



e-ISSN No.: 2582-4228

# Journal of Indian Association for Environmental Management

Journal homepage: [www.http://op.niscair.res.in/index/php/JIAEM/index](http://op.niscair.res.in/index/php/JIAEM/index)



## Community-Scale Greenhouse Gas Inventory: Methodological Framework and Findings for Rural Climate Action

Prem Kumar<sup>1</sup>, Prashant<sup>1\*</sup>

<sup>1</sup>Department of Environmental Science, Central University of South Bihar, Gaya, India, 824236

\*Corresponding Author: Dr. Prashant, [drprashant@cub.ac.in](mailto:drprashant@cub.ac.in)

Submitted: 23 March 2025

Revised: 18 May 2025

Accepted: 31 May 2025

**Abstract:** This study develops a community-scale Greenhouse Gas (GHG) inventory for a rural village, providing a 2023 baseline for emission reduction strategies. It assesses eight key emission sources, including LPG consumption, electricity use, transportation, waste management, and agriculture. Using methodologies from the 2019 Refinement to the 2006 IPCC Guidelines and the Global Protocol for Community-Scale GHG Inventories (GPC), emissions were categorized into Scopes 1, 2, and 3 and expressed in CO<sub>2</sub>-equivalents (CO<sub>2</sub>e). Findings estimate total emissions at 604.02 tCO<sub>2</sub>e, with domestic wastewater discharge, enteric fermentation, and electricity consumption as primary contributors. Agriculture-related emissions align with studies identifying mineral fertilization, irrigation, and methane from paddy fields as significant sources. The study highlights disparities across sectors, emphasizing the need for targeted mitigation measures. By adopting an activity-based and territorial assessment framework, this inventory fills a critical data gap at the rural level, providing a model for localized GHG inventories. The insights support sustainable policymaking and climate action, enabling rural communities to design effective carbon reduction strategies.

**Author Keywords:** Village Emission Inventory, GHG Accounting, Community Scale Activities, Rural Emissions, Enteric Fermentation Emissions (EFE)

### I. INTRODUCTION

Greenhouse gases (GHGs) are key drivers of climate change (Montzka, Dlugokencky, and Butler 2011; Zheng et al. 2019; Ramanathan and Feng 2009; Röck et al. 2020). The heat-trapping ability of GHGs warms the lower part of the atmosphere causing global warming (Kweku et al. 2018; Yoro, Daramola, and Daramola 2020). The GHGs effects have been amplified leading to a rise in the earth's temperature due to the emission of gases from anthropogenic activities in the last few decades (YUE and GAO 2018). Technical summary of Assessment Report 6 ratifies the findings of Assessment Report 5 of IPCC (Intergovernmental Panel on Climate Change) that "there exists a near-linear relationship between cumulative CO<sub>2</sub> emissions and the increase in global average temperature caused by carbon dioxide over this century for global warming levels up to at least 2°C relative to 1850–1900". Further, World Meteorological Organization's GHG bulletin of 2023 reported global annual surface mean abundances of 417.9±0.2 ppm, 1923±2 ppb and 335.8±0.1 ppb respectively for CO<sub>2</sub>, CH<sub>4</sub>, and

N<sub>2</sub>O in the year 2022 (Chevallier et al. 2023). Current elevation in carbon dioxide, methane, and nitrous oxide is 150%, 124%, and 264%, respectively as compared to levels in the year 1750 when the natural equilibrium of Earth began to be disturbed by human activities. World Resource Institute identifies India as the third largest emitter of GHGs after China and the United States. There exists a significant difference in community activities, lifestyle, economy, and energy consumption in urban and rural pockets. Hence, their amount of emission from similar sources varies (Bhoyar et al. 2014). The GHG accounting is one of the relevant approaches to gauge emissions at the local environment level. It is a method of conducting an assessment that lists the major emission sources and quantifies different GHGs emitted in terms of carbon dioxide equivalents (CO<sub>2</sub>e). The GHG accounting tool enables local environments like villages to comprehend the emissions contribution of different activities at the community scale. GHG accounting of a non-industrialized village as per IPCC guidelines involves the calculation of emissions through three major sectors; energy, waste, and AFOLU (Agriculture, Forestry and Other Land

