ESTIMATION OF WASTE SECTOR GREENHOUSE GAS EMISSIONS IN TYRE CAZA, LEBANON, USING THE SOLID WASTE EMISSIONS ESTIMATION TOOL (SWEET)

ISWA
International Solid Waste Association

CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

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Final Report Completed by SCS Engineers for ISWA under the Climate and Clean Air (CCAC) funded project on reducing Short Lived Climate Pollutants

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1. EXECUTIVE SUMMARY

A Solid Waste Emissions Estimation Tool (SWEET) published by the Climate and Clean Air Coalition (CCAC) was used to investigate waste sector emissions of short-lived climate pollutants (SLCPs) and other greenhouse gases (GHGs) from Tyre Caza in southern Lebanon, under multiple waste management scenarios. Publications on waste management in Lebanon, including an Integrated Waste Management Plan (IWMP) for Tyre Caza and Updated Master Plan for the closure and rehabilitation of uncontrolled dumpsites throughout Lebanon, provided data that were used in this study along with updated information provided by Lebanon's Office of the Minister of State for Administrative Reform (OMSAR).

Tyre Caza generated an estimated 100,000 metric tons (Mg) of waste per year in 2018, of which 9.5 percent was diverted from disposal by the informal recycling sector. Waste collection services are provided throughout the caza, and deliver wastes either to the Ain Baal Solid Waste Treatment Facility (Ain Baal SWTF) for processing, or directly to dumpsites for disposal. No sanitary landfills currently exist in Tyre Caza. A survey of dumpsites in 2016 found 33 operating dumpsites with an inplace volume of 131,510 cubic meters (m^3) and another 21 closed dumpsites with a volume of 317,960 m3. The closed dumpsites included the Ras El-Ain Dumpsite (Ras El-Ain), which is located about 5 km south of Tyre City. Ras El-Ain operated from 1990 through 2015, and received an estimated 54,000 Mg of waste in its last full year of operation. The dumpsite had an estimated volume of 300,000 m3 in 2016, which is less than half of the volume of waste delivered after reductions from extensive waste burning, decay of organic materials, and ground surface settlement.

Estimates of the amount of waste burning, aerobic, and anaerobic waste decay were developed to recreate a waste disposal history and to estimate the mass of waste disposed after burning (about 600,000 Mg) and the amount of methane being generated at the site (less than 200 m3/hour currently and declining rapidly).

The Ain Baal SWTF was upgraded in 2018 and (based on 2019 data) currently processes 40,230 Mg of wastes per year, of which 8.9 percent is recycled, 5.2 percent is used to produce compost, 17.5 percent consists of moisture that is lost to evaporation during the composting process, and the remaining 68.5 percent is rejected and delivered to the Teir Debba Dumpsite for disposal. Adding the informal sector diversion (9.5% of generated wastes) to the Ain Baal figures, the estimated waste diversion rate for Tyre Caza in 2019 was 21.9 percent of generated wastes.

Future increases in waste diversion proposed in the IWMP will require increases in waste processing and diversion rates be achieved at Ain Baal by 2025, including a Phase 1 Plan to divert 31 percent of generated wastes, and a Phase 2 plan to include the production of a refuse-derived fuel (RDF) and diverting 43 percent of generated wastes.

SWEET model runs were prepared using available data on waste composition and current and projected annual rates of waste generation, collection, disposal, and diversion in Tyre Caza. The Baseline Scenario reflects current and future conditions under the continuation of "business-as-usual" waste management practices. Four alternative future waste management scenarios evaluate potential emissions reduction achieved by the following activities:
remediation of all dumpsites in Tyre Caza, closure of all dumpsites in the caza, development of a regional sanitary landfill to receive all wastes disposed in the caza, and increased recycling, composting, and the production of RDF.

SWEET's estimates of waste sector SLCP emissions from Tyre Caza under different scenarios show that the management of methane emissions from disposal sites achieves the greatest amount of emissions reduction, followed by the reduction in black carbon emissions by ending waste burning.

Future waste sector GHG emissions will increase at roughly the waste generation growth rate (projected to be 2 percent) if current diversion and disposal practices continue. Large emissions reductions are achievable by Tyre Caza if dumpsites are closed and remediated and a new sanitary landfill is developed. Once a landfill is receiving all disposed wastes, emissions under alternative scenarios vary based on the year that methane collection begins, the amount of waste diversion and accumulation of methane emissions reduction over time, and the addition of emissions from combustion if RDF is produced and used.

For most years in SWEET's emissions forecasts for Tyre Caza, Alternative Scenario 3, which includes the development of the Integrated Waste Management Plan's Phase 1 diversion program without RDF, produces the lowest SLCPs. Under this scenario, SLCP emissions are reduced from baseline levels by 30,660 Mg carbon-dioxide equivalent (CO2e) to 73,230 Mg emissions in 2025, reduced by 37,130 Mg to 79,560 Mg emissions in 2030, reduced by 72,830 Mg to 57,040 Mg emissions in 2035, and reduced by 84,730 Mg to 59,550 Mg emissions in 2040.

2. PROJECT BACKGROUND

2.1. ISWA DUMPSITE CLOSURE AND CCAC WASTE INITIATIVES

ISWA's Task Force on Closing Dumpsites was established in 2018 to promote ISWA's dumpsite closure initiative, which showcases how eliminating dumpsites is urgently needed to improve local, regional, and global health and the environment. ISWA has developed publications on the benefits of closing dumpsites and managing waste in a sustainable manner, and offers support and help to countries and cities addressing this issue. ISWA has determined that uncontrolled dumpsites hold 40 percent of the world's waste, that the world's 50 largest dumpsites directly affect the lives of 64 million people, and that 38 of these 50 dumpsites directly impact coastal areas and are potential sources of disease outbreaks and the release of wastes to waterways. Catastrophic structural failures at non-engineered dumpsites have killed hundreds of people in Asia, Africa, and South America. Uncontrolled dumps and landfills without landfill gas (LFG) collection are one of the largest sources of global anthropogenic methane, and black carbon emissions from open burning of wastes typically are the second largest source of SLCP emissions at dumpsites after methane.

CCAC's Waste Sector Initiative works with cities and national governments to reduce methane, black carbon, and other air pollutants emitted by the waste sector. CCAC offers a public knowledge platform with resources and tools to assist with these emissions reduction efforts. One of the tools CCAC has published is the Solid Waste Emissions Estimation Tool or SWEET, which CCAC members are using to benchmark waste sector GHG emissions and estimate the amount of emissions reduction achievable under alternative future waste management and diversion scenarios. CCAC is promoting the use of SWEET by working with ISWA to support this technical evaluation of waste sector emissions in Tyre Caza, Lebanon, under alternative management scenarios using SWEET.

The information used prepare this report and inputs for SWEET model runs were obtained from documents that were publicly available on-line or were provided by the Lebanese Republic's Office of the Minister of State for Administrative Reform (OMSAR). OMSAR also provided supplemental information on waste management in Tyre Caza and at the Ain Baal SWTF to update the reports.

2.2. SOLID WASTE EMISSIONS ESTIMATION TOOL ("SWEET")

This report documents the application of SWEET to quantify waste sector SLCP and other GHG emissions, and potential future emissions reductions, in Tyre Caza, Lebanon, in support of ISWA and CCAC. SWEET was developed by Abt Associates and SCS Engineers for the U.S. EPA's Global Methane Initiative and CCAC, which has published the latest version of the tool (v. 3.0) on its website[1] SWEET provides estimates for the full suite of SLCPs and other GHG emissions in the waste sector, including methane, black carbon, carbon-dioxide, nitrogen oxides, sulfur oxides, particulates, and organic carbon. Emissions sources covered include: (1) waste collection and transportation; (2) open burning of waste; (3) landfills and open dumps; (4) organic waste management facilities (composting and anaerobic digesters); (5) waste-to-energy facilities; and (6) waste handling equipment.

SWEET can analyze multiple waste management scenarios while incorporating disposal site data and accounting for collected wastes over a 100-year period. LFG generation and recovery is calculated using default model assumptions derived from U.S. EPA's Colombia Landfill Gas Model,[2] which includes adjustments to account for the effects of site conditions including climate. SWEET provides annual SLCP emissions estimates which can be used to evaluate the effects of waste management planning decisions over the short- and medium-term horizon.

This project involves using SWEET to estimate SLCP emissions from municipal solid wastes (MSW) generated and collected in Tyre Caza, Lebanon, under business-as-usual and alternative future management scenarios. A secondary focus of this project is to use SWEET to assess the effects on SLCP emissions of closing and remediating dumpsites in Tyre Caza, including the effects of remediating the Ras El Ain Dumpsite that was closed in 2015. Open burning of waste was reported to have been extensive at the Ras El Ain Dumpsite during its operation, and continues to occur at dumpsites in Tyre Caza.

SWEET (3.0) has improved the ability to evaluate the effects of dumpsite closure and remediation on emissions over prior versions by allowing the user flexibility in assigning varying rates of open burning over time in alternative scenarios, which yields more realistic estimates of black carbon emissions. The application of SWEET for this project has helped to identify additional modifications needed to fully implement these improvements, and has led to the development of SWEET v. 3.1, which was used in this study. SWEET 3.1 has not yet been published but is expected to be released later in 2020.this project has helped to identify additional modifications needed to fully implement these improvements, and has led to the development of SWEET v. 3.1, which was used in this study. SWEET 3.1 has not yet been published but is expected to be released later in 2020.

[1] http://www.waste.ccacoalition.org/document/solid-waste-emissions-estimation-tool-sweet

[2] U.S. Environmental Protection Agency, Colombia Landfill Gas Model, 2010. https://www.globalmethane.org/documents/models/xls/ColombiaModelv1English.xls

2. PROJECT BACKGROUND

2.3. WASTE MANAGEMENT CHALLENGES IN LEBANON

In 2014, 5.6 million Lebanese and 2.5 million refugees living in Lebanon generated 2.04 million metric tons (Mg) of municipal solid wastes and 0.25 million Mg of industrial, medical, and slaughterhouse wastes. [3] Waste collection services are provided to all residents. Lebanon still relies on unmanaged open dumpsites to dispose of a high percentage of collected waste. About 29 percent of wastes collected in Lebanon in 2014 were disposed in open dumps, 8 percent recycled, 15 percent composted, and the remaining 48 percent disposed in sanitary landfills.

Lebanon experienced an eight-month-long waste management crisis in 2015 and 2016[4] that was precipitated by the closure of the Naameh Landfill serving Beirut and Mount Lebanon.[5] Following the landfill closure, the Ministry of Environment (MoE) could not reach a political consensus on a solution, and waste collection services were suspended, causing waste to pile up in the cities and towns. The crisis ended in March 2016 after Lebanon developed an emergency four-year plan, but the lack of a long-term solution creates the potential for another waste management crisis.[6]

The 2015-2016 waste collection and disposal crisis has led to a number of studies of Lebanon's waste management system that provide data for this report, including a 2017 update to a 2011 "Master Plan for the Closure and Rehabilitation of Uncontrolled Dumps in Lebanon" prepared by the Lebanon MoE and the United Nations Development Program (UNDP).[7]

2.4. WASTE MANAGEMENT IN TYRE CAZA

2.4.1. Waste Generation, Collection and Disposal

Tyre (Sour) Caza is one of three cazas or districts in the South Lebanon Governorate, and includes the historic City of Tyre, which is one of the oldest coastal cities on the MediterraOnean. The population of Tyre Caza varies by season, and was estimated to include 244,505 Lebanese citizens in the winter season and 314,200 Lebanese in the summer season in 2016.7 Another 55,000 Syrian refugees, 66,600 Palestinian refugees, and 10,500 United Nations Interim Force in Lebanon (UNIFIL) personnel also produce waste managed in Tyre Caza, which results in a total of about 394,000 persons in 2016 (annual average population) receiving waste collection services.

