

Baseline Methane Emissions from a Large Solid Waste Disposal Site Receiving Oil Palm Empty Fruit Bunch (EFB)

Quantifying the Dump-Site Baseline with the UNFCCC First-Order Decay Methodology

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Article 3 of a series on the characterisation and valorisation of oil palm empty fruit bunch

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Abstract

Oil palm empty fruit bunch (EFB) is generated in very large quantities at every palm oil mill and, in the absence of a valorisation route, must be disposed of. One of the principal disposal routes is a large, dedicated solid waste disposal site (SWDS) located beside the mill, into which the mill's entire EFB output is tipped continuously and left to rot. This article establishes the greenhouse-gas baseline for that route at a representative Malaysian mill — the Kilang Sawit Maran mill in Pahang — whose on-site dump occupies a cleared area of roughly 100 m by 150 m and receives of the order of 203,400 tonnes of EFB per year. Decomposition in the bulk of the wet, uncompacted mass is predominantly anaerobic and releases methane, a greenhouse gas with a global warming potential 28 times that of carbon dioxide over a 100-year horizon. Baseline methane generation is quantified using the UNFCCC Methodological Tool 04, "Emissions from solid waste disposal sites", which applies a first-order decay (FOD) model to the disposed mass. With the parameters appropriate to a large but unmanaged tropical disposal site — a degradable organic carbon content of 0.20, a decay rate of 0.17 yr^{-1} and a methane correction factor of 0.4 — the model returns a first-year baseline of 4,328 t CO₂e and, because the disposed waste continues to decay for many years after it is tipped, a value that accumulates toward roughly 27,500 t CO₂e yr⁻¹ as the site approaches steady state. Over a thirty-year horizon the cumulative baseline approaches 682,000 t CO₂e, equivalent to an average of about 22,700 t CO₂e per year. This baseline is the reference against which any project that diverts EFB from the dump — by combustion, composting or conversion — would later be credited. The alternative and more dispersed practice of dumping EFB in rotating windrows in the plantation fields is treated separately in the next article in this series.

1. Introduction

The first two articles in this series characterised EFB as a feedstock and demonstrated its conversion to a fermentable hydrolysate [1, 2]. Both rest on the premise that EFB is an abundant, under-utilised residue. This article quantifies what happens to that residue when it is not valorised, because the environmental cost of the do-nothing case is itself an asset: it is the baseline against which the climate benefit of any diversion project is measured, and, under recognised carbon-market methodologies, the source of avoided-emission carbon credits.

Throughout the palm oil industry the default fate of EFB is disposal close to the mill. The material is bulky, wet and acidic, costs money to handle, and is generated faster than a mill can use it, so most mills simply discard it at the most convenient location. Two disposal patterns dominate. In the first, a mill operates a large, dedicated solid waste disposal site (SWDS) immediately adjacent to the plant, into

which EFB is tipped continuously, building up a substantial standing mass of decomposing material. In the second, EFB is trucked out into the plantation and dumped in dispersed windrows along field roads, which are periodically rotated. This article addresses the first pattern — the large on-site SWDS — which is a solid waste disposal site in the precise sense of the UNFCCC methodologies even though it is informal, uncompacted and unlined. The dispersed field-dumping pattern is the subject of the next article.

The greenhouse-gas consequence of dumping is methane. The interior of a wet EFB mass is rapidly depleted of oxygen, so the dominant decomposition pathway is anaerobic, and anaerobic decomposition of organic carbon produces a landfill gas that is roughly half methane by volume. Methane is a far more potent greenhouse gas than the carbon dioxide that would be released were the same material to decay aerobically or be combusted, so the disposal route is the worst of the realistic options from a climate standpoint. The purpose of this article is to put a defensible number on the emission from a large EFB dump using the established UNFCCC first-order decay model, and to do so transparently enough that the calculation can be reproduced and audited.

2. The Baseline Scenario

In the baseline scenario the EFB is not processed or utilised in any way. It is conveyed from the mill, loaded onto trucks and tipped into the adjacent solid waste disposal site, where it is left to rot. There is no shredding, no turning, no aeration, no cover and no leachate or gas management; the only mechanical intervention is periodic reshaping of the dump by a tracked excavator to consolidate fresh deliveries and make room for more. The dump is therefore an unmanaged disposal site: large in plan area and holding a substantial standing mass, but with none of the engineering controls — compaction, capping, gas extraction — of a sanitary landfill. Because the material is wet and the mass is deep enough to exclude air from its interior, the primary mode of decomposition within the bulk is anaerobic. Aerobic stabilisation, by contrast, would require active composting — shredding the fibre and turning it regularly so that air reaches the interior — which is not done in the baseline.