Use). A study (Parikh et al. 2009) accounted emission structure of CO<sub>2</sub> in the rural bottom class of India, highlighting the significant disparities in emissions across socio-economic groups. Ramachandra et al. (2015), reported GHG inventories of major cities of India, using IPCC guidelines where local data were unavailable, to estimate emissions based on fuel consumption and associated activities in each city, while Mohan (2018) prepared emission estimates resulting through energy consumption in residential, commercial, agriculture and fisheries sectors in India, for the period 2005 to 2014. When it comes to the GHG footprint of villages, investigations considered mainly the agricultural sector, that were linked with the economic status and per capita emissions. Hemingway et al. (2023) revealed emission contribution of livestock and per hectare amount of tCO<sub>2e</sub> emission in a village from agriculture in the semi-arid alluvial plain of Gujarat (India). The study carried out by Simon et al. (2018) quantified the GHG emissions from the categories of agriculture, land use, land-use change, and forestry (LULUCF) and waste, for a semiurban transiting village in the state of Uttarakhand, India. Srinivasarao et al. (2016), conducted emission assessment for climate-smart agricultural practices at village level. However, with economic growth, an increase in mobility and electrification changed the energy as well as commodity consumption in villages hence, the nature of emission also (Das Gupta, 2011; Mohammed et al., 2019; Roy J, 2020; Roy et al., 2018). Internationally various studies have been conducted at an urban level to develop GHG inventory (Sówka and Bezyk 2018; Lin et al. 2013; Sanna et al. 2014; Yukuo, Xing, and Ye 2016; Jia et al. 2018). Similar attempts were made for village inventory too (Ge, Luo, and Lu 2017; Froemelt et al. 2018). In India, very few attempts have been made to capture Greenhouse Gas inventory, especially in the rural areas that are changing fastly. Tanveer and Srivastava (2019) estimated carbon footprint attributed to stationary and mobile energy combustion based on consumption of electricity, diesel/petrol, firewood, and LPG in J&K village. Village-level accounting of GHG emissions resulting in complete inventory still remains unrevealed. This study, seeks to prepare GHG emission inventory of a village located in south Bihar using primary data collection of eight selected GHG linked activities falling under the scope framework of GPC. It has also compared the scope-wise emissions occurring as well as individual activities contribution within the same scope.

## II. MATERIALS AND METHODS

Globally, over 3.4 billion people - approximately 43% of the world's population live in rural areas, in contrast in India, 65% of the population resides in villages, whereas in Bihar an Indian state, 88.71% of the population lives in the rural areas. The urban areas are usually seen as the main contributor to the GHG emission; however rural areas also have significant emission sources such as agriculture, livestock management, biomass burning, and traditional energy usage. The rural sectors of emissions are often underreported in global climate frameworks.

Thus, the GHG accounting of a village is critical for an elevated understanding and tailoring localized climate action for rural sustainability.

To develop a comprehensive GHG inventory for the village, a systematic approach was adopted, aligning with established protocols such as the 2019 Refinement to the 2006 IPCC Guidelines and the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC). This methodology ensures that emissions are accurately accounted, categorized by source, and reported in a consistent manner. The process includes defining clear boundaries, quantifying emissions from various sources, and scaling activities to reflect the community's impact. The procedure used for creating the GHG inventory for the village has been outlined in the following steps

- i) Defining the inventory boundary.
- ii) Categorizing emissions by scope framework; Scope 1 - GHG emissions occurring from sources within the territory of village boundary. Scope 2 - GHG emissions as a result of the consumption of grid-supplied electricity, within the village boundary. Scope 3 - Rest other GHG emissions that occur outside the village boundary but are attributed to community activities within the village boundary (table 1).
- iii) Scaling magnitude of the activities taking place.
- iv) Quantification of greenhouse gas emissions.
- v) Computation of CO<sub>2e</sub> of the non-CO<sub>2</sub> gases by multiplying with their corresponding Global Warming Potential (GWP).
- vi) Aggregate of the CO<sub>2e</sub> of all the three scopes accounts for the complete inventorization of the village regarding GHG footprint.

### Study Area

Tepa, is a village located in the humid subtropical climate of Bihar state in the Gaya district of India (Figure 1) was selected for the Community-Scale Greenhouse Gas (GHG) inventory study. The rationale for the selection of village *Tepa* lies in the fact that it is predominantly an agriculture-dominant area that serves as a representative microcosm of rural communities. Strong community participation and engagement are also required for the accurate collection of data, which was evident in the selected village. Tepa comes under gram panchayat Nepa of Tekari block. The village code 254832 has been assigned to the village according to Census 2011. The integrated geographical area of village Tepa along with peripheral settlements is 510 hectares. There are about 300 households in this village which includes all socio-economic groups having a current population of 2200. The village has an agriculture area of 425 acres with two major crops of paddy and wheat. The farmers of Tepa are engaged in farming and cattle rearing.

### GHG Quantification Protocols

Village Tepa was studied to assess greenhouse gas (GHG) emissions from various activities contributing to the carbon footprint. The study covered multiple sectors (table 1), including LPG consumption, solid waste disposal, wastewater disposal, and livestock rearing, each of which plays a role in methane (CH<sub>4</sub>) and Carbon Dioxide (CO<sub>2</sub>) emissions. CO<sub>2</sub> emissions from urea fertilization in agriculture were also analyzed, highlighting the environmental impact of chemical

fertilizers. Additionally, the GHG emissions from grid-supplied electricity and transportation activities were evaluated, providing a comprehensive understanding of the village's total carbon emissions profile. The emissions were quantified based on activity data of waste generation, livestock rearing, cooking, fertilizer application etc., and corresponding emission factors. Due to the unavailability of activity data from government departments, we collected primary activity data through a tailored questionnaire survey and focused group discussion. Tier 1 default emission factors provided by the 2019 Refinement to the 2006 IPCC Guidelines were used along with country-specific emission factors for the corresponding activity being carried out in the study area. In the present inventory carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) have been quantified. The estimated amount of GHG is represented in terms of tonnes of carbon dioxide equivalent (tCO<sub>2</sub>e). Methane and nitrous oxide are converted to CO<sub>2</sub>e by multiplying with their respective 100-year global warming potential (GWP) value i.e. 27 and 273 taken from Assessment Report 6 of IPCC (“The Earth’s Energy Budget, Climate Feedbacks and Climate Sensitivity” 2023). The GHG accounting for activities that emit all three gases (CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O) shall be the sum total of their CO<sub>2</sub>e.

