted for under the AFOLU sector and double counting should be avoided.

The national statistics for Fiji shows that a total of 707 million litres of fuel was imported of which 50% was re-exported to other PICs. Sectoral breakdown showed that 29% of the fuel stock was used for electricity generation, 64% was consumed by the transport sector; land transport (16%), air (26%), marine (22%) and the remainder was used for off grid electricity generation, household lighting and cooking (Holland et al. 2014). It was noteworthy that for PIC based scenario, emissions from the marine transport is sizeable portion and there have been some efforts in the emission reduction in maritime transport through sustainable sea transport research programme at the University of the South Pacific (Holland et al. 2014). The Maritime Technology Cooperation Center in the Pacific (MTCC-Pacific) provides initiatives for climate mitigation in the maritime industry and has contributed significantly to Kiribati's Nationally Determined Contributions (NDCs) and broader Sustainable Development Goals.

1.2.2 Uncertainties in Energy Sector Estimation

The uncertainties in estimating emissions in the energy sector arise from the fact that activity data is not available in the correct format to be used directly in the equation above. The fuel data is usually provided in litres and to convert it into mass, the

density is used which is dependent on temperature. However the temperature effects on density are not considered and this could introduce a bias of ±3%. In compiling the national greenhouse gas inventory for TNC, it was noted that instead of fuel consumption data, the total amount of fuel imported was used to calculate the emissions for combustion activities. This may add bias to the emission estimate as the total fuel imported in the particular year is not what is consumed in that particular year. The quality of emission inventories for the most important greenhouse gas, CO_2, depends mainly on the accuracy of fuel use statistics. Ideally the fuel consumption data should be used for estimating emissions but the major challenge in the PICs is the unavailability of the sale data of different fuel types from the private oil companies. Although IPCC 2006 guidelines assign the uncertainty levels at 2% for emissions from fuels but for PICs it estimated to be approximately 10% due to unavailability of consumption data.

1.3 Agriculture, Forestry and Other Land Use (AFOLU) Sector

The AFOLU sector deals with the estimation of GHG emissions and removals from managed lands through biological and physical processes. Managed land is defined as land where anthropogenic activities influence the natural ecosystem for agricultural, ecological and social functions (IPCC 2006). This sector considers emissions from the agricultural subsectors such as CH_4 emissions from livestock enteric fermentation, CH_4 and N_2O emissions from manure management, CH_4 emissions from rice cultivation, direct N_2O emissions from N-based fertilizer application, indirect N_2O application from managed soils, CO_2 emissions from liming and urea application and non-CO_2 emissions from biomass burning. The Forestry and other land use sub-sectors take into account emissions and removals from forest land remaining and land converted from one category to another such as forest land converted to cropland or grassland or settlements. The forestry sector uses net changes in C stock over time to estimate CO_2 emissions and removals from dead organic matter, soil organic matter of organic and mineral soils and harvested woody products (HWP) for all managed lands.

In the PICs context, the key categories identified in the agricultural sector are CH_4 emissions from ruminant animals and CH_4 emissions from manure management whereas CH_4 emissions from rice cultivation and N_2O emission from fertilizer application are negligible. In Fiji the estimated emissions from the ruminants and manure management accounted for 37%, as reported in second national communication to UNFCCC, whereas Vanuatu recorded the highest emissions from the agricultural sector amounting to 86% in 2010.

1.3.1   Estimating Emissions from Forestry and Other Land Use

The key source category under this section is estimating emissions or removals from managed forest land. Chapter 4 of Volume 4 of IPCC 2006 guidelines describes three tiers in estimating changes in carbon stock from managed forests that have been under the forest land for over 20 years. The primary step in calculating emissions/removals from the forestry sector is to estimate the biomass gain or loss. There are basically two different methods for estimating biomass gains and losses: Gain-Loss method and a stock difference method. The Gain–Loss method is more appropriate for Tier 1 approach where country specific activity data are not available. There are seven basic steps outlined in Volume 4 of IPCC 2006 to estimate change in carbon stocks in biomass (ΔC_B) using the Gain-Loss method. The seven steps are as follows:

Step 1:   Categorizing the area of forest land into appropriate forest types of different climatic or ecological zones.
Step 2:   Estimate the annual biomass gain in forest land using equations 2.9 and 2.10 in chapter 2 of IPCC 2006 guidelines.
Step 3:   Estimate annual carbon loss due to wood removals
Step 4:   Estimate annual carbon loss due to fuelwood removals
Step 5:   Estimate annual carbon loss due to disturbance
Step 6:   from the estimated losses in steps 3–5 estimate the annual decrease in carbon stock due to biomass losses (ΔC_L) from equation 2.11 in chapter 2
Step 7:   Estimate the annual change in carbon stocks biomass (ΔC_B) using equation 2.7 in chapter 2.

