

Emissions of Short-Lived Climate Pollutants (SLCPs) from the Waste Sector in Grand Lomé: Contribution of Local Data and Climate Implications

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Abstract

In African cities, landfilling and open burning of municipal solid waste emit short-lived climate pollutants (SLCPs) and associated air pollutants. This study estimates emissions of methane (CH₄) and black carbon (BC), together with carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs) and nitrogen oxides (NO_x), air pollutants and ozone precursors co-emitted during open burning, from the waste sector of the Autonomous District of Grand Lomé (DAGL). Following the IPCC 2006 Guidelines and their 2019 Refinement, estimates draw on twenty waste characterizations over five years and a survey of 800 households on burning practices. Open burning is practiced by 41.67% of the population (95% CI: 38.2% - 45.2%), versus 67% by default. Local composition departs from the default profile: in 2025, green waste 26.3%, plastics 22.8%, food waste 11.8% (versus 53.9%). Between 2021 and 2025, waste generation rose by 30.2% and landfilled quantities by 51.9%. CH₄ from landfilling increased from 1090 to 4866 t/year (+346.4%), CH₄ from open burning from 391 to 509 t/year and BC from 69 to 90 t/year. In 2025, open burning emitted 5281 t/year of CO, 3141 t/year of NMVOCs and 681 t/year of NO_x. The climate impact of CH₄ and BC grew from 103.5 to 231.1 Gg CO₂-eq (+123.3%; 48.7 to 98.6 kg CO₂-eq/capita). Landfilling became the main source (29.4% to 58.8%), open burning declined from 70.5% to 41.2%, composting remained marginal (<0.1%); the BC share of impact fell from 60.0% to 35.1%. Against IPCC defaults, local estimates are approximately 37.9% lower for open burning (CH₄ and BC) and lower for landfill CH₄ (-50.1% in 2021, -44.3% in 2025; mean -46.9%). Uncertainty reaches ±52.2% for landfill CH₄; GWP-100 values of 100 - 1700 for BC give totals of 159.1 - 303.1 Gg CO₂-eq. Priorities are reduc-

ing open burning and curbing landfill methane through organic-fraction diversion and biogas capture at the Aképé Technical Landfill Center (CET).

Keywords

Household Waste, Open Burning, Landfilling, Climate Impact, SLCPs

1. Introduction

Short-lived climate pollutants (SLCPs) perturb the climate system [1] [2]. They comprise mainly methane (CH₄), black carbon (BC), tropospheric ozone (O₃) and hydrofluorocarbons (HFCs). Black carbon, produced in part by the incomplete combustion of biomass and waste, acts as a warming agent because it absorbs solar radiation, with a mass absorption cross-section estimated at approximately $7.5 \pm 1.2 \text{ m}^2/\text{g}$ at 550 nm [3] [4]. Tropospheric ozone is not emitted directly, but is formed in the atmosphere from precursor air pollutants, namely nitrogen oxides (NO_x), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOCs), which are themselves released by the incomplete combustion of waste. An SLCP reduction strategy could lower tropospheric ozone concentrations by 7% to 17% by 2030, with benefits concentrated in developing countries [5].

The municipal solid waste management sector is one of the main anthropogenic sources of these emissions, with consequences for both the climate and public health [6] [7]. According to the IPCC, the waste sector accounts for approximately 18% to 20% of global anthropogenic methane emissions, owing to the anaerobic decomposition of the organic fraction of solid waste [8]. Rapid urbanization and population growth in sub-Saharan Africa are intensifying these challenges, particularly with regard to municipal solid waste management. In Togo, municipal solid waste is characterized by a high proportion of fermentable organic matter, consisting mainly of food waste and green waste, which together accounted for approximately 38% of the total waste stream of Grand Lomé in 2025. In the absence of systematic treatment and recovery pathways, this biodegradable fraction gives the waste stream a high methanogenic potential, leading to uncontrolled biogas production and substantial greenhouse gas emissions during its storage or landfilling [9] [10]. An assessment of this energy resource at the Aképé Technical Landfill Center (CET) by Hundjoe *et al.* (2025) [9] reported a biogas production potential ranging from $14.81 \times 10^{-3} \text{ m}^3/\text{kg VS}$ in the rainy season to $26.33 \times 10^{-3} \text{ m}^3/\text{kg VS}$ in the dry season. Quantifying these organic flows and controlling their anaerobic degradation kinetics are therefore essential steps towards developing energy recovery pathways suited to the Togolese context. In Grand Lomé, however, waste management remains subject to technical, organizational and financial constraints, which limit collection performance and encourage uncontrolled dumping and open burning [11].

Studies conducted in the Togolese context have improved knowledge of waste generation and management, but they have focused mainly on physical characterization, chemical composition and recovery. By contrast, the estimation of SLCP emissions from the waste sector remains largely unexplored. This study aims to estimate emissions of CH₄ and BC, together with those of the associated air pollutants CO, NMVOCs and NO_x, and to assess the resulting climate impact of the waste sector of Grand Lomé over the period 2021–2025. The approach adopted is based on the [1] Guidelines and their 2019 Refinement, using local data on waste quantities and management practices. Emissions are estimated for the main management pathways, namely landfilling, open burning and composting, and are then compared with estimates obtained using the IPCC default parameters. This comparison quantifies the influence of local data on SLCP estimates and on the contribution of the sector to climate impact.