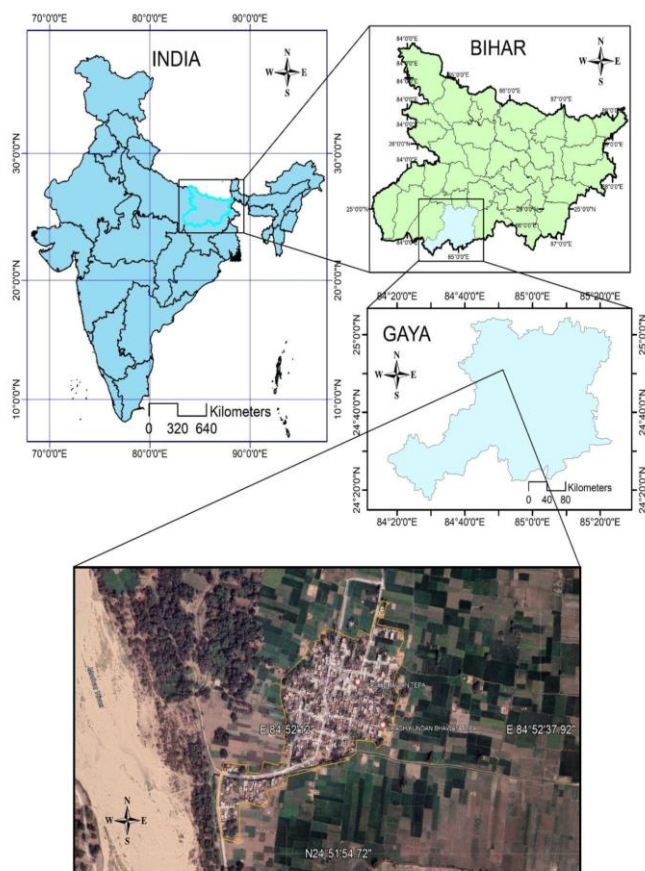


Figure 1 Map of the Study Area

TABLE 1  
GHGs Emission Sources and their Scope Categorization

Sectors and sub-sectors	Scope 1	Scope 2	Scope 3
Stationary energy			
Residential	Emissions from LPG combustion	Grid-supplied electricity	
Transportation			
On-road transportation			Emission from fuel (Gasoline, diesel) combustion
Waste			
Solid waste disposal	Emission from in boundary generation		
Wastewater discharge	Emission from in boundary generation		
Agriculture, forestry and other land use (AFOLU)			
Livestock	Emission from enteric fermentation and manure management		
Aggregate sources and non-CO <sub>2</sub> emission sources on land	Emission from urea application to soil		

### LPG Consumption

The Pradhan Mantri Ujjwala Yojana (PMUY), launched in 2016, significantly increased LPG consumption in rural India, including Bihar. This initiative aimed to provide clean cooking fuel to low-income households, replacing traditional fuels like wood, cow dung, and kerosene, which are known for causing indoor air pollution and health issues (Ranjan and Singh 2020).

In rural Bihar, the distribution of subsidized LPG connections under the Ujjwala Yojana led to a rise in LPG usage as more households gained access to this cleaner energy source (Sharma and Dash 2022). While this shift has helped reduce indoor pollution and health hazards, it has also resulted in an increase in LPG consumption. The LPG is used for cooking and heating purposes in the study area. The tier 1 approach (Buendia et al. 2019) provided by IPCC Guidelines has been applied to quantify the emission from this source category. LPG consumption data was taken as the number of LPG used in a month (one LPG bottle contains 14.2 kg gas) from the respective households of different socioeconomic groups through survey questionnaire and focused group discussion. Collected data on fuel consumption in mass units (kg) was converted into the energy content of LPG (terajoules) to be as representative unit of the default emission factor. The

sum total of GHG emissions from LPG consumption was calculated using equation 3.1

$$E_{LPG} = \text{LPG consumption (TJ)} * EF_{LPG} \text{ (kg gas/ TJ)} \dots \text{Eq. 3.1}$$

Where,

$E_{LPG}$  = the emission of specific GHG from annual LPG consumption,

LPG consumption = the amount of LPG combusted in terajoules (TJ) and

$EF_{LPG}$  (kg gas/TJ) = the default emission factor of a particular GHG.

The respective outcome was converted to tonnes of GHG for uniformity among other activity results.