In addition to calculating the changes in biomass, changes in carbon stock from other carbon pools needs to be estimated such as dead organic matter (DOM) and soil organic matter (SOM) and emissions of CO_2 and non-CO_2 gases from forest burning. In Tier 1 approach it is assumed that changes in carbon stock due to DOM is zero. It is also noteworthy that in Tier 1 method, carbon stock changes for mineral soils it is assumed there is no change with forest management and it is assumed to be zero. However, for organic soils, carbon emissions due to drainage of forest organic soils are addressed. The C emissions can be calculated by multiplying the area of drained organic soil with the emission factor for annual losses of CO_2.

Basically similar approaches as above are applied to estimate emissions from croplands and grasslands. There is also guidance provided to report GHG emissions from managed wetlands particularly peat lands managed for peat extraction and lands flooded in reservoirs as flooded lands. The emissions due to croplands, grasslands, wetlands and settlements are detailed in chapter 5, 6, 7 and 8 of Vol 4, IPPC 2006 guidelines respectively.

1.3.2 Estimating Emissions from the Agricultural Activities

1.3.2.1 Enteric Fermentation

Methane emissions from enteric fermentation in ruminant animals and to a lesser extent, of non-ruminants are estimated as such:

$$\text{Emissions}\left(CH_4\right)_T = EF(T) \times \frac{N_T}{10^6}$$

Where;

Emissions $(CH_4)_T$ = methane emissions for animal category T, Gg CH_4 year^{-1}
$EF_{(T)}$ = emission factor for animal type, T, kg CH_4 head^{-1}
$N_{(T)}$ = number of heads for animal category T
T = animal category

1.3.2.2 Manure Management

This source category considers CH_4 emissions from anaerobic manure decomposition processes and direct and indirect N_2O emissions from animal excretion. Direct N_2O emission is related to the total amount of N in manure treated in different manure management systems (MMS). The indirect N_2O emission refer to N in manure that volatilizes as NH_3 and NO_x or lost through run-offs and leaching and when these N is deposited in some other place through the redeposition processes, it will be transformed by microbial activity into N_2O.

The methane emission from the manure management is estimated as such:

$$CH_{4(T)} = N_T{}^* EF$$

Where;

$CH_{4(T)}$ = CH_4 emissions in kg CH_4year^{-1} for animal category, T.
N_T = number of head f animal category T, heads year^{-1}
EF = default emission factors expressed in units of kg CH_4 head^{-1} year^{-1}.

To estimate the direct N_2O emissions from animal excretion in a particular MMS it is imperative to estimate the total N excreted from manure management systems for animal category as such:

Firstly, calculate the excretion rate per animal using the equation below:

$$Nex_{(T)} = N_{rate} \times TAM_{(T)} / 1000 \times 365$$

$Nex_{(T)}$ = Nexcreted in manure for animal category T, kg N animal^{-1} year^{-1}
$Nrate_{(T)}$ = default N excretion rate per mass, kg N (tonnes animal mass)$^{-1}$ day^{-1}
$TAM_{(T)}$ = typical mass for animal category T, kg animal^{-1}

Then calculate the manure N content in a particular MMS as such:

$$NE_{MS(T)} = \left(N_{(T)} \times Nex_{(T)} \times MS_{(S,T)} \right)$$

Where:

$NE_{MS(T)}$ = Total nitrogen excreted from MMS for animal category, T, heads year^{-1}.
$N_{(T)}$ = number of head f animal category T, heads year^{-1}
$Nex_{(T)}$ = annual N excretion for animal category T, kg N animal^{-1} year^{-1}
$MS_{(S,T)}$ = share of manure treated in each systems S for animal category T
T = animal category
S = manure management system