2. Materials and Methods

2.1. Study Area

The selection of Grand Lomé as the study area is based on three considerations. From a scientific standpoint, it is the main municipal solid waste generation area in Togo and encompasses a diversity of urban, peri-urban, residential, commercial and industrial municipalities representative of national waste-management challenges. From an environmental standpoint, waste management there combines several disposal pathways (landfilling, open burning, uncontrolled dumping), and the district hosts the Aképé Technical Landfill Center (CET), which provides the type of disposal infrastructure required to apply the IPCC first-order decay (FOD) method. The average household waste generation rate in Grand Lomé is estimated at 0.56 to 0.65 kg/capita/day [11]. From a methodological standpoint, the district benefits from statistical and operational monitoring that provides the activity data required for the estimates. Grand Lomé is therefore among the priority areas of national policies on sustainable waste management and SLCP reduction, within the framework of Togo's Nationally Determined Contributions (NDCs). The locations of Grand Lomé and the Aképé CET are presented in **Figure 1**.

2.2. Activity Data

2.2.1. Sources and Scope

Table 1 presents the main activity data used to estimate SLCP emissions in Grand Lomé over the period 2021–2025. Demographic data were obtained from the National Institute of Statistics and Economic and Demographic Studies (INSEED), while data on waste generation and management were obtained from the National Agency for Sanitation and Public Health (ANASAP) and from the Directorate of Technical Services of the Autonomous District of Grand Lomé (DST-DAGL). Data from the technical services directorates of the thirteen municipalities were also used to complement the information on waste management. Taken together, these data document trends in population, daily per capita waste generation,

quantities generated and landfilled, and the waste flows associated with each management pathway. The reported management pathways do not necessarily account for the entire generated waste stream, as additional fractions may be recovered, recycled or managed through other pathways not explicitly quantified in this study.

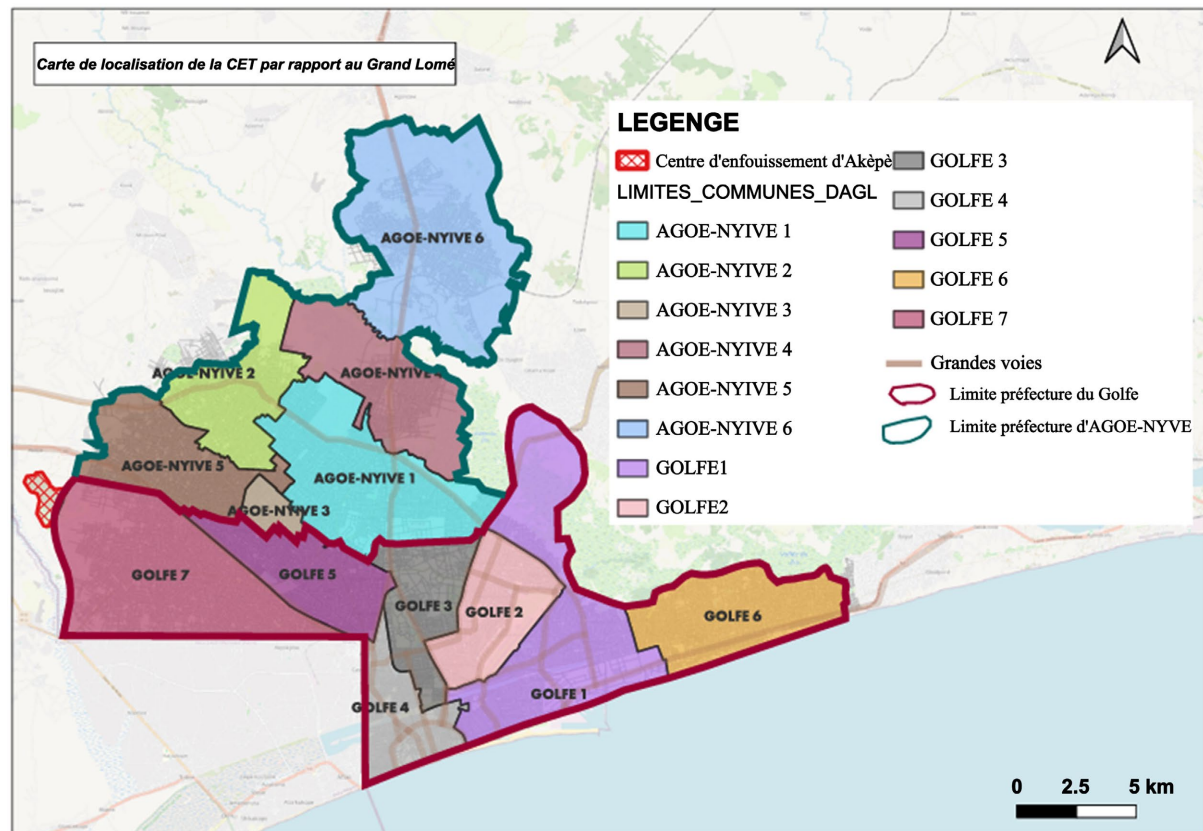


Figure 1. Location of the DAGL and the Aképé CET.

Table 1. Activity data.

Category	Parameter	2021	2022	2023	2024	2025
Demographic data	Population (inhabitants)	2,127,020	2,188,387	2,238,927	2,290,647	2,342,873
Waste generation	Rate (kg/capita/day)	0.55	0.56	0.60	0.60	0.65
	Quantity generated (t/year)	426,999	447,306	490,325	501,652	555,847
Waste landfilling	Landfilled fraction (%)	60	65	70	69	70
	Quantity landfilled (t/year)	256,200	290,749	343,228	346,140	389,093
Open burning	Quantity burned (t/year) (local)	106,732	111,836	122,591	125,423	138,973
	Quantity burned (t/year) (IPCC)	171,954	180,177	197,504	202,067	223,897
Waste composting	Quantity composted (t/year)	4269	4473	4903	5328	6826

For the FOD calculation, historical waste-disposal data preceding the study period were also used to initialize the decay model. The historical activity data used

for this initialization are presented in **Table 2**.

Table 2. Historical waste-disposal data used for FOD model initialization.