### Disposal of Solid Waste

Solid waste (SW) in rural areas mostly contains biodegradable materials like leftover food waste, straw, and yard waste; partially degradable items such as wood, disposable napkins, and sludge and animal faecal matter (Bansal et al. 2023). SW is commonly managed by collecting it from houses, streets and disposing of it in landfills. When SW undergoes anaerobic decomposition, it produces roughly 60% methane (CH<sub>4</sub>) and 40% carbon dioxide (CO<sub>2</sub>), along with trace amounts of other gases (Hegde, Chang, and Yang 2003). In rural setup the management of the solid waste is at a rudimentary stage. The household discards are placed into the waste heaps at some designated areas or scattered in unmanaged disposal sites. Methane is the prime gas emitted from the decay of disposed municipal solid waste (Singh, Kumar, and Roy 2017). Based on implementation simplicity and the requirement of the data the ‘‘Methane Commitment’’ method adopted from GPC (Fong et al. 2021) has been applied to estimate the CH<sub>4</sub> emission from unmanaged disposal sites based on the amount of waste disposed in a specific year. Two main factors that determine the quantification of emissions from the disposed solid waste are (a) the quantity of waste disposal and (b) the DOC (degradable organic content) within the waste, which in turn determines the methane generation potential. To get accurate and reliable information a baseline survey was exercised to determine the amount of waste generation and then scaled up accordingly. The baseline survey of the village was conducted by adopting the stratified random sampling method. A sample of 10 % of households from all three socio-economic groups were selected for detailed information on waste generation. As per the Solid Waste Management Rule (2016) collection of dry and wet waste separately is an efficient way to gauge the composition of solid waste generation. House hold solid waste was collected and weighed daily for seven days during different seasons including festive and non-festive days. Methane emission was estimated through equation 3.2

$$E_{MSW_{methane}} = MSW * L_o * (1-f_{rec}) * (1-OX) \dots \text{Eq. 3.2}$$

Where,

$E_{MSW_{methane}}$  = the tonnes of CH<sub>4</sub> emitted,

MSW = disposed waste mass in tonnes during inventory year,

$L_o$  = methane generation potential,

$f_{rec}$  = methane recovered fraction at disposal site and

OX = oxidation factor.

Since unmanaged waste disposal system accounts no recovery of methane, zero value is assigned to  $f_{rec}$ . Value of OX is also taken 0 in case of unmanaged landfills. Further, value of methane generation potential was found using equation 3.3

$$L_o = MCF * DOC * DOC_F * F * 16/12 \dots \text{Eq. 3.3}$$

Where,

MCF = methane correction factor,

DOC = degradable organic carbon in the inventory year of deposited waste (tonnes C/ tonnes waste),

$DOC_F$  = ultimately degraded fraction of DOC,

F = methane fraction in landfill gas,

16/12 = Stoichiometric ratio of CH<sub>4</sub> and CO<sub>2</sub>.

As the village under the study has scattered waste dumping sites (unmanaged shallow waste heaps), a value of 0.4 was taken for methane correction factor. The computed value for DOC was 0.13 based on primary data generated on waste mass and composition of inventory area. 0.5 is the default value recommended by the 2019 IPCC Guidelines for  $DOC_F$  bulk waste. F in landfill gas generation taken as 0.5 (IPCC default value).

### Wastewater

All the wastewater generated in the village was discharged into open stagnant water bodies and land. The extent of CH<sub>4</sub> production depends primarily on the factors like amount of degradable organic material in the wastewater, temperature, and the type of treatment system. With temperature rise, the rate of CH<sub>4</sub> production increases (Chen et al. 2021). This is an important principle in uncontrolled systems with warm climates. Below 15°C, significant CH<sub>4</sub> production doesn't take place because of the inactivity of methanogens. However, methane production is likely to resume once the temperature rises above 20 °C. Quantity of degradable organic material in the wastewater is main factor in determination of the methane generation potential of discharged wastewater. Biochemical oxygen demand (BOD) is a parameter that measures the biodegradable organic component in wastewater. CH<sub>4</sub> emission from the discharge of domestic wastewater was calculated using equation (3.3) suggested in 2019 IPCC Guidelines (Buendia et al. 2019c).

$$E_{DWW_{methane}} = [(TOW_j - S_j) * EF_j - R_j] \dots \text{Eq. 3.3}$$

Where,

$E_{DWW_{methane}}$  = the methane emission (kg CH<sub>4</sub>/year) in study year,

$TOW_j$  = total organics present in discharged wastewater (kg BOD/year) of discharge system (j)

$S_j$  = the removed sludge in year (kg BOD/year), for wastewater going to aquatic body, sludge removal is zero ( $S_j = 0$ )

$j$  = discharge system (stagnant water body)

$EF_j$  = emission factor (kg  $CH_4$ / kg BOD),

$R_j$  = the recovered amount of methane (kg  $CH_4$ /year) in inventory year. Default value of zero is taken for this parameter as there is no recovery in case of natural aquatic environment.

Emission factor was derived using equation 3.4

$$EF_j = B_o \times MCF_j \dots\dots\dots \text{Eq. 3.4}$$

Where,

$B_o$  = maximum methane-producing capacity in kg  $CH_4$ /kg BOD

$j$  = discharge system

$MCF_j$  = methane correction factor

The total amount of TOW in discharged wastewater is a function of the population of inventory area and per capita BOD. Its unit is kg BOD year<sup>-1</sup> and was calculated with the help of equation 3.5

$$TOW = P \times BOD \times 0.001 \times 365 \dots\dots\dots \text{Eq. 3.5}$$

Where,

$P$  = Population of village in inventory year,

$BOD$  = India-specific per capita BOD (g/person/day), 0.001 is used for converting grams BOD to kg BOD.