Hence direct N$_2$O emissions are calculated as follow:

$$\text{Direct emissions} \left(N_2O \right)_T = \Sigma \left[NE_{MS} \times EF_{3(s)} \right] \times 44 / 28 \times 10^{-6}$$

Where;

Direct emissions $(N_2O)_T$ = Direct N$_2$O emissions from MMS for animal category T, kg N year^{-1}
$EF_{3(S)}$ = Emission factor for direct N2O emissions from each MMS system, S, kgN20N/kg N.
T = Animal Category
S = manure management system (MMS)

The indirect emissions of N$_2$O is estimated as follows:

$$\text{Indirect emissions N2O} = NE_{MS(T)} \times \left[\left(\text{Frac}_{GASMS(S)} \times EF_4 \right) + \left(\text{Frac}_{LeachMS} \times EF_5 \right) \right] \times 44 / 28 \times 10^{6}$$

Where;

Indirect emissions $(N_2O)_T$ = Indirect N$_2$O emissions produced from the atmospheric deposition of N volatilized from manure management systems for animal category T, Gg N$_2$O year^{-1}
$NE_{MS(T)}$ = Total N excreted from manure management
$\text{Frac}_{GASMS(S)}$ = fraction of N from MMS that volatilizes as NH$_3$ and NO$_x$, kg N volatilized from each system S
EF_4 = emission factor indirect N$_2$O emissions from atmospheric deposition of N on soils.

$Frac_{Leach}$ = fraction of N leaches as NH_3 and NO_x

EF_5 = Emission factor indirect N_2O emissions from N leaching and run-off, kg N_2O/ kg N

T = animal category

S = manure management

1.3.2.3   Rice Cultivation

Methane emission from rice cultivation is the result of anaerobic decomposition of organic matter in paddy fields. The default IPCC seasonally integrated EF of 20 g CH_4 m^{-2} $year^{-1}$ is used and this is further modified by the scaling factor for the water regime and application of organic amendments. For irrigated farms the scaling factor is one whereas the rainfed is 0.7 and 0 for upland and dry conditions. If organic manure or straw incorporation is applied in the rice paddies then a scaling factor of 1.4 is considered.

$$\text{Emissions}(CH_4) = \frac{EF \; x \; SF_o \; x \left(Ai + \left[Aj \; x \; SFj \right] \right)}{10^5}$$

Where;

Emissions (CH_4) = Methane emissions per rice paddy, Gg CH_4 $year^{-1}$

EF = Seasonal methane emission factor, g m^{-2} $year^{-1}$

Ai,j = Rice paddy area harvested in the two water regimes, irrigated and rainfed, ha $year^{-1}$

SFo = 1.4 correction factor for organic amendments, for all countries

SFj = 0.7 scaling factor for Aj

In the PICs, Fiji has limited rice farming with total methane emissions of 0.09 Gg/year in 2004 and a recent assessment showed emissions to be 2.29 Gg/year in 2017 (Chand 2018). The increase in methane emission was observed due to the commitment from the Fiji Government to promote rice farming and to become self-sufficient by 2030 which led to an increase in land area of rice farming. The study also derived the emission factor for both rainfed and continuously flooded water regimes and it was noted that the country specific emission factors were within the range of the IPCC default emission factors (Chand 2018).

1.3.2.4   Synthetic Fertilizers

The application of nitrogen based synthetic fertilizers lead to direct emission of N_2O from the agricultural land due to microbial nitrification and denitrification processes. To estimate emissions of N_2O the following formula is used:

$$\text{Direct Emissions}(N_2O) = N \times 44 / 28 \times EF \times 10^{-6}$$

Where;

Direct emissions (N_2O) = Direct N_2O emissions from synthetic nitrogen additions to the managed soils, GgN_2O year^{-1}

N = Consumption in nutrients of nitrogen fertilizers, kg N input year^{-1}

EF = Emission factor for N_2O emissions from N inputs, kg N_2O–N/kg N′

The FAOSTAT database could be used to attain the main activity data on consumption of fertilizer in different years. The default emission factor for direct N_2O emissions from the application of synthetic fertilizer is 1% of N-input (IPCC 2006).

