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The Estimation of Greenhouse Gas Emissions from the Waste Sector in Laos

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Abstract

Greenhouse gases (GHGs), such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases, are key contributors to global climate change by trapping heat in the Earth's atmosphere. The waste sector, encompassing solid waste disposal, biological treatment, incineration, and wastewater management, is a significant source of GHG emissions. This study aims to assess and quantify GHG emissions from the waste sector in Lao PDR, analyze the contribution of wastewater treatment and discharge to methane emissions, and identify gaps in the current data on waste management emissions.

Using the Tier 1 methodology outlined in the 2006 IPCC (Intergovernmental Panel on Climate Change) guidelines, this research evaluates emissions from the waste sector in Lao PDR from 1960 to 2022. The results reveal a total of 1,631.89 $GgCO_2eq$ emissions, with methane (CH_4) contributing 1,536.25 $GgCO_2eq$, nitrous oxide (N_2O) 95.47 $GgCO_2eq$, and carbon dioxide (CO_2) 0.17 $GgCO_2eq$. Wastewater treatment and discharge emerge as the primary source of methane emissions, responsible for 980.68 $GgCO_2eq$.

Despite these findings, the study identifies significant gaps in data collection, particularly in areas like biological treatment and open burning of waste, which were not comprehensively included. These limitations highlight the need for further research to gather more extensive and accurate data across Lao PDR, especially to better understand the full emissions profile of the waste sector.

Keywords: Greenhouse gas emission; waste sector; solid waste disposal; waste burning; wastewater treatment.

1. Introduction

Greenhouse gas (GHG) emissions have been recognized as a critical driver of global climate change, with increasing calls for countries to adopt national strategies to mitigate these impacts. International agreements such as the Paris Agreement emphasize the need for collective action, where countries pledge to reduce emissions to limit global temperature increases to well below 2^{oC} above pre-industrial levels (United Nations Framework Convention on Climate Change, 2015). These commitments require nations to target key sectors that contribute to GHG emissions, including energy, agriculture, and waste management. The waste sector, in particular, is responsible for significant methane (CH_4) and nitrous oxide (N_2O) emissions, which have a greater global warming potential than carbon dioxide (CO_2) (Intergovernmental Panel on Climate Change, 2006 & Bogner et al., 2007).

For developing countries like the Lao People's Democratic Republic (Lao PDR), addressing emissions from the waste sector is critical due to increasing urbanization, which leads to higher volumes of waste. Waste management practices such as landfilling and wastewater treatment are major sources of methane emissions, which, if not managed effectively, could undermine the country's climate action commitments (World Bank, 2020). Lao PDR, as a signatory to the Paris Agreement, has pledged to reduce its GHG emissions as part of its Nationally Determined Contributions (NDCs) (Government of Lao PDR, 2020). However, achieving these targets presents challenges, especially given that plastic bags have become an inseparable part of daily life. Their widespread use enhances convenience, and they are included almost every time people make purchases, contributing significantly to waste (Amphonesavanh et al., 2023). As the waste sector plays a crucial role in Lao PDR's sustainability efforts, reducing plastic consumption and improving waste management practices are essential for balancing environmental goals with economic development (OECD, 2021).

According to Lao PDR's Third National Communication on Climate Change (2023), the waste sector released approximately 283.22 $GgCO_2eq$ of greenhouse gases in total. This includes 7.79 Gg of CO_2, 8.59 Gg of CH_4, and 0.31 Gg of N_2O. Wastewater treatment and discharge were identified as the largest contributors, accounting for 176.48 $GgCO_2eq$, or almost 62% of the sector's total emissions. Solid waste disposal, based on the First Order Decay method, generated 23.25 $GgCO_2eq$, while biological treatment, solid waste incineration, and open burning contributed 75.70 $GgCO_2eq$ (26.72%) and 7.79 $GgCO_2eq$ (2.75%), respectively.