Parameter	2018	2019	2020
Waste generated (t/year)	428188.80	467651.56	562840.41
Waste sent to landfill (t/year)	239785.73	261884.87	315190.63

2.2.2. Field Survey for the Estimation of Pfrac

The household survey used to estimate the fraction of the population practicing open burning (Pfrac) was conducted in 2025. A random sample proportional to the population of the thirteen municipalities of Greater Lomé was selected using the RGPH-5 population data [12], with a minimum of 18 households per municipality. A total of 800 households were surveyed, of which 756 questionnaires were usable (94.5%). The survey estimated that 41.67% of the population practiced open burning (95% CI: 38.2% - 45.2%). The resulting Pfrac value was applied consistently to each year of the 2021-2025 study period to estimate the annual quantity of waste burned under the local approach.

2.2.3. Waste Sampling and Physical Characterization

Waste sampling was carried out in proportion to the tonnages delivered from the various municipalities. Composite samples were characterized according to the MODECOM approach of ADEME, based on the AFNOR standard XP X30-408, with sorting into three particle-size classes (coarse: >100 mm; medium: 20 - 100 mm; fines: <20 mm), and then classified into eleven waste categories: food waste, green waste, disposable nappies, paper and cardboard, wood, textiles, plastics, rubber and leather, metals, glass and other waste. Sampling and characterization were carried out over the period 2021-2025. Four characterizations were performed each year, and annual mean values were calculated.

The composition of municipal waste obtained from delivery records was used as a proxy for the composition of household waste considered to be burned under the local approach. This represents an extrapolation because the waste samples were collected from municipal waste deliveries rather than directly at household burning sites.

2.3. Emission Estimation

The estimation of SLCP emissions is based on the IPCC 2006 Guidelines and their 2019 Refinement, implemented using the official “IPCC Waste Model Template”, which applies the first-order decay (FOD) method for methane emissions from landfilling. Emissions were estimated for the three main waste management pathways of Grand Lomé: landfilling, open burning and biological treatment. The pollutants considered are methane (CH₄) and black carbon (BC), treated as the short-lived climate pollutants of interest, together with carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs) and nitrogen oxides (NO_x), which

are accounted for as air pollutants and tropospheric ozone precursors.

All emissions are calculated using the general IPCC inventory equation:

$$E_{i,j,k} = \sum AD(j,k) * EF(i,j,k) \quad (1)$$

where AD is the activity data, EF is the emission factor, i is the pollutant type, j is the management pathway and k the waste category.

2.3.1. Waste Landfilling (First-Order Decay Method)

Methane (CH_4) emissions from the landfilling of municipal solid waste were estimated using the first-order decay (FOD) method.

To account for the delayed decomposition of waste deposited before the study period, the FOD model was initialized using historical waste-disposal data for 2018-2020. These data were used to establish the initial stock of degradable organic carbon (DDOC) entering the 2021-2025 simulation period. The undecomposed DDOC remaining at the end of each year was carried forward to the following year according to the first-order decay constant (k). Consequently, the methane emissions estimated for 2021 include the contribution of waste deposited during the pre-2021 initialization period, in addition to waste deposited in 2021. Waste deposited before 2018 was not included because corresponding historical activity data were not available.

In the local FOD calculation, all waste quantities considered as landfilled were allocated to the Aképé Technical Landfill Center (CET), classified as a managed anaerobic solid waste disposal site. Accordingly, 100% of the landfilled waste was assigned to the managed anaerobic category (MCF = 1.0). This allocation was applied consistently over the modeled period. All variables were expressed in tonnes to ensure that the calculations were consistent with the activity data. For the local FOD calculation at the Aképé CET, the methane fraction in landfill gas was set to $F = 0.50$. No methane recovery was considered during the study period ($\text{CH}_{4,\text{recovered}} = 0$), and the methane oxidation factor was set to $\text{OX} = 0$.

The degradable organic carbon potentially available for decomposition (DDOC_m) is calculated as follows:

$$\text{DDOC}_m = W * \text{DOC} * \text{DOC}_f * \text{MCF} \quad \text{with} \quad \text{DOC} = \sum \text{DOC}_i * W_i \quad (2)$$

where W is the mass of landfilled waste (t), DOC is the degradable organic carbon content of the waste, DOC_f is the fraction of DOC that decomposes, and MCF is the methane correction factor accounting for the landfilling conditions.

The decomposition rate of the organic matter is described by the kinetic constant k , calculated as:

$$k = \frac{\ln 2}{t_{1/2}} \quad (3)$$

where $t_{1/2}$ denotes the half-life of the degradable organic carbon, which depends on climatic conditions and waste composition.

The amount of organic carbon actually decomposed during year T is then estimated by:

$$\text{DDOCm decomposed}(T) = \text{DDOC}_{m(T-1)} * (1 - e^{-k}) \quad (4)$$

where $\text{DDOC}_{m(T-1)}$ represents the stock of degradable organic carbon accumulated at the end of the previous year.

The amount of methane generated is obtained as follows:

$$\text{CH}_4 \text{ generate} = \text{DDOCm decomposed} * F * 16/12 \quad (5)$$

Net methane emissions are then calculated after accounting for methane recovery and oxidation:

$$\text{Emission CH}_4 = (\text{CH}_{4,\text{generated},T} - \text{CH}_{4,\text{recovered},T})(1 - \text{OX}) \quad (6)$$

where $\text{CH}_{4,\text{generated},T}$ is the amount of methane generated in year T , $\text{CH}_{4,\text{recovered},T}$ is the amount of methane recovered in year T ($\text{t CH}_4 \text{ year}^{-1}$), and OX_T is the methane oxidation factor. This formulation follows the structure implemented in the IPCC Waste Model Template, in which methane recovery is accounted for before applying the oxidation factor. The waste-fraction parameters used in the FOD calculation are presented in **Table 3**, while the methane correction factors associated with the disposal-site typology are presented in **Table 4**.

Table 3. Default parameters adopted per waste fraction (FOD model and open burning).