1.3.3   Uncertainties in the Agriculture Sector

The major uncertainty usually comes from the Tier 1 (default) methodology of the IPCC 2006 guidelines. The uncertainties in the agriculture sector emanate from the reliability of the activity data and the emission factors. The Food and Agriculture Organization (FAO) database is normally used to extract the activity data such as ruminant animal population, however during the compilation of Fiji's SNC it was noted that there were large discrepancies between the national statistics and the FAO database on ruminant animal population. The FAO database for Fiji ruminant population was projected from the animal surveys done in 1990s but in reality the cattle and dairy industry suffered huge loss due to economic viability and the foot and mouth disease that saw ruminant animal population dwindling in the recent two decades. The emission factors in the agricultural sectors were derived from studies in advanced western countries and have been used for tropical developing countries. There is a dire need for research to derive country or region specific emission factors. A study carried out in Sub-Sharan African region taking into account the field measurements of live weight, live weight change, milk production, dry matter intake and local climatology showed that the country specific emission factors were approximately 30–40% lower than IPCC default emission factors (Goopy et al. 2018). A study on measuring N_2O flux from the application of N-fertilizer in sugarcane plantations in Fiji suggested an emission factor of 5% as compared to the default value of 1% (Nisbat 2018). A thorough assessment of published literature on emission factors showed that the emission factor for direct N_2O emissions from synthetic fertilizer ranges from 0.013% to 21% with very few studies done in the tropical region (Nisbat 2018). Hence the default emission factor of 1% is a very poor proxy and introduces large uncertainty in the estimates. It is highly recommended that country specific emission factor should be derived to enable N_2O emission estimates from synthetic fertilizer more robust.

1.4 Industrial Processes and Product Use (IPPU)

The IPPU sector is considered to be less significant in PICs compared to the energy and the AFOLU sector. This is primarily due to the absence of mineral industry, chemical industry and metal industry in PICs. The cement production process emits significant amounts of CO_2 during the clinker production. The default emission factor is 0.51 t CO_2/t clinker. In the Fiji's initial national communication to UNFCCC, it was reported that cement production emitted 45,000 tonnes of CO_2 but more recently the emission from cement production was reported to be zero in Fiji's second national communication to UNFCCC because there is no clinker production in Fiji. The clinker used in the cement production in Fiji is now sourced from outside. However, it should be cautioned that IPPU emissions are bound to increase in developing countries due to ODS substitutes in the refrigeration and air conditioning source category. The use of HFCs is on significant rise after the phasing out of HCFCs in 2013 under the amendments to the Montreal Protocol.

The common hydro-fluorocarbon (HFC) refrigerants used in commercial air conditioning systems include R-410A, R-407C and R-134a. Emissions of HFC-134a as approximated from atmospheric observations are 60% higher compared with the United Nations Framework Convention on Climate Change (UNFCCC) inventory from 2009 to 2012 (Xianga et al. 2014). The projected increases in recent years are the consequence of phasing out HCFC, which is an ozone depleting substance, leaving HFC as the most desirable replacement that could be used directly in equipment. Recent analysis shows that HFC emissions will significantly increase in developing countries provided there is no regulation on HFC consumption and emission. The projected emissions of HFC in developing countries will increase by as much as 800%, greater than in developed countries by 2050 (Velders et al. 2009).

It is a known fact that HFCs are not produced in PICs, however it is imported by Fiji and then re-exported to other PICs to be used as a charging gas in refrigeration and air conditioning (RAC) industry. Section 2F1 of Volume 3 of IPCC 2006 guidelines highlights the process of estimating emissions for HFC use in RAC application. The IPCC inventory software enables you to estimate actual emissions even if the historic data is not available. To enable estimation, the following data is required:

- Year of introduction of chemical
- Domestic production of chemical in the current year
- Imports of chemical in current year
- Exports of chemical in current year
- Growth rate of sales of equipment that uses the chemical

Tier 1 approach is simple and less data intensive than Tier 2 because emissions are carried out at the application level rather than for individual products or equipment types. There are two types of Tier 1methods; Tier 1a –Emission factor approach at the application level and Tier 1b – mass balance approach at the application level.