In addition, the results from the Second National Communication on Climate Change of Laos PDR (Ministry of Natural Resource and Environment of Laos, 2013) and the Vietnam National Greenhouse Gas Inventory for 2016 (Ministry of Natural Resource and Environment of Vietnam, 2020) both emphasize the role of methane (CH_4) and nitrous oxide (N_2O) as the key greenhouse gases emitted from landfills, wastewater, and their treatment systems. In Lao PDR, methane emissions from solid waste disposal and wastewater handling ranged between 1.1 and 1.3 Gg, with nitrous oxide emissions totaling 0.27 Gg. In contrast, the Vietnam National Greenhouse Gas Inventory reported total GHG emissions from the waste sector at 20,738.38 ktCO2 eq, with 10,438.86 ktCO2 eq attributed to methane from solid waste disposal. Both reports highlight the challenges in estimating emissions from waste incineration due to limited data availability.

This study focuses on the estimation of GHG emissions from the waste sector in Lao PDR, covering the period from 1960 to 2022. Using the Tier 1 approach from the 2006 Intergovernmental Panel on Climate Change (IPCC) software and guidelines, it assesses emissions from key waste management practices, including solid waste disposal, biological treatment, incineration, and wastewater treatment and discharge (Intergovernmental Panel on Climate Change, 2006). Specifically, the objectives of this study are: 1) to assess and quantify greenhouse gas (GHG) emissions from the waste sector in Lao PDR; 2) to analyze the contribution of wastewater treatment and discharge to methane (CH_4) emissions in the waste sector; and 3) to identify gaps and limitations in the current data on waste management emissions in Lao PDR. The findings highlight that wastewater treatment is the largest source of methane emissions, contributing significantly to the country's GHG inventory. As Lao PDR works toward meeting its climate commitments, understanding and addressing emissions from the waste sector will be essential for achieving long-term sustainability (United Nations Environment Programme, 2021).

2. Materials and Methods

This study employed the Tier 1 approach from the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines to estimate greenhouse gas (GHG) emissions from the waste sector in Lao PDR. The research focused on four primary waste management practices: solid waste disposal, biological treatment of solid waste, incineration and open burning of waste, and wastewater treatment and discharge.

2.1 Data Collection and Sources

The activity data for the estimation of GHG emissions were derived from desk interview, international organizations, national sources, including waste production statistics, waste management records, and environmental reports from relevant government bodies, such as the Ministry of Natural Resources and Environment and Ministry of Industrial and Commerce. Two types of solid waste disposal systems were identified: Uncategorized Solid Waste Disposal Sites (SWDS) for the period from 1960 to 1997, and Unmanaged SWDS shallow for the period from 1998 to 2022.

2.2 Estimation Methodology

The emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) were calculated using the Tier 1 methodology outlined in the 2006 IPCC guidelines (Intergovernmental Panel on Climate Change, 2006). This approach requires the use of default emission factors, along with activity data specific to each waste management practice. The IPCC software was used to process the collected data and estimate emissions for the study period. The methodology included:

- Solid Waste Disposal:
  - Emissions from solid waste disposal were calculated based on the quantity of waste disposed of in landfills, using default methane correction factors (Intergovernmental Panel on Climate Change, 2006).
  - The parameter for estimating GHG emissions in Lao PDR has been in use since 1960. In Lao PDR, we applied two types of solid waste disposal: unmanaged SWDS and unmanaged SWDS shallow. The start year of Unmanaged SWDS was from 1960–1997, and Unmanaged SWDS shallow was from 1998–2022.
- Biological Treatment of Waste:
  - Emissions from composting and other biological treatments were calculated by applying IPCC default values for methane emissions based on the composition of waste treated (Intergovernmental Panel on Climate Change, 2006).
- Incineration and Open Burning:
  - The emissions from incineration were calculated by assessing the amount of waste incinerated and applying the IPCC's default values for CO_2, CH_4, and N_2O emissions (Intergovernmental Panel on Climate Change, 2006).
  - Tier 1 approach has applied to estimate the emission of waste incineration; The equation to estimate the CO_2 emission during the clinical waste combusted based on IPCC Guideline 2006, Equation 5.1, Page 5.7, Chapter 5, Volume 5.