### Livestock Sector

Enteric fermentation and manure management are two major activities that result in the emission of greenhouse gases from the livestock sector. Among all livestock, the major source category of methane is ruminant livestock like cattle. A tier 1 approach (Buendia et al. 2019) for emission estimate from 2019 IPCC Guidelines was adopted for conducting this assessment. This approach needs animal population data of different species present within the inventory area and default emission factors. Primary data on animal populations was collected with the help of a survey questionnaire. Estimation of methane emission through enteric fermentation was done with the application of equation 3.6.

$$E_{L\text{Smethane}} = EF_T \times N_T \times 10^{-6} \dots\dots\dots \text{Eq. 3.6}$$

Where,

$E_{L\text{Smethane}}$  =  $CH_4$  emissions in Gg  $CH_4$  yr<sup>-1</sup>,

$EF_T$  = emission factor for different livestock populations (kg  $CH_4$  head<sup>-1</sup> yr<sup>-1</sup>),

$N_T$  = number of livestock species and T is species of livestock.

For emission estimate of methane from manure management, Tier 1 approach requires data on livestock population of respective animal category and climate (cool, temperate and warm) cum average annual temperature dependent default emission factors for specific region. The climate of study area is warm and temperate having the average annual temperature of 25.6 °C. Emission was estimated using equation 3.7.

$$E_{\text{MANURE methane}} = EF_T \times N_T \times 10^{-6} \dots\dots\dots \text{Eq. 3.7}$$

Where,

$E_{\text{MANURE methane}}$  is methane emission, for a given population (Gg  $CH_4$  yr<sup>-1</sup>),  $EF_T$  is emission factor for livestock population (kg  $CH_4$  head<sup>-1</sup> yr<sup>-1</sup>)  $N_T$  is the number of livestock species and T is livestock category.

### CO<sub>2</sub> Emissions from Urea Fertilization

The total amount of urea used as fertilizer in inventory year is activity data needed for calculating emission. Paddy and wheat are primarily cultivated crops in the village under study. Both crops are grown in around 250 – 275 acres of the study area. As per the primary survey, appx 160 kg per acre of urea were being applied in the paddy fields during germination to final harvest while 115 kg/ acre were being applied in the wheat cultivation. Tier 1 approach of IPCC (Buendia et al. 2019b) was used for the estimate of CO<sub>2</sub> emission from urea fertilization.

$$CO_2\text{-C E} = M \times EF \dots\dots\dots \text{Eq. 3.8}$$

Where,

$CO_2\text{-C E}$  is annual carbon emissions from urea addition to soil (tonnes C yr<sup>-1</sup>),  $M$  is the amount of urea applied to soil annually (tonnes urea yr<sup>-1</sup>) and  $EF$  is emission factor, 0.20 tonne of carbon (t urea)<sup>-1</sup> is taken as default value.

### Grid-supplied Electricity

Electricity is supplied to domestic line and agriculture line in village. Electricity from domestic line is used mainly for lighting the houses and running domestic electrical appliances while irrigation is done through agriculture line. Units of electricity consumed (MWh) is activity data for estimation of emission from grid-supplied electricity. Power substation from where electricity is supplied to the village provided the data on electricity consumption. Emission is calculated by multiplying the electricity consumption by the corresponding emission factor. GPC guides to use national electricity production emission factor, therefore emission factor (0.931 tCO<sub>2</sub>e/MWh) formulated by the Central Electricity Authority (Ministry of power, Govt. of India) was used for estimating emission. GHG emission was accounted using equation 3.9.

$$E_{GSE} = E_c \times EF_e \dots\dots\dots \text{Eq. 3.9}$$

Where,

$E_{GSE}$  is GHG emission from grid-supplied electricity in tCO<sub>2</sub>e,  $E_c$  is electricity consumption by the village in

inventory year in MWh and  $EF_e$  is the emission factor in  $tCO_2e/MWh$ .

### Transportation

Vehicles directly emit greenhouse gas like  $CO_2$ ,  $CH_4$  and  $N_2O$  from the internal combustion of different fuels such as gasoline, diesel, CNG etc. Emissions in this study have been calculated considering fuel consumed (fuel purchased) as activity data. Vehicles in the village are mainly used to commute outside the inventory boundary. From primary survey it was found that most vehicles were refueled at the three nearest fuel stations. Vehicle fuel consumption data was collected from vehicle owners through survey questionnaire. The Tier 1 approach of IPCC Guidelines (Eggleston 2006) was applied to calculate GHG emissions. Tier 1 uses estimated fuel consumption (fuel sold) as activity data along with default emission factors for  $CO_2$ ,  $CH_4$ , and  $N_2O$ . GHG emission due to vehicular emission has been accounted using equation 3.10.

$$E_{transportation} = \sum_a [Fuel_a * EF_a] \dots\dots\dots Eq. 3.10$$

Where,

$E_{transportation}$  denotes tonnes of carbon dioxide/methane/nitrous oxide emitted,  $fuel_a$  is combusted fuel in TJ and  $EF_a$  is the emission factor in  $kg/TJ$ .