The emission factor approach takes into account the annual consumption multiplied by the composite EF for that specific application. The net consumption within Tier 1A is computed as:

$$Net \ consumption = Production + imports - exports - destruction$$

The net consumption calculated is then used to calculate annual emissions as such:

$$Annual \ Emissions = Net \ Consumption \times Composite \ EF$$

The mass balance approach estimates emission from assembly, operation and disposal of a pressurized system and does not rely on emission factor. The emissions can be computed as:

$$\begin{aligned} Emissions = {} & Annual \ Sales \ of \ New \ Chemical \\ & - \left(total \ charge \ of \ New \ Equipment \right. \\ & \left. - Original \ Total \ Charge \ of \ Retiring \ Equipment \right) \end{aligned}$$

For PICs, the emission factor approach is preferred as the emissions from different stages of assembly, operation and disposal of refrigerant in equipment is not documented. Although the emissions of HFCs are generally not estimated in the National Greenhouse Gas Inventory for PICs but there is a need for institutional arrangements between government agencies and private companies to look into proper record keeping of different types of HFCs imported and destroyed in the country. Since the GWP of HFCs are very high, a small emission of HFC can contribute significantly when expressed in CO_2 eq terms.

1.4.1   Uncertainties in the IPPU Sector

The major source of uncertainty in this sector is from the activity data on net consumption. During the compilation of the Fiji's SNC it was noted that there is very poor record of HFCs imported in the country due to mismatch of custom codes. Data availability on the amounts of HFCs imported in equipments and appliances is very limited and how much of these gases are released into atmosphere after the end life of the product is very scarce or non-existent. The emission estimate in this sector is highly uncertain but since it is not a key category source for PICs not much attention is given and is usually not estimated.

1.5   Waste Sector

The key gas emitted from the waste sector is CH_4, which is produced from the anaerobic degradation of organic matter. There are three sub-categories within this sector, namely: emissions from the landfill, waste water treatment and incineration of waste. The CO_2 emission from incineration of waste in the PICs is very small and almost negligible and has not been accounted for in the national greenhouse gas inventory. Hence the discussions are more focused on emissions from solid waste disposal sites (SWDS) and waste water treatment. The methane emissions from SWDS and wastewater treatment contribute 4% of the total global GHG emissions (Cai et al. 2014). However in the PICs the total emissions from the waste sector as highlighted in Table 1.1 tends to vary and can be as high as 30% in some countries although these estimations are subjected to approximately 30% uncertainty.

When organic matter (food waste, garden waste, paper, wood, textiles and diapers) decomposes in the absence of oxygen then CH_4 and CO_2 are produced. The CO_2 emissions is not accounted for in the greenhouse gas inventory because it is considered to be carbon neutral as this is the CO_2 released back into the atmosphere that were initially removed by these biomasses. Similar anecdote applies to emissions from the wastewater treatment, however in addition to CH_4 a negligible amount of N_2O is also produced in the wastewater sub-sector which is reported by many countries. Fiji's second national communication to UNFCCC clearly states that 3.12 Gg of methane was emitted by the SWDS and 1.10 Gg of methane was emitted by the wastewater treatment. Clearly, this demonstrates that the SWDS is a dominant sub sector within the waste sector and mitigation efforts in implementing integrated solid waste management (ISWM) policies could bring about fruitful reduction targets in the waste sector.

1.5.1   Estimating Methane Emissions from the Solid Waste Disposal Sites

There are numerous methods for estimating methane emissions from the landfill such as the mass balance method, flux chamber method, IPCC 2006 Waste Model and USEPA Landfill Gas Emission model (LandGEM) (Kamalan et al. 2011).

When waste is placed in the landfill, the degradable carbon content in the waste depletes or decays over a period of time and therefore First Order Decay (FOD) kinetics are used to explain the emissions from the landfill (Santalla et al. 2013). The two most commonly used FOD models are LandGEM and IPCC 2006 Waste Model. The major drawback for IPCC 2006 Waste Model is that it needs historical dataset back to 1950 for the amount of waste placed in the landfill. If such activity

data exists then Tier 2 of the IPCC 2006 Guidelines will be used. However, in the case of missing data then amount of waste generated could be estimated from population and default waste generation rate. For reporting emissions from the waste sector to UNFCCC, it is strongly recommended to use the IPCC 2006 Guidelines.