- Wastewater Treatment and Discharge: Methane emissions from wastewater treatment were calculated using the IPCC default methodology, which takes into account the type of treatment processes used and the amount of organic material in the wastewater (Intergovernmental Panel on Climate Change, 2006).

The total GHG emissions were calculated using the formula:

Total GHG Emissions (Gg CO2eq) = E_m + E_w + E_i + E_b (1)

Where:

E_m = Emissions from solid waste management (e.g., landfilling)

E_w = Emissions from wastewater treatment

E_i = Emissions from incineration

E_b = Emissions from biological treatment (e.g., composting)

2.3 Software and Tools

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories and the accompanying software were used to estimate the emissions. The Tier 1 approach was selected as it is appropriate for countries with limited data availability and allows for the use of default emission factors provided by the IPCC (Intergovernmental Panel on Climate Change, 2006). The software facilitated the calculation of total emissions in CO_2-equivalent (CO_2eq) values, which allowed for a comprehensive assessment of the GHG emissions from the waste sector in Lao PDR.

3. Results

The GHG in the waste sector encompass CO_2, CH_4, and N_2O. Those emission were estimated from different sources: Solid Waste Disposal, Biological Treatment of Solid Waste, Incineration and Open Burning of Waste, and Waste Treatment and Discharge.

The waste sector has a total emission of 1,631.89 (GgCO2eq), with the largest emission coming from CH4 at 1,536.25 (GgCO2eq), followed by N2O at 95.47 (GgCO2eq) and CO2 at 0.17 (GgCO2eq). Table 1 (Appendix) presents the details of the GHG emissions in the waste sector for 2022.

4. Discussion

The results of this study indicate that total greenhouse gas (GHG) emissions from Laos' waste sector amount to 1,631.89 $GgCO_2eq$, with methane (CH_4) emissions being the most significant contributor at 1,536.25 $GgCO_2eq$. Nitrous oxide (N_2O) emissions totaled 95.47 $GgCO_2eq$, while carbon dioxide (CO_2) emissions were comparatively minimal at 0.17 $GgCO_2eq$. Notably, wastewater treatment and discharge were found to be the dominant sources of emissions, contributing 980.68 $GgCO_2eq$ of CH_4.

This study's findings exceed previous estimates provided in the Third National Communication on Climate Change of Lao PDR (Ministry of Natural Resources and Environment of Lao PDR, 2023), which reported total waste sector emissions of 341 $GgCO_2eq$. Although both studies highlight wastewater treatment as a significant source of emissions (199.83 $GgCO_2eq$ in the 2023 report), the current analysis reveals higher overall emissions. The prior report also included emissions from biological treatment (100.94 $GgCO_2eq$) and incineration/open burning (7.79 $GgCO_2eq$), underscoring the need to expand this study to include those sources, particularly as they play a role in Laos' waste sector emissions.

When compared with the Second National Communication on Climate Change of Lao PDR (Ministry of Natural Resources and Environment of Lao PDR, 2013), which estimated CH_4 emissions from solid waste disposal and wastewater at 1.1–1.3 Gg and N_2O emissions from waste handling and wastewater at 0.27 Gg, the current study shows a notable increase in overall emissions, particularly in CH_4. This suggests that waste generation and emissions from waste management have increased significantly over the last decade, likely due to urbanization and industrial growth. Moreover, the exclusion of waste incineration in the 2013 report due to insufficient data highlights an ongoing gap in emissions reporting, as this study also omits emissions from certain sources, such as biological treatment and open burning, due to limited data availability. Future research should focus on filling these gaps to create a more complete emissions inventory.