Fraction	DOC (fraction)	DOC _f	DM (fraction)	CC (fraction)	FC (fraction)	OX (burn.)	Source
Food waste	0.15	0.60	0.40	0.38	0.00	0.15	[1]
Green waste	0.20	0.65	0.40	0.40	0.00	0.10	
Disposable nappies	0.05	0.55	0.40	0.70	0.10	0.08	
Paper/cardboard	0.40	0.48	0.90	0.46	0.01	0.08	
Wood	0.43	0.45	0.85	0.50	0.00	0.09	
Textiles	0.24	0.50	0.80	0.50	0.20	0.08	
Plastics	0.00	0.50	1.00	0.67	1.00	0.05	
Metal/glass	0.00	0.00	0.00	0.00	0.00	0.00	
Other	0.09	0.50	0.00	0.00	0.00	0.00	

Table 4. Typology of disposal sites in Grand Lomé and methane correction factors (MCF) adopted.

Type of disposal site	IPCC category	MCF	Source
Aképe CET (official, managed site, with cover)	Managed SWDS	1.0	[1]
Deep uncontrolled dumpsites (≥ 5 m, anaerobic)	Unmanaged Deep SWDS	0.8	
Permanent illegal dumpsites (≥ 5 m)	Unmanaged Deep SWDS	0.8	
Scattered informal dumpsites (< 5 m, unmanaged)	Unmanaged Shallow SWDS	0.4	
Transfer stations (temporary, non-final)	Unclassified SWDS	n.a.	

n.a. = not applicable.

2.3.2. Open Burning

Unlike landfilling, open burning generates emissions directly during waste combustion, in the absence of any control device. This pathway is a source of CH₄, BC, CO, NMVOCs and NO_x. The annual amount of waste burned in the open (IW) is estimated by:

$$IW = P * P_{\text{frac}} * MSWP * B_{\text{frac}} * 365 \quad (7)$$

where P is the population of the DAGL, P_{frac} is the fraction of the population practicing open burning, $MSWP$ is the daily per capita waste generation (kg/capita/day) and B_{frac} is the fraction of waste actually burned. Emissions by pollutant and by waste fraction are then calculated by:

$$E(i, k) = IW_i * EF(i, k) * 10^{-6} \quad (8)$$

where $E(i, k)$ is the emission of pollutant i from waste fraction k , IW_i is the quantity of fraction k actually burned and $EF(i, k)$ is the corresponding emission factor (kg/tonne of waste burned). The emission factors adopted are presented in **Table 5**.

Table 5. Emission factors adopted for the open burning of waste.

Pollutants	CH ₄	BC	CO	NMVOCs	NO _x	Source
Emission factors (kg/tonne of waste)	3.66	0.65	38	22.6	4.9	[13]

2.3.3. Biological Treatment

In Grand Lomé, composting is the dominant biological treatment, whereas anaerobic digestion remains marginal; only the organic fractions (food waste and green waste) are composted. N₂O emissions were not considered, since the study focused on short-lived climate pollutants. The associated CH₄ emissions are estimated by:

$$\text{Emission CH}_4 = M * EF \quad (9)$$

where M is the mass of organic waste treated (t) and EF is the emission factor. In line with the approach adopted for the other pathways, two emission factors were compared: the IPCC default value of 4 kg CH₄/t of waste treated, and a local value of 2 kg CH₄/t of waste treated. In the local approach, the mass of waste treated was expressed on a dry-matter basis, that is, adjusted for the moisture content measured locally, whereas the IPCC default factor applies to waste on a wet-weight basis.

2.4. Calculation of the Climate Impact

The climate impact of each pollutant was converted into CO₂ equivalent (CO₂-eq) using the 100-year global warming potential (GWP-100), according to the standard IPCC formula:

$$\text{CO}_2\text{-eq (Gg)} = \text{Emission (t)} * \text{GWP}/1000 \quad (10)$$

The GWP-100 values adopted are 27.9 for CH₄ and 900 for black carbon (BC), the latter corresponding to a central scenario. Since the climate budget varies appreciably with the GWP metric adopted, a sensitivity analysis was conducted on this parameter. CO, NMVOCs and NO_x are reported only in t/year, as indicators of air-pollution and ozone-precursor co-benefits, because no harmonized GWP-100 value is currently recommended by the IPCC for these pollutants.

2.5. Uncertainty and Sensitivity Analysis

The uncertainty associated with the emission estimates was assessed in order to evaluate the representativeness of the results and to identify the parameters that govern the climate budget. The analysis was conducted separately for CH₄ emissions from landfilling, emissions from open burning and their conversion into CO₂-eq. The uncertainty values adopted for the parameters of the landfilling model are based on the 2019 Refinement to the IPCC Guidelines [14].

For landfilling, the analysis covers the following parameters: the quantity of waste deposited (MSWT), the fraction destined for landfilling (MSWF), the degradable organic carbon (DOC), the decomposable fraction of DOC (DOC_f), the methane correction factor (MCF), the methane fraction in the biogas (*F*) and the degradation constant *k*. The uncertainties of the multiplicative parameters were combined by quadratic propagation according to the equation:

$$U_c = \sqrt{\sum_{i=1}^n U_i^2} \quad (11)$$

where U_c denotes the combined relative uncertainty and U_i is the uncertainty of parameter *i*. The parameters and uncertainties adopted for the sensitivity analysis are presented in **Table 6**.

Table 6. Parameters and uncertainties used for the sensitivity analysis of the landfilling model.

Parameter	Value/uncertainty	Source
MSWT	±30%	[14]
MSWF	±30%	
DOC	±10%	
DOC _f	±20%	
MCF	±20%	
<i>k</i>	±5%	

For open burning, CH₄ and BC emissions were recalculated at the two bounds of the Pfrac interval, with the other parameters held constant.