1.5.1.1   IPCC 2006 Waste Model

The methane emissions from the SWD is calculated from the equation given below after taking into account the oxidation loss in the soil cover and if methane is recovered for flaring or utilisation for energy generation. Hence methane emissions are always lower than the methane generated and it is noteworthy that the methane recovered should be subtracted from the total methane generated and portion that is not recovered will only be subjected to oxidation.

$$CH_4 \text{ Emissions} = \sum_x \left[CH_4 generated_{x,T} - R_T \right] * \left(1 - OX_T \right)$$

Where;

CH_4 emissions = CH_4 emitted in year T, Gg
T = inventory year
R_T = recovered CH_4 in year T, Gg
OX_T = oxidation factor in year T, fraction

The CH_4 generation potential of a particular waste type will decrease gradually throughout the following decades. Hence the FOD model is built on the exponential factor that describes the fraction of decomposable degradable organic carbon (DDOC) that is degraded into CH_4 and CO_2 for each year. The DDOC is calculated as follows:

$$DDOC_m = W * DOC * DOC_f * MCF$$

Where;

$DDOC_m$ = mass of decomposable DOC deposited, Gg
W = mass of waste deposited, Gg
DOC = degradable organic matter in the year deposition, fraction, Gg C/Gg waste
DOC_f = fraction of DOC that can decompose
MCF = CH_4 Corrected factor for anaerobic decomposition in the year of deposition.

The default values for DOC for individual waste type are as follows: 40% for paper/cardboard, 24% textiles, 15% food waste, 43% wood, 20% garden and park waste and 24% diapers. It is also imperative for a highly reliable estimation that a country has undertaken waste characterization studies and in the absence of such data default values could be used for the Oceania region. DOC_F is fraction of degrad-

Table 1.3 MCF values for different types of SWDS

Type of site	Description	MCF values
Managed anaerobic	Controlled placement of waste, control of scavenging and fires and should meet one of the following criteria (i) cover material, (ii) mechanical compacting or (iii) levelling of waste	1
Managed semi-anaerobic	Controlled placement of waste and must include all of the following (i) permeable cover material, (ii) leachate drainage system, (iii) regulating pondage, (iv) gas ventilation system	0.5
Unmanaged deep	Not meeting the criteria of managed SWDS and has depths greater than or equal to 5 m and/or high water table at near ground level	0.8
Unmanaged shallow	Not meeting the criteria for managed SWDS and have depths <5 m	0.4
Uncategorized	Any SWDS that does not fall within any of the four categories above	0.6

able carbon content and usually a default value of 0.5 is used. The MCF values vary with the different types of SWDS and are given by IPCC 2006 guidelines as in Table 1.3.

Finally, the FOD kinetics is applied to calculate the methane generated, which is dependent on the total mass of decomposing material currently in the site. The FOD equation is mathematical expressed as:

$$CH_4 \text{generated}_T = (\text{DDOCmd}_T + (\text{DDOCma}_{T-1} * e^{-k}) * (1 - e^{-k}) * F * 16/12$$

Where;

DDOCmd$_T$ = DDOCm deposited into SWDS in year T, Gg
DDOCma$_{T-1}$ = DDOCma accumulated in the SWDS at the end of the year (T-1), Gg
k = methane generation rate constant, k = ln2*$t_{1/2}$
$t_{1/2}$ = half-life time (y)
F = fraction of methane by volume in generated LFG
16/12 = the molecular weight ratio for CH$_4$/C

The methane generation rate constant is dependent on the local environmental conditions such as mean annual temperature(MAT) and pressure(MAP) and potential vapo-transpiration. Table 1.4 below summarizes the k values applied for different categories of waste depending on the environmental conditions for the tropical region.

A study conducted in a tropical landfill in Thailand highlighted that the methane generation rate constant, k, determined through field measurements was approximately 0.33 year^{-1}. This rate was much higher than the default value for bulk waste of 0.17 (Wangyao et al. 2010). This high rate was attributed to high moisture content of the waste in which the food waste was the main component that degrades rapidly. This degradation was further enhanced by tropical meteorology with high rainfall and high temperatures. This high methane generation rate would be applicable for

Table 1.4 Methane generation rate constant depending on type of waste and meteorological conditions for tropical regions