In comparison to Vietnam's National Greenhouse Gas Inventory for 2016 (2020), Laos' waste sector emissions are significantly lower. Vietnam's total waste sector emissions were 20,738.38 $ktCO_2eq$ in 2016, with the majority coming from solid waste disposal (10,438.86 $ktCO_2eq$), and wastewater treatment and discharge contributing 7,062.71 $ktCO_2eq$ of CH_4. In contrast, Laos' emissions from solid waste disposal are much smaller, reflecting differences in waste management infrastructure and industrial activity between the two countries. However, the pattern of wastewater treatment being a key emissions source is consistent across both countries, further underscoring the need for improved waste management practices in Laos.

Additionally, the limitations in this study, such as the use of waste generation data from only six major cities in Laos, highlight the need for more comprehensive data collection. Expanding data coverage to include rural areas and integrating more accurate methods for tracking biological treatment, incineration, and open burning will allow for more precise emission estimates. As Laos continues to develop, particularly in urban centers, addressing gaps in waste management and emissions data will be crucial for meeting the country's climate commitments.

Future studies should also prioritize improving data collection on wastewater, especially from industrial sources, to gain a clearer understanding of its contribution to the country's overall GHG emissions. The comparison with Vietnam highlights the potential for Laos to improve its waste management practices, especially in high-emission areas like wastewater treatment, to better align with regional standards.

5. Conclusion

This study provides a comprehensive assessment of greenhouse gas emissions from the waste sector in Laos, revealing a total emission of 1,631.89 $GgCO_2eq$. The primary contributor to these emissions is wastewater treatment and discharge, responsible for 980.68 $GgCO_2eq$ in methane emissions. However, limitations exist due to the lack of data on key sources such as biological treatment of solid waste and open burning, which were not included in the final analysis.

Data for waste generation was derived from a World Bank study that covers only six major cities, indicating that future studies should strive to collect more comprehensive data that includes regions across the entire country. Additionally, the absence of reliable data on open burning and biological treatment points to the need for more focused research efforts in these areas.

Comparing the results with a previous study, it is evident that this study provides higher emission estimates, particularly from the wastewater sector. The previous study included emissions from biological treatment and open burning, areas not accounted for in this analysis, underscoring the need for further data collection to provide a more complete emissions inventory.

While this study offers valuable insights into the emissions profile of Laos' waste sector, future research should aim to address the identified data gaps to ensure a more accurate and holistic understanding of emissions. Enhanced data coverage, particularly for waste generation, biological treatment, and open burning, will be critical for informing more effective waste management and emissions reduction strategies in the future.

6. Conflict of Interest

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

7. References

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Table 1. Total GHG Emissions from Waste Sector in Lao PDR (1960-2022)

Categories	Global Warming Potential Values Emission (GgCO2eq)						
	CO_2	CH_4	N_2O	CO	NMVOCs	SO_2	Total
I - Waste	**0.17**	**1,536.25**	**95.47**				**1,631.89**
I.1 - Solid Waste Disposal	-	555.56	-				555.56
I.1.1 - Managed Waste Disposal Sites	-	-	-				-
I.1.2 - Unmanaged Waste Disposal Sites	-	539.83	-				539.83
I.1.3 - Uncategorized Waste Disposal Sites	-	15.73	-				15.73
I.2 - Biological Treatment of Solid Waste	-	-	-				-
I.2.1 - Composting	-	-	-				-
I.2.1 - Anaerobic digestion at biogas facilities	-	-	-				-
I.3 - Incineration and Open Burning of Waste	0.17	-	-				0.17
I.3.1 - Waste Incineration	0.17	-	-				0.17
I.3.2 - Open Burning of Waste	-	-	-				-
I.4 - Wastewater Treatment and Discharge	-	980.68	95.47				1,076.15
I.4.1 - Domestic Wastewater Treatment and Discharge	-	267.96	95.47				363.43
I.4.2- Industrial Wastewater Treatment and Discharge	-	712.72	-				712.72

Table 2 specifically displays the methane (CH_4) emissions that result from solid waste disposal, not the overall emissions. The emissions from unmanaged waste disposal and uncategorized waste disposal in solid waste disposal sites from 1960 to 2022 are 539.83 GgCO2eq and 15.73 GgCO2eq, respectively, resulting in a total of 555.56 GgCO2eq.