This distinction matters because it determines the emission. Anaerobic decay yields methane; aerobic decay yields mostly carbon dioxide. Adopting anaerobic decomposition as the baseline is both the industry-standard assumption for a disposal site of this type and consistent with observation: inspection of EFB dumps confirms that methane is emitted from the decomposing mass once it passes into its anaerobic phase, as expected for a wet, deep, undisturbed heap. There is no electricity or heat generated in the baseline scenario, since no energy is recovered from the biomass.

3. The Reference Site

The reference site for this study is the dedicated solid waste disposal site of the Kilang Sawit Maran palm oil mill, in Pahang, Malaysia (approximately 3.57° N, 102.68° E). The dump occupies a cleared area a short distance from the mill buildings, surrounded by mature plantation, and is fed directly by the mill's EFB conveyor and short-haul trucks; it serves no purpose other than receiving waste from the mill. Its extent is readily measured from satellite imagery (Figure 1): the cleared, light-coloured area is

approximately 100 m wide by 150 m long, a scale far larger than a dispersed field windrow and characteristic of a permanent, single-source disposal site.

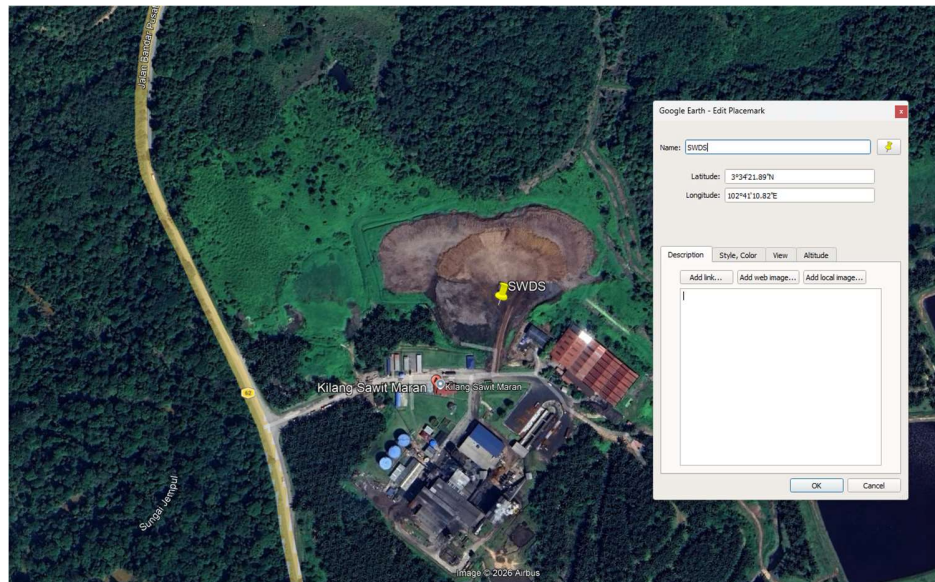


Figure 1. Satellite view of the Kilang Sawit Maran mill and its adjacent EFB solid waste disposal site (SWDS), with the placemark marking the dump. The large cleared area beside the mill buildings is the active disposal site, roughly 100 m by 150 m; surrounding land is mature oil palm plantation.

Within the site the EFB is tipped and then pushed and consolidated by a tracked excavator (Figure 2), building and reshaping the standing mass as fresh material continually arrives. The dump is broad and uncompacted, with no cover, no liner and no gas-collection system — an unmanaged disposal site rather than an engineered landfill cell. This management status is what fixes the methane correction factor used in the calculation (Section 4): an unmanaged site supports less complete methane generation than a deep, compacted, capped sanitary landfill, and the methodology accounts for this through a reduced correction factor rather than the value of unity used for managed anaerobic landfills.



Figure 2. The EFB dump being worked. Fresh and partially decomposed empty fruit bunch is consolidated by a tracked excavator into the standing mass of the disposal site. The darkened, matted material in the foreground is well into anaerobic decomposition.