Type of waste		Tropical (MAT >20 °C)			
		Dry (MAP <1000 mm)		Moist and Wet (MAP>1000 mm)	
		Default	Range	Default	Range
Slowly degrading waste	Paper/textiles waste	0.045	0.04–0.06	0.07	0.06–0.085
	Wood/straw waste	0.025	0.02–0.04	0.035	0.03–0.05
Moderately degrading waste	Other (nonfood) organic putrescible/garden and park waste	0.065	0.05–0.08	0.17	0.15–0.2
Rapidly degrading waste	Food waste/sewage sludge	0.085	0.07–0.1	0.4	0.17–0.7
Bulk waste		0.065	0.05–0.07	0.17	0.15–0.2

tropical PIC countries as the waste generated are mostly food waste or organic waste with high moisture content. A feasibility study to capture and utilise methane from Naboro landfill in Fiji showed that methane generation is very fast given the high organic content of waste and tropical climatology and therefore such fast degradation rate posed real challenges in achieving high recovery rates using vertical wells as a mitigation option (Mani et al. 2016).

The above methodology is also used to estimate methane emissions if any emission reduction strategies are implemented by the countries. It is evident that the methane generated in the landfill is mostly from the DOC content of waste and therefore diverting organic waste from landfill through nationwide composting could lead to reduction in methane generated. In many developed countries landfill methane is recovered and utilised as either cooking gas or to run a gas turbine to generate electricity. There have been studies to demonstrate how to increase the efficiency of the recovery systems to enhance capture of landfill methane (Thompson et al. 2009; Spokas et al. 2006). This will increase the methane recovery factor in the equation above which will tend to reduce methane emission further. Such technology for methane recovery is expensive and is yet to be installed in the PICs landfills.

1.5.1.2 LandGEM Model

LandGEM is a Microsoft Excel based tool which incorporates the first order equation of decomposition rate to quantify methane emissions from the decomposition of urban wastes in landfill and has been developed by USEPA (Ghasemzade and Pazoki 2017; Chaudhary and Garg 2014). The LandGEM FOD model is based on the equation below:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_o \left(\frac{M_i}{10} \right) e^{-kt_{ij}}$$

Where;

Q_{CH4} = annual methane emission in the specified year of calculation (m^3/year)
I = 1 year time increment
n = (year of calculation) – (initial year of waste acceptance)
j = 0.1 year time increment
k = methane generation rate (year^{-1})
L_o = potential methane generation rate (m^3/Mg)
M_i = mass of waste accepted in the i year (Mg)
t_{ij} = age of the j section of waste mass M_i accepted in the ith year

USEPA protocols state that the composition of waste used in the model reflects US waste composition of MSW, inert material and other non-hazardous wastes. For a landfill containing non-biodegradable waste (i.e., inert material), such as ash from waste combustion, this portion may be subtracted from the waste acceptance rates. LandGEM recommends subtracting inert materials only when documentation is provided and approved by a regulatory authority. LandGEM provides methane generation constant utilising both CAA (Clean Air Act) and AP42 standards. It is recommended to use AP42 default values for standard landfills. CAA default values have a high methane generation potential (L_0) of 180 m^3CH_4 Mg^{-1} waste (Scharff and Jacobs 2016).

LandGEM is based on the first-order decomposition rate equation and the inputs required in the model are similar to IPCC 2006 Waste Model such as design of the landfill, amount of waste placed, acceptance of hazardous waste, the methane generation rate constant (k), methane generation potential (L_o) and the years of waste acceptance. Default values for k and L_o can be used or site-specific values can be developed through field test measurement. Both FOD models were tested on Danish landfills and it was concluded that the LandGEM overestimated methane generation and the plausible explanation for such discrepancies was that the waste composition at Danish landfills was different to US waste composition of MSW. This highlights the point that waste composition is a critical factor in the model which then determines the methane generation potential and the methane generation rate constant.