The activity data (fuel consumption) collected from the survey was in volume (liter) units. The default emission factor is provided in terms of mass unit and energy content of fuel ( $kg/TJ$ ). To obtain the mass of respective fuel, the density of fuel at all three nearest refueling points were estimated and used in the study.

## III. RESULTS AND DISCUSSION

In the present study, eight activities were investigated under different sectors for developing the GHG inventory of the study area. The specific sector activities have been further grouped into three scopes. The GHG emissions from the different source categories have been presented in Table 2. Scope 1, Scope 2 and Scope 3 has total GHG emission of 439.74, 137.26 and 27.02  $tCO_2e$  respectively.

### Scope 1

Scope 1 includes community-scale activities cum GHG emission sources like LPG consumption, solid waste disposal, domestic wastewater discharge, enteric fermentation and manure management of livestock and urea application to soil which were taking place within inventory boundary (Table 1).

### LPG Combustion

The findings of this study shows that total of 57.17  $tCO_2e$  was emitted from domestic LPG consumption annually (table 2). The rainy season, summer season, and winter season accounted for 27.17, 23.76, and 6.23  $tCO_2e$  respectively (figure 2). The highest emission (47.5%) has been observed in rainy season, winter season accounted for least emission (10.9%)

while 41.6% of emission was during the summer season (figure 2). Due to bad weather conditions and rainfall residents of village prefer to cook using LPG in rainy days while during the winter season conventional methods of wood and dung cake combustion were in practice for the same purpose which in turn reduces emissions from LPG uses.

TABLE 2  
Amount of GHGs Emission from Different Source Categories

Sl. No.	Source category	Greenhouse gases ( $tCO_2e$ )			$\sum tCO_2e$
		$CO_2$	$CH_4$	$N_2O$	
<b>A Scope 1</b>					
1.	LPG combustion	57.02	0.12	0.03	57.17
2.	Solid waste disposal		2.78		2.78
3.	Domestic wastewater discharge		157.64		157.64
4.	Enteric fermentation		152.04		152.04
5.	Manure management		13.44		13.44
6.	Urea application	56.67			56.67
	<b>Total</b>	<b>113.69</b>	<b>326.02</b>	<b>0.03</b>	<b>439.74</b>
<b>B Scope 2</b>					
1.	Grid-supplied electricity				137.26
<b>C Scope 3</b>					
1.	Transportation	26.35	0.35	0.32	27.02
	<b>Net Emission</b>	<b>140.04</b>	<b>326.37</b>	<b>0.35</b>	
<b>Total GHG emission in inventory year</b>					<b>604.02</b>

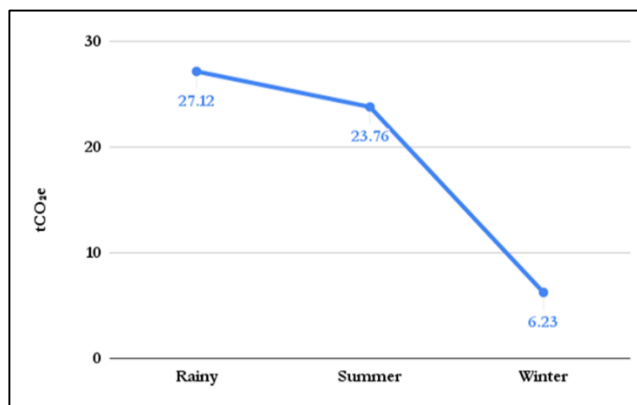


Figure 2 Seasonal variation in GHG Emission from LPG Combustion

### Waste

The waste sector includes two categories: emissions associated with the solid waste disposal and domestic wastewater discharge. In the present study, only  $CH_4$  emission estimation was done for solid waste disposal as well as wastewater discharge. It was found that total 2.78  $tCO_2e$  was emitted annually from disposed solid waste and 157.64  $tCO_2e$

was associated with wastewater discharge (table 2). Amount of methane produced in case of solid waste disposal is based on methane generation potential which in turn depends on DOC content of waste. Calculated value of DOC is 0.16 for waste composition of Varanasi (Kumar et al. 2004), nearest city from the study areas where similar study has been carried out. Rapidly biodegradable matter fraction is a fundamental parameter in determining DOC. In case of Varanasi, it was 30.98%. As per the primary survey done in this study for waste generation rate and waste composition, a fraction of food in waste (which is a considerable part of biodegradables) of the village was very low since villagers feed most of the leftover food to livestock. This fluctuation caused slight difference in DOC value (0.13 in case of the waste composition of inventory area). Methane emission from domestic wastewater discharge depends on factors like population, total organics present in discharged wastewater (TOW), degree of utilization of treatment for rural income groups etc. With reference to the 2019 refinement to IPCC Guidelines for National Greenhouse Gas Inventories (Buendia et al. 2019c), there is 0.00% degree of utilization of septic tanks for treatment in the case of rural income group. However, in current scenario there found to be significant numbers of septic tanks in the village. Since the dawn of Swachh Bharat Mission Gramin villages witnessed in accelerated construction of septic tanks to eliminate open defecation. In a study conducted by (Diaz-Valbuena et al. 2011) it was found that 11 g CH<sub>4</sub> capita<sup>-1</sup> day<sup>-1</sup> emission from septic tank systems occurs. The current findings of this study will fluctuate when 2019 IPCC Guidelines will incorporate the future modification in default emission factor.