Finally, the sensitivity of the climate budget to the choice of the GWP-100 value for BC was assessed. The GWP of 900 used in the main analysis was compared with other values, in particular the value of 342 proposed by [15], in order to quantify the effect of the choice of climate metric on the final budget.

3. Results and Discussion

3.1. Trends in Waste Flows and Composition

The total quantity of waste generated in Grand Lomé increased from 426,999 t/year in 2021 to 555,847 t/year in 2025, *i.e.*, an increase of 30.2%. Over the same period, the quantities destined for landfilling rose from 256,200 to 389,093 t/year (+51.9%), while the quantities estimated to be burned in the open increased from 106,732 to 138,973 t/year. This trend reflects population growth and the gradual expansion of waste collection services.

The composition of waste in Grand Lomé also departs from the IPCC default profiles (**Table 7**). In 2025, the main fractions identified are green waste (26.3%), plastics (22.8%), food waste (11.8%) and textiles (4.5%), whereas the IPCC default profile adopted in this study assigns 53.9% to food waste, 6.4% to plastics and 0% to green waste. The urban context of Grand Lomé partly explains this discrepancy: gardening and green-space maintenance residues are abundant, and diets rely on fresh produce. Conversely, the relatively low proportion of food waste may reflect local biowaste management practices.

Table 7. Waste composition in Grand Lomé (2021-2025).

Fraction	2021	2022	2023	2024	2025	IPCC (def.)
Food waste	11.6	16.9	13.2	12.3	11.8	53.9
Green waste	23.0	19.1	19.1	19.3	26.3	0
Disposable nappies	4.4	3.3	2.5	2.4	3.3	0
Paper/cardboard	3.0	3.4	3.2	3.1	2.9	7.5
Wood	2.3	4.0	3.9	2.8	2.3	0
Textiles	3.5	5.2	4.6	4.3	4.5	1.9
Plastics	23.0	16.0	16.9	20.7	22.8	6.4
Metal/glass	1.1	1.5	1.4	1.2	1.2	4.0
Other	28.1	30.6	35.2	33.9	24.9	26.6

Compared with previous work, the share of plastics has more than doubled, whereas it did not exceed 11% in the earlier characterization of Lomé [10]. Likewise, the combined share of green waste and food residues reaches approximately 38.1% in 2025 in the present study, compared with 22% in the work of Koledzi *et al.* (2011) [10]. These differences may be explained by the recovery of plastic bottles along the collection chain and by changes in waste composition between the study periods.

3.2. SLCP Emissions by Management Pathway

CH₄ emissions associated with landfilling increased from 1090 t/year in 2021 to 4662 t/year in 2025, *i.e.*, an increase of 327.7%. This increase exceeds that of the total quantity of waste generated (+30.2%) and that of landfilled waste (+51.9%).

The discrepancy arises because emissions do not follow tonnage growth alone, but also depend on the nature of the landfilled waste and on the parameters governing its methanogenic potential, in particular the organic carbon content and the degradation dynamics. Among the waste management pathways, landfilling is the main source of CH₄ in Grand Lomé (**Figure 2**). Open burning is the second-largest emitting pathway in the sector, and the resulting emissions increased by approximately 30% between 2021 and 2025 for all pollutants studied: CH₄ (+30.2%), BC (+30.4%), CO (+30.2%), NMVOCs (+30.2%) and NO_x (+30.2%). Emissions therefore increase approximately in proportion to the quantity of waste burned. In 2025, CO reaches 5281 t/year and NMVOCs 3141 t/year, *i.e.*, 10.4 and 6.2 times the CH₄ emissions (509 t/year), respectively; BC amounts to 90 t/year. The emission profile of this pathway is thus dominated by products of incomplete combustion.

Composting, by contrast, contributes only marginally to the estimated emissions: the associated CH₄ emissions increase from 2.95 to 4.24 t/year between 2021 and 2025, which is negligible compared with those from landfilling and open burning. In terms of source ranking, landfilling dominates CH₄ emissions, whereas open burning dominates BC, CO, NMVOCs and NO_x emissions.

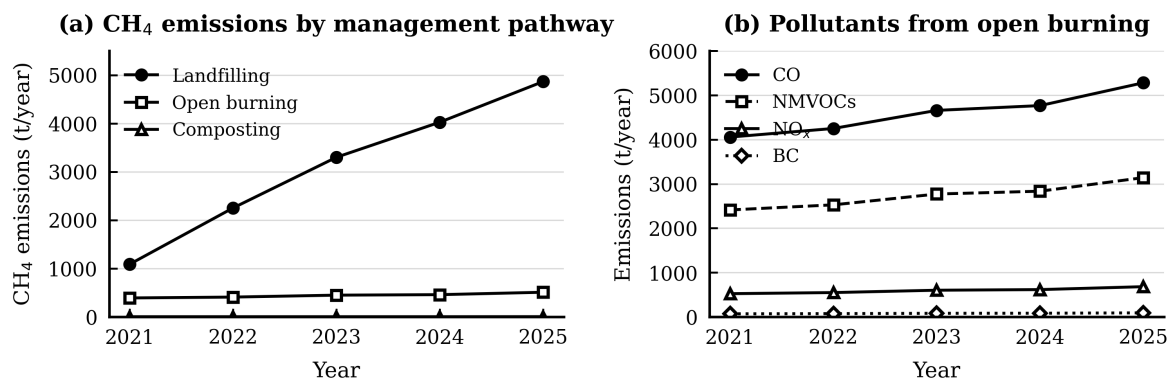


Figure 2. Trends in SLCP emissions in Grand Lomé: CH₄ by management pathway (a) and pollutants from open burning (b), 2021-2025.

A small number of African studies provide points of comparison for the present results. In South Africa, [16] estimated CH₄ emissions from a landfill site at 6363.43 t/year. The estimate obtained for Grand Lomé is approximately 26.7% lower. In Cameroon, Paddy *et al.* (2025) [17] estimated 21.33 Gg of CH₄ over the period 2010-2030. For a given management pathway, the emission level remains closely dependent on the quantities landfilled, the composition of the waste stream and the emission parameters adopted.