1.5.2 Estimating Methane Emissions from the Wastewater Treatment

Methane emissions from the anaerobic wastewater treatment plants are estimated according to the procedure outlined in chapter 6 of Vol. 5 IPCC 2006 guidelines. The method for estimating CH_4 from wastewater handling requires three basic steps and the three worksheets provided by IPCC are used to calculate each of the following steps:

- Step 1: Estimation of Organically Degradable Material in Domestic Wastewater
- Step2: Estimation of CH_4 emission factor for Domestic Wastewater
- Step 3: Estimation of CH_4 emissions from Domestic Wastewater

To calculate the total organics in the wastewater in inventory year expressed as kg BOD/year, biologic oxygen demand (BOD) per capita in g/pers/year and the population (P) data is required. The equation used to calculate total organics is as follows:

$$TOW = P * BOD * 0.001 * 365$$

The emission factor for a particular treatment system (EF_j) is based on methane producing capacity (B_o) and the methane correction factor (MCF) and is calculated as follows:

$$EF_j = B_o \times MCF_j$$

The default value for B_o used is 0.6 kg CH_4/kg BOD and the MCF used is dependent on the treatment system as outlined in Table 6.3, Chapter 6 of Volume 5. The MCF for a well-managed aerobic plant is 0; for aerobic not well managed and overloaded is 0.3; septic system with anaerobic system is 0.5 and anerobic system is 0.8.

Methane emissions for this category are estimated as follows:

$$CH_4 Emissions = \left[\sum_{ij} \left(U_i * T_{ij} * EF_j \right) \right] * \left(TOW - S \right) - R$$

Where:

TOW = total organics in wastewater in inv year, kg BOD/year

S = organic component removed as sludge in inventory year, kg BOD/year

U_i = fraction of population in income group i in inventory year (See Table 6.5, IPCC 2006)

T_{ij} = degree of utilisation of treatment/discharge pathway or system, J, for each income group i in inventory year.

i = income group; rural, urban income and urban income low

j = each treatment/discharge pathway or system

There is N_2O emissions in kg N_2O-N/kg N to some extent in wastewater treatment and are calculated as follows:

$$N_2O \, emissions = N_{effluent} * EF_{effluent} \times 44 / 28$$

$EF_{effluent}$ is the emission factor for N_2O emissions from discharged wastewater and the default factor is 0.005 kg N_2O-N/kg N. The $N_{effluent}$ factor is nitrogen in the effluent discharge to aquatic environment, kg N/year and is calculated as:

$$N_{effluent} = \left(P * protein * F_{NON\,COM} * F_{IND\,COM} \right) - N_{sludge}$$

Where P is human population, protein is the annual per capita consumption, $F_{NON\ COM}$ is the factor for non-consumed protein added to the wastewater (default value of 1.1 is applied as per the IPCC 2006 guidelines), $F_{IND\ COM}$ is the factor of industrial and commercial protein co-discharged into sewer system (default value of 1.25 is applied) and N_{sludge} is the nitrogen removed in sludge, kg N/year (a default value of zero is applied). The N_2O emission from wastewater is not a key category in PICs and is not usually estimated in the national greenhouse gas inventory.

1.5.3 Uncertainties in the Waste Sector

As stated earlier if the default methodology is used for estimation then the uncertainty level is approximately 30%. In the PICs the uncertainty in estimation could be higher as the amount of waste generated is not very well recorded and the waste composition is not known. None of the SWD sites in Fiji apart from Naboro landfill have a weighbridge so the bulk weight is estimated by number of truckloads. To constraint the uncertainty in the waste sector it is strongly recommended to weigh the amount of waste deposited in the SWD sites and to carry out a thorough study on waste characterization of the waste generated in the PICs. If the studies revealed that the organic waste matter is higher than the default values, then certainly the emissions calculated previously were underestimated. In the wastewater sector the major challenge is the data limitations on the type of wastewater treatment systems such as the number of households that use septic tanks within the urban and peri-urban areas. It is very unclear as to how to assess emissions from such treatments.

1.6 Conclusion

It is obvious that a high degree of confidence in the activity data and country specific emission factors are mandatory for an accurate estimation of greenhouse gas emissions from different sectors. In the absence of activity data and emission factor, the default methodology or Tier 1 methodology can be used to enable calculation with highest uncertainty in the estimate. In the PICs, default methodology is used but there is a need for a strong institutional arrangement between government and private sectors to provide data in the correct format needed to estimate emissions. Once the country specific emission factors and activity data are present then a more robust inventory could be attained and consequently provide insights on potential sectors where emission reduction could be targeted effectively. A comprehensive review of the greenhouse gas inventory reported to UNFCCC indicates that more than 50% of emissions are from the energy sector in most of the PICs followed by agriculture and then the waste sector. To transform the Paris Agreement into reality, more focused attention is needed in the energy sector and removals of CO_2 of the AFOLU sector.

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