4. Methodology

Baseline methane generation from the dump is determined using the UNFCCC Methodological Tool 04, “Emissions from solid waste disposal sites” [3], which is the tool invoked by the large-scale consolidated methodology ACM0018, “Electricity generation from biomass in power-only plants” [4], applicable to projects that would otherwise divert this waste biomass. Tool 04 implements the IPCC first-order decay (FOD) model [5]. The choice of an FOD model, rather than a simple one-off emission factor, reflects the physical reality that a tonne of EFB tipped today does not release its methane instantaneously: it decays over years, so the emission in any given year is the sum of the still-decaying contributions of all the waste tipped in that year and in every preceding year.

4.1 The first-order decay equation

Tool 04 gives the methane generated at the SWDS in year y as:

$$BE_{CH4,SWDS,y} = \varphi_y \cdot (1 - f_y) \cdot GWP_{CH4} \cdot (1 - OX) \cdot (16/12) \cdot F \cdot DOC_{f,y} \cdot MCF_y \cdot \sum_x [W_x \cdot DOC_j \cdot e^{(-k(y-x))} \cdot (1 - e^{(-k)})]$$

written here in compact form, where the summation runs over every year x from the first year of disposal ($x = 1$) to the year of interest ($x = y$). In words, the bracketed term is the methane-generating organic carbon tipped in year x that has not yet decayed by year y ; this is summed over all past years and then multiplied by a chain of factors that convert decayed carbon into a tonnage of CO₂-equivalent methane actually reaching the atmosphere. The factor (16/12) is the stoichiometric mass ratio of methane to carbon, F is the methane fraction of the landfill gas, OX is the share oxidised in the cap

before escaping, and ϕ and the uncertainty factor account for model error. Because f (the captured fraction) is zero at an open dump, none of the methane is destroyed before release.

4.2 Parameter selection

The parameters applied to the reference site are listed in Table 1. They follow the default values and selection rules of Tool 04 except where a site-specific or literature value is better justified, as noted.

Symbol	Parameter	Value	Basis / note
W _x	EFB disposed per year (t)	203,400	Mill throughput, client data
DOC _j	Degradable organic carbon fraction of EFB	0.20	Tool 04 default for wood/agro-residue
DOC _{f,y}	Fraction of DOC that decomposes	0.157	Computed for site conditions
k	Decay rate (yr ⁻¹)	0.17	Tool 04, wet tropical, readily degradable
MCF _y	Methane correction factor	0.40	Unmanaged disposal site
F	Methane fraction of landfill gas	0.50	Tool 04 default
OX	Oxidation factor	0.10	Tool 04 default, uncovered
f _y	Fraction of methane captured	0	Open dump, no capture
GWP _{CH4}	Global warming potential of CH ₄	28	IPCC AR5, 100-year
ϕ_y	Model correction factor	0.644	Tool 04, with uncertainty factor

Two choices warrant comment. First, the methane correction factor of 0.40 is the value Tool 04 assigns to unmanaged disposal sites — those lacking the compaction, capping and controlled placement of an engineered sanitary landfill. The reference dump, although large in plan area, is uncompacted, uncovered and otherwise unmanaged, so it falls into this category; applying the value of unity reserved for deep, managed anaerobic landfills would overstate the baseline. Second, the decay rate k of 0.17 yr⁻¹ is the value for a readily degradable waste in a wet tropical climate, which matches both the high moisture content of fresh EFB and the high rainfall of the site; it governs how quickly the accumulated emission approaches its steady state.

4.3 Degradable organic carbon of EFB

The degradable organic carbon content is the single most influential feedstock-specific input. The conservative Tool 04 default of 0.20 (weight fraction) is adopted here for the baseline calculation. This is well below the intrinsic organic carbon content of EFB reported in the literature — measurements of the fraction of organic carbon in EFB that is in principle degradable run as high as 0.98 [6] — but the methodology deliberately discounts the laboratory-degradable fraction to the share that actually decomposes under real field conditions within the modelling horizon, which is what DOC_f captures. Retaining the default DOC_j keeps the baseline defensible and auditable rather than maximised.

5. Results

5.1 Worked example: year one

For the first year of disposal the summation collapses to a single term ($x = y = 1$), because only the first year's waste has been tipped. Substituting the Table 1 parameters:

$$W_x \cdot DOC_j \cdot (1 - e^{(-k)}) = 203,400 \cdot 0.20 \cdot (1 - e^{(-0.17)}) = 203,400 \cdot 0.20 \cdot 0.1563 = 6,360 \text{ t C}$$

This is the degradable organic carbon that decays during the first year. Multiplying by the chain of conversion factors — ϕ (0.644), GWP (28), (1–OX) (0.9), 16/12, F (0.5), DOC_f (0.157) and MCF (0.4) — gives:

$$BE_{CH4,SWDS} (\text{year } 1) = 0.6794 \cdot 6,360 \approx 4,328 \text{ t CO}_2\text{e}$$

The first year therefore contributes a baseline of approximately 4,328 t CO₂e. This is comparatively modest because most of the carbon tipped in year one has not yet decayed; the emission builds in subsequent years as that backlog continues to break down.