For open burning, the emission profile obtained, dominated by products of incomplete combustion, with CO and NMVOCs greatly exceeding CH₄ and BC, is consistent with the findings of Das *et al.* (2018) [18] in five municipalities of Nepal. For 7400 tonnes of waste burned in 2016, the authors estimated 630 t/year of CO, 112 t/year of NMVOCs, 30 t/year of CH₄, 25 t/year of BC and 19.2 t/year of

NO_x. In Grand Lomé, emissions are higher, owing to a burned waste stream almost twenty times larger. At the national level, Togo's first biennial update report indicates, for the year 2017 and for the entire national territory, 4.23 Gg of CH₄ for solid waste disposal and 0.84 Gg of CH₄ for open burning, as well as 6.33 Gg of CO, 0.14 Gg of NMVOCs and 0.36 Gg of NO_x from open burning [19]. Despite the different spatial scopes and inventory periods, the same waste management issues emerge. Agbossou *et al.* (2022) [20] also showed that CH₄, NO_x and BC are, respectively, the first, second and third most emitted of these pollutants. Emission levels differ between studies depending on meteorological conditions (temperature and precipitation), the heterogeneity of the waste burned and the input data used.

3.3. SLCP Emissions under the Local Approach and under the IPCC Approach

The discrepancies between the local approach, based on the physical characterizations and the household survey conducted in Grand Lomé, and the IPCC default approach (Tier 1) vary from one pathway to another. For CH₄ from landfilling, the difference between the local approach and the IPCC approach is negative over the whole period: the local estimate is 42.3% lower in 2021 (1090 versus 1889 t/year), 45.8% to 56.9% lower over 2022-2024 and 44.4% lower in 2025 (4662 versus 8384 t/year), *i.e.*, a mean deviation of -47.7% over 2021-2025. For open burning, the local approach estimated 509 t/year of CH₄ and 90 t/year of BC in 2025, compared with 819.5 t/year of CH₄ and 145.5 t/year of BC under the IPCC default approach, corresponding to approximately 37.9% lower emissions under the local approach (Figure 3). Over 2021-2025, the IPCC estimates increase from 629.4 to 819.5 t/year for CH₄ and from 111.8 to 145.5 t/year for BC, compared with 391 to 509 t/year and 69 to 90 t/year, respectively, under the local approach.

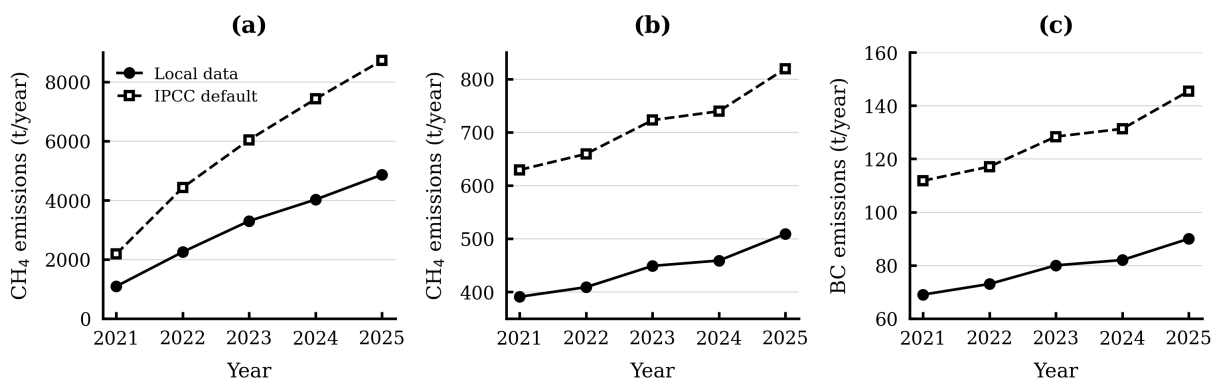


Figure 3. Comparison of emissions estimated under the local approach and under the IPCC approach (CH₄ from landfilling, CH₄ and BC from open burning), 2021-2025.

The discrepancies observed for CH₄ from landfilling are related to waste composition: the reduced share of food waste (11.8%) and the share of green waste (26.3%) and plastics (22.8%) in the local approach alter the amount of degradable

organic carbon introduced into the FOD model and lower the estimate relative to the default approach. For open burning, since the emission factors are identical in both approaches, the discrepancy arises from the activity data. The local estimate indicates that 41.67% of the population practiced open burning, whereas the default approach assumes that the entire population not served by collection burns its waste, in addition to the waste burned by the served population, which raises this proportion to 67%. In 2025, the local approach estimated 138,973 tonnes of waste burned, compared with 223,897 tonnes under the IPCC default approach, corresponding to a 37.9% lower activity level under the local approach. Because the same emission factors were used for the corresponding pollutants, this difference in activity data directly affects the estimated CH₄ and BC emissions from open burning. The value of the local approach lies both in the magnitude of the deviation from the default approach and in the representation of the underlying emission mechanisms. Rather than being inherently more accurate, local data provide estimates that are more specific to the waste composition and management practices observed in Grand Lomé: they quantify the extent of household burning and account for a waste composition that differs from the regional default profile.

3.4. Contribution of the Management Pathways to the Climate Impact

The climate impact reaches 225.4 Gg CO₂-eq in 2025, compared with 103.5 Gg CO₂-eq in 2021, *i.e.*, an increase of 117.8%. The climate pressure exerted by the sector is increasing, and the distribution among pathways is shifting (**Figure 4**). Open burning dominates at the beginning of the period, whereas landfilling becomes the main source by the end of the period, with its share rising from 29.4% in 2021 to 57.7% in 2025. Conversely, the contribution of open burning, considering CH₄ and BC, decreases from 70.5% to 42.2%. This relative decline reflects the faster increase in the impact associated with landfilling. Composting contributes only marginally to the estimated climate impact, below 0.1% over the whole period, since its associated CH₄ emissions are very small compared with those from landfilling and open burning.