### **Livestock Enteric Fermentation**

Enteric fermentation and manure management are two activities considered in this study for the estimation of methane emissions from the livestock sector. Enteric fermentation resulted in an annual emission of 152.18 tCO<sub>2</sub>e (equivalent to 5.63 tonnes CH<sub>4</sub>) while 13.44 tCO<sub>2</sub>e (0.49 tonnes CH<sub>4</sub>) was emitted through the management of manure (table 2). In the village under the study area, cattle dung was stacked in an open area so decomposition tends to occur aerobically as it is handled in solid form which results in lower methane production.

### **Urea Application**

The findings of this study estimated the emission of 56.67 tCO<sub>2</sub>e (table 2) from urea application to soil in agricultural fields. Paddy and wheat cultivation resulted in 33.49 and 23.18 tCO<sub>2</sub>e respectively. The carbon emission in paddy cultivation is higher as compared to the wheat cultivation. The paddy cultivation uses higher quantity of urea thus resulting higher emissions than wheat cultivation.

### **Scope 2**

Scope 2 emission results due to consumption of grid-supplied electricity (table 1). Annual emission resulting from electricity consumption in the domestic sector and agriculture sector of the village was estimated at 137.26 tCO<sub>2</sub>e in

the inventory year (table 2). Domestic uses of electricity caused an emission of 61.02 tCO<sub>2</sub>e (44.46%) while irrigation resulted in 76.24 tCO<sub>2</sub>e (55.54%) (table 2). Since the village under the study area was fully dependent on electricity-based irrigation methods it has a significant contribution to emissions.

### **Scope 3**

Scope 3 in the present study includes on-road transportation beyond the periphery of the inventory area as most of the vehicles owned by the residents of the village is used for traveling outside the village. The estimate of emission from 2-wheelers and 4 wheelers were calculated and analyzed. It was found that 27.02 tCO<sub>2</sub>e is emitted annually from automobile combustion of fuels used in vehicles. Carbon dioxide accounts for 26.35 tCO<sub>2</sub>e (97.5 %) GHG emissions from vehicular combustion while CH<sub>4</sub> and N<sub>2</sub>O emission was 0.35 (1.3%) and 0.32 (1.2%) tCO<sub>2</sub>e respectively (table 2). As compared to other activities it has moderate emission, this is because 33.80 % of population doesn't own any private vehicle, particularly the lower income socio-economic group. This reduced fraction of the activity data minimizes the emission from this category.

### **Comparative Account**

The total emission of 604.02 tCO<sub>2</sub>e from eight selected activities (table 2) is occurring in the inventory year. Following this value, the per capita GHG emission of the village was estimated as 0.27 tCO<sub>2</sub>e. Scope 1 activities resulted in emission of 439.74 tCO<sub>2</sub>e in the inventory year which accounts for 72.80% of the total emission (figure 3). Scope 1 comprises six activities from different sectors while Scope 2 and 3 have single activities respectively. Scope 2 emitted 137.26 tCO<sub>2</sub>e annually (table 2 & figure 3). Scope 3 estimated emission was the least with 27.02 tCO<sub>2</sub>e (4.48%).

The analysis of activities within scope 1 shows that domestic wastewater discharge resulted in the highest emission with 157.64 tCO<sub>2</sub>e (35.85%) (figure 4). Enteric fermentation has an emission value next to wastewater discharge with 152.04 tCO<sub>2</sub>e representing 34.57 % share in total emission of Scope 1. Methane emission due to both of these activities was estimated in this study. Urea application to soil only emits carbon dioxide, resulting in annual emission of 56.67 tCO<sub>2</sub>e. As CO<sub>2</sub> has GWP value 1, despite of large amount of emission it is lesser in terms of carbon dioxide equivalents as compared to enteric fermentation and wastewater discharge. Solid waste disposal resulted in least emission among all the scope 1 activities with amount of 2.78 tCO<sub>2</sub>e representing 0.63 % of total emission. Six activities out of eight selected activities emit methane hence its emission was compared among these activities to identify the key emitter (table 1 & figure 5). Wastewater discharge and enteric fermentation are significantly releasing methane while LPG combustion emits it in least amount. It has been observed that in rural community methane emission is a major contributor to the GHG (326.37 tCO<sub>2</sub>e) followed by Carbon Dioxide (140.04 tCO<sub>2</sub>e) and Nitrous Oxide (0.35 tCO<sub>2</sub>e).