Table 2. Methane emission from Unmanaged and Uncategorized Waste Disposal from 1960-2022

Categories	Global Warming Potential Values (AR5) Emission (GgCO2eq)						
	CO_2	CH_4	N_2O	CO	NMVOCs	SO_2	Total
I - Waste							
I.1 - Solid Waste Disposal	-	555.56					555.56
I.1.1 - Managed Waste Disposal Sites	-	-	-				-
I.1.2 - Unmanaged Waste Disposal Sites	-	539.83	-				539.83
I.1.3 - Uncategorized Waste Disposal Sites	-	15.73	-				15.73

Table 3 specifically displays the carbon dioxide (CO2) emissions that result from the incineration and open burning of waste, not the overall emissions. The table reveals that the incinerator's combustion of clinical waste emits 0.17 GgCO2eq of CO2.

Table 3. CO_2 emission from incinerator's combustion of clinical waste from 1960-2022

Categories	Global Warming Potential Values (AR5) Emission (GgCO2eq)						
	CO_2	CH_4	N_2O	CO	NMVOCs	SO_2	Total
I.3 - Incineration and Open Burning of Waste	**0.17**	-	-				**0.17**

I.3.1 - Waste Incineration	0.17	-	-				0.17
I.3.2 - Open Burning of Waste	-	-	-				-

Table 4 specifically displays the results of methane (CH4) from both domestic and industrial wastewater treatment and discharge, which are 267.96 and 712.72 GgCO2eq, respectively. In addition, nitrous oxide (N_2O) The emissions released from the treatment and discharge of domestic wastewater amount to 95.47 GgCO2eq. These emissions only represent the total emissions from wastewater treatment and discharge, not the total emissions from all categories.

Table 4. CH_4 and N_2O emission from both domestic and industrial wastewater treatment and discharge from 1960–2022.

Categories	Global Warming Potential Values (AR5) Emission (GgCO2eq)						
	CO2	**CH_4**	**N_2O**	**CO**	**NMVOCs**	**SO_2**	**Total**
I.4 - Wastewater Treatment and Discharge	**-**	**980.68**	**95.47**				**1,076.15**
I.4.1 - Domestic Wastewater Treatment and Discharge	-	267.96	95.47				363.43
I.4.2- Industrial Wastewater Treatment and Discharge	-	712.72	-				712.72

To calculate the greenhouse gas emissions from solid waste disposal, Table 5 presents the input data on waste generation in Laos. The Lao PDR lacked historical data on waste generation (ton/year) for the years 1960-1999 and 2016-2022 across all provinces. The World Bank report on Supporting Lao PDR to improve solid and plastic waste management (2021) provided waste generation for the six major provinces: Vientiane Capital, Savannakhet, Khammoun, Luangprabang, Xayaboury, Champasak, and others.

Table 5. Waste generation input data for estimating emissions from the waste sector.