In 2018, OMSAR published a series of reports on upgrading the solid waste management capacities in Lebanon, including an Integrated Waste Management Plan (IWMP) for Tyre Caza.8 The IWMP provides the latest published information on waste generation, recycling, and material flows to treatment and disposal facilities within the caza. The IWMP estimated that 100,000 Mg per year of MSW, excluding construction, demolition, and institutional waste, was generated in Tyre Caza in 2018, of which approximately 9.5 percent is diverted from disposal by the informal recycling sector. Regular waste collection services collect all generated waste in Tyre Caza remaining after informal sector diversion and deliver it to the Ain Baal SWTF for processing, or directly to dumpsites for disposal. In 2018, approximately 82 percent of generated

[3] I.I. Abbas, et al., 2017. "Solid Waste Management in Lebanon: Challenges and Recommendations." Journal of Environment and Waste Management. Vol. 4(2), pp. 053-063, October, 2017.

[4] Elias Azzi, 2017. "Waste Management Systems in Lebanon – The benefits of a waste crisis for improvement of practices." Kth Royal Institute of Technology, School of Architecture and the Built Environment, Stockholm, Sweden (Master's Thesis).

[5] Antonis Mavropoulos, 2019. "Lebanon Waste Crisis: how it all started?" Wasteless Future, January 12, 2017.

[6] Michael Young, 2019. "Your Poison, My Profit". Carnegie Middle East Center, August 28, 2019.

[7] Ministry of Environment, June 2017. "Updated Master Plan for the Closure and Rehabilitation of Uncontrolled Dumpsites Throughout the Country of Lebanon – Volume A." Republic of Lebanon and United Nations Development Program.

[8] European Union External Actions, September 2018. "Technical support to upgrading the solid waste management capacities in Lebanon – Integrated Waste Management Plan – Tyr Caza." ENPI/2017/389-095.

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MSW, including processing rejects and unused compost from the Ain Baal SWTF, was disposed in dumpsites operating in Tyre Caza. No sanitary landfills exist in the caza.

OMSAR has provided information on the current fleet of waste collection trucks in Tyre Caza and reports that waste is collected from all 58 municipalities using 25 compactor trucks and 53 non-compacting trucks. Roughly half of the collection fleet (15 compactors and 22 non-compacting trucks) delivers waste to the Ain Baal SWTF, and the
remaining trucks deliver wastes directly to the dumpsites.

The 2017 update of the Master Plan for closing Lebanon's dumpsites provides the results of comprehensive surveys of the in-place volumes of dumpsites in each region of Lebanon in 2011 and 2016. Total in-place waste volumes in operational and non-operational dumpsites in Tyre Caza (from Table B-19 in Appendix B of the Master Plan) are listed in Table 1 below. All 33 dumpsites operating in Tyre Caza in 2016 had surveyed in-place volumes that were less than 50,000 m^3. The operating dumpsites included 21 which were operational in 2011, 5 which existed but were non-operational in 2011, and 7 which were new after 2011. Despite the 7 new sites, there was a decline in operational waste volume largely due to the closure of the Ras El-Ain Dumpsite (Ras El-Ain), which is located about 5 km south of Tyre City. Ras El-Ain had been operating in 2011, was closed in 2015, and had an estimated volume of 300,000 m^3 in 2016.

Waste burning often occurs at many of the dumpsites in the caza. OMSAR reports that 22 of the dumpsites operating in Tyre Caza in 2019 conduct waste burning. Large operating dumpsites, including sites in Abbasiyeh (receives 40-50 Mg/day) and in Teir Debbah (receives 60-70 Mg/day), do not always burn waste and implement some amount of covering waste with soil after sorting out of recyclables. The Teir Debbah Dumpsite is one of the largest in the caza and receives wastes from 12 municipalities.

The IWMP proposes the development of sanitary landfills in the region by 2022, which would allow the dumpsites in Tyre Caza to close and promote ending the practice of waste burning. However, Tyre Union of Municipalities has not enacted a plan to end this practice.

Another significant source of waste sector black carbon and CO_2 emissions besides waste burning is the operation of large diesel-fueled equipment at disposal sites. Equipment used at active dumpsites for handling wastes will vary depending on site size and operations. OMSAR reports that larger dumpsites typically operate an excavator and a bulldozer, while smaller dumpsites may only use a skid loader (Bobcat).wastes collected in Lebanon in 2014 were disposed in open dumps, 8 percent recycled, 15 percent composted, and the remaining 48 percent disposed in sanitary landfills.

Table 1. Volumes of Municipal Waste Dumpsites in Sour Caza

YEAR	OPERATIONAL		NON-OPERATIONAL (CLOSED)				TOTAL	
			NOT REHABILITATED		REHABILITATED (COVERED/REMOVED)			
	#	Volume (m^3)	#	Volume (m^3)	#	Volume (m^3)	#	Volume (m^3)
2011	35	268,886	8	5,380	8	15,148	51	289,415
2016	33	131,510	7	304,697	14	13,266	55	449,443

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2.4.2. Waste Composition

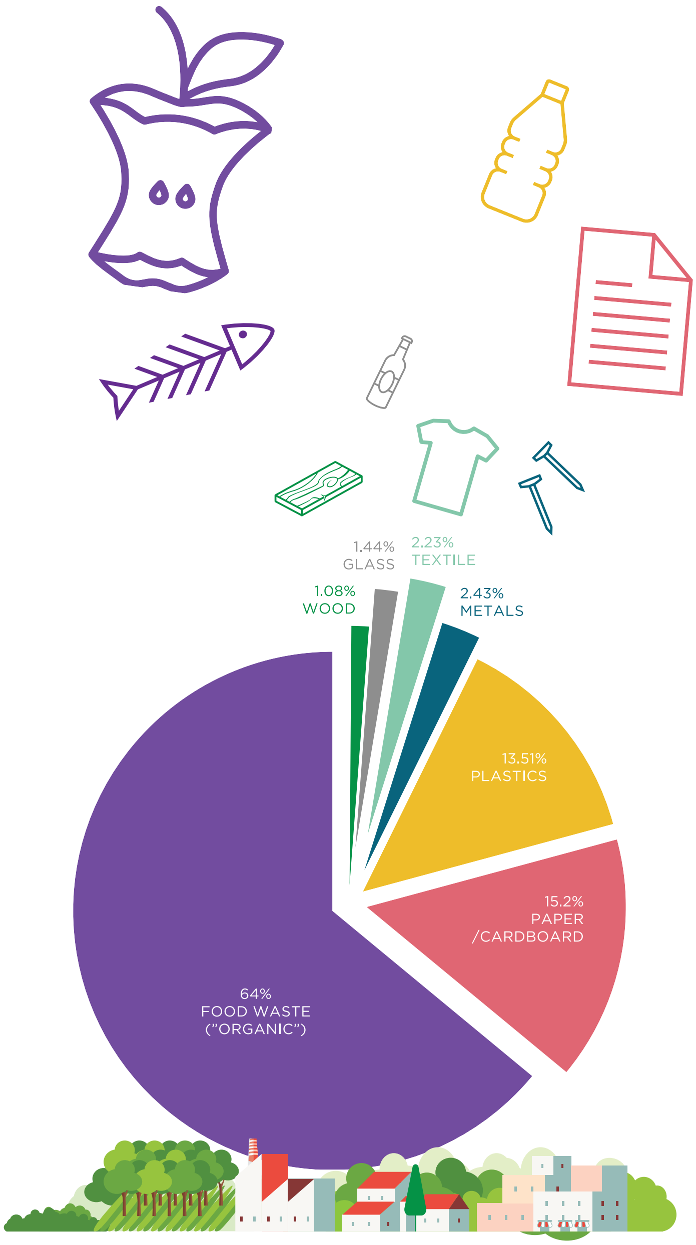
The composition of wastes collected in Tyre Caza was presented in a July 2018 report evaluating the Ain Baal SWTF ("MBT Plant Evaluation") that was part of the series of reports published by OMSAR, providing technical support to upgrading the solid waste management capacities in Lebanon.[9] However, OMSAR has commented that this waste composition data was not based on actual waste sampling and characterization. The latest field study evaluating the composition of collected wastes in the caza was conducted in 2005,[10] and was used to assign the composition of municipal solid waste collected in Tyre Caza for this report. The percentages of each category of MSW are shown in Table 2.

Note that the composition of wastes disposed in dumpsites is different from the collected percentages due to differences in the amounts of materials recycled, composted, and burned at the dumpsites.

Table 2. Waste Composition – MSW Collected in Tyre Caza

WASTE CATEGORY	% OF TOTAL
Food Waste ("Organics")*	64.0%
Wood	1.08%
Paper/Cardboard	15.2%
Textiles	2.23%
Plastics	13.51%
Metals	2.43%
Glass	1.44%
Other	0.11%

**The waste composition data includes a category called "organics" which consists primarily of food waste, but which likely contains small amounts of green waste.*



[9] *European Union External Actions, July 2018. "Technical support to upgrading the solid waste management capacities in Lebanon – Technical and Environmental Evaluation of the MBT Plant of Ain Baal." ENPI/2017/389-095.*

[10] *Unpublished draft report, "EIA for the Closure and Rehabilitation of Ras El Ain Dump, Tyre Caza-Lebanon."*

2. PROJECT BACKGROUND

2.4.3. Ras El-Ain Dumpsite

The 2017 update to the Master Plan included data on Ras El-Ain, and ranked it as the seventh highest priority dumpsite in Lebanon on the target list to be closed and remediated. A summary of data on the dumpsite listed in the two-page “Rehabilitation Report” in Appendix E of the 2017 report is shown in Table 3 below. The Rehabilitation Report includes a listing of technical requirements for closing and rehabilitating Ras El Ain and an estimated cost ($4.75 million U.S. dollars) of constructing two new lined disposal cells, installing a gas collection system, and transferring waste from the dumpsite to newly developed nearby disposal cells. OMSAR reports that the proposed rehabilitation plan was rejected by the Mayor of Tyre, who is advocating instead for the siting of a sanitary landfill at an alternative site that can receive the wastes excavated from Ras El-Ain.

The Ras El Ain Dumpsite reportedly operated from 1990 through 2015. No records of annual amounts or types of wastes disposed at the site are available. OMSAR reports that at least half of the municipalities in Tyre Caza used Ras El Ain when it was operating, and the dump also received wastes from UNIFIL and Palestinian refugee camps. Based on this information, waste disposal at the dumpsite likely reached about 150 Mg per day or 54,000 Mg per year.

Recent photographs of the Ras El-Ain Dumpsite that were provided by OMSAR for this report are shown in Appendix A.

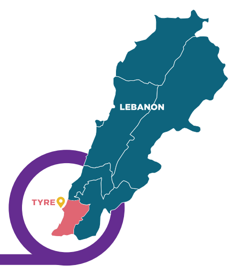
The reported in-place volume of 300,000 m^3 observed in 2016 in the survey of dumpsites7 is significantly smaller than the volume of waste originally placed in the dumpsite due to reductions from waste burning, organic waste decay, and surface settlement over time. The estimated annual disposal tonnage attained in the final years of operation (54,000 Mg), which is 18 percent of the in-place volume, provides evidence of a large volume reduction, considering that the site operated for 25 years. SWEET and other models that calculate waste decay over time to estimate methane generation require the user to input original waste tonnages disposed at the site. The methods for calculating the amount of waste delivered to the landfill, burned on site, and decayed over time to yield an in-place volume of 300,000 m^3 in 2016 are described below and summarized in Table 4 on the following page.