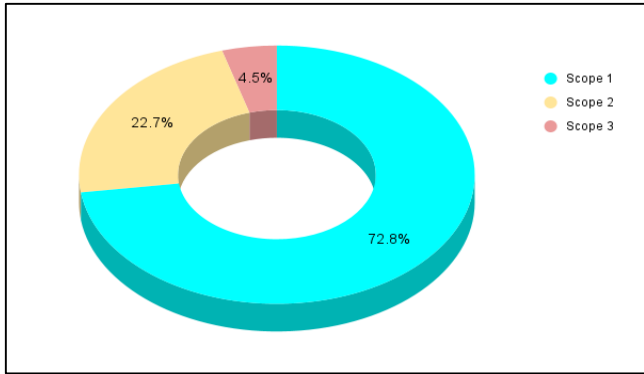


Figure 3 Emission Contribution of Different Scopes

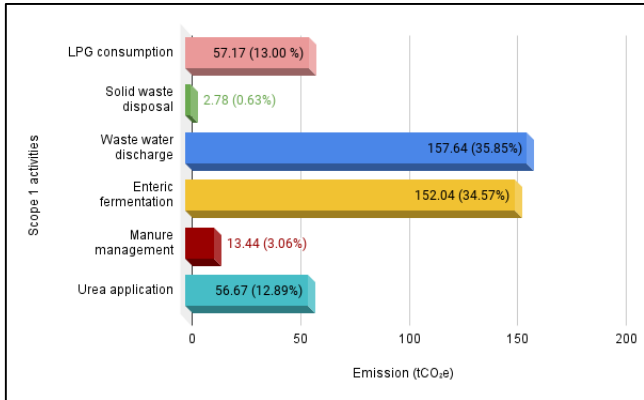


Figure 4 Emission of Activities within Scope 1

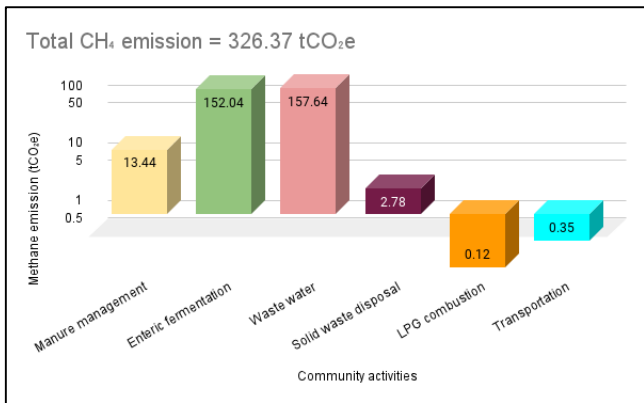


Figure 5 Methane Emission from Community Activities

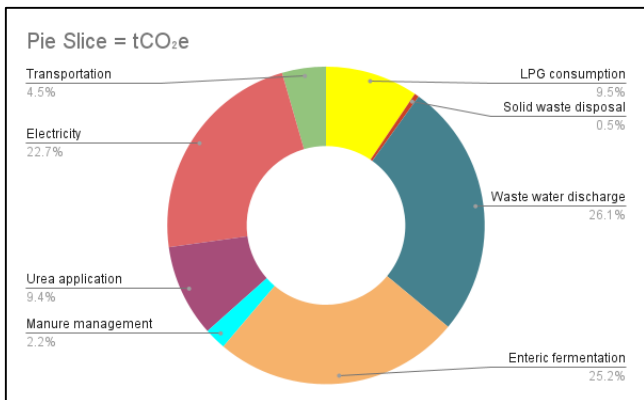


Figure 6 Collective Emission Contributions of all Eight Activities from Scope 1, 2 and 3.

## IV. CONCLUSION

An increase in GDP parallel to global digital connectivity has transformed our lifestyle to new extreme. Greenhouse gases emission is now associated with every activity that is part of the rural community. Some activities have direct associations while other can be related to indirect emissions. A total of 604.02 tCO<sub>2</sub>e emission estimate was found in the current inventory year with 0.27 tCO<sub>2</sub>e as annual per capita emission of the village. Following GPC guidelines selected activities have been grouped into scope 1, scope 2 and scope 3. Scope 1 accounted for major emissions (figure 3). Wastewater discharge has the highest contribution towards the emission followed by livestock enteric fermentation and electricity consumption (Figure 6). The haphazard disposal of wastewater through unmanaged drains in to open areas and waterbodies are twin swords, polluting the land and water bodies as well as emission of GHGs. The scientific collection, treatment and disposal of wastewater is an urgent need to manage the GHG emissions from the rural areas. The local administration is recommended to come up with the construction of a nature-based wastewater treatment facility like a constructed wetland system to minimize the major portion of emission. 55.42 % of tCO<sub>2</sub>e of scope 2 results from the grid-supplied electricity consumption in irrigation. A shift in the irrigation scenario is required and farmers need to be acquainted with the benefits of solar-driven irrigation and the optimum utilization of water resources for irrigation purposes. Bihar Renewable Energy Development Agency (BREDA) offers subsidies to farmers for availing solar pumps for irrigation purposes under the solar energy irrigation scheme. Adopting this method will reduce reliance on electricity and GHG emission reduction. Urea, a widely used nitrogen fertilizer, is a one of the sources of GHG emissions, particularly nitrous oxide, which has a high global warming potential. Alternatives like biofertilizers, organic compost and need based application of urea can help to reduce GHG emissions while enhancing soil health. To mitigate urea-related emissions, it is recommended to implement integrated nutrient management practices. The complete inventorization at the micro level will not only aide in setting mitigation measures at the target area but also drive the scientific scope of carbon credit at the lower administrative level in India as per the COP26 commitment of net zero emission by 2070 in the upcoming years.

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