5.2 Multi-year accumulation

Because each year's disposal keeps decaying for years afterward, the annual baseline rises steadily while fresh waste is added and old waste is still emitting. The second year emits the residual of the first year's pile plus the first-year emission of the second year's pile, and so on. With a constant annual disposal of 203,400 t the annual emission climbs from 4,328 t CO₂e in year one toward an asymptote near 27,500 t CO₂e, which it approaches but never quite reaches within the thirty-year horizon as generation and decay come into balance. Table 2 and Figure 3 give the trajectory.

Year (y)	Annual baseline (t CO ₂ e yr ⁻¹)	Cumulative baseline (t CO ₂ e)
1	4,328	4,328
2	7,979	12,307
3	11,059	23,366
4	13,658	37,024
5	15,850	52,874
6	17,700	70,574
7	19,261	89,835
8	20,577	110,412
9	21,688	132,100
10	22,625	154,725
15	25,521	277,510
20	26,758	409,242
25	27,287	544,798
30	27,513	681,989

Table 2. Baseline SWDS methane emissions over the thirty-year horizon (selected years), at constant annual EFB disposal of 203,400 t.

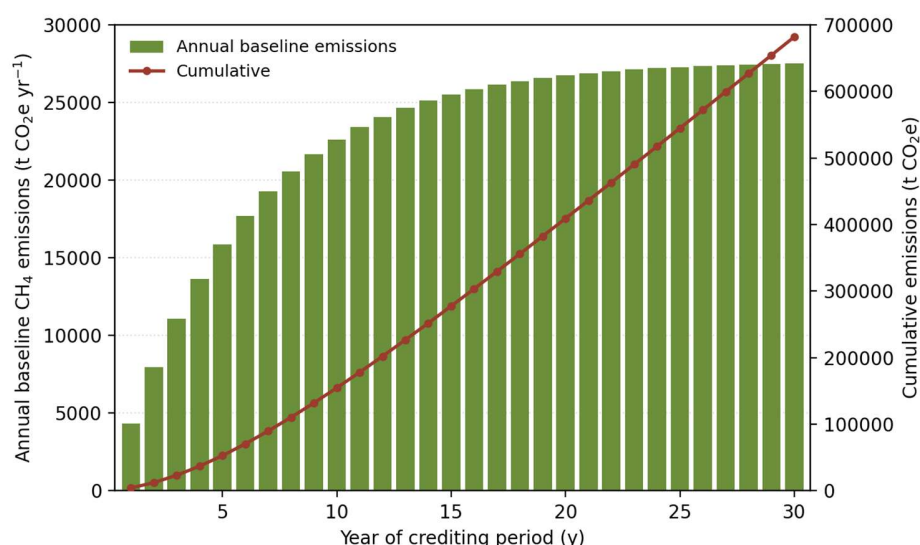


Figure 3. Annual (bars) and cumulative (line) baseline methane emissions from the EFB dump over thirty years. The annual emission rises as the still-decaying backlog of earlier years accumulates, approaching a steady state near 27,500 t CO₂e yr⁻¹.

Over the full thirty-year horizon the cumulative baseline reaches approximately 682,000 t CO₂e, which is equivalent to an average of about 22,700 t CO₂e per year across the crediting period. This is the quantity of methane-driven warming that operating the dump commits to the atmosphere, and that an effective diversion project would avoid.

5.3 Methane yield per tonne and cross-checks

It is useful to express the result per tonne of EFB and to compare it against independent estimates of EFB methane potential. The FOD baseline implies an emission factor that, at steady state, corresponds to roughly 0.03 t CH₄ per tonne of EFB. This is consistent with a biochemical-methane-potential estimate derived from the volatile-solids content of EFB (about 45 % volatile solids at a specific methane yield of ~104 L CH₄ per kg volatile solids, giving ≈ 30 kg CH₄ per tonne, i.e. 0.030 t CH₄ t⁻¹). A field study of methane emission from EFB co-composting reported a substantially lower 8.96 kg CH₄ per tonne (0.009 t CH₄ t⁻¹) [7], and an IPCC default emission-factor approach gives a value of similar order. The biochemical-potential figure represents the upper bound achievable under complete anaerobic conversion, whereas the field and FOD values reflect the incomplete conversion of an actual unmanaged dump; the agreement in order of magnitude supports the parameter choices made in Section 4.