OMSAR reports that waste burning was almost continuous at the Ras El Ain Dumpsite when it was in operation, and that smoke was observed emitting from the site as late as 2017. Waste samples taken in 2016 from near the surface of the dump showed that nearly all remaining waste consisted of inert materials, including mostly soil and ash.[10] The amount of waste burned at the dumpsite was estimated by assuming that 90 percent of plastics, paper, and wood and 50 percent of green waste and textiles were burned prior to burial in the dumpsite. Based on these assumptions and available waste composition data, and considering the estimated density of these materials, approximately 14 percent of the mass of delivered waste was burned at the dumpsite.

Organic waste delivered to the dumpsite that was not burned underwent aerobic decay until it was buried under new waste deposits and experienced anaerobic conditions for a period of about six months. Due to the limited amount of soil cover, wastes near the surface of the dumpsite never attained anaerobic conditions or generated methane. The amount of waste that decayed aerobically can be calculated using assumptions developed by the Intergovernmental Panel on Climate Change (IPCC) for dumpsites greater than 5m deep,[11] that 50 percent of degradable carbon in a disposal site will actually decay (remainder will be stored), of which 20 percent will decay aerobically and 80 percent will decay anaerobically. Given the estimated fraction of organic

Table 3. Ras El-Ain Dumpsite

Name	Depth	Area (m2)	Volume (m3)	Opening Date	Closing Date
Deir Qanoun El-Aain (Ras El Ain)	25	15,000	300,000	Sept- 1990	Sept-2015



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waste (82.5%), this results in approximately 7 percent of waste remaining after burning that undergoes aerobic decay.

Burning and aerobic decay combined resulted in an estimated 21 percent reduction in waste mass (31% volume reduction), leaving 79 percent of delivered wastes available to undergo anaerobic decay. Calculating the amount of waste that had decayed anaerobically by 2016 requires running a landfill gas (LFG) generation model to estimate the volume of LFG generated from 1990 until 2016 and converting that volume to a mass loss. SCS used a modified version of the Colombia LFG Model to perform these calculations, and estimated that approximately 17 percent of the disposed waste (14.6% of delivered waste including burned waste) had decayed by 2016.

SCS estimates that ground surface settlement occurring through 2016 accounted for an additional volume reduction approximately equal to the volume reduction from aerobic and anaerobic waste decay combined. As shown in Table 3, this amounted to about 19 percent of the delivered waste volume (25 percent of the disposed waste volume).

Estimated total combined volume reduction from waste burning, aerobic and anaerobic decay, and settlement by 2016 is 500,000 m^3, or 62.5 percent of the originally placed volume of approximately 800,000 m^3. Considering the high percentage of food waste being disposed, and the fact that most of the low-density material (plastics and paper) is being burned, we assume a relatively high in-place waste density of 1 Mg per m^3 for disposed waste (prior to settlement), resulting in an estimated total of 700,000 Mg of waste delivered to Ras El-Ain Dumpsite between 1990 and 2015. The allocation of the waste tonnages and estimated volumes to yield 300,000 m^3 in place in 2016 is shown below in Table 4.

[12] *U.S. Environmental Protection Agency, Colombia Landfill Gas Model, 2010. https://www.globalmethane.org/documents/models/xls/ColombiaModelv1English.xls*

Table 4. Ras El Ain Dumpsite – Waste Mass and Volume Reductions

	Mass Delivered, Reduced, or Remaining (Mg)	Volume Equivalent in Dumpsite (m^3)
Total amount of waste delivered to site from 1990-2015 (= sum of amounts listed below)	700,000 Mg	800,000 m^3
Amount of waste burned at site (90% of plastics, paper, wood; 50% of textiles = 27% x 50% volume adjustment to convert to m=ass)	98,000 Mg 14.0%	196,000 m^3 24.5%
Amount of waste decayed aerobically	50,000 Mg 7.1%	50,000 m^3 6.3%
Amount of waste decayed anaerobically (as of 2016)	102,000 Mg 14.6%	102,000 m^3 12.8%
Volume loss due to settlement	0 Mg	152,000 m^3 19.0%
Amount of waste remaining in 2016	450,000 Mg 64.3%	300,000 m^3 37.5%

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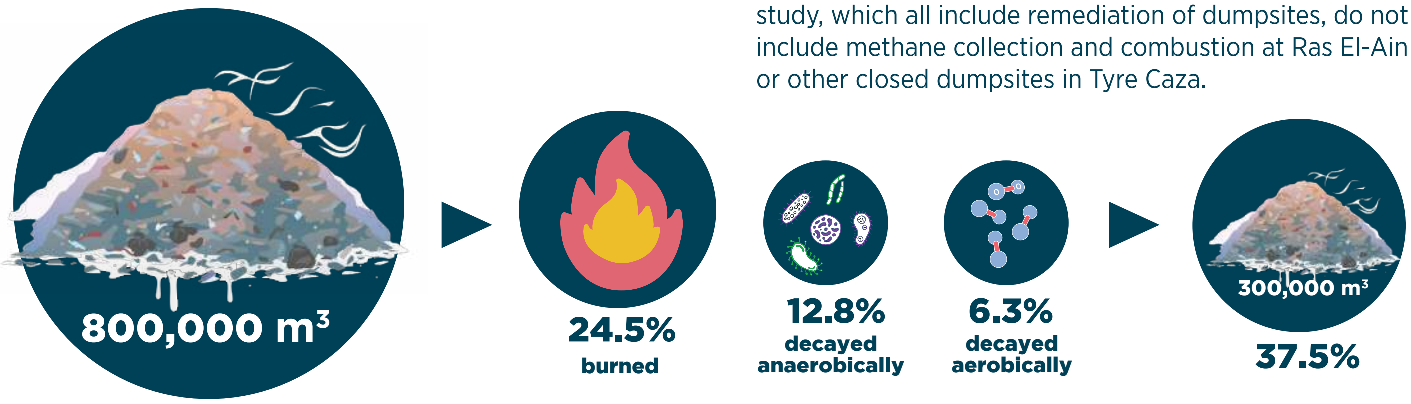
A waste delivery history was developed for Ras El-Ain which assigns annual tonnages increasing from 10,600 Mg in 1991 (first full year of operation) to 54,000 Mg in 2014 (last full year of operation) to achieve 700,000 Mg of waste in place at closure. The 14 percent reduction for waste burning was applied to develop a waste disposal history that results in the cumulative amount of placed in the dumpsite reaching 602,240 Mg when it closed in September 2015. Appendix B provides the annual post-burn waste disposal estimates.

The annual waste delivery and disposal estimates for Ras El-Ain were applied in SWEET model runs discussed in Section 3. The annual waste disposal estimates, with adjusted waste composition percentages to account for waste burning, also were applied to develop LFG generation estimates using the Colombia LFG Model. The model results are provided in Appendix B. The estimates produced by the Colombia LFG Model show that LFG generation increased over time while the dumpsite remained in operation and reached a maximum of 395 m3/hour (26,000 Mg/year CO2e) in 2015, before declining rapidly. LFG generation from the Ras El-Ain Dumpsite is estimated to be 196 m3/hour (12,900 Mg/year CO2e) in 2020, 86 m3/hour in 2025, and 41 m3/hour in 2030.

The estimates of relatively low and rapidly declining LFG generation at the dumpsite imply that installing an LFG collection system to collect and combust the gas could yield very limited amounts of methane emissions reduction. Furthermore, the site conditions (particularly poor waste compaction and the lack of a soil cover or proper surface water drainage) would make effective LFG extraction difficult, even with extensive remediation. Based on these observations, we do not recommend installing an LFG extraction system at the dumpsite. The alternative waste management scenarios evaluated in this study, which all include remediation of dumpsites, do not include methane collection and combustion at Ras El-Ain or other closed dumpsites in Tyre Caza.



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2.4.4. Ain Baal Solid Waste Treatment Facility

The Ain Baal SWTF is a mechanical-biological treatment (MBT) plant located approximately 8 km east of Tyre City in the municipality of Ain Baal. Information on the historical and estimated future facility capacity, material throughputs, and waste diversion rates was taken from the IWMP for Tyre Caza, the MBT Plant Evaluation Report, an Environmental and Social Impact Assessment (ESIA) of Ain Baal SWTF upgrades published in December 2017, and information provided by OMSAR. Recent photographs of the SWTF that were provided by OMSAR are shown in Appendix A.

2.4.4.1. Historical Facility Waste Processing Capacity

In 2009 OMSAR constructed the Ain Baal SWTF with financing by the European Union. The facility was originally designed for the capacity to sort 150 Mg/day of incoming waste and process 90 Mg/day of organic waste at the compost facility. Actual waste delivery rates have been significantly lower than the planned capacity due to a number of issues that were discussed in the SWTF Evaluation Report and the ESIA. The SWTF Evaluation Report and IWMP state the facility operated at an average of 100 Mg/day. The ESIA provides a detailed description of the facility in 2017 and states that it was treating around 70-80 Mg/day. Both reports described a number of design limitations and operational challenges at the facility and the upgrades needed to be able to treat 150 Mg per day of MSW.

The amounts of materials diverted from disposal by the SWTF prior to facility upgrades were calculated using the mass balance for wastes generated in Tyre Caza in 2018 provided as Figure 2-1 in the IWMP. The waste flow diagram shows that the SWTF received 36,000 Mg of waste per year for processing, of which 2,000 Mg was recovered as recycled materials or compost, 6,653 Mg reduced through moisture losses, and the remaining 27,347 Mg of plant rejects was disposed, including processing residues and unused compost. Residual waste from the facility was sent to a private dumpsite.

The materials diversion rate for the Ain Baal facility prior to upgrades was limited to about 6 percent of materials received, which amounted to only 2 percent of wastes generated in Tyre Caza. A primary reason for the low diversion rate was the poor quality of the compost or "compost-like output" (CLO) produced from mixed waste in the MBT process. Moisture and volume losses during the composting process accounted for the largest amount of waste reduction achieved at the facility, equal to 6.5 percent of waste generated in Tyre Caza. Adding informal sector recycling (9.5%) to the 2 percent recovered at the facility resulted in an estimated materials recovery rate of 11.5 percent of generated waste. Total waste diversion from disposal including moisture losses was 18 percent, leaving 82 percent of collected waste in Tyre Caza to be disposed in dumpsites in 2018.

[13] Council for Development and Reconstruction, December 2017, "Environmental and Social Impact Assessment – Upgrade of Ain Baal Solid Waste Treatment Facility".

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2.4.4.2. Current Waste Processing Capacity

The Ain Baal SWTF was upgraded in 2018 in an effort to address the existing design and operational issues. Proposed facility upgrades were described in the ESIA and the MBT Plant Evaluation Report, but were not completed at the time the reports were written. The facility upgrades were to include capacity increases and other improvements to the sorting process, composting process, inorganic waste management process, odor control system, and leachate collection and treatment system.

According the facility operator, the Ain Baal SWTF currently has a treatment capacity of 160-170 Mg of MSW per day, with the potential for reaching 200 Mg/day. However, complaints about odors in the area led the Union of Tyre Municipalities to require that waste deliveries be substantially reduced as a mitigation measure. Furthermore, the upgrades did not include infrastructure improvements to address some of the facility design flaws which OMSAR believes were required to achieve planned waste throughput and materials diversion rates.