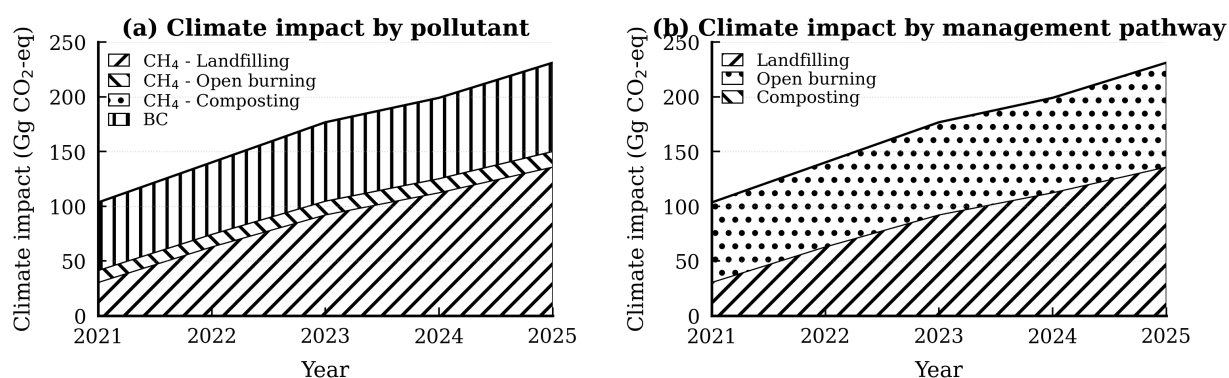


Figure 4. Trends in the climate impact of the waste sector, by pollutant (a) and by management pathway (b), 2021-2025.

The growing predominance of landfilling is associated with the increasing quantities of waste delivered to the Aképé CET and with their progressive degradation, which is liable to generate methane. CH₄ from landfilling now accounts for most of the increase in the climate budget. Reducing these emissions would require, in particular, controlling the amount of organic matter landfilled and capturing, recovering and treating the biogas. Although open burning emits a smaller mass of CH₄ than landfilling, the presence of BC increases its relative climate importance. Between 2021 and 2025, the impact associated with CH₄ from open burning increases from 10.9 to 14.2 Gg CO₂-eq, whereas that attributed to BC increases from 62.1 to 81.0 Gg CO₂-eq. Within open burning, BC is the dominant contributor. Across the three pathways, its contribution to the total climate impact decreases from 60.0% in 2021 to 35.9% in 2025.

The increase in the climate impact is also accompanied by a rise in per capita intensity, which increases from 48.66 to 96.2 kg CO₂-eq/capita between 2021 and 2025, *i.e.*, an increase of 97.7% (Figure 5).

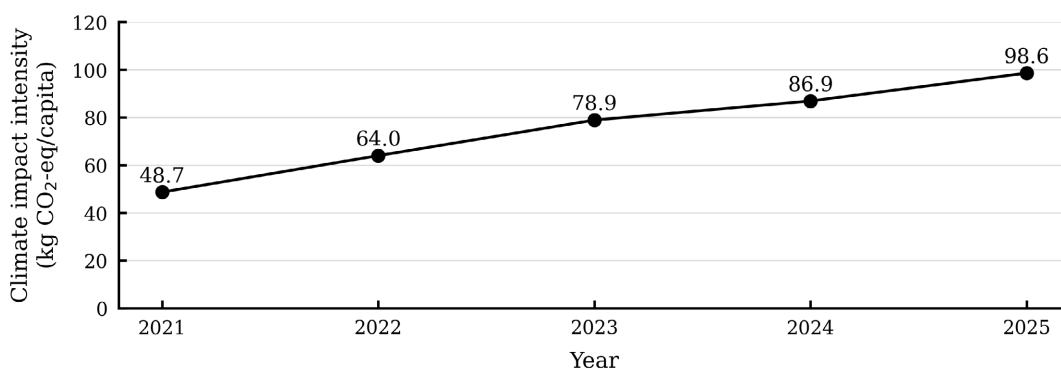


Figure 5. Trends in the per capita climate impact of the waste sector (2021-2025).

3.5. Quantitative Uncertainty Analysis

The propagation of the uncertainties associated with the multiplicative parameters of the FOD model results in a relative uncertainty of $\pm 52.2\%$ for CH₄ emissions from landfilling. This is comparable to the value of $\pm 50\%$ adopted by default when the available data are limited [1]. For open burning, accounting for the 95% confidence interval of Pfrac (38.2% - 45.2%) results in a variation of -8.3% to $+8.5\%$ in CH₄ and BC emissions (Figure 6). The influence of this parameter on the central estimate therefore remains limited.

A second source of uncertainty concerns the GWP-100 value for BC. When this value varies from 100 to 1700 [3], the total climate budget varies from 153.4 to 297.4 Gg CO₂-eq. Furthermore, the use of a GWP of 342 [15] reduces the budget by 22.3% relative to the main scenario based on 900. The climate importance attributed to BC therefore depends strongly on the metric adopted.

The absence of direct measurements of CH₄ emissions at the Aképé CET and of BC from open burning limits the experimental validation of the estimates. The main sources of uncertainty differ according to the emission pathway and the cli-

mate metric adopted: the estimation of CH₄ from landfilling is mainly limited by the parameters of the FOD model, whereas the climate assessment of BC is sensitive to the GWP-100 value adopted.