Waste generation (Ton/Year) from 1960 - 2022							
Year	**Vientiane Capital**	**Savanakhet**	**Khammoun**	**Laungprabang**	**Xayaboury**	**Champasak**	**Others**
1960	53,427	71,798	44,259	39,014	29,506	53,111	212,458
1961	54,651	73,442	45,273	39,907	30,182	54,327	217,323
1962	55,921	75,150	46,325	40,835	30,883	55,590	222,376
1963	57,220	76,895	47,401	41,783	31,601	56,881	227,541
1964	58,536	78,664	48,492	42,744	32,328	58,190	232,776
1965	59,894	80,489	49,616	43,736	33,078	59,540	238,175
1966	61,289	82,363	50,772	44,754	33,848	60,926	243,721
1967	62,725	84,293	51,962	45,803	34,641	62,354	249,433
1968	64,214	86,294	53,195	46,890	35,463	63,834	255,353
1969	65,750	88,359	54,468	48,012	36,312	65,361	261,463
1970	67,341	90,496	55,785	49,173	37,190	66,942	267,786
1971	68,988	92,710	57,150	50,376	38,100	68,580	274,337
1972	70,689	94,995	58,558	51,618	39,039	70,270	281,100
1973	72,432	97,338	60,003	52,891	40,002	72,004	288,034
1974	74,177	99,683	61,448	54,166	40,966	73,738	294,972
1975	75,834	101,910	62,821	55,376	41,881	75,386	301,562
1976	77,327	103,916	64,058	56,466	42,705	76,869	307,498
1977	79,433	106,704	65,778	58,008	43,891	79,005	308,766
1978	81,540	109,491	67,498	59,550	45,078	81,140	309,674
1979	83,646	112,279	69,218	61,092	46,264	83,275	311,424
1980	85,753	115,067	70,938	62,634	47,450	85,410	315,087
1981	86,681	118,103	66,952	64,248	48,684	87,640	327,463

Waste generation (Ton/Year) from 1960 - 2022							
Year	**Vientiane Capital**	**Savanakhet**	**Khammoun**	**Laungprabang**	**Xayaboury**	**Champasak**	**Others**
1982	87,609	121,140	62,966	65,861	49,918	89,871	342,027
1983	88,537	124,177	58,981	67,474	51,151	92,101	358,363
1984	89,465	127,214	54,995	69,087	52,385	94,331	376,106
1985	90,393	130,251	51,009	70,701	53,619	96,561	395,166
1986	94,331	134,521	52,432	72,551	51,673	98,744	408,781
1987	98,269	138,792	53,856	74,402	49,728	100,927	423,468
1988	102,208	143,062	55,279	76,252	47,782	103,109	439,095
1989	106,146	147,333	56,703	78,103	45,837	105,292	455,505
1990	110,084	151,603	58,126	79,954	43,891	107,475	472,472
1991	113,311	153,311	59,550	81,377	49,016	109,847	486,323
1992	116,538	155,020	60,973	82,801	54,141	112,220	500,435
1993	119,764	156,728	62,397	84,224	59,265	114,592	514,620
1994	122,991	158,436	63,820	85,648	64,390	116,965	528,441
1995	126,217	160,144	65,244	87,071	69,514	119,337	541,509
1996	129,349	164,462	66,952	89,396	71,413	122,611	552,489
1997	132,481	168,780	68,660	91,721	73,311	125,885	561,131
1998	135,613	173,098	70,369	94,046	75,209	129,159	567,343
1999	138,744	177,416	72,077	96,371	77,107	132,433	572,784
2000	141,876	181,734	73,785	98,696	79,005	135,707	577,671
2001	146,636	184,553	75,026	98,279	79,297	137,382	588,515
2002	151,396	187,370	76,268	97,862	79,590	139,057	598,774
2003	156,156	190,188	77,508	97,443	79,882	140,730	608,217
2004	160,916	193,004	78,749	97,024	80,173	142,404	616,742
2005	165,676	195,820	79,990	96,605	80,464	144,076	626,618
2006	171,262	202,283	82,914	99,843	83,251	148,177	642,244
2007	176,849	208,742	85,844	103,081	86,038	152,259	658,009
2008	182,435	106,318	88,828	88,779	215,197	156,323	673,590
2009	188,021	109,554	91,619	91,719	221,649	160,371	688,944
2010	193,608	112,791	94,412	94,664	228,100	164,403	704,043
2011	197,867	115,233	96,533	96,786	232,993	167,037	714,983
2012	202,127	117,421	98,654	99,161	237,886	169,918	725,527
2013	206,386	119,862	100,776	101,284	242,777	172,794	735,901
2014	210,646	122,622	103,288	103,796	247,788	175,792	738,393
2015	214,905	113,080	99,731	102,610	253,907	181,661	810,781
2016	243,924	126,897	112,797	114,771	283,403	201,343	860,181
2017	272,943	140,168	125,073	127,538	314,531	223,037	952,502
2018	301,962	152,812	137,165	140,161	345,575	244,366	1,043,386
2019	330,981	165,134	149,084	152,294	375,920	264,999	1,102,081
2020	360,000	177,342	160,633	164,810	406,329	285,949	1,349,913
2021	367,975	178,861	162,911	167,089	412,405	289,367	1,207,975
2022	375,570	180,000	164,810	169,367	418,481	293,165	1,225,063