OMSAR provided data on material flows in and out of the Ain Baal plant during the first half of 2019, which was used to estimate current annual material flow rates at the facility. An estimated annual total of 40,230 Mg of waste material was delivered to the Ain Baal SWTF in 2019. The fate of the delivered materials is estimated based on the data provided as follows:

- 3,570 Mg, or 8.9 percent of delivered materials (3.5% of total waste generated in Tyre Caza), is recovered as recycled materials.
- 2,080 Mg, or 5.2 percent of delivered materials (2.0% of waste in Tyre Caza) is used to produce compost.
- 7,040 Mg, or 17.5 percent of delivered materials (6.9% of waste in Tyre Caza), is evaporated (mass loss) during the composting process. This estimated evaporation rate is based on a process flow diagram provided in Section 2.3 of the MBT Plant Evaluation Report, which shows 15-20 percent evaporation losses.
- 27,540 Mg, or 68.5 percent of delivered materials (27.0% of waste in Tyre Caza), is rejected as residual waste to be disposed in the Teir Debba Dumpsite.

The material diversion, waste reduction, and residual disposal estimates for the Ain Baal SWTF were applied in SWEET model runs discussed in Section 3. The estimated total facility materials diversion rate including used compost in 2019 was 5,650 Mg, or 14.0 percent of delivered waste (5.6% of waste generated in Tyre Caza). After adding the estimated 7,040 Mg of evaporation losses at the plant, the facility diverted an estimated 12,690 Mg, which was 31.5 percent of delivered wastes, or 12.4 percent of waste generated in Tyre Caza. Adding informal sector recycling (9.5% of generated waste) results in an estimated **2019 diversion rate of 22,380 Mg, or 21.9 percent of generated waste.**

OMSAR representatives plan to visit the SWTF again in early 2020 to get updated data on actual waste throughputs, material diversion rates, and residues for disposal. This latest data will be incorporated into SWEET model runs and discussed in the final version of this report.

There are no current plans for additional SWTF expansions or improvements, and the head of the Union of Tyre Municipalities is advocating for the construction of another waste sorting facility. In the meantime, OMSAR is supporting efforts to improve operations at Ain Baal under capacity-building activities as part of their Technical Assistance project. OMSAR is looking to provide technical training to all operators of the facility on best practices for MBT operations, which will cover improved operational efficiency, odor management, emissions control, and proper maintenance of mechanical equipment. In addition, OMSAR plans to conduct environmental audits to assess the performance of the Ain Baal SWTF and produce an Environmental Management Plan, which the facility operator will be required to follow.

2. PROJECT BACKGROUND

2.4.5. Proposed Integrated Waste Management Plan

The 2018 IWMP proposes implementing changes to the waste management system in two phases. Phase 1 involves local actions and policies to revise the system of waste collection, develop recycling activities, and improve operations at the Ain Baal SWTF. Full implementation of Phase 1 of the IWMP is projected to achieve the following in 2025, when total waste generation in Tyre Caza is projected to be 114,590 Mg:

- Increase the materials recovery rate at the SWTF (including compost used) from 5.5 percent to 15.5 percent of Tyre Caza's waste, or 17,760 Mg in 2025. We assume approximately the same ratio of recyclables to compost produced in 2019, resulting in 11,370 Mg of recyclables and 6,390 Mg of compost in 2025.

- Increase the total materials recovery rate including informal recycling in Tyre Caza from 15 percent to 25percent, or 28,650 Mg in 2025.

- Increase total diversion (including informal recycling and moisture and volume loss during composting) from 22 percent to 40 percent of wastes generated in Tyre Caza.

- Develop a sanitary landfill before 2025, which will receive all remaining wastes generated in Tyre Caza (60% of total generation).

The figures listed above imply the following regarding waste flows in 2025 under Phase 1 of the IWMP:

- All operating dumpsites in Tyre Caza will be closed.

- All collected wastes (103,700 Mg in 2025) will be delivered to Ain Baal for processing.

- Evaporation losses from composting organic waste at Ain Baal amount to 17,190 Mg or 16.6 percent of total wastes delivered to the facility in 2025, which is 15.0 percent of wastes generated in Tyre Caza.

Phase 2 of the IWMP will require national policies in support of utilization of materials produced by the Ain Baal SWTF, including refuse derived fuel (RDF) and "compost-like outputs" (CLO). If Phase 2 is fully implemented, the projected 2025 diversion and disposal rates are calculated as follows:

- The SWTF materials recovery rate including RDF is 27.5 percent of generated wastes for a total of 37.0 percent materials recovery rate including informal recycling. The increase over the Phase 1 SWTF diversion rate in Phase 2 (13,750 Mg) is assumed to represent the amount of RDF produced.

- The SWTF diversion rate is 42.5 percent of generated wastes, for a total diversion rate of 52.0 percent including informal recycling.

- Disposal in sanitary landfills is 48.0 percent of generated wastes.

The IWMP provided recommended strategies to achieve these waste management goals that included the following steps:

- Re-arrange waste collection by clustering of municipalities, including providing five mobile "Small Transfer Stations" (STS).

- Provide for separate collection of street sweepings.

- Provide for separate collection of paper and cardboard from institutions/offices.

- Provide for separate collection of organic waste from main restaurants and hotels using 120 or 240 liter plastic bins. Work with the tourism industry to increase source separation and curbside collection of recyclables and organics generated by hotels. Gradually expand the organic source-separation program into selected neighborhoods.

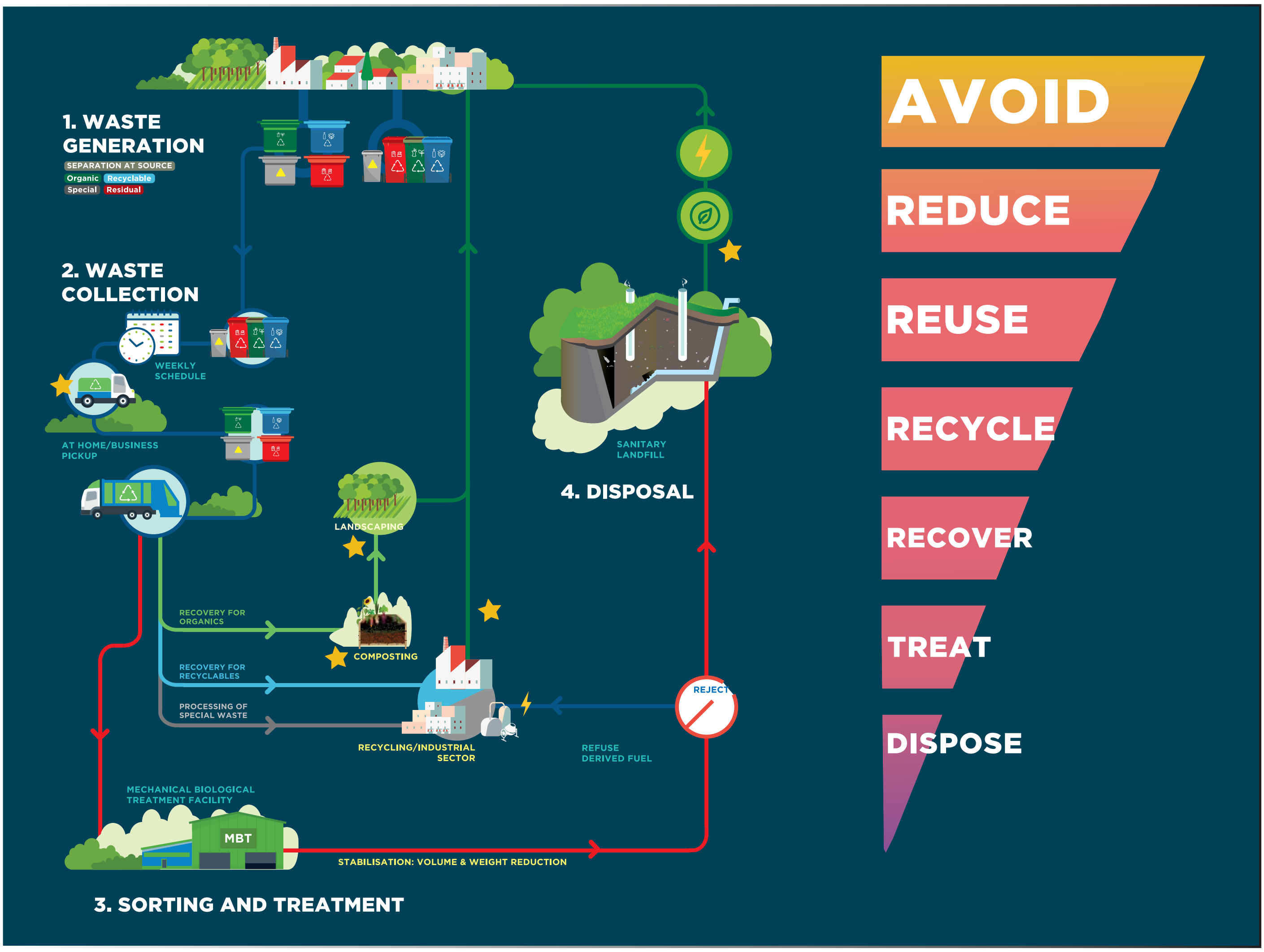
- Advance resource recovery through proposing the following targets:
  - 60 percent of recyclables to be source-separated by 2025 (including informal recyclers)
  - 15 percent of organic fraction to be source-separated by 2025
  - 5 percent of remaining MSW to be diverted through voluntary drop-off centers (Green Points) and STS.

- Advance resource recovery markets through national policies and local measures for the utilization of: (1) compost from source-separated organics; (2) CLO from treatment of mixed MSW; and (3) other products (e.g. fuels) of waste treatment.

- Find a suitable site, plan for, and develop a sanitary landfill.

2. PROJECT BACKGROUND

These proposed IWMP strategies for Tyre Caza have guided the selection of future waste management scenarios evaluated in this study using SWEET to estimate waste sector GHG emissions and achievable emissions reduction. OMSAR reports that the achievement of the targets proposed in the IWMP will depend on the willingness of the Tyre Caza Union of Municipalities to commit the resources to implement the plan's recommendations.



3. DEVELOPMENT OF SWEET MODEL INPUTS AND SCENARIOS

SWEET MODEL RUNS WERE PREPARED USING AVAILABLE DATA ON THE FOLLOWING CATEGORIES OF INFORMATION:

1. Annual amounts waste generation, collection, and disposal rates for Tyre Caza.
2. Informal sector waste diversion rates (percent of generated wastes).
3. Waste composition data (shown in Table 2 above).
4. Information on waste management practices including the extent of waste burning at dumpsites in Tyre Caza in general and Ras El-Ain in particular.
5. Waste tonnage throughputs and types of MSW delivered to Ain Baal SWTF, recycled or composted, and delivered to local dumpsites for disposal (facility rejects).
6. Number and types of waste collection trucks.
7. Number and types of equipment used at dumpsites for handling wastes.

WHILE APPLYING THESE DATA TO ASSIGN INPUTS AND SCENARIOS TO RUN SWEET, THE MODEL USER NEEDS TO CONSIDER LIMITS ON THE FLEXIBILITY OF SWEET TO INCLUDE SITE-SPECIFIC DATA, WHICH INCLUDE THE FOLLOWING:

- Annual waste generation and collection rates are assigned by calendar year for all scenarios based on the estimated collection rate in the current year (2020), and growthrate assumptions, with separate rates assigned for historical (5%) and future (2%) growth.
- During all years in the Baseline Scenario, and during years through the present year in alternative scenarios, SWEET assigns fixed percentages of the total amount of waste generated that is diverted from disposal or delivered to dumpsites and is buried or burned. SWEET allows only one set of assumptions to define baseline conditions through the current year, which are assumed to continue in all future years in the Baseline Scenario.
- In some cases, input values need to be modified from the original data in order to compensate for the model's limitations when selecting parameters used in its calculations. For example, material-specific reject rates for waste delivered to diversion facilities are fixed in SWEET and cannot be adjusted to reflect a facility's actual reject rates. This limitation requires the SWEET model user to adjust tonnage inputs to diversion facilities from actual values so that the resulting amounts of waste diverted in the SWEET calculations match the actual reported diversion rates.