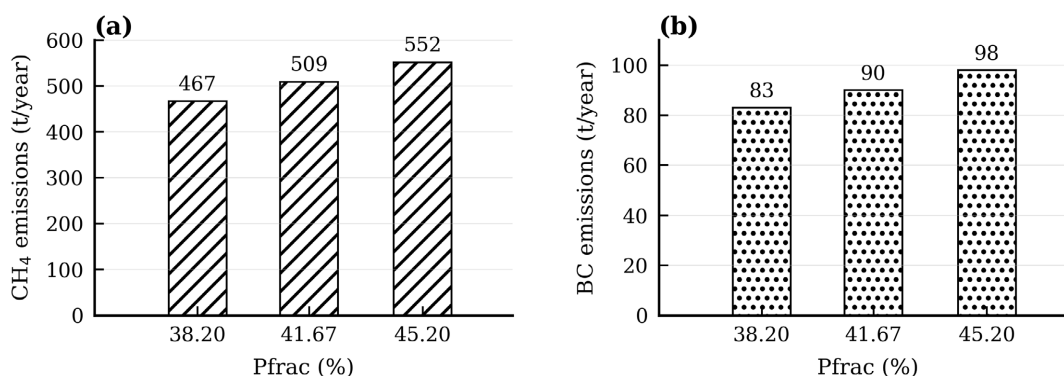


Figure 6. Sensitivity of CH₄ (a) and BC (b) emissions from open burning to variation in Pfrac.

3.6. Climate Significance of SLCP Emissions and Mitigation Priorities

Emissions from the waste sector of Grand Lomé constitute a short-term climate issue, driven by CH₄ generated by landfilling and by BC from open burning. The main mitigation options are twofold and complementary. The first is the elimination of open burning, for which the extension of collection is a prerequisite; it simultaneously addresses BC, CO, NMVOCs and NO_x emissions and offers potential health co-benefits. The second, which becomes increasingly important for climate mitigation over the period, is the reduction of methane generation from landfilled waste through the diversion of the organic fraction and the modernization of landfilling combined with biogas capture. Sorting and recovering recyclable waste acts on both pathways.

Studies carried out in Gulu and Kisumu have shown that the extension of collection is among the priority measures, since it led to emission reductions there [21] [22]. In Grand Lomé, the scale of the problem is substantial: an estimated 138,973 t of waste were burned in the open in 2025.

Reducing open burning remains a major mitigation lever: this pathway accounted for 70.5% of the climate impact of the sector in 2021 and still 42.2% in 2025, with BC alone representing 35.9%. The progressive elimination of this practice would reduce BC emissions as well as those of other air pollutants (NMVOCs, CO, NO_x), thereby providing both climate and health co-benefits. A review of 170 publications from Asia and Africa by [23] identified the persistence of open burning as one of the main obstacles to the effectiveness of waste management systems in developing countries.

The diversion of the organic fraction directly targets the leading source of the sector: composting and anaerobic digestion reduce the amount of biodegradable matter liable to produce CH₄ in landfills. Its implementation nevertheless requires separate collection of biowastes, treatment capacity commensurate with the flows

concerned, and outlets for the compost produced.

Improved landfill management and biogas capture apply specifically to the Aképé CET. The estimates presented assume that all the CH₄ generated is emitted after partial oxidation in the cover layer. Equipping the site with a capture network, coupled with energy recovery or, failing that, with controlled flaring, would act directly on the leading emission source of the sector.

Source separation and the recovery of recyclables complement these levers by acting on both pathways simultaneously. The high share of plastics in the waste stream (22.8% in 2025) indicates a recoverable flow whose diversion would simultaneously reduce the mass landfilled and the mass burned.

Finally, the implementation of these measures remains contingent on the availability of financing, infrastructure development, the strengthening of institutional capacity and changes in household behavior.

4. Conclusions

The waste sector of Grand Lomé shows increasing climate pressure between 2021 and 2025, with a total climate impact rising from 103.5 to 225.4 Gg CO₂-eq (+117.8%). This increase is mainly attributable to landfilling, whose contribution reaches 57.7% in 2025, with CH₄ emissions rising from 1090 to 4662 t/year; open burning adds, in 2025, 5281 t/year of CO, 3141 t/year of NMVOCs and 681 t/year of NO_x.

The use of local data, particularly on open burning, can better capture the practices specific to Grand Lomé and help explain some of the differences from estimates based on the IPCC default parameters. The results point to two complementary mitigation priorities: reducing open burning, which addresses BC and the co-emitted air pollutants, and reducing methane generation from landfilled waste through organic waste diversion and biogas capture at the Aképé CET. Improving collection coverage is a prerequisite for the first, while organizing the sorting of recyclables acts on both pathways.

The uncertainty of $\pm 52.2\%$ for CH₄ from landfilling and the sensitivity of the budget to the GWP adopted for BC underline the need to improve local data and to develop direct measurements. This work provides a quantitative basis for initiating SLCP reduction measures and for steering waste management in Grand Lomé towards less emission-intensive pathways.

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Author Contributions

Conceptualization and methodology, Baba Tounde Lassissi Balogun, Maglwa Tcha-Thom; software, Baba Tounde Lassissi Balogun, Maglwa Tcha-Thom; validation, Baba Tounde Lassissi Balogun, Maglwa Tcha-Thom, and Edem Komi Koledzi; formal analysis, Baba Tounde Lassissi Balogun, Maglwa Tcha-Thom; investigation, Baba Tounde Lassissi Balogun, Maglwa Tcha-Thom and Edem Komi Koledzi; resources Baba Tounde Lassissi Balogun, Maglwa Tcha-Thom; data curation, Baba Tounde Lassissi Balogun, Maglwa Tcha-Thom and Edem Komi Koledzi; writing—original draft preparation, Baba Tounde Lassissi Balogun, Maglwa Tcha-Thom; writing—review and editing, Baba Tounde Lassissi Balogun; supervision, Edem Komi Koledzi. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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