Table 6 presents the input data from the Vientiane City Office for Management and Service (VCOMS), revealing that the incinerators only burned clinical wastes at Vientiane Capital from 2018 to 2022. The GHG emissions from incineration were calculated using these input data.

Table 6. Amount of Clinical Waste combusted in the incinerator at Vientiane Capital (Vientiane City Office for Management and Service, 2023)

Year	Amount of Clinical Waste (Kg/day)	Number of days in year	Amount of Clinical Waste (Ton/Year)
2018	383	365	0.14
2019	373.7	365	0.14
2020	375	365	0.14
2021	1,193.60	365	0.44
2022	816	365	0.30
2023	466	365	0.17

Table 6 shows the input data for safely treated household wastewater in Lao PDR. We used these to calculate the GHG emissions from domestic wastewater treatment and discharge, a category that encompasses wastewater treatment and discharge.

Table 7. shows the estimation of safely treated household wastewater in Lao PDR (World Health Organization, 2020)

Sources of Treated Wastewater		Volume (million m^3/year)
Estimated household wastewater generated	Stream 1: Households connected to sewers	2.864
	Stream 2: Households connected to septic tanks	52.617
	Households using all other types of sanitation	165.865
	Total generated	**221.346**
Estimated household wastewater collected at treatment facilities	Stream 1: Collected from piped sewers at wastewater treatment plants	2.864
	Stream 2a: Wastewater collected at septic tanks and faecal sludge at wastewater treatment plants (off-site)	4.604
	Stream 2b: Wastewater collected at septic tanks and faecal sludge at on-site treatment (on-site)	20.915
	Total collected	**28.383**
Estimated household wastewater safely treated	Stream 1: Safely treated from piped sewers at wastewater treatment plants	1.432
	Stream 2a: Wastewater safely treated at septic tanks and faecal sludge at wastewater treatment plants (off-site)	0.000
	Stream 2b: Wastewater safely treated at septic tanks and faecal sludge at on-site treatment (on-site)	20.915
	Total safely treated	**22.347**

Table 7 provides the input data for estimating CH4 emissions, specifically the total industrial product (ton/year). We calculated the GHG emissions from industrial wastewater treatment and discharge using these input data, a category that includes wastewater treatment and discharge.

Table 8. Total industrial product from 2020 (Ministry of Industrial and Commerce of Lao PDR, 2021)

	Industry type	Unit	2020
Total industrial product for industrial sector	Alcohol Refining	ton/year	22,045
	Beer & Malt	ton/year	131,598
	Coffee	ton/year	100,281
	Dairy Products	ton/year	19,494
	Fish Processing	ton/year	66,358
	Meat & Poultry	ton/year	400,992
	Organic Chemicals	ton/year	421,645
	Plastics & Resins	ton/year	346,598
	Pulp & Paper (combined)	ton/year	58,226
	Soap & Detergents	ton/year	23,955
	Starch Production	ton/year	858,417
	Sugar Refining	ton/year	22,558
	Vegetable Oils	ton/year	60,189

	Vegetables, Fruits & Juices	ton/year	600,816
	Wine & Vinegar	ton/year	42,085