3.1. BASELINE SCENARIO INPUTS

The Baseline Scenario assumptions are based on the amounts of waste generated, collected, diverted, burned, and disposed in Tyre Caza in 2019. The Baseline Scenario model inputs, calculations, and outputs are used for all scenarios to estimate emissions in years up to at least the present year (2020) and until the year an alternative scenario starts.

The IWMP for Tyre Caza reports that MSW generation was approximately 100,000 Mg in 2018 and the population was about 409,900 persons (including Palestinian refugees and UNIFIL personnel), producing an average per capita waste generation rate of about 0.7 kg per day. Approximately 9.5 percent of generated wastes are collected and recycled by the informal sector. The remaining 90.5 percent is collected by formal collection services. Using a 2 percent population growth rate, the projected population and waste generation rates for Tyre Caza are 418,100 persons and 102,000 Mg, respectively, in 2019 and 426,500 persons and 104,040 Mg, respectively, in 2020.

The estimated amounts of waste collected from Tyre Caza in 2019 and delivered to dumpsites for disposal or burning, or to the Ain Baal SWTP for processing, are listed below in Table 5.[14] Amounts of collected waste in 2019 delivered to the Ain Baal SWTP (after the upgrades) for processing, recovered as recycled materials and compost, reduced due to evaporation losses during composting, and delivered to a private dumpsite, are provided in the table.

[14] Because SWEET does not allow two sets of Baseline recycling rates, we used the current rates for estimating historical and future emissions instead of using estimated historical rates prior to facility upgrades.

Table 5. MSW Generation, Collection, Diversion, Disposal, and Waste Burning in Tyre Caza in 2019

	Tonnes (Mg)	% of Generated	% of Collected	% of Facility Inputs
MSW Generation	102,000	100%	-	
Informal Reccling Sector MSW Diversion	2,080	9.5%	-	
MSW Collected	9,690	90.5%	100%	
MSW Delivered to Ain Ball SWTF for Processing	92,310	39.4%	43.6%	100%
Material Recycled	40,230	3.6%	3.9%	8.9%
Compost Produced	2,080	2.0%	2.2%	5.2%
Evaporation Loss From Composting	7,040	6.9%	7.6%	17.5%
Total Waste Diverted	12,690	21.9%	24.2%	31.5%
Ain Baal Rejects to dumpsite	28,990	27.2%	30.0%	68.5%
Total MSW Diverted	22,380	21.9%	24.2%	-
Total MSW Delivered to Dumpsites	79,620	78.1%	86.3%	100%
MSW Burned at Dumpsites	11,150	10.9%	12.1%	14.0%
MSW Disposed in Dumpsites	68,470	67.1%	74.2%	86.0%

Notes to Table 5:
**All informal sector recycling is assumed to occur prior to formal waste collection for simplifying calculations, although some informal recycling also is expected to occur at dumpsites.*

3. DEVELOPMENT OF SWEET MODEL INPUTS AND SCENARIOS

The values listed in Table 5 have been used as the primary inputs in the Baseline Scenario SWEET model runs. Data inputs for waste collection vehicle use and waste handling equipment operation at disposal sites were estimated based on information provided by OMSAR, and are as follows:

- A total of 25 compactor trucks and 53 non-compacting trucks collect waste from Tyre Caza.
- A total of 15 excavators and 15 bulldozers operate at larger dumpsites, and 18 skid loaders are operating at smaller dumpsites in the caza (use Forklifts category).

The Baseline Scenario assumes that a sanitary landfill is developed by 2031 to receive 55 percent of wastes disposed in Tyre Caza, but not a regional landfill large enough to receive all wastes that are not diverted under baseline conditions. Most of the dumpsites will be closed, and the remainder will receive approximately 45 percent of wastes disposed in the caza after 2030.

3.2. ALTERNATIVE WASTE MANAGEMENT SCENARIOS INPUTS

Alternative waste management scenarios were developed to evaluate GHG emissions reductions achieved by the following activities: remediation of all dumpsites in Tyre Caza, closure of all dumpsites in the caza, development of a regional sanitary landfill to receive all wastes disposed in the caza, and increased waste diversion. The changes in waste management from baseline conditions implemented under the alternative scenarios, the start dates for the alternative scenarios, and the resulting diversion and disposal rates are described in the following subsections.

Alternative 1

3.2.1. Remediate Dumpsites

Alternative Scenario 1 involves the remediation of current dumpsites by 2022, including converting closed and active dumpsites from open dumps to controlled dumpsites, covering waste, closing all dumpsites by the end of 2035, and phasing out waste burning to less than 6 percent of generated wastes by 2022, and to 0 percent of generated wastes in 2036. The conversion of open dumpsites to controlled dumpsites results in less aerobic waste decay at dumpsites and slightly higher methane generation rates, which are offset by an increase in methane oxidation from 0 percent to 5 percent. No increases in waste diversion rates from baseline percentages are assumed in this scenario. No increases in the number of waste collection vehicles over the baseline are required in this scenario.

Site remediation activities undertaken in Alternative Scenario 1 are assumed to require 45 pieces of heavy equipment to be operating at disposal sites in Tyre Caza starting in 2021 (an increase of 15 from the Baseline Scenario). An estimate representing the long-term average equipment use was applied, although more equipment operation is likely needed in the first few years. In addition, smaller dumpsites that are still active will be preferentially closed in this scenario, allowing for a reduction in the average number of skid loaders in use from 18 to 10.

As in the Baseline Scenario, a sanitary landfill is developed to begin receiving 55 percent of disposed wastes in Tyre Caza by 2031, with the remaining 45 percent disposed in dumpsites. Unlike in the Baseline Scenario, the following also occurs:

- All dumpsites in Tyre Caza will be closed by the end of 2035 and all disposed waste will go to a sanitary landfill.
- The landfill will begin collecting and combusting 60 percent of the LFG generated at the landfill starting in 2038, after enough waste accumulates to accommodate a wellfield.

3.
DEVELOPMENT OF SWEET MODEL INPUTS AND SCENARIOS

Alternative 2

3.2.2. Remediate Dumpsites and Develop Landfill

Alternative Scenario 2 involves the closure and remediation of current dumpsites by the end of 2022 and the development of a new sanitary landfill that by 2023 starts to receive all disposed wastes in Tyre Caza. Closed and active dumpsites are converted from open dumps to controlled dumpsites, and all active dumpsites will be closed by the end of 2022. Waste burning is reduced to less than 6 percent of generated wastes by 2022, and ends completely by 2023. The conversion of open dumpsites to controlled dumpsites, and the startup of the sanitary landfill in 2023, results in less aerobic waste decay in disposal sites and higher methane generation rates, which are offset by an increase in methane oxidation from 0 percent to 5 percent at the dumpsites and to 22 percent at the new landfill. LFG collection and combustion is projected to occur at the sanitary landfill with 60 percent collection efficiency achieved starting in 2029, after enough waste accumulates to accommodate a wellfield.

No increases in waste diversion rates from baseline percentages are assumed in this scenario. No increases in the number of waste collection vehicles over the baseline are required in this scenario. Site remediation and landfill development activities are estimated to require an additional 15 pieces of heavy equipment to be operating at disposal sites in Tyre Caza on average over the long term (compared to the Baseline Scenario), for a total of 40 starting in 2021. Higher rates of heavy equipment use in the early years are likely offset by lower use after only one landfill is operating. This scenario also assumes that the use of skid loaders will be reduced to 10.

Alternative 3

3.2.3. Remediate Dumpsites, Develop Landfill, and Implement Phase 1 Diversion

Alternative Scenario 3 involves the closure and remediation of current dumpsites by the end of 2022, the development of a new sanitary landfill by 2023, and the implementation of Phase 1 of the diversion program outlined in the IWMP for Tyre Caza. Closed and active dumpsites are converted from open dumps to controlled dumpsites in 2022, all active dumpsites are closed, and all disposed wastes go to the new landfill starting in 2023. Waste burning reduced to less than 6 percent of generated wastes by 2022, and ends completely by 2023. The conversion of open dumpsites to controlled dumpsites, and the startup of the sanitary landfill in 2023 results in less aerobic waste decay in disposal sites and higher methane generation rates, which are offset by an increase in methane oxidation from 0 percent to 5 percent at the dumpsites and to 22 percent at the new landfill. LFG collection and combustion is projected to occur with 60 percent collection efficiency achieved starting in 2031, after enough waste accumulates to accommodate a wellfield.

Increased recycling is assumed to require an increase in the number of heavy-duty waste collection vehicles from 25 in the Baseline Scenario to 40 required in this scenario. Site remediation and landfill development activities are assumed to require the same number of pieces of heavy equipment to be operating at disposal sites in Tyre Caza starting in 2021 as estimated for Alternative Scenario 2.

Projected waste diversion in 2025 under Phase 1 of the IWMP was discussed in Section 2.4.5. Increases in waste diversion are assumed to start in 2023. Table 6 below shows the projected total waste generated in Tyre Caza in 2023, and the percentages and amounts diverted by the informal sector, or collected and delivered to the Ain Baal SWTF for processing, recycling, composting, evaporation, and disposal.

As Table 6 shows, waste diversion, including evaporation during composting at the SWTP and informal recycling, is projected to increase to 40 percent of generated waste in Tyre Caza in 2023.

3.
DEVELOPMENT OF SWEET MODEL INPUTS AND SCENARIOS

Alternative 4

3.2.4. Remediate Dumpsites, Develop Landfill, and Implement Phase 2 Diversion

Alternative Scenario 4 involves the closure and remediation of current dumpsites by the end of 2022, the development of a new sanitary landfill by 2023, and the implementation of Phase 2 of the diversion program outlined in the IWMP for Tyre Caza. As in Alternative 3, closed and active dumpsites are converted from open dumps to controlled dumpsites in 2022, all active dumpsites are closed, and all disposed wastes go to the new landfill starting in 2023. Waste burning is reduced to less than 6 percent of generated wastes by 2022, and ends completely by 2023. The conversion of open dumpsites to controlled dumpsites, and the startup of the sanitary landfill in 2023 results in less aerobic waste decay in disposal sites and higher methane generation rates, which are offset by an increase in methane oxidation from 0 percent to 5 percent at the dumpsites and to 22 percent at the new landfill. LFG collection and combustion is projected to occur with 60 percent collection efficiency achieved starting in 2033, after enough waste accumulates to accommodate a wellfield.

Increased recycling is assumed to require an increase in the number of heavy-duty waste collection vehicles from 25 in the Baseline Scenario to 40 required in this scenario. Site remediation and landfill development activities are assumed to require the same number of pieces of heavy and light equipment to be operating at disposal sites in Tyre Caza starting in 2021 as estimated for Alternative Scenarios 2 and 3.

Projected waste diversion under Phase 2 of the IWMP was discussed in Section 2.4.5. Increases in waste diversion are assumed to start in 2023. Table 7 below shows the projected total waste generated in Tyre Caza in 2023, and the percentages and amounts diverted by the informal sector, or collected and delivered to the Ain Baal SWTF for processing, recycling, composting, evaporation, production of RDF, and disposal. RDF produced is combusted, with emissions from waste combustion added in this scenario.

As Table 7 shows, waste diversion, including evaporation during composting at the SWTP, RDF production, and informal recycling, is projected to increase to 52.0 percent of generated waste in Tyre Caza in 2023.

3.
DEVELOPMENT OF SWEET MODEL INPUTS AND SCENARIOS

Table 6. MSW Generation, Collection, Diversion, and Disposal in Tyre Caza in 2023 Under Alternative Scenario 3 (Phase 1 Diversion Plan)

	Tonnes (Mg)	% of Generated	% of Collected & Delivered to SWTP
MSW Generation	110,135	100%	-
Informal Reccling Sector MSW Diversion	10,465	9.5%	-
MSW Collected	99,670	90.5%	100%
MSW Delivered to Ain Ball SWTF for Processing	99,670	90.5%	100%
Material Recycled	10,925	9.9%	11.0%
Compost Produced	6,145	5.6%	6.2%
Evaporation Loss From Composting	16,520	15.0%	16.6%
Total Waste Diverted at Ain Baal	33,590	30.5%	33.7%
Ain Baal Rejects to Landfill	66,080	60.0%	66.3%
Total MSW Diverted	44,055	40.0%	-

Table 7. MSW Generation, Collection, Diversion, and Disposal in Tyre Caza in 2023 Under Alternative Scenario 4 (Phase 2 Diversion Plan)

	Tonnes (Mg)	% of Generated	% of Collected & Delivered to SWTP
MSW Generation	110,135	100%	-
Informal Reccling Sector MSW Diversion	10,465	9.5%	-
MSW Collected	99,670	90.5%	100%
MSW Delivered to Ain Ball SWTF for Processing	99,670	90.5%	100%
Material Recycled	10,925	9.9%	11.0%
Compost Produced	6,145	5.6%	6.2%
Evaporation Loss From Composting	16,520	15.0%	16.6%
RDF Produced	13,215	12.0%	13.3%
Total Waste Diverted at Ain Baal	46,805	42.5%	47.0%
Ain Baal Rejects to Landfill	52,865	48.0%	53.0%
Total MSW Diverted	57,270	52.0%	-

4.
RESULTS OF SWEET MODEL RUNS

The results of the SWEET model runs are provided in tables and figures in Appendix C. Two of the figures from Appendix C summarizing waste sector emissions are shown below as Figures 1 and 2. Figure 1 shows the total SLCP emissions by scenario, and Figure 2 shows methane emissions by scenario.

Figure 1. Total SLCP Emissions by Scenario

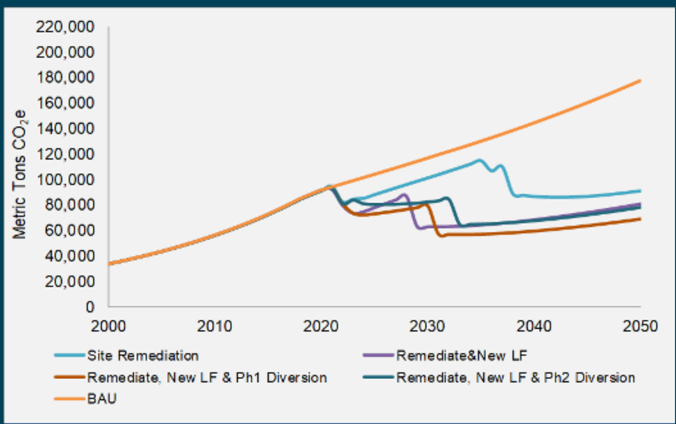
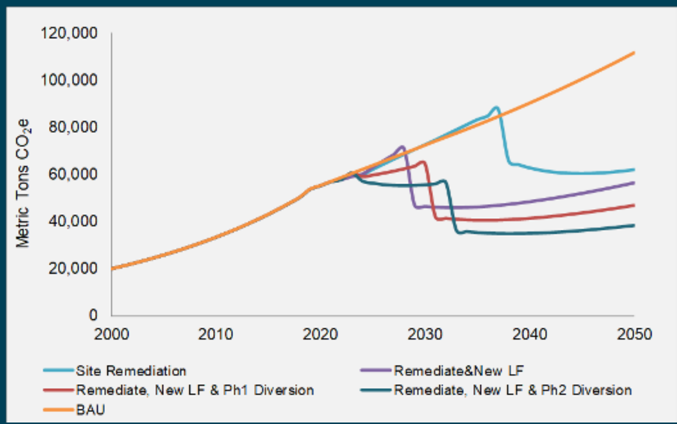


Figure 2. Methane Emissions by Scenario



As Figure 1 shows, the scenario that produces the lowest estimated SLCP emissions in 2024-2028 and after 2030 is Alternative Scenario 3 (Remediate Dumpsites, Develop New Landfill, and Implement Phase 1 Diversion). Alternative Scenario 2 (Remediate Dumpsites and Develop New Landfill) produces slightly lower emissions in 2021-2023 because it has fewer waste collection trucks than Alternative Scenario 3, but this difference is offset over time by higher waste disposal and methane emissions. Alternative Scenario 2 also yields the lowest emissions in 2029 and 2030 because the more rapid accumulation of waste in the new landfill allows for methane collection and combustion two years earlier than in Alternative Scenario 3.

Alternative Scenario 4, with Phase 2 diversion including RDF production and use, has higher emissions than Alternative Scenario 3 in all years after 2022 due to combustion of RDF. Alternative Scenario 4 also has higher emissions than Alternative Scenario 2 in 2021-2025 and 2029-2038.

Alternative Scenario 1 produces the smallest amount of emissions reduction from the Baseline Scenario due to the continued delivery of a significant fraction of collected wastes to dumpsites with some waste burning until 2036, and the delay in the startup of LFG collection and combustion at the new landfill until 2038.

Figure 2 shows that methane production is lowest in Alternative Scenario 4, which has the highest waste diversion rate, except from 2029 through 2032, when other scenarios have earlier LFG collection. Alternative Scenario 2 has the lowest methane emissions in 2029 and 2030, followed by Alternative Scenario 3 which has the lowest methane emissions in 2031 and 2032. Alternative Scenario 1 has slightly higher methane emissions than the Baseline Scenario in 2030 through 2037 due to higher methane generation in the new landfill (less aerobic decay than in dumpsites), which has LFG collection starting in 2038. Alternative Scenario 2 has slightly higher methane emissions than the Baseline Scenario from 2026 through 2028 due to higher methane generation rates in the new landfill, which has LFG collection starting in 2029.

Total waste sector SLCP emissions in Tyre Caza are estimated to be 91,550 Mg CO_2e in 2020, and are projected to increase in the Baseline Scenario to 103,890 Mg CO_2e in 2025, 116,680 Mg in 2030, and 144,280 Mg in 2040. Waste sector emissions under Alternative Scenario 3 are projected to be 73,230 Mg in 2025,79,560 Mg in 2030, and 59,550 Mg in 2040. Projected SLCP emissions under each scenario are shown below in Table 8.

Table 8.
Waste Sector Emissions in Tyre Caza Under All Scenarios (Mg CO2e)

Year	Baseline Scenario	Alt. Scenario 1	Alt. Sc. 2	Alt. Sc. 3	Alt. Sc. 4
2020	91,550	91,550	91,550	91,550	91,550
2025	103,887	88,365	77,755	73,231	80,664
2030	116,684	101,630	62,626	79,556	82,523
2035	129,867	115,302	64,062	57,038	65,017
2040	144,279	86,936	68,166	59,550	67,745
2045	160,120	87,042	73,809	63,755	72,410
2050	177,509	91,436	80,564	69,083	78,361

Table 9.
Waste Sector Emissions Reductions in Tyre Caza Under Alternative Scenarios (% of Baseline Scenario Emissions)

Year	Alt. Sc. 1	Alt. Sc. 2	Alt. Sc. 3	Alt. Sc. 4
2025	15%	25%	30%	22%
2030	13%	46%	31%	29%
2035	11%	51%	56%	50%
2040	40%	53%	59%	53%
2045	46%	54%	60%	55%
2050	48%	55%	61%	56%

Estimated percentages of Baseline Scenario emissions reduced in the alternative scenarios are shown in Table 9. Emissions reductions in Alternative Scenario 3 reach 56% of Baseline Scenario emissions in 2035 and 59 percent in 2040.

Figures and tables from SWEET's outputs provided in the "Summary-Graphics", "Summary-Emissions", and "Summary-Changes vs BAU" worksheets are reproduced in Appendix C.

The following figures showing the most important SLCP emissions types and sources are included in Appendix C:

- Total SLCP emissions by scenario (Figure 1)
- Methane emissions by scenario (Figure 2)
- Black carbon emissions by scenario (Figure 3)
- Baseline all climate-forcing emissions by source (Figure 4)
- Emissions from Ras El-Ain and other closed dumpsites by scenario (Figure 5)
- Emissions of current dumpsites by scenario (Figure 6)
- Emissions of future disposal sites by scenario (Figure 7)

The following summary tables showing annual emissions estimates by scenario and waste sector source are included in Appendix C:

- Total emissions by scenario (Table 1)
- Baseline (BAU) emissions by waste sector source (Table 2)
- Site Remediation (Alternative Scenario 1) emissions by waste sector source (Table 3)
- Remediate & New Landfill (Alternative Scenario 2) emissions by waste sector source (Table 4)
- Remediate, New Landfill, and Phase 1 Diversion (Alternative Scenario 3) emissions by waste sector source (Table 5)
- Remediate, New Landfill, and Phase 2 Diversion (Alternative Scenario 4) emissions by waste sector source (Table 6)
- Total emissions changes from the Baseline (BAU) Scenario by scenario (Table 7).

5. CLOSING REMARKS

5.1. REPORT CONCLUSIONS

SWEET estimates of SLCP emissions from Tyre Caza confirm that methane emissions from disposal sites are the largest waste sector emissions source under all management scenarios. Future waste sector GHG emissions will increase at roughly the waste generation growth rate (projected to be 2 percent) if current diversion and disposal practices continue as projected under the Baseline Scenario. Moderate emissions reductions can be achieved with reduced waste burning and reliance on dumpsites for disposal. Large emissions reductions are achieved primarily by closing and remediating dumpsites, fully ending waste burning, and developing a new sanitary landfill that receives all disposed MSW. Once a landfill is receiving all disposed wastes, emissions under alternative scenarios vary based on the year that methane collection begins, the amount of waste diversion and accumulation of methane emissions reduction over time, and the addition of emissions from combustion of RDF if produced and used. For most years in SWEET's emissions forecasts for Tyre Caza, Alternative Scenario 3, which includes the development of the Integrated Waste Management Plan's Phase 1 diversion program without RDF, produces the lowest SLCPs.

Because mass burn combustion emissions factors were used by SWEET (which has no RDF module), it may overestimate SLCP emissions from RDF combustion, and net emissions from the diversion, production, and combustion of RDF could be closer to zero, making Alternative Scenario 4 emissions similar to Alternative Scenario 3. The additional effort to produce RDF would need to be offset by indirect emissions reduction from the use of RDF as an alternative to fossil fuels. Additional calculations outside of SWEET's capabilities are required to estimate indirect emissions reduction.

Feasibility studies should be conducted before choosing to execute any solid waste management plan. A diversion program featuring RDF production will require the most work to evaluate its technical and financial feasibility because it is the most complex and potentially risky of the alternatives. Besides finding potential outlets that are suitable markets for the RDF product, project proponents will need to first evaluate whether the wastes that can be recovered at the Ain Baal SWTF will be suitable for producing RDF.

5.2. ACCOUNTING FOR EMISSIONS IN SOLID WASTE PLANNING

Different management options for reducing emissions of SLCPs over the short- and medium-term. Comparing emissions reductions achieved by implementing a range of programs over a meaningful time horizon provides greater clarity of vision to see which strategies produce the most climate benefits and are worth a high level of effort and commitment of resources to achieve.