6. Discussion

The baseline established here has three features worth drawing out. First, it is conservative by construction. The methane correction factor, the degradable organic carbon fraction and the oxidation factor are all set to values that reduce, rather than inflate, the calculated emission, and no credit is taken for the higher intrinsic degradability of EFB reported in the literature. A baseline used to justify

carbon credits must be defensible against a sceptical auditor, and the figures here are chosen with that audience in mind.

Second, the accumulating shape of the curve has practical consequences for any diversion project. Because the dump keeps emitting for years after tipping stops, the avoided emission in the early years of a project is smaller than the eventual steady-state value; the climate benefit of diverting EFB grows over time as it both prevents new emissions and forgoes the long tail of the existing backlog. This is why the methodology credits emissions year by year over the crediting period rather than as a single up-front figure.

Third, the result is sensitive to site-specific decomposition, which varies between mills with climate, site management and feedstock moisture. The methane correction factor in particular is the lever that separates this large unmanaged dump from other disposal patterns: a deep, managed anaerobic landfill would carry a factor of unity and emit more, whereas the dispersed field windrows examined in the next article — thinner, more frequently disturbed and rotated — present a different decomposition regime again. It is therefore recommended that the degradation behaviour be studied for each site where a project is proposed, rather than transferring this single baseline wholesale; the method, not the specific numbers, is the transferable result.

Finally, the baseline excludes two emission sources by design, so that it isolates the SWDS methane term cleanly. It does not include the diesel emissions of the trucks that haul EFB to the dump, nor the soil-carbon dynamics of the receiving land; these belong to the project-boundary and baseline-adjustment accounting that a full project assessment.

7. Conclusion

Disposal of oil palm empty fruit bunch in a large on-site solid waste disposal site is an anaerobic, methane-generating practice, and its greenhouse-gas baseline can be quantified rigorously with the UNFCCC first-order decay methodology. For the reference Malaysian mill dumping of the order of 203,400 t of EFB per year into a dedicated dump of roughly 100 m by 150 m, the baseline methane emission is approximately 4,328 t CO₂e in the first year, rises toward a steady state near 27,500 t CO₂e yr⁻¹, and accumulates to roughly 682,000 t CO₂e over thirty years — an average of about 22,700 t CO₂e per year. These figures, derived from conservative, auditable parameters and cross-checked against independent estimates of EFB methane potential, constitute the reference case against which the climate benefit of diverting EFB to combustion, composting or conversion is to be measured. The companion practice of dispersed field dumping is quantified in the next article.

Author Contributions

D.S.: conceptualisation, methodology, calculation, investigation, writing — original draft. A.B.: review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Spagnuolo, D. & Broughton, A. (2026). Basic Properties of Oil Palm Empty Fruit Bunch (EFB): Dry Solids, Moisture and a Comparative Review of Compositional, Proximate, Ultimate, Calorific and Inorganic Data. Article 1 of this series.
- [2] Spagnuolo, D. & Broughton, A. (2026). Hydrolysate Production from Oil Palm Empty Fruit Bunch (EFB): Field-Scale Bucket Testing of Hot-Water Oil Stripping, Alkaline Hydrolysis and Enzymatic Saccharification. Article 2 of this series. <https://doi.org/10.5281/zenodo.20520978>
- [3] UNFCCC CDM Executive Board. Methodological Tool 04: Emissions from solid waste disposal sites. Clean Development Mechanism, UNFCCC.
- [4] UNFCCC CDM Executive Board. ACM0018: Electricity generation from biomass in power-only plants (large-scale consolidated methodology). Clean Development Mechanism, UNFCCC.
- [5] IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 3: Solid Waste Disposal. Intergovernmental Panel on Climate Change.
- [6] Lim, K. C. & Zakarah, A. R. (2000). Journal of Oil Palm Research, 12(2), 55-62. (Degradable organic carbon of empty fruit bunch.)
- [7] Methane Emission Reduction in Palm Oil Mill through Co-composting Empty Fruit Bunch and Palm Oil Mill Effluent. Procedia Environmental Science, Engineering and Management, 6(3), 2019.
- [8] Verra (2023). Verified Carbon Standard (VCS) Program. Verra, Washington, D.C.