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Concept Note
Trujillo, Perú

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English Version

Contents

1. Executive Summary

The objective of this concept note is to analyse options for investment into infrastructure for final disposal of solid waste and greenhouse gas (GHG) emissions reduction technologies for landfill gas in Trujillo, Peru. As part of this analysis, the concept note considers the impact of recycling and composting programs on the final volumes of disposed waste, but contains no further analysis of such programs. This concept note is focused on the current municipal management of waste in the province of Trujillo in the Libertad region of Peru. The analysis is focused on the infrastructure for final disposal of solid waste for the ten districts within this region, which have been strategical grouped for the purpose of waste disposal on the basis of geographic proximity by the Peruvian Ministry of Environment (Ministerio de Ambiente - MINAM).

The Law of Integrated Management of Solid Waste (Ley N° 27314, D.L. N°1278) and its regulation dictates that, for solid waste disposal infrastructure with the dimensions that would be required in the case of Trujillo, GHG emissions reductions technologies must be integrated. This concept note analyses and compares three potential GHG emissions reductions technologies for the Trujillo landfill site. As part of this analysis, the GHG emissions reductions potential of each technology has been estimated using the current and projected volumes of solid waste generation as well as the solid waste composition studies that are available in the Comprehensive Environmental Management Plan for Solid Waste (Plan Integral de Gestión Ambiental de Residuos Sólidos – PIGARS).

An important criteria taken into consideration in the evaluation of the various technologies is the replicability of the technology in other parts of Peru. Although this concept note is based on the city of Trujillo, it can be applied to similar projects in other provinces of Peru with a comparable climate, geography and solid waste stream. The aim of this analysis is to identify the amount of investment required, operation costs, implementation risks and estimated GHG reductions of the technologies, to be disseminated among private actors and encourage their involvement in the waste management sector. The ultimate purpose of the analysis is to mobilise private sector investment to provide an efficient and sustainable solution to the issues experienced in Trujillo regarding the final disposal of municipal waste.

2. Baseline information

2.1. Context

The province of Trujillo faces challenges in the disposal and management of its solid waste. Since 1989, all solid waste has been disposed of in a controlled dump called “El Milagro”, which amounts to approximately 1000 tons each day. The dump has no mechanism for leachate collection and treatment, and no technology for emissions capture. The large volume of waste, coupled with a present lack of appropriate infrastructure for final disposal, presents an opportunity that could be addressed through private sector investment.

The “El Milagro” dump is located 12 kilometres from the city of Trujillo and covers an area of approximately 58 hectares, receiving approximately 1,000 tons of waste daily. It is an open-air dump with basic compaction and burning of solid waste, and generates emissions of toxic vapours and odours. Located close to the site is El Milagro Village Centre where about 1,000 families live, mainly subsisting on income from informal work related to the segregation and commercialization of recyclable solid waste that they collect from the dump.

The Provincial Municipality of Trujillo (hereinafter the Municipality) has been working towards solving the challenges associated with final disposal of waste. It has secured an agreement with the Regional Government for the donation of 67 hectares of government-owned land for the construction of a landfill that will meet the requirements for proper final disposal of municipal solid waste. The area of land has already undergone a site selection study, and has received a certificate stating that there are no archaeological remains. Therefore, the concessional use of this area of land for the development of a sanitary landfill will underpin the analysis presented in this concept note. No analysis of emission reduction options at the "El Milagro" dump is considered in this concept note, as there are no residue composition studies currently available or planned to be carried out meaning it would not be possible to estimate actual GHG emissions at the dump site.

2.2. Area of Focus

The area of focus for this project is a group of ten districts within the region of La Libertad, located on the north coast of Peru. These ten districts have been chosen by the Ministry of Environment (Ministerio de Ambiente – MINAM) of Peru to use the new landfill territory for their final waste disposal[1]. Of these ten districts, nine are within the province of Trujillo and one is within the province of Ascope. These are as follows:

- Trujillo
- Florencia de Mora
- La Esperanza
- Moche
- Víctor Larco Herrera
- El Porvenir
- Huanchaco
- Laredo
- Salaverry
- Santiago de Cao

The district of Santiago de Cao (Ascope province) was chosen for two reasons: its proximity to the site and the large quantity of solid waste generated by its population. All of these districts currently dispose of all municipal waste in the “El Milagro” controlled dump, and for this reason the analysis of this concept note considers that these ten districts will direct their waste to the new sanitary landfill due to the proximity factor mentioned above. As a result, the new sanitary landfill could maximize environmental and social impact through managing the waste of the large number of districts in its locality that would otherwise use the “El Milagro” dump.

[1]Nine districts of Trujillo in accordance with the Municipal Ordinance Nº 010-2007-MPT, and one district of Ascope (Santiago de Cao)

Figure N° 01 shows a map with the ten districts considered in the scope of this study, as well as the location of the new sanitary landfill.

Figure. N° 01: Districts included in the area of interest of the project

Source : Google Earth

Based on the results of the 2017 census carried out by the National Institute of Statistics (Instituto Nacional de Estadística e Informática – INEI), Trujillo is the fourth most populous province in the country with an average annual growth rate of 1.8%, over the period of 2007 to 2017. Table N° 01 shows the beneficiary population of the project in accordance with the 2017 Census.

Table N° 01: Beneficiary Population – New Trujillo Sanitary Landfill

Districts	Population 2017
Trujillo	314,939
El Porvenir	190,461
La Esperanza	189,206
Huanchaco	68,409
Víctor Larco Herrera	68,506
Florencia de Mora	37,262
Laredo	37,206
Moche	37,436
Salaverry	18,944
Santiago de Cao	19,204
Total	**981,573**

Source : INEI Censos Nacionales 2017: XII de Populación VII de vivienda[2]

2.3. Climate and Environmental Factors[3]

The local environmental conditions will be a determining factor of the viability of the project, due to their influence on the GHG emissions from the sanitary landfill. Information provided by the meteorological station of Huanchaco (Peruvian Corporation of Airports and Commercial Aviation, hereinafter CORPAC,

[2] http://censos2017.inei.gob.pe/redatam/
[3] http://www.corpac.gob.pe/app/Meteorologia/TRClimatologicas/Tables.html

see Figure N° 01) was used to understand the local climate for the purpose of this concept note, as it is closer to the sanitary landfill (approximately 12km) than the Trujillo districts.

Table N° 02 shows the average temperature and precipitation in Trujillo.

Table N° 02. Temperature and Precipitation in Trujillo

Month	Mean Minimum Daily Temp. (°C)	Mean Maximum Daily Temp. (°C)	Mean Daily Temp. (°C)	Mean Total Rainfall (mm)
Jan	19	25	22	5
Feb	21	26	23.5	6
Mar	20	26	23	7
Apr	19	25	22	8
May	18	23	20.5	4
Jun	18	23	20.5	0
Jul	17	22	19.5	0
Aug	17	21	19	0
Sep	17	21	19	2
Oct	17	22	19.5	3
Nov	17	23	20	3
Dec	18	24	21	3
Total	**18.2**	**23.4**	**20.8**	**41**

Source: CORPAC [4] and Weather Spark[5]

In general terms, the city of Trujillo has a dry climate with an average annual temperature of 20.8°C and average annual rainfall of 41mm. It is important to mention that, in recent years, changes in seasonality, temperature and rainfall have been observed. According to the National Service of Meteorology and Hydrology of Peru (Servicio Nacional de Meteorología e Hidrología del Perú hereinafter SENAMHI) the rate of evapotranspiration is 48.8mm.

4 http://www.corpac.gob.pe/app/Meteorologia/TRClimatologicas/Tables.html
5 https://es.weatherspark.com/y/19239/Clima-promedio-en-Trujillo-Per%C3%BA-durante-todo-el-a%C3%B1o

3. Current Waste Management Situation

3.1. Generation of Municipal Solid Waste

The generation of solid waste is closely linked to the number of residents that live within the Province of Trujillo along with their purchasing power, their consumption habits and the principle economic activities of the region. The Generation per Capita (GPC) of solid waste in the ten selected districts was 0.53kg/person/day[6] in 2017, which is actually less that the national estimated GPC per capita of 0.55 Kg/person/day[7] in 2017. This statistic was obtained through estimating the weighted average of the household GPC of all of the districts against the total population of the province using information on GPC obtained from Studies on the Characterisation of Solid Waste (Estudios de Caracterización de Residuos Sólidos - ECRS)[8].

The total waste generation for the landfill site is estimated to be 933 tons per day, amounting to 340,516 tons per year with 56.2% of this being from domiciliary generation, 30.7% from commercial waste and 13.07% from neighbourhood activities. Table N° 03 shows the total waste generation in the ten districts, although this is not the total amount of waste that would reach the sanitary landfill as it is necessary to first discount the fraction of waste that would be recovered through segregation, recycling and composting programmes.

Table N° 03. Generation of Solid Waste - Trujillo Province

Districts	Population 2017 (1)	Per capita Generation of SW (kg/hab/day) (2)	Domestic SW Generated (Ton/Day) (3)	Commercial SW Generated (Ton/Day) (3)	SW from Street Sweeping (Ton/Day) (3)	Total Solid Waste Generated (Ton/Day)
Trujillo	314,939	0.511	160.950	87.970	37.473	286.393
El Porvenir	190,461	0.560	106.658	58.296	24.833	189.786
La Esperanza	189,206	0.536	101.414	55.429	23.612	180.456
Huanchaco	68,409	0.640	43.782	23.930	10.193	77.905
Victor Larco Herrera	68,506	0.410	28.087	15.352	6.539	49.978
Florencia de Mora	37,262	0.570	21.239	11.609	4.945	37.793
Laredo	37,206	0.529	19.682	10.757	4.582	35.022
Moche	37,436	0.590	22.087	12.072	5.142	39.302
Salaverry	18,944	0.600	11.366	6.212	2.646	20.225
Santiago de Cao	19,204	0.470	9.026	4.933	2.101	16.061
TOTAL	**981,573**	**0.53**	**524.29**	**286.56**	**122.07**	**932.92**

Sources: (1) INEI[9], (2) ECRS of each district, (3) Estimation, from market research of SW in Trujillo

According to a report entitled 'Current Situation of the Controlled Dump "El Milagro"' prepared by Servicio de Gestión Ambiental de Trujillo (SEGAT) in August 2016, 1,061 tons/day of waste are admitted to the dump, of which 31% corresponds to the district of Trujillo, 36% to other districts, 28% to construction waste and 5% to green waste from tree pruning. These statistics are rough estimates as there is no scale on site and as such they are based on visual estimates. Because the new sanitary landfill, located on land donated by the regional government, is planned to replace the current controlled dump, this concept note assumes that almost all of the waste currently disposed of in the dump (932.92 tons per day) will be disposed of in the new sanitary landfill once it is opened.

[6] http://sinia.minam.gob.pe/indicador/1601
[7] Estimación PwC
[8] http://sial.segat.gob.pe/documentos/estudio-caracterizacion-residuos-solidos-municipales-area-urbana
[9] http://censos2017.inei.gob.pe/redatam/

It is also assumed that a percentage of the total waste generated with be either recycled or composted. The Studies on the Characterisation of Solid Waste (Estudios de Caracterización de Residuos Sólidos - ECRS)[10] are key to gaining an understanding of the composition of the solid waste generated by each district, and therefore how much of it will be recycled or composted. This can be subtracted from the amount of waste sent to the "El Milagro" dump, to give an indication of how much will be received by the new landfill. Table No. 04 shows the composition of the solid waste of the ten districts considered within this analysis. Of note is the fact that 52.07% of waste is organic material, which has important implications for the volume of gas and leachate liquid that will be generated through decomposition in the sanitary landfill.

Table N° 04: Solid Waste Composition - Trujillo

Type of Solid Waste	Trujillo	El Porvenir	La Esperanza	Huanchaco	Víctor Larco	Florencia de Mora	Laredo	Moche	Salaverry	Santiago de Cao	Average
Organic Waste	53.56	46.94	50.1	72.17	30.55	53.56	52.8	58.63	53.88	53.23	**52.07%**
Wood, foliage	1.62	1.6	1.22	4.23	6.74	3.57	1.72	1.6	0.97	7.29	**2.22%**
Paper	2.6	3.07	2.01	2.34	9.51	2.15	2.62	4.75	3.51	3.06	**3.01%**
Cardboard	3.02	2.97	1.64	0.86	3.65	3.77	2.91	2.64	5.25	1.23	**2.62%**
Glass	2.77	2.79	2.23	2.74	0.74	4.74	4.78	2.68	2.27	2.03	**2.70%**
Plastic (PET)	1.43	1.19	1.45	1.19	3.69	1.79	3.1	0.98	3.3	2.34	**1.60%**
Plastic (strong)	2.15	3.01	2.5	6.36	3.55	1.99	1.75	1.98	1.66	1.62	**2.76%**
Bags	7.45	7.14	1.21	1.19	0.83	0.62	6.32	3.2	5.75	2.96	**4.67%**
Tetra pack	0.6	0.84	0.18	0.32	1.85	0.46	0.83	0	0.62	0.45	**0.58%**
Polystyrene and similars	1.2	0	0.15	0.08	1.57	0.54	0.85	0.16	0.7	0.64	**0.57%**
Metal	1.8	1.03	3.05	0.36	6.51	1.88	1.42	1.75	1.35	1	**1.97%**
Fabrics, textiles	0.79	3.14	2.14	0.78	2.49	1.36	1.41	1.78	0.87	1.87	**1.73%**
Tires, leather, rubber	0.23	1.53	1.58	0.24	3.23	1.54	1.2	0.59	1.28	0.18	**1.04%**
Batteries	0.03	0.01	0.35	0.04	0.05	0.02	0.06	0.05	0.08	0.11	**0.09%**
Medicine leftovers, bulbs, etc.	0.13	0.08	0.4	0.04	0.83	0.11	0.32	0	0.3	0.03	**0.20%**
Sanitary Waste	12.54	7.88	8.61	7.06	15.74	6.97	7.89	9.92	8.25	7.48	**9.82%**
Inert Waste	8.05	15.76	19.39	0	7.84	14.83	9.6	7.62	9.94	14.34	**11.66%**
Others (specify)	0.03	1.02	1.79	0	0.63	0.1	0.42	1.67	0.02	0.18	**0.68%**

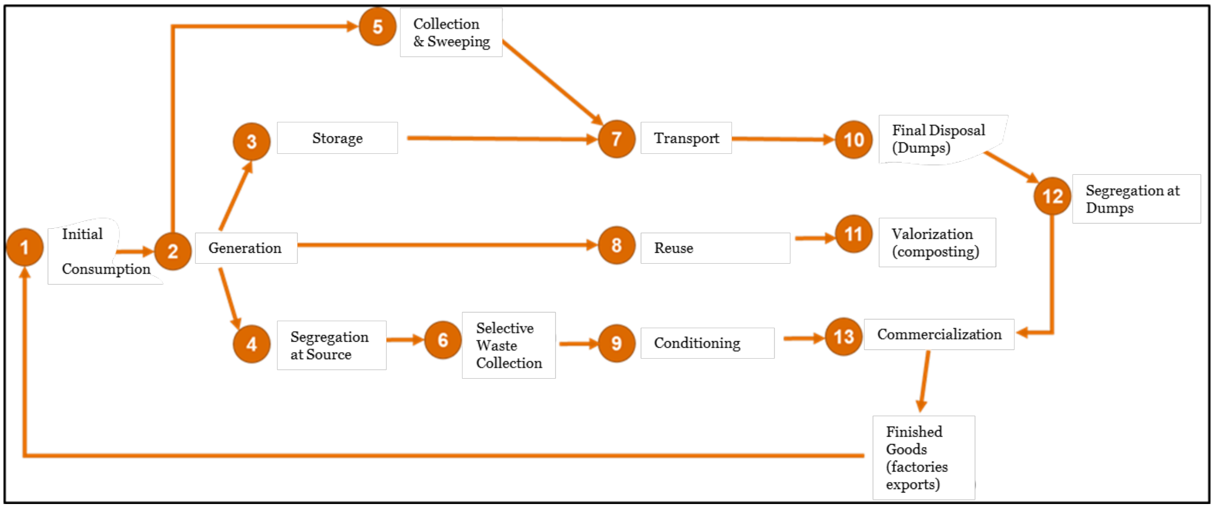
Source: PIGARS Trujillo 2016-2020

[10] http://sial.segat.gob.pe/documentos/estudio-caracterizacion-residuos-solidos-municipales-area-urbana

3.2. Final Disposal of Solid Waste

There are various stages in the waste management cycle; initial consumption and generation, segregation, recovery and transport, and final disposal. Figure N° 02 illustrates a general overview of the flow of solid waste in at different stages in the waste management cycle. Certain aspects of the cycle, such as waste recovery processes and segregation activities, are considered for purpose of estimating the volumes of waste that reach the sanitary landfill for final disposal. However, in general the scope of analysis of this concept note is limited to the final disposal of solid waste[11].

Figure. N° 02. Solid Waste Management Cycle in the Trujillo Province



Source: Own creation

In parts of Peru, it is common practise for municipalities without proper final disposal infrastructure to use uncontrolled dump sites, usually at a substantial distance from the population centre. When the dump reaches capacity, the municipality moves onto a new area. This practice results in multiple dump sites with large accumulations of solid waste.

For the ten districts analysed in this note, municipal solid waste is currently disposed of untreated in the controlled dump “El Milagro”. At this site there is exposed and uncontrolled burning of waste, and a large number of informal ‘separator’ workers are exposed to hazardous materials and fumes as a result. This has led to complaints from the “Organismo de Evaluación y Fiscalización Ambiental” (OEFA[12]) to the Public Prosecutor's Office and the National Comptroller's Office.[13] Photographs N° 01. and N° 02. illustrate the poor conditions in the “El Milagro” dump.

Photographs N° 01. and N° 02.: Conditions in the “El Milagro” Controlled Dump

[11] Plan Regional de Saneamiento Ambiental – La Libertad http://sir.regionlalibertad.gob.pe/admin/docs/Plan%20Regional%20Saneamiento%20Actualizado%20-%20Enero%202012.pdf

[12] Government agency that oversees Regional and Local Governments for compliance with environmental law

[13] https://www.oefa.gob.pe/noticias-institucionales/el-oefa-interviene-por-la-inadecuada-disposicion-de-residuos-solidos-en-el-botadero-el-milagro-en-la-provincia-de-trujillo

Photograph N° 01: Uncontrolled burning of exposed solid waste

Photograph N° 02: Presence of a large number of informal separators

3.3. Proposed Solution

In order to address the unsustainable method of final disposal of waste in the Trujillo province, an alternative for final disposal must be found. In support of this, the regional government has donated an area of 67 hectares - close to the "El Milagro" controlled dump - to the municipality of Trujillo for the construction of a new sanitary landfill. This land was chosen following a site selection study, and it has received a certificate of no existence of archaeological remains. Figure N°03 shows the location of "El Milagro" as well as the land on which the new sanitary landfill is intended to be built - approximately 4km away.

Figure. N° 03. Location of the New Landfill Trujillo Sanitary

Source : Google Earth

The new Regulation of Law 1278 on the Comprehensive Management of Solid Waste established minimum technical requirements for new sanitary landfills, regarding final disposal infrastructure, location, facilities and operations. One of these requirements specifies that a sanitary landfill with volume characteristics such as that which would be required for the new Trujillo sanitary landfill must incorporate a centralised landfill gas capture and burn technology. It is possible to model the construction of a sanitary landfill that meets these minimum technical requirements in the area designated by the regional government.

Table N° 05, shows a projection of the demand for final disposal of solid waste in the new Trujillo sanitary landfill assuming that the landfill would come into operation in 2019. Based on various assumptions (see Annex 1 for assumptions used in projections and estimations), the total demand for final disposal for solid waste in this landfill is estimated to be 311,985 tons / year in 2019. Projections have been made for 30 years in order to establish the ongoing demand for final disposal in the region, which can then be used then estimate the capacity requirements and useful life of the landfill.

Table N° 05. Projection of Demand for Final Disposal in the Trujillo Sanitary Landfill

Nº	Year	Population Total (1)	GPC (kg/h/day) (2)	Domestic SW (Ton/day) (3)	Commercial SW (Ton/day) (3)	SW from Street Sweeping (Ton/day) (3)	Total SW Generated (Ton/year) (4)	Recyclable SW (Ton/year) (5)	Compostable SW (ton/year) (5)	Total SW Demand Final Disposition (ton/year) (6)
0	2019	1,017,977	0.545	555	301	127	358,603	28,688	17,930	311,985
1	2020	1,036,693	0.550	570	310	130	368,801	29,504	18,440	320,857
2	2021	1,055,761	0.556	587	318	134	379,291	30,343	18,965	329,983
3	2022	1,075,186	0.561	603	327	138	390,081	31,206	19,504	339,370
4	2023	1,094,977	0.567	621	337	142	401,180	32,094	20,059	349,026
5	2024	1,115,141	0.572	638	346	146	412,596	33,008	20,630	358,959
6	2025	1,135,684	0.578	657	356	150	424,340	33,947	21,217	369,176
7	2026	1,156,614	0.584	675	366	154	436,420	34,914	21,821	379,685
8	2027	1,177,939	0.590	695	377	158	448,846	35,908	22,442	390,496
9	2028	1,199,667	0.596	715	387	163	461,629	36,930	23,081	401,617
10	2029	1,221,805	0.602	735	398	167	474,778	37,982	23,739	413,057
11	2030	1,244,362	0.608	756	410	172	488,304	39,064	24,415	424,825
12	2031	1,267,345	0.614	778	421	177	502,219	40,177	25,111	436,930
13	2032	1,290,764	0.620	800	433	182	516,532	41,323	25,827	449,383
14	2033	1,314,627	0.626	823	446	187	531,257	42,501	26,563	462,194
15	2034	1,338,943	0.632	846	458	192	546,405	43,712	27,320	475,372
16	2035	1,363,721	0.638	870	471	198	561,988	44,959	28,099	488,929
17	2036	1,388,970	0.645	895	485	203	578,019	46,241	28,901	502,876
18	2037	1,414,699	0.651	921	499	209	594,511	47,561	29,726	517,224
19	2038	1,440,918	0.658	947	513	215	611,477	48,918	30,574	531,985
20	2039	1,467,637	0.664	975	527	221	628,931	50,314	31,447	547,170
21	2040	1,494,866	0.671	1,003	542	227	646,888	51,751	32,344	562,792
22	2041	1,522,615	0.677	1,031	558	234	665,362	53,229	33,268	578,865
23	2042	1,550,895	0.684	1,061	574	240	684,368	54,749	34,218	595,400
24	2043	1,579,716	0.691	1,091	590	247	703,922	56,314	35,196	612,412
25	2044	1,609,089	0.698	1,123	607	254	724,039	57,923	36,202	629,914
26	2045	1,639,026	0.705	1,155	624	261	744,737	59,579	37,237	647,921
27	2046	1,669,537	0.712	1,188	642	269	766,032	61,283	38,302	666,448
28	2047	1,700,635	0.719	1,222	660	276	787,942	63,035	39,397	685,509
29	2048	1,732,332	0.726	1,257	679	284	810,484	64,839	40,524	705,121
30	2049	1,764,639	0.733	1,294	699	292	833,678	66,694	41,684	725,300

Source : (1) Estimation, http://censos2017.inei.gob.pe/redatam, (2) Estimation, ECRS of each District, (3) Estimation, market study of municipal solid waste in Trujillo, (4) Sum of domestic, commercial and municipal solid waste (5) Private market study, (6) Total municipal solid waste generated, minus the volume of recyclable and compostable waste (see annex 01 for details regarding assumptions)

Table N° 06 shows the capacity – in terms of volume – needed to meet the demand for final disposal of waste in Trujillo. Here it is assumed that the density of the solid waste after compaction is 0.55ton / m^3 and that the landfill will have a platform depth of 8 m with 60 cm of cover material that will be added on top. It is also estimated that due to decomposition of solid waste inside the landfill, the volume of waste will reduce by up to 6% per year leading to a reduction in initial volume occupied by each ton of waste over time. The projections estimate that in the year 2019 the volume of the landfill that will be occupied will be 348,070 m^3 and by the end of 2049 it would be 19'783,033 m^3.

Table N° 06: Volume Requirement for Solid Waste in the Trujillo Sanitary Landfill

Nº	Year	Population Total (1)	Accumulated SW (ton/year) (2)	Compacted SW (m³) (2)	Stabilized SW (m³) (2)	Platform depth (m)	Thickness of Cover Material (m)	Cover Material (m³/year) (3)	Total Volume (m³/year) (4)	Accumulated Occupied Volume (m³/year)
0	2019	1,017,977	311,985	567,245	305,527	8.00	0.60	42,543	348,070	348,070
1	2020	1,036,693	632,842	583,376	314,215	8.00	0.60	43,753	357,969	706,039
2	2021	1,055,761	962,825	599,969	323,153	8.00	0.60	44,998	368,150	1,074,189
3	2022	1,075,186	1,302,195	617,037	332,346	8.00	0.60	46,278	378,623	1,452,812
4	2023	1,094,977	1,651,222	634,593	341,802	8.00	0.60	47,595	389,396	1,842,208
5	2024	1,115,141	2,010,181	652,652	351,528	8.00	0.60	48,949	400,477	2,242,686
6	2025	1,135,684	2,379,356	671,229	361,534	8.00	0.60	50,342	411,876	2,654,562
7	2026	1,156,614	2,759,042	690,337	371,826	8.00	0.60	51,775	423,601	3,078,163
8	2027	1,177,939	3,149,538	709,993	382,413	8.00	0.60	53,249	435,663	3,513,826
9	2028	1,199,667	3,551,155	730,213	393,304	8.00	0.60	54,766	448,070	3,961,895
10	2029	1,221,805	3,964,212	751,012	404,507	8.00	0.60	56,326	460,832	4,422,728
11	2030	1,244,362	4,389,036	772,408	416,031	8.00	0.60	57,931	473,961	4,896,689
12	2031	1,267,345	4,825,967	794,418	427,886	8.00	0.60	59,581	487,467	5,384,156
13	2032	1,290,764	5,275,350	817,060	440,081	8.00	0.60	61,280	501,360	5,885,517
14	2033	1,314,627	5,737,543	840,352	452,626	8.00	0.60	63,026	515,653	6,401,170
15	2034	1,338,943	6,212,915	864,313	465,532	8.00	0.60	64,823	530,356	6,931,525
16	2035	1,363,721	6,701,845	888,963	478,809	8.00	0.60	66,672	545,481	7,477,006
17	2036	1,388,970	7,204,721	914,320	492,467	8.00	0.60	68,574	561,041	8,038,047
18	2037	1,414,699	7,721,945	940,408	506,518	8.00	0.60	70,531	577,048	8,615,095
19	2038	1,440,918	8,253,930	967,245	520,973	8.00	0.60	72,543	593,516	9,208,611
20	2039	1,467,637	8,801,100	994,855	535,844	8.00	0.60	74,614	610,458	9,819,069
21	2040	1,494,866	9,363,893	1,023,259	586,322	8.00	0.60	76,744	663,067	10,482,136
22	2041	1,522,615	9,942,757	1,052,481	641,560	8.00	0.60	78,936	720,496	11,202,632
23	2042	1,550,895	10,538,157	1,082,546	702,007	8.00	0.60	81,191	783,197	11,985,829
24	2043	1,579,716	11,150,569	1,113,476	768,154	8.00	0.60	83,511	851,664	12,837,494
25	2044	1,609,089	11,780,483	1,145,298	840,539	8.00	0.60	85,897	926,437	13,763,930
26	2045	1,639,026	12,428,405	1,178,039	919,752	8.00	0.60	88,353	1,008,105	14,772,035
27	2046	1,669,537	13,094,853	1,211,723	1,006,438	8.00	0.60	90,879	1,097,317	15,869,353
28	2047	1,700,635	13,780,362	1,246,380	1,101,302	8.00	0.60	93,479	1,194,780	17,064,133
29	2048	1,732,332	14,485,483	1,282,038	1,205,116	8.00	0.60	96,153	1,301,269	18,365,402
30	2049	1,764,639	15,210,783	1,318,727	1,318,727	8.00	0.60	98,904	1,417,631	19,783,033

Source: (1) Estimation, http://censos2017.inei.gob.pe/redatam/, (2) Own calculations (See Annex 01), (3) Cover material volume, (4) Total Volume, from adding Stabilized SW Volume and Cover Material Volume

The useful life of the landfill is based on the demand for disposal of solid waste, the capacity of the landfill and the fact that there are 67 hectares of land available, of which 57 hectares can be used for landfill cells leaving ten hectares for access roads and other required landfill infrastructure. The proposed plans are to build six cells covering 9.5 hectares each with a depth of 8 m and four levels of platforms in each cell within the 57 hectares of land. The cells would follow a pyramid trunk design structure with sufficient adjacent work space to allow for offloading of solid waste at the peak disposal time. Table N° 07 shows the total volume available for the disposal of solid waste in the landfill cells. Given the total available volume of 15,818,598.18m³, the useful life of the sanitary landfill has been estimated in Table N° 08 as 27 years.

Table N° 07. Volume Available for Disposal of Solid Waste in the Sanitary Landfill

Projected Cells	Levels per Cell	Platform depth (m)	Service area %	Total Available Area / Cell (he)	Available Volume (m³)
1	4	8.6	85%	30.66	2,636,433
2	4	8.6	85%	30.66	2,636,433
3	4	8.6	85%	30.66	2,636,433
4	4	8.6	85%	30.66	2,636,433
5	4	8.6	85%	30.66	2,636,433
6	4	8.6	85%	30.66	2,636,433
				Total (m³)	15,818,598.18

Source : Own creation

Table N° 08. Calculation of the Useful Life of the Sanitary Landfill

Useful Life		
A. Cell	9.49	Hectares
A. Terrain	67	Hectares
A. Available	57	Hectares
N° of Cells	6.0	-
Total Volume	15,818,598	m3
Useful Life	**27**	**Years**

The Clean Development Mechanism (CDM) of the United Nations Framework Convention on Climate Change have been used (UNFCCC) was used to estimate the generation and potential emissions reductions from capturing gas generated through the decomposition of solid waste in the sanitary landfill [14]. Based on the estimated volume of solid waste, the composition of the solid waste and the climatic characteristics of the site, it is estimated that by 2019 there would be a volume of approximately 1,145,033 Nm^3 of "Landfill Gas" produced (LFG).

Methodology and Tools
ACM0001 / Version 15.0.0 "Flaring or use of landfill gas"
Emissions from solid waste disposal sites" (Version 06.0.1)
Project emissions from flaring" (Version 02.0.0)
Tool to calculate baseline, project and/or leakage emissions from electricity consumption" (Version 01)

Using the LFG projections and the composition of the waste, the amount of GHG emissions from the solid waste can be estimated. With this information, estimates can also be made regarding how many tons of CO_2 equivalent (tCO_2e) could be mitigated by installing emissions reductions technologies. Table N° 09 shows the estimated LFG emissions over the useful life of the landfill (from Y1 in 2019 to Y27 in 2046).

Year	LFG (Nm^3/year)	Year	LFG (Nm^3/year)	Year	LFG (Nm^3/year)
1	1,145,033	10	9,613,007	19	16,515,896
2	2,237,156	11	10,420,351	20	17,262,646
3	3,281,504	12	11,212,312	21	18,011,743
4	4,282,828	13	11,991,376	22	18,764,671
5	5,245,534	14	12,759,869	23	19,522,846
6	6,173,706	15	13,519,978	24	20,287,627
7	7,071,136	16	14,273,754	25	21,060,320
8	7,941,349	17	15,023,132	26	21,842,183
9	8,787,621	18	15,769,937	27	22,634,431

Table N° 09: Estimation of LFG generated in the sanitary landfill

Source: Own creation

[14] https://cdm.unfccc.int/methodologies/index.html

4. Selection Criteria and Classification Levels

4.1. Analysis of options

Eight criteria have been established for the selection of a technology, covering cost, risk, flexibility, suitability and impact. Table N° 11 shows the percentage weighting, the decision criteria and the scoring for each technology alternative to be chosen based on judgement by experts. In the scoring a '1' is considered the worst and a '3' the best.

Table N° 12. Description and Scoring for Selection Criteria

Score (A)	Weight (B)	Descripción	Descision Criteria
Cost Optimization (Score 1-3)	20%	Costs of the alternative taking into account CAPEX and OPEX. The potential income flows generated by the alternative (in relation to other technologies) over its useful life are considered as an additional benefit.	The alternative with the lowest net costs over the course of its useful life will receive the highest score (3). The alternative with the highest net costs will receive the lowest score (1).
Risk Level (Construction) (Score 1-3)	5%	Risk associated with delays in the implementation and deviations of the project plan / schedule. Simplicity in the implementation of the technologies is awarded a higher score than technologies which are more complex to implement.	The alternative with the lowest level of risk will receive the highest score (3). The alternative with the highest level of risk will receive the lowest score (1).
Rick Level (Operation) (Score 1-3)	5%	Level of risk regarding the ability of the technology to provide satisfactory operation without failures during its useful life/over long periods of time.	The alternative with the lowest level of risk will receive the highest score (3). The alternative with the highest level of risk will receive the lowest score (1).
Suitability (Score 1-3)	10%	Capacity of the technology to adapt well to the physical characteristics and requirements of the chosen site. Technologies tested locally and / or internationally in similar locations obtain higher scores, as well as technologies with specific benefits for the environment in which it will be implemented.	The alternative with the highest level of suitability will receive the highest score (3). The alternative with the lowest level of suitability will receive the lowest score (1).
Flexibility (Score 1-3)	10%	Flexibility of the alternative in terms of potential to adapt to future demands e.g. scalability potential in the case of increased demand. If the scalability does not require more investment or effort, the technology gets higher score.	The alternative with the highest level of flexibility will receive the highest score (3). The alternative with the lowest level of flexibility will receive the lowest score (1).
Emissions Reduction (Score 1-3)	20%	The potential reductions in projected emissions relative to the levels of reference GHG emissions (baseline) over the lifetime of the technology. The more emission reduction generated, the higher the score.	The alternative with the greatest potential for GHG emission reduction will receive the highest Score (3). The alternative with the lowest GHG emission reduction potential will receive the lowest Score (1)
Environmental and Social Impact (Score 1-3)	15%	Potential for generating social impact e.g. employment opportunities for the local community and greater access to energy as a result of energy generation, among others. Potential for reducing environmental damage.	The alternative with the highest level of possible positive environmental and/or social impact will receive the highest Score (3). The alternative with the lowest positive impact potential will receive the lowest score (1)
Replicability (Score 1-3)	15%	Possibility for replicating the use of the technology in other landfills in the country. If the technology can be applied in a greater number of places with similar benefits, it is awarded a higher score.	The alternative with the highest level of replicability will receive the highest score (3). The alternative with the lowest GHG emission reduction potential will receive the lowest Score (1).

Source: Own creation

4.2. Analysis of viability

For each alternative presented, a multi-criteria analysis is carried out using the framework above. The overall score is determined by the total scores (AxB) of eight criteria to which a score (A) and a weighted weight (B) have been assigned. Scores that are greater than 2 deem the project to be very viable; between 1 and 2 viable and less than 1 not viable (Table N ° 12).

Table N°13. Scale of Viability Scores for the Options Analysis

Viability Score	Description
Greater than 2	Very Viable
Between 1 and 2	Viable
Less than 1	Not Viable

Source: Own elaboration

5. Technology options

In addition to the construction of the landfill, this concept note evaluates options for GHG emissions reduction technologies, which could also be used to convert the LFG generated into electricity for both on-site consumption and sale. Three potentially appropriate technology alternatives where chosen for evaluation based on the characteristics of the Trujillo sanitary landfill:

- Alternative 1: Biogas capture and centralised flare
- Alternative 2: Biogas capture, centralised flare and electricity generation
- Alternative 3: Electric power generation through gasification

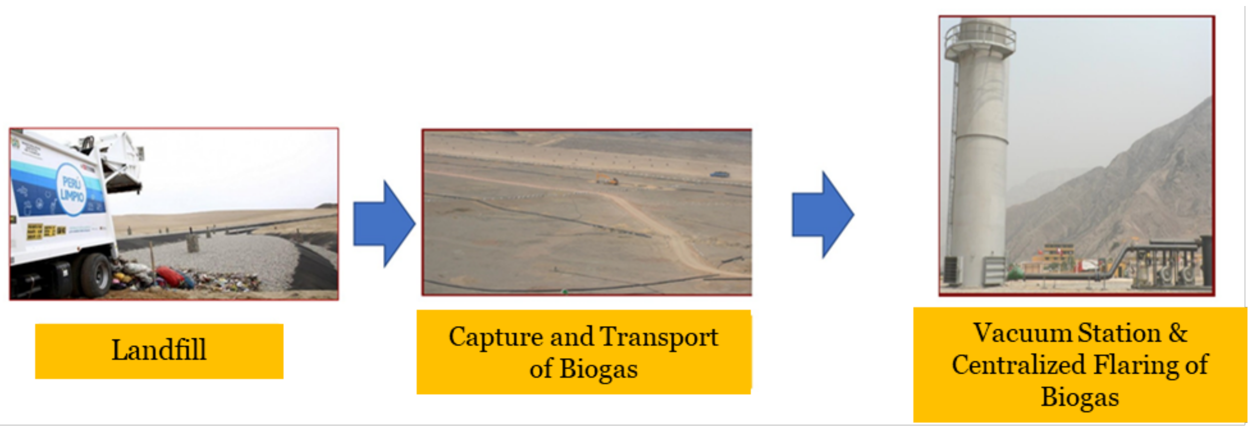
These three technologies were chosen based on their maturity, the existence of prior experience of the technology within the country, the volume of waste specific to this location and the potential for operating cost reductions, energy recovery and GHG emissions reductions. These technologies are all available in the global market and have the potential to be replicated at other landfill site in Peru and internationally. The financial and non-financial impacts of each technology can be projected, based on assumptions of a certain level of technical management of the final disposal process and a constant stream of waste throughout the useful life of the landfill.

5.1. Option 1: Biogas capture and centralised flare

5.1.1. Technology Overview

This technology involves the construction of biogas wells in the platforms of the sanitary landfill to capture the biogas, which is then transported to a controlled combustion station through pipelines using an active suction system. GHG emissions are destroyed in the controlled combustion station via flaring in line with the ACM0001 methodology of the UNFCCC[15]. Figure N° 04 illustrates the flow of activities involved in the capture and centralised flaring of biogas.

Figure. N° 04: Biogas capture and centralised flare diagram



5.1.2. Cost Optimization

Costs are incurred for this technology in the construction of the biogas capture wells, the biogas transport duct, the suction stations and the controlled combustion station. The estimated cost of installing these at the scale required for the Trujillo site, including a reserve for contingencies and management, would be

[15] https://cdm.unfccc.int/methodologies/documentation/meth_booklet.pdf#ACM0001

approximately US$ 1.12 million (for more details see Annex No. 03). This estimation was reached using the "Perú: Huaycoloro Landfill Gas Recovery" CDM Project as a reference (*"World Bank Documents"*).[16]

5.1.3. Risk Level

The construction and implementation of this technology is relatively straightforward and its operation would be simple and automatable. The selection of suppliers for construction and installation of the technology would be made through a private tender through the landfill operator and the installation of the technology should require a maximum of 12 months. However, potential implementation delays have been identified as project risks. Given these risks, a contingency reserve of 10% of the estimated overall cost of the project has been built into the budget.

5.1.4. Suitability and Flexibility

This technology is well suited to the chosen site given its viability for a landfill of this magnitude and its GHG emissions reductions potential. This technology also has a significant level of maturity within the country and region, having been implemented in a number of similar projects. This technology is able to cater to unexpected increases in the volume of LFG, either by unexpected changes in local climate or by an increase in amount of solid waste. This is because any unanticipated additional volume of gas could be stored in the gas pipes of the landfill, or an alternative storage facility that could be installed, until it is ready to be burned.

5.1.5. GHG Emissions Reduction Potential

It has been estimated that over the useful life of this landfill (27 years), this technology could achieve emissions reductions of 2,711,513 tCO2e. The GHG emissions reduction potential of this technology was estimated using tools provided by the CDM of the UNFCCC (for the assumptions used in this estimation see Annex No. 02).

5.1.6. Track Record, Potential Suppliers & Private Sector Interest

As of October 2018, this technology has been implemented at three sanitary landfills in Peru: Huaycoloro, Modelo del Callao and Ancón. There are a variety of suppliers of this technology, including: ABISA, Haug, Jhon Zink, Jorvex, Cidelsa and TDM. It is also possible to include the cost of operating the technology into the landfill operational costs in order to attract private sector interest from waste service provider companies such as Petramás, KDM, Veolia, Proactiva, and Acciona.

5.1.7. Impact and Replicability

This alternative does not have any additional environmental benefits beyond GHG emissions reductions and does not have any social impacts such as additional generation of employment. This technology is the most simple, low cost and replicable of the three alternatives. Given that it is now required by law that landfills that generate over 200 tonnes of waste per day incorporate a centralised biogas capture and flare technology, this could be replicated in the cities of Arequipa, Piura, Tacna, Maynas, Ayacucho, Ucayali and Lambayeque.

5.1.8. Analysis Results

Using the methodology described in section 4, the following scoring (shown in Table N° 11) was established through a working session between PwC and the Department of Waste Management (Dirección de Gestion de Residuos Solidos- DGRS) and the Department of Climate Change and Desertification (Dirección de Cambio Climático y Desertificación – DGCCD) of the Ministry of Environment (MINAM).

[16] http://documents.worldbank.org/curated/en/951071468293396238/pdf/337610PAD0P0941aycoloro0PAD0Sept030.pdf (Revisar Annex 5 de este documento)

Table N° 11 Score for Alternative 1

Score (A)	Weight(B)	Score out of 3	Weighted Score
Cost Optimization	20%	3	0.6
Risk Level (Construction)	5%	3	0.15
Rick Level (Operation)	5%	3	0.15
Suitability	10%	2	0.2
Flexibility	10%	3	0.3
Emissions Reduction	20%	1	0.2
Environmental and Social Impact	15%	1	0.15
Replicability	15%	2	0.3
Total	**100%**	**-**	**2.05**

Source : Own elaboration

5.2. Option 2: Biogas capture, centralised flare and electricity generation

5.2.1. Technology Overview

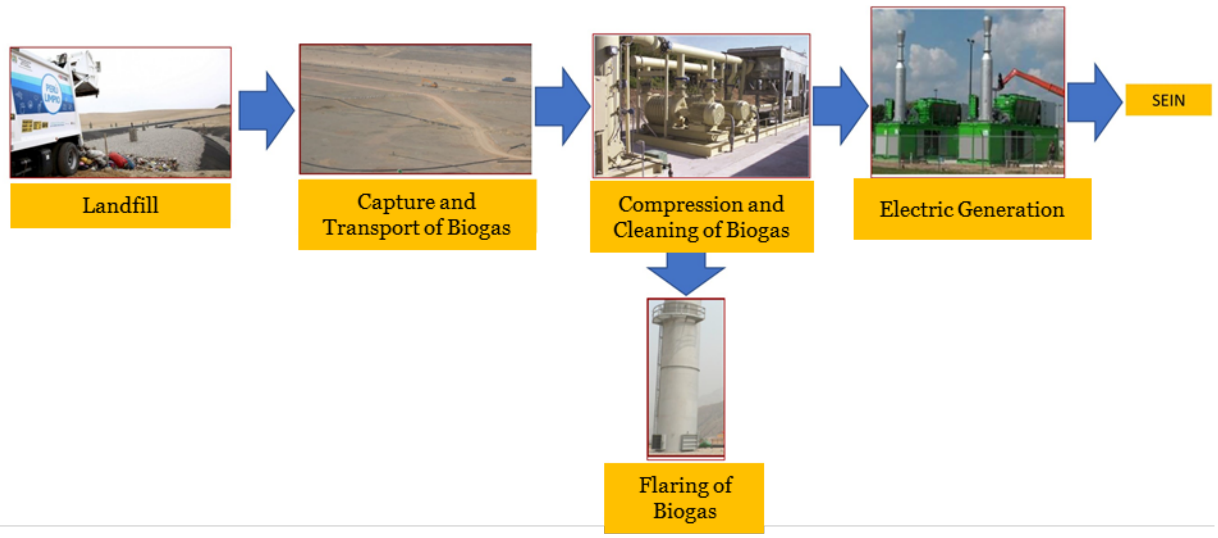
This technology involves the construction of biogas wells in the platforms of the sanitary landfill in order to capture biogas which is then transported to be cleaned and compressed. The treated gas is converted into electricity in high efficiency combustion engines and is then fed into the national electricity grid (Sistema Eléctrico Interconectado Nacional – SEIN). This technology also integrates centralised flaring as a safety measure to be used in the case the combustions engines need to be stopped for maintenance.

Since 2010 the Peruvian state has held periodic renewable energy auctions with electricity generated from biomass as one of the eligible renewable energies[17]. Energy sales contracts with a guaranteed rate for up to 20 years backed by the Peruvian state can be established at these auctions. The electricity generated at the landfill site could be fed into the grid at a fixed tariff if an energy sales contract is established for this project at the renewable energy auction.

Figure N° 05 illustrates the flow of activities involved in the biogas capture, centralised flare and electricity generation.

Figure N° 05: Biogas capture, centralised flare and electricity generation diagram

[17] http://www.osinergmin.gob.pe/empresas/energias-renovables/subastas/cuarta-subasta.



5.2.2. Cost Optimization

Costs are incurred in construction of the biogas capture wells, the biogas transport duct, the stations for the compression and cleaning of the biogas, the combustion engines, the electricity generation station and the line to transmit electricity to the grid. It is projected that from the third year of the landfill's useful life, sufficient landfill gas will have been produced to install a 1MW combustion engine and there will be sufficient gas to install a second in year eight and a third in year twelve. Given this, the landfill will have an installed generating capacity of 3MW by the twelfth year of its useful life.

It has been estimated that the cost of installing these at the scale required for the Trujillo site, including a reserve for contingencies and management, would be approximately US$7.5 million (for more details see Annex No. 03). This estimation was reached using the "Perú: Huaycoloro Landfill Gas Recovery" CDM Project as a reference in a similar approach to that used for the previous technology.[18] A return on this investment would be secured by the framework contract agreed through the renewable energy auction to feed electricity into the SEIN at a fixed tariff.

5.2.3. Risk Level

The selection of suppliers for construction and installation of the technology would be made through a private tender through the landfill operator and the installation of the technology should require a minimum of 12 months. However, potential implementation delays have been identified as project risks. Given these risks, a contingency reserve of 10% of the estimated overall cost of the project has been built into the budget.

Given the vast supply of cheap energy in the country, largely due to large scale and low cost solar and wind energy, there may be the risk that the government will not agree to a competitive tariff through the renewable energy auction to facilitate investment into energy generation technologies in the biomass sector.

5.2.4. Suitability and Flexibility

This technology is highly suitable for the site as it not only achieves the goal of directly reducing emissions from the capture and flaring of landfill gas but also indirectly through the generation of electricity from a renewable source that could replace electricity from non-renewable sources. This technology also meets the goal of mobilising private investment as it enables a potentially steady stream of cash flows which

[18] http://documents.worldbank.org/curated/en/951071468293396238/pdf/337610PAD0P0941aycoloro0PAD0Sept030.pdf (See Annex 5 of this document)

increases the attractiveness of this project to private sector investors. This alternative is less flexible to adaptation than Option 1 (see section 5.1) and excess GHG emissions that are not converted must be redirected for centralised flaring. However, there is the option to add additional motor generation to take advantage of excess GHG emission if necessary.

5.2.5. GHG Emissions Reduction Potential

It has been estimated that over the useful life of this landfill (27 years), this technology could achieve emissions reductions of 3,005,097 tCO_2e. The GHG emissions reduction potential of this technology was estimated using tools provided by the CDM from the UNFCCC. This figure includes the direct emissions reductions from the landfill and the indirect emissions reductions achieved through the provision of renewable energy that could displace consumption of conventional, non-renewable energies that generate GHG emissions. Using the CDM model, it is estimated that each MWh of biomass generated electricity supplied to the SEIN is equivalent to a reduction of 0.45338 tCO_2e[19].

5.2.6. Track Record, Potential Suppliers & Private Sector Interest

As of October 2018, this technology has been implemented at the Huaycoloro sanitary landfill in Peru. There are a variety of suppliers of this technology, including: Caterpillar, Jenbacher and Perennial Energy. Given the potential return on investment from the sale of renewable energy to the SEIN, there may also be private sector interest from waste service provider companies such as Petramás, KDM, Veolia, Proactiva, Acciona and other companies that generate renewable energy.

5.2.7. Impact and Replicability

The positive environmental impact of this technology is greater than that of Option 1 due to the generation of renewable energy that could displace consumption of non-renewable energy, in addition to the GHG emissions reductions from the gas capture at the landfill site. In terms of social benefits, this technology does not create significant employment opportunities as its instalment and operation are not labour-intensive. This alternative is less widely replicable than the former as it require a substantial amount of waste to generate sufficient landfill gas along with favourable climatic conditions (similar to those described in Table N° 2) in order for it to be profitable to sell electricity to the SEIN.

5.2.8. Analysis Results

Using the methodology described in section 4, the following scoring (shown in Table N° 12) was established through a working session between PwC and the DGRS and the DGCCD of the MINAM.

Table N° 12. Score for Alternative 2

Score (A)	Weight(B)	Score out of 3	Weighted Score
Cost Optimization	20%	3	0.6
Risk Level (Construction)	5%	3	0.15
Rick Level (Operation)	5%	3	0.15
Suitability	10%	3	0.3
Flexibility	10%	3	0.3
Emissions Reduction	20%	2	0.4
Environmental and Social Impact	15%	2	0.3
Replicability	15%	2	0.3
Total	**100%**	**-**	**2.5**

Source: Own creation

[19] UNFCCC: Project 0708

5.3. Option 3: Electric power generation through gasification

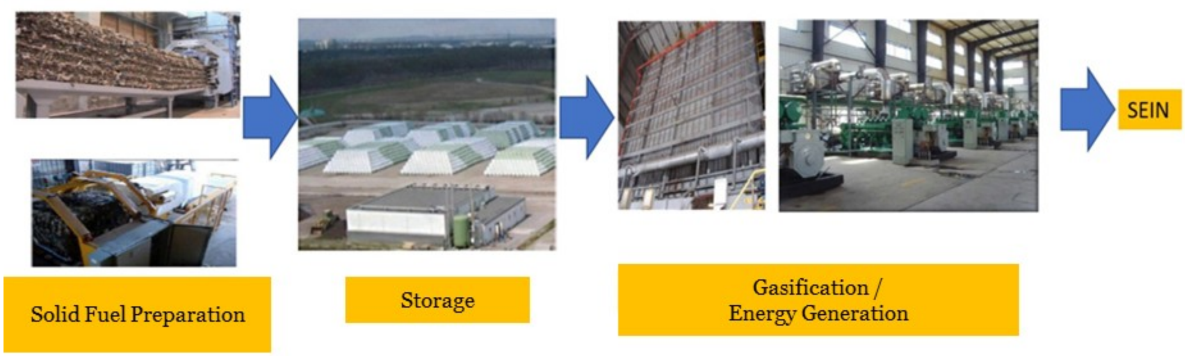
5.3.1. Technology Overview

This technology involves the installation of a large solid waste processing centre at the landfill in order to remove metals, glass and other waste items that are ineligible for gasification. The purpose of this process is to separate solid waste suitable for gasification that will be transported to designated units to be transformed into syngas fuel (containing methane and carbon monoxide) and then taken to an electricity generation plant to be converted into electricity that will be fed into the SEIN. As with the former technology, the intention would be to sell the electricity to the SEIN at a fixed tariff guaranteed by the Peruvian government if an energy sales contract is established for this project at the renewable energy auction.

This technology separates and destroys solid waste in such a way that only 3-5% of solid waste ends up in the final disposal cells of the sanitary landfill, significantly extending the useful life of the landfill and reducing operation and maintenance costs. Another advantage of this alternative in terms of social benefits is that it involves considerable labour requirements for the waste separation element of the process, which creates a more positive social impact.

Figure N° 05 illustrates the flow of activities involved in the generation of electric power through gasification of solid waste.

Figure N° 06: Electric power generation through gasification diagram



5.3.2. Cost Optimization

Costs are incurred in the construction of the waste processing station, the gasification units, the electricity generation station and the power line to transfer electricity to the grid. It is projected that the cost of installing this technology would be approximately US$55 million for a 18MW plant that could process approximately 450 tonne/day of solid waste (for more details see Annexes No. 05 and 06). It is estimated that the plant would feed 145,798MWh a year to the SEIN and would generate return on investment secured by the framework contract agreed through the renewable energy auction.

5.3.3. Risk Level

The selection of suppliers for construction and installation of the technology would be made through a private tender through the landfill operator and the installation of the technology should require a minimum of 36 months. However, potential implementation delays have been identified as project risks. Given these risks, a contingency reserve of 10% of the estimated overall cost of the project has been built into the budget.

Given the high supply of cheap energy in the country, largely due to large scale and low cost solar and wind energy, there is a risk that the government will not agree to a competitive tariff through the renewable energy auction, to facilitate investment into energy generation technologies in the biomass sector.

An additional consideration is the fact that this technology is relatively new to South America and there is the risk that there will not be sufficient local or domestic capability to manage this technology and there may be a need to either invest in relevant capacity building or contract foreign personnel to operate the technology.

5.3.4. GHG Emissions Reduction Potential

It has been estimated that over the useful life of this landfill (27 years), this technology could achieve emissions reductions of 1,464,789 tCO2e through the generation of renewable energy to be sold to the SEIN alone due to the fact the landfill will be able to process a great volume of waste (for more details see Annex No. 06). The GHG emissions reduction potential of this technology was estimated using the CDM model which estimates that each MWh of biomass generated electricity supplied to the SEIN is equivalent to a reduction of 0.45338 tCO2e[20]. However, taking into consideration the reductions in emissions resulting from the separation and treatment of solid waste that it would have otherwise gone into the sanitary landfill and contribute to additional GHG emissions, the total reduction of emissions would be approximately 4,176,303 tCO2e (i.e. 1,464,789 tCO2e plus the 2,711,513 tCO2e of emissions reductions calculated for the first alternative).

5.3.5. Suitability and Flexibility

Although this alternative has the greatest potential impacts, it is also the most difficult and costly to implement and may not be an entirely realistic option given the context at this point in time. This alternative is also the least flexible of the three options given that the gasification plant has a limited daily capacity that would result in excess waste having to be sent to a complementary landfill if there is an increase in the flow of solid waste to the plant.

5.3.6. Track Record, Potential Suppliers & Private Sector Interest

As of October 2018, this technology has not yet been implemented in Peru, however there are many examples of this technology being successfully used to address the issue of waste management globally. There are a number of suppliers of this technology internationally, including: Westinghouse, Caterpillar, Jenbacher and Baker Hughes General Electric. Given this is an innovative technology with high energy generation potential, it may attract private sector interests from energy generation companies such as Petramás, Acciona or other private companies that generate renewable energy.

5.3.7. Impact and Replicability

This technology has the greatest positive impact of all the alternatives in terms of GHG emissions reductions potential from the landfill and displaced consumption of energy from non-renewable sources. It also has a positive social impact of employment generation due to the significant need for labour in the waste separating process to prepare biomass that will be used for gasification. An additional benefit of this technology is that it would extend the useful life on the landfill beyond the 27 years initially projected. Given the scale of the landfill required for this type of technology, it could only be replicated for sanitary landfills serving other large cities in Peru such as Piura, Lima y Arequipa. As such it is the least replicable for the three alternatives presented.

5.3.8. Analysis Results

Using the methodology described in section 4, the following scoring (shown in Table N° 13) was established through a working session between PwC and the DGRS and the DGCCD of the MINAM.

[20] UNFCCC: Project 0708

Table N° 13. Score for Alternative 3

Score (A)	Weight(B)	Score out of 3	Weighted Score
Cost Optimization	20%	1	0.2
Risk Level (Construction)	5%	1	0.05
Rick Level (Operation)	5%	1	0.05
Suitability	10%	1	0.1
Flexibility	10%	1	0.1
Emissions Reduction	20%	3	0.6
Environmental and Social Impact	15%	3	0.45
Replicability	15%	1	0.15
Total	**100%**	**-**	**1.7**

Source : Own creation

6. Evaluation of the Technology Alternatives

6.1. Technology Options Scoring

Table N° 14 illustrates the advantages and disadvantages of each technology alternative and the weighted score that was awarded to each by a panel of experts, through a working session between PwC and the DGRS and the DGCCD of the MINAM.

Table N° 14. Technology Options Scoring

	Option 1: Biogas capture and centralised flare	**Options 2: Biogas capture, centralised flare and electricity generation**	**Options 3: Electric power generation through gasification**
Advantages	• Lowest cost • Most adaptable to deviations/changes • Two existing national examples	• Medium costs • Proven (tried and tested) technology • Four existing national examples	• Waste recovery and waste to energy results in destruction of almost all solid waste • Employment generation • High energy generation
Disadvatages	• Low labour requirements	• Gradual implementation of infrastructure over the useful life of the landfill	• Highest cost • New technology and no local experience
Weighted score	2.05	2.5	1.7

Source: Own creation

6.2. Decision on the Most Appropriate Technology

The second technology, '*biogas capture, centralised flare and electricity generation*', was deemed to be the most appropriate. This is due to the enhanced emissions reduction potential of producing renewable energy from the LFG generated. It was also considered that the level of investment required for this technology was more reasonable and realistic than that required for the Option 3. The fact that the technology has been implemented previously in the country was also a deciding factor over Option 3.

7. Conclusions

The per capita generation of solid waste in Trujillo is slightly lower than the national average, however population and income level growth projections in this region suggest that there will likely be a significant increase in the generation of solid waste in coming years. Given the current undesirable waste management situation of the "El Milagro" dumpsite, these increases in solid waste generation will considerably worsen the current problem. If these issues remain unaddressed, the mismanagement of municipal solid waste will likely result in escalating negative consequences for society and the environment in Trujillo.

Both the involvement of private sector actors with experience in the waste management sector and the potential to mitigate negative environmental and social impacts of the present waste management system, could present an efficient alternative to the traditional management of municipal waste by municipal governments. The rationale behind this is that private sector waste management operators would be incentivized to carry out the management of their operations in a more sustainable manner as they have both the capacity and experience to do so as well as the monetary incentive of their returns being linked to successful management of the sanitary landfill operations. This is assuming that the private sector waste management operators would be subject to scrutiny by municipal authorities that would be able to terminate their contract for the final disposal of municipal waste and central government authorities that could enforce regulations in the case of mismanagement of sanitary landfill operations.

For sanitary landfills located in zones with favourable climatic characteristics for the generation of GHG emissions and with a significant generation of solid waste the incorporation of a biogas capture, centralised flare and electricity generation technology would enable not only mitigation of GHG emissions, but also a stream of cash flows to provide a return on investment. The generation of renewable electricity from biogas that is fed into the national grid will also result in the displacement of conventional non-renewable energy and contribute to a transition towards more sustainable development.

The biogas capture, centralised flare and electricity generation technology was chosen as the most appropriate option for Trujillo as the municipality generates a sufficient quantity of solid waste to be feasible and enable these positive outcomes. This technology, however, has not yet been implemented at sanitary landfills outside of Lima. In order to assess the feasibility of implementing this technology in other regions in Peru, it is necessary to first undertake detailed feasibility analyses, based on primary data, to evaluate the profitability and potential risks of undertaking this type of projects at specific sanitary landfill sites.

When analysing potential projects for the incorporation of technologies to reduce the environmental impacts of sanitary landfills, it also important to analyse the potential benefits that investments may have on relevant stakeholders, such as solid waste operating companies, which may experience economic benefits from the implementation of these type of technologies even if they are small scale. These benefits could be crucial in drawing interest from the private sector to mobilise much needed private investment into the construction and operation of these technologies and in creating partnerships that aid the country in its ambitions to protect the environment and foster sustainable development.

Annexes

Annex 01: Assumptions for the estimation of SW

Assumption	Estimation	Source
Population Growth	1.8%	Annual avg. growth http://censos2017.inei.gob.pe/redatam
GPC Growth	1%	Conservative assumption
Domestic SW Volume	56.15%	Estudio de caracterización de RRSS municipales (Municipal study)
Commercial SW Volume	30.69%	Estudio de caracterización de RRSS municipales (Municipal study)
SW from Street Sweeping Volume	13.97%	Estudio de caracterización de RRSS municipales (Municipal study)
Recyclable SW Volume	8%	Private market research
Compostable SW Volume	5%	Private market research
Compacted SW Density	0.55 ton/m^3	Standard assumption
Volume reduction from stabilization	6% annual	Standard assumption

Annex 02: Assumptions for the estimation of gas emissions

Physical parameters of compounds				
Parameters	Unit	Value	Explanation	Source
Φ	-	0.75	Model correction factor to account for model uncertainties	According to the ""Emissions from solid waste disposal sites" (Version 06.0.1)", page 2
F	%	0.0	Fraction of CH4 captured to the SWDS	Considered 0 since the Tool - Annex 13 also considers an Adjustment Factor
GWP (1st Crediting Period)	tCO2e/tCH4	25	Global Warming Potential	According to the "Emissions from solid waste disposal sites" (Version 06.0.1), page 2
GWP (2nd Crediting Period)	tCO2e/tCH4	25	Global Warming Potential	According to the "Emissions from solid waste disposal sites" (Version 06.0.1), page 2
OX	-	0.1	Oxidation factor	According to the "Tool v.6" page 3, considering the material utilized for covering the landfill (at the closure)
F	%	0.5	Fraction of CH4 in the SWDS gas	According to the "Emissions from solid waste disposal sites" (Version 06.0.1), page 2
DOC_f	%	0.5	Fraction of degradable organic carbon that can decompose	According to the "Emissions from solid waste disposal sites" (Version 06.0.1), page 3
MCF	-	1.0	Methane Correction Factor	According to the "Emissions from solid waste disposal sites" (Version 06.0.1) page 4, considering the management of the landfill
r_{CH4}	$tonnes/m^3$	0.0007168	Density CH4	According to the ""Emissions from solid waste disposal sites" (Version 06.0.1), page 9 (density of methane at normal conditions)
OX_{top_layer}	-	0.1	Fraction of methane that would be oxidized in the top layer of the SWDS in the baseline	Consistent with how oxidation is accounted for in the methodological tool "Emissions from solid waste disposal sites"
CH4 (%v/v)	%	50%	CH4 concentration	To be monitored (this value as a default per PDD calculations)
Equipment Details				
Parameters	Unit	Value	Explanantion	Source
η_{PJ}	%	0.75	GCE of the equipment installed	Default value as per page 10/23 of ACM0001 / Version 13.0.0 "Flaring or use of landfill gas"
Blower	HP	30	1 blower engine 60HP; 3,600 RPM; 03Phase; 60HZ	Project Developer
Compressor	HP	4.00	1 compressor INGERSOLL RAND; 7,5HP; 1,800 RPM; 480V; 03 Phase; 60HZ.	Project Developer
Blower purge	HP	0.50	1 blower purge that functions only when the system is operating: 3/4 HP; 1,800 RPM; 01 Phase.	Project Developer
Cooler	HP	1.50	1 cooling system of 3 HP	
Electronic System	kW	2	Various	Project Developer
$EC_{PJ,y}$	MWh/yr	252.7	Electricity Consumption, yearly	Calculated
hflare,m	%	1.0	Flare Efficiency in the minute m	Default value according to the tool "Project emissions from flaring" version 02.0.0
CEG	MW	1.14	Capacity of Each Generator	Project Developer
GE	%	40.20%	Generator efficiency	"ESTUDIO DE DETERMINACIÓN DE LA POTENCIA EFECTIVA Y RENDIMIENTO DE LOS GRUPOS CAT 1, 2 Y 3 DE LA CENTRAL TÉRMICA HUAYCOLORO"
FLGE	m3/h	510.74	Flow LFG each generator	Calculated
Tcn	m3/h	0	Thermal Consumption	NA
ε_{boiler}	%	0	Boiler efficiency	NA
Electrical considerations				
Parameters	Unit	Value	Explanation	Source

EFgrid,y	tCO2e/MWh	0.45338	Grid Emission Factor	Provided to DOE as per the "Tool to calculate the emission factor for an electricity system" Version 4.0
TDLy	ratio	5.00%	Technical losses in the grid	Default value
Working times				
Parameters	Unit	Value	Explanation	Source
Helec	h/year	8,000	Hours of generators	Project developer
Hbl	h/year	8,000	Hours of blowers	Project developer
Hth	h/year	0	Hours of thermal consumption	NA
Other parameters				
Parameters	Unit	Value	Explanation	Source
$PE_{FC,j,y}$	tCO2e/year	CALCULATED	Emissions from heat consumption by the project activity	Project evaluator
CH_{4LHV}	KJ/mol	890	Methane LHV	IPCC
FCi,j,y	m3/year	0.0000	Fuel consumption	Project developer
NCVi,y	GJ/ m3	26.3000	Weighted average net calorific value of the fuel type i (LPG)	Values from the fuel supplier will be used.
EFCO2i,y `	tCO2/GJ	0.0656	Weighted average CO2 emission factor of fuel type i (LPG)	Values from the fuel supplier will be used.
Site characteristics				
Parameters	Unit	Value	Explanation	Source
MAT	ºC	20.79	Mean Average Temperature	http://www.worldweather.org/029/c00108.htm
MAP	mm/year	41.00	Mean average Precipitation	http://www.worldweather.org/029/c00108.htm
PET	mm^3/mm^2	48.80	Potential evapotranspiration	http://www.fao.org/geonetwork/srv/fr/graphover.show?id=12739&fname=aridity_index.gif&access=public
Waste basis	-	wet	Waste basis (wet / dry)	Project developer

Source: https://cdm.unfccc.int/methodologies/index.html. Data established according to characteristics of landfill

Annex 03: Alternative Budget 01

Item	Amount (US$)	Participation
Project Management	16,118	1%
Project Supervision & Quality Assurance	40,295	4%
Basic Engineering (Studies & Design)	16,118	1%
Detailed Engineering (Studies & Design)	48,354	4%
Licensing	40,295	4%
Piping	331,534	30%
Centralized Capture and Flaring System	392,927	35%
Electric work & Instrumentation	81,445	7%
Commissioning-ITF	24,177	2%
Project Estimates	**991,264**	
Contingency Reserves	99,126	9%
Costs Base Line	**1,090,391**	
Management Reserves	32,712	3%
Total Budget	**1,123,103**	**100%**

Source: Based on CDM Project "Perú: Huaycoloro Landfill Gas Recovery" (*"World Bank Documents"*)[21].

Annex 04: Alternative Budget 02

Item	Amount (US$)	Participation
Project Management	107,296	1%
Project Supervision & Quality Assurance	268,239	4%
Basic Engineering (Studies & Design)	107,296	1%
Detailed Engineering (Studies & Design)	321,887	4%
Licensing	268,239	4%
Centralized Capture and Flaring System	805,906	11%
Biogas Cleaning & Conditioning System	366,839	5%
Electric Generation System 3MW[22]	2,893,893	39%
Electric Sub Station System	414,691	6%
Transmission System (5Km)	605,906	8%
Others	277,549	4%
Commissioning-ITF	160,944	2%
Project Estimates	**6,598,684**	
Contingency Reserves	659,868	9%
Costs Base Line	**7,258,552**	
Management Reserves	217,757	3%
Total Budget	**7,476,309**	**100%**

Source: Based on CDM Project "Perú: Huaycoloro Landfill Gas Recovery" (*"World Bank Documents"*)[23].

[21] http://documents.worldbank.org/curated/en/951071468293396238/pdf/337610PAD0P0941aycolor00PAD0Sept030.pdf (Check Annex 5 of this document)

[22] Could be implemented in three different times according to Biogas Volume availability.

[23] http://documents.worldbank.org/curated/en/951071468293396238/pdf/337610PAD0P0941aycolor00PAD0Sept030.pdf (Check Annex 5 of this document)

Annex 05: Alternative Budget 03

Item	Amount (US$)	Participation
Licensing/Engineering/Project	1,500,000	3%
Gasification Plant	24,750,000	45%
Generation Plant 18MW	8,550,000	16%
Fuel Preparation Plant	3,300,000	6%
Drying & Pelletization Plant	7,500,000	14%
Civil Infrastructure	6,000,000	11%
Connection to Grid	750,000.00	1%
Project Estimates	**52,350,000**	
Contingency Reserves	1,825,000	3%
Costs Base Line	**54,175,000**	
Management Reserves	825,000	2%
Total Budget	**55,000,000**	**100%**

Source: Based on Rio +20 Project.

Annex 06: Estimation of Additional Emissions Reduction for Alternative 03

Detail	Unit	Quantity	Ref.	Source
Treated Quantity RSU	ton/year	164,450		Proposal Rio+20
Central Installed Power	MW	18.22	A	Proposal Rio+20
Self-consumption Power	MW	3.26	B	Proposal Rio+20
Effective Power	MW	14.96	C=A - B	Proposal Rio+20
Uptime Hours	h/year	8,000.00	D	Proposal Rio+20
Delivered Annual Energy	MWh/year	119,660.00	E=C x D	Proposal Rio+20
Peruvian Emission Factor	ton CO2/MWh	0.45338	F	PDD Huaycoloro
Period	Years	27	G	Landfill Useful Life
Reduced Emissions by Electric Displacement	ton CO2/period	**1,464,789**	ExFxG	

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