SWEET was designed to be used by solid waste planning professionals world-wide. It allows some degree of flexibility in selecting key inputs, which gives it greater control and ability to reflect local conditions, but adds a level of complexity which may be difficult for some users to navigate. While offering users control of some model assumptions, SWEET includes many calculations and assumptions that are necessarily fixed and can produce unintended results given the model's limitations. In addition, the assignment of input data that appropriate reflects actual and expected conditions can be challenging, especially when there is a large amount of information to be considered. The reports on solid waste management in Lebanon and Tyre Caza following the waste management crisis provided multiple sources of data that required evaluation and processing before being used in SWEET. ISWA and CCAC will be sponsoring a training workshop on the use of SWEET in 2020.

5.3. SWEET UNCERTAINTIES AND REPORT LIMITATIONS

SWEET was intended to provide waste management planners with a method to rank program options based on estimated SLCP emissions. SWEET users should understand that all waste sector emissions estimation tools, no matter how complex or capable of incorporating site-specific data, yield results that have a high level of uncertainty. Waste sector emissions estimates are very uncertain because the largest emissions source, landfill methane, is not directly measured, leaving modelers without a scientific consensus about how to assign rates of waste decay and methane production for different waste types and moisture conditions, or estimate LFG collection efficiency.

The authors of this report have prepared the estimates of SLCP emissions based on our scientific and engineering judgement as of the date of this report, and in accordance with the care and skill generally exercised by reputable solid waste professionals. No warranty, expressed or implied, is made as to the professional opinions presented. Changes from current or expected conditions affect rates of waste generation, collection, diversion, and disposal, methane generation and emissions, and other SLCP emissions. SCS Engineers and ISWA do not guarantee the achievement of GHG emissions or emissions reductions estimated in this report.

APPENDIX A

RAS EL-AIN DUMPSITE

Photographs of Ras El-Ain Dumpsite and Ain Baal Solid Waste Treatment Facility (Photographs courtesy of OMSAR)

AIN BAAL SOLID WASTE TREATMENT FACILITY

APPENDIX B

Estimated Waste Disposal and LFG Generation at the Ras El-Ain Dumpsite Using the Colombia LFG Model

Year	Disposal (Mg/yr)	Refuse In-Place (Mg)	LFG Generation		Methane Emissions
			(m^3/hr)	(cfm)	(tonnes CO_2eq/yr)
1990	2,600	2,600	0	0	0
1991	8,910	11,510	5	3	309
1992	9,850	21,360	20	12	1,317
1993	10,590	31,950	35	20	2,273
1994	11,380	43,330	48	28	3,163
1995	12,230	55,560	61	36	4,003
1996	13,160	68,720	73	43	4,810
1997	14,140	82,860	85	50	5,597
1998	15,200	98,060	97	57	6,376
1999	16,350	114,410	109	64	7,155
2000	17,580	131,990	121	71	7,948
2001	18,890	150,880	133	78	8,760
2002	20,310	171,190	146	86	9,599
2003	21,840	193,030	159	94	10,473
2004	23,470	216,500	173	102	11,390
2005	25,230	241,730	188	110	12,355
2006	27,130	268,860	203	120	13,377
2007	29,160	298,020	220	129	14,462
2008	31,340	329,360	237	140	15,616
2009	33,690	363,050	256	151	16,846
2010	36,220	399,270	276	162	18,160
2011	38,940	438,210	297	175	19,567
2012	41,860	480,070	320	188	21,074
2013	44,740	524,810	345	203	22,688
2014	46,460	571,270	370	218	24,389
2015	30,970	602,240	395	233	26,024
2016	0	602,240	388	228	25,563
2017	0	602,240	327	192	21,506
2018	0	602,240	275	162	18,111
2019	0	602,240	232	136	15,271
2020	0	602,240	196	115	12,894
2021	0	602,240	166	97	10,903
2022	0	602,240	140	83	9,236
2023	0	602,240	119	70	7,839
2024	0	602,240	101	60	6,668
2025	0	602,240	86	51	5,685
2026	0	602,240	74	43	4,860
2027	0	602,240	63	37	4,168
2028	0	602,240	54	32	3,585
2029	0	602,240	47	28	3,095
2030	0	602,240	41	24	2,683
2031	0	602,240	35	21	2,334
2032	0	602,240	31	18	2,040
2033	0	602,240	27	16	1,792
2034	0	602,240	24	14	1,581
2035	0	602,240	21	13	1,402
2036	0	602,240	19	11	1,249
2037	0	602,240	17	10	1,120
2038	0	602,240	15	9	1,008
2039	0	602,240	14	8	913
2040	0	602,240	13	7	831

APPENDIX C

SWEET Model Run Outputs (Summary Figures)

Figure 1. Total SLCP Emissions by Scenario

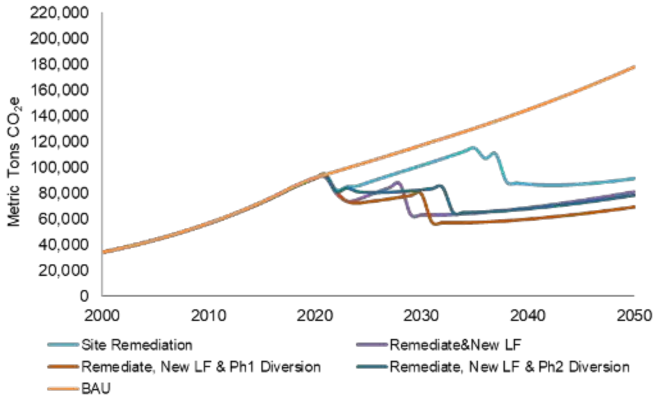


Figure 2. Methane Emissions by Scenario

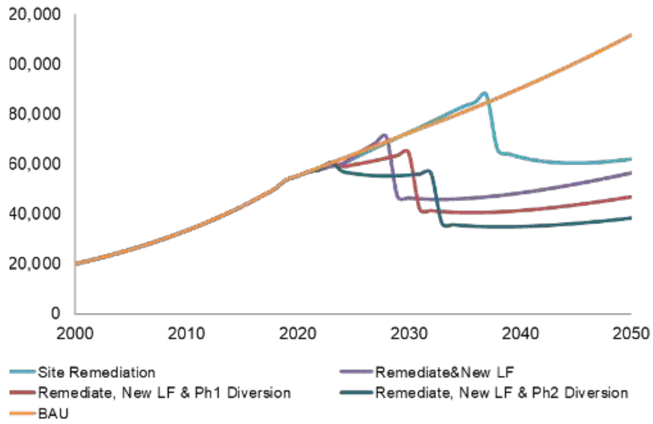


Figure 3. Black Carbon Emissions by Scenario

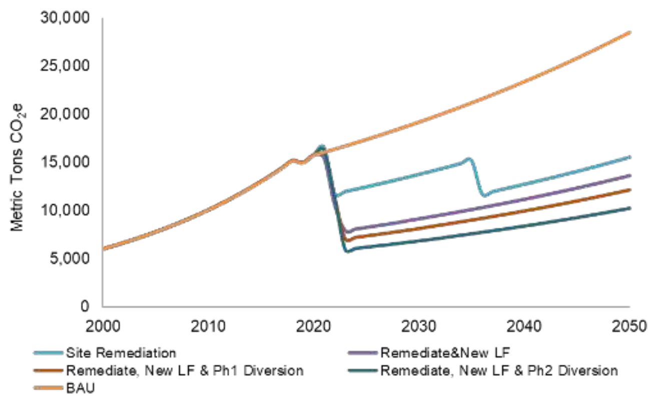


Figure 4. Baseline Emissions by Source

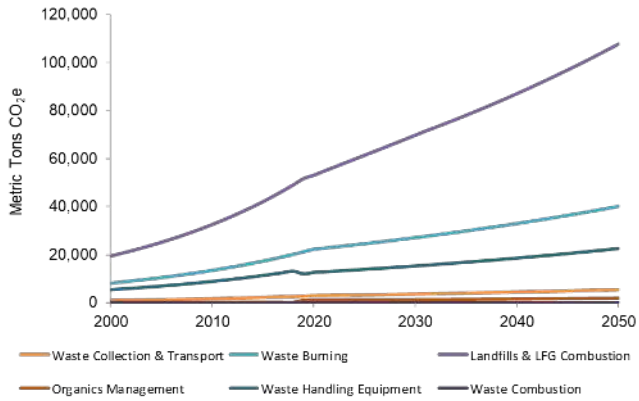


Figure 5. Ras El-Ain/Other Closed Dumpsites Emissions by Scenario

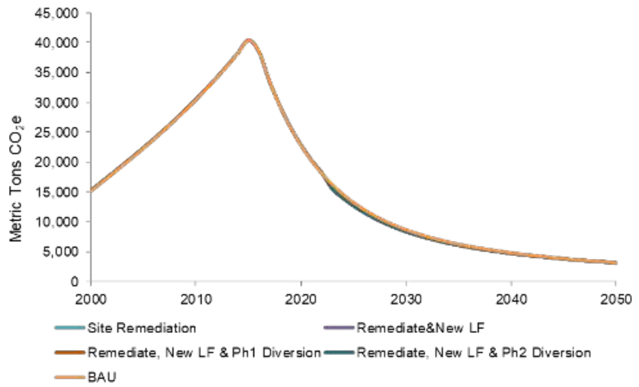
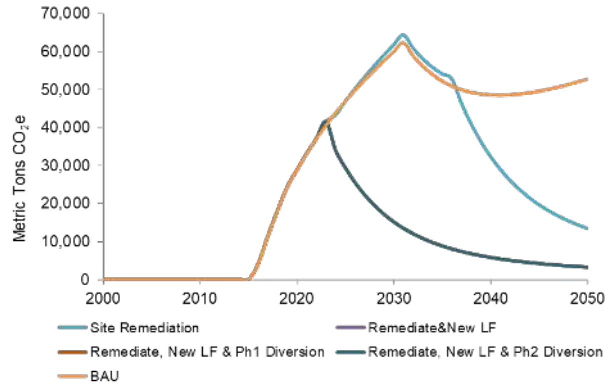


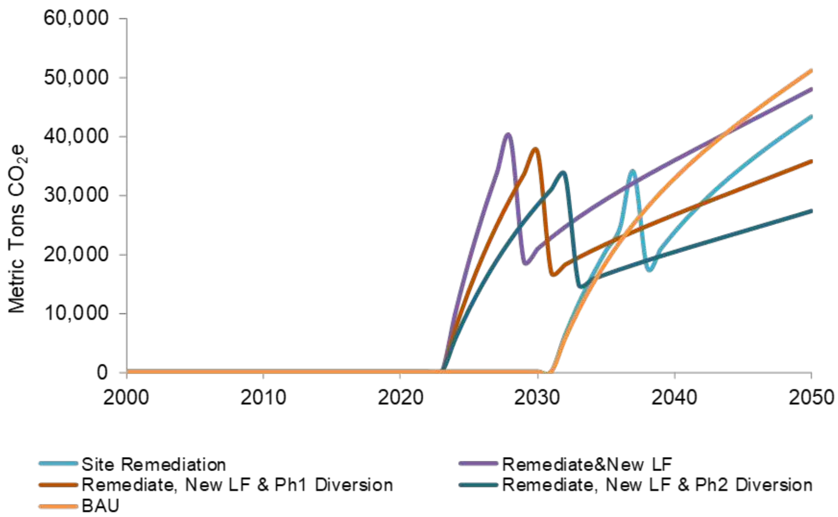
Figure 6. Current Dumpsites Emissions by Scenario



APPENDIX C

SWEET Model Run Outputs (Summary Figures)

Figure 7. Future Disposal Sites Emissions by Scenario



Summary Tables

Table 1: Total Emissions (Metric Tons CO_2e)					
Year	BAU	Site Remediation	Remediate&New LF	Remediate, New LF & Ph1 Diversion	Remediate, New LF & Ph2 Diversion
2020	91,550	91,550	91,550	91,550	91,550
2021	94,009	94,907	91,902	93,602	93,602
2022	96,466	82,517	79,452	81,186	81,186
2023	98,928	84,797	73,247	73,618	84,007
2024	101,400	85,584	74,553	72,309	81,105
2025	103,887	88,365	77,755	73,231	80,664
2026	106,393	91,084	80,812	74,288	80,551
2027	108,923	93,758	83,753	75,463	80,718
2028	111,479	96,399	86,603	76,740	81,124
2029	114,066	99,020	62,858	78,107	81,735
2030	116,684	101,630	62,626	79,556	82,523
2031	119,338	104,238	62,602	57,167	83,464
2032	121,885	107,008	62,756	56,881	84,540
2033	124,490	109,771	63,064	56,781	64,782
2034	127,151	112,533	63,505	56,841	64,821
2035	129,867	115,302	64,062	57,038	65,017
2036	132,638	107,189	64,721	57,355	65,351
2037	135,465	110,569	65,470	57,776	65,803
2038	138,347	88,995	66,299	58,289	66,361
2039	141,285	87,765	67,200	58,883	67,011
2040	144,279	86,936	68,166	59,550	67,745
2041	147,330	86,449	69,191	60,282	68,553
2042	150,439	86,254	70,272	61,073	69,428
2043	153,606	86,310	71,404	61,918	70,366
2044	156,833	86,582	72,584	62,813	71,361
2045	160,120	87,042	73,809	63,755	72,410
2046	163,469	87,665	75,078	64,740	73,509
2047	166,882	88,431	76,389	65,768	74,655
2048	170,358	89,324	77,741	66,835	75,847
2049	173,900	90,329	79,133	67,940	77,083
2050	177,509	91,436	80,564	69,083	78,361

APPENDIX C

SWEET Model Run Outputs (Summary Figures)

Table 2: BAU Pollutants by Sector (Metric Tons CO_2e)							
Year	**Waste Collection & Transport**	**Waste Burning**	**Landfills & LFG Combustion**	**Organics Management**	**Waste Handling Equipment**	**Waste Combustion**	**Total**
2020	3,000	22,227	52,932	912	12,479	0	91,550
2021	3,060	22,671	54,619	930	12,729	0	94,009
2022	3,121	23,124	56,289	949	12,983	0	96,466
2023	3,183	23,587	57,947	968	13,243	0	98,928
2024	3,247	24,059	59,599	987	13,508	0	101,400
2025	3,312	24,540	61,250	1,007	13,778	0	103,887
2026	3,378	25,031	62,904	1,027	14,054	0	106,393
2027	3,446	25,531	64,564	1,048	14,335	0	108,923
2028	3,515	26,042	66,233	1,069	14,621	0	111,479
2029	3,585	26,563	67,914	1,090	14,914	0	114,066
2030	3,657	27,094	69,610	1,112	15,212	0	116,684
2031	3,730	27,636	71,322	1,134	15,516	0	119,338
2032	3,804	28,189	72,909	1,157	15,827	0	121,885
2033	3,881	28,752	74,534	1,180	16,143	0	124,490
2034	3,958	29,327	76,196	1,203	16,466	0	127,151
2035	4,037	29,914	77,893	1,227	16,795	0	129,867
2036	4,118	30,512	79,625	1,252	17,131	0	132,638
2037	4,200	31,123	81,391	1,277	17,474	0	135,465
2038	4,284	31,745	83,192	1,303	17,823	0	138,347
2039	4,370	32,380	85,027	1,329	18,180	0	141,285
2040	4,458	33,027	86,895	1,355	18,543	0	144,279
2041	4,547	33,688	88,799	1,382	18,914	0	147,330
2042	4,638	34,362	90,737	1,410	19,292	0	150,439
2043	4,730	35,049	92,710	1,438	19,678	0	153,606
2044	4,825	35,750	94,719	1,467	20,072	0	156,833
2045	4,922	36,465	96,764	1,496	20,473	0	160,120
2046	5,020	37,194	98,846	1,526	20,883	0	163,469
2047	5,120	37,938	100,966	1,557	21,300	0	166,882
2048	5,223	38,697	103,124	1,588	21,726	0	170,358
2049	5,327	39,471	105,322	1,620	22,161	0	173,900
2050	5,434	40,260	107,559	1,652	22,604	0	177,509

Table 3: Site Remediation Pollutants by Sector (Metric Tons CO2e)							
Year	**Waste Collection & Transport**	**Waste Burning**	**Landfills & LFG Combustion**	**Organics Management**	**Waste Handling Equipment**	**Waste Combustion**	**Total**
2020	3,000	22,227	52,932	912	12,479	0	91,550
2021	3,060	22,671	54,619	930	13,627	0	94,907
2022	3,121	8,259	56,289	949	13,900	0	82,517
2023	3,183	8,424	58,045	968	14,178	0	84,797
2024	3,247	8,592	58,296	987	14,461	0	85,584
2025	3,312	8,764	60,532	1,007	14,750	0	88,365
2026	3,378	8,940	62,694	1,027	15,045	0	91,084
2027	3,446	9,118	64,800	1,048	15,346	0	93,758
2028	3,515	9,301	66,862	1,069	15,653	0	96,399
2029	3,585	9,487	68,892	1,090	15,966	0	99,020
2030	3,657	9,676	70,900	1,112	16,286	0	101,630
2031	3,730	9,870	72,893	1,134	16,611	0	104,238
2032	3,804	10,067	75,036	1,157	16,944	0	107,008
2033	3,881	10,269	77,159	1,180	17,282	0	109,771
2034	3,958	10,474	79,269	1,203	17,628	0	112,533
2035	4,037	10,684	81,373	1,227	17,981	0	115,302
2036	4,118	0	83,478	1,252	18,340	0	107,189
2037	4,200	0	86,384	1,277	18,707	0	110,569
2038	4,284	0	64,326	1,303	19,081	0	88,995
2039	4,370	0	62,603	1,329	19,463	0	87,765
2040	4,458	0	61,271	1,355	19,852	0	86,936
2041	4,547	0	60,271	1,382	20,249	0	86,449
2042	4,638	0	59,552	1,410	20,654	0	86,254
2043	4,730	0	59,074	1,438	21,067	0	86,310
2044	4,825	0	58,802	1,467	21,489	0	86,582
2045	4,922	0	58,706	1,496	21,918	0	87,042
2046	5,020	0	58,762	1,526	22,357	0	87,665
2047	5,120	0	58,950	1,557	22,804	0	88,431
2048	5,223	0	59,253	1,588	23,260	0	89,324
2049	5,327	0	59,657	1,620	23,725	0	90,329
2050	5,434	0	60,150	1,652	24,200	0	91,436

APPENDIX C

SWEET Model Run Outputs (Summary Figures)

Table 4: Remediate&New LF Pollutants by Sector (Metric Tons CO2e)

Year	Waste Collection & Transport	Waste Burning	Landfills & LFG Combustion	Organics Management	Waste Handling Equipment	Waste Combustion	Total
2020	3,000	22,227	52,932	912	12,479	0	91,550
2021	3,060	22,671	54,619	930	10,622	0	91,902
2022	3,121	8,259	56,289	949	10,834	0	79,452
2023	3,183	0	58,045	968	11,051	0	73,247
2024	3,247	0	59,046	987	11,272	0	74,553
2025	3,312	0	61,938	1,007	11,498	0	77,755
2026	3,378	0	64,679	1,027	11,728	0	80,812
2027	3,446	0	67,298	1,048	11,962	0	83,753
2028	3,515	0	69,819	1,069	12,201	0	86,603
2029	3,585	0	45,737	1,090	12,445	0	62,858
2030	3,657	0	45,163	1,112	12,694	0	62,626
2031	3,730	0	44,790	1,134	12,948	0	62,602
2032	3,804	0	44,588	1,157	13,207	0	62,756
2033	3,881	0	44,532	1,180	13,471	0	63,064
2034	3,958	0	44,603	1,203	13,741	0	63,505
2035	4,037	0	44,782	1,227	14,015	0	64,062
2036	4,118	0	45,055	1,252	14,296	0	64,721
2037	4,200	0	45,411	1,277	14,582	0	65,470
2038	4,284	0	45,838	1,303	14,873	0	66,299
2039	4,370	0	46,330	1,329	15,171	0	67,200
2040	4,458	0	46,879	1,355	15,474	0	68,166
2041	4,547	0	47,478	1,382	15,784	0	69,191
2042	4,638	0	48,125	1,410	16,099	0	70,272
2043	4,730	0	48,814	1,438	16,421	0	71,404
2044	4,825	0	49,542	1,467	16,750	0	72,584
2045	4,922	0	50,306	1,496	17,085	0	73,809
2046	5,020	0	51,105	1,526	17,427	0	75,078
2047	5,120	0	51,937	1,557	17,775	0	76,389
2048	5,223	0	52,800	1,588	18,131	0	77,741
2049	5,327	0	53,693	1,620	18,493	0	79,133
2050	5,434	0	54,615	1,652	18,863	0	80,564

Table 5: Remediate, New LF & Ph1 Diversion Pollutants by Sector (Metric Tons CO2e)

Year	Waste Collection & Transport	Waste Burning	Landfills & LFG Combustion	Organics Management	Waste Handling Equipment	Waste Combustion	Total
2020	3,000	22,227	52,932	912	12,479	0	91,550
2021	4,760	22,671	54,619	930	10,622	0	93,602
2022	4,855	8,259	56,289	949	10,834	0	81,186
2023	4,952	0	58,045	2,406	8,215	0	73,618
2024	5,051	0	56,425	2,454	8,379	0	72,309
2025	5,152	0	57,029	2,503	8,547	0	73,231
2026	5,255	0	57,762	2,553	8,718	0	74,288
2027	5,360	0	58,606	2,604	8,892	0	75,463
2028	5,468	0	59,546	2,656	9,070	0	76,740
2029	5,577	0	60,570	2,709	9,251	0	78,107
2030	5,688	0	61,668	2,763	9,436	0	79,556
2031	5,802	0	38,920	2,819	9,625	0	57,167
2032	5,918	0	38,270	2,875	9,818	0	56,881
2033	6,037	0	37,798	2,932	10,014	0	56,781
2034	6,157	0	37,478	2,991	10,214	0	56,841
2035	6,281	0	37,288	3,051	10,419	0	57,038
2036	6,406	0	37,210	3,112	10,627	0	57,355
2037	6,534	0	37,228	3,174	10,840	0	57,776
2038	6,665	0	37,330	3,238	11,056	0	58,289
2039	6,798	0	37,505	3,302	11,277	0	58,883
2040	6,934	0	37,744	3,368	11,503	0	59,550
2041	7,073	0	38,040	3,436	11,733	0	60,282
2042	7,214	0	38,386	3,505	11,968	0	61,073
2043	7,359	0	38,777	3,575	12,207	0	61,918
2044	7,506	0	39,209	3,646	12,451	0	62,813
2045	7,656	0	39,679	3,719	12,700	0	63,755
2046	7,809	0	40,183	3,793	12,954	0	64,740
2047	7,965	0	40,719	3,869	13,213	0	65,768
2048	8,125	0	41,286	3,947	13,478	0	66,835
2049	8,287	0	41,880	4,026	13,747	0	67,940
2050	8,453	0	42,501	4,106	14,022	0	69,083

APPENDIX C

SWEET Model Run Outputs (Summary Figures)

Table 6: Remediate, New LF & Ph2 Diversion Pollutants by Sector (Metric Tons CO2e)							
Year	Waste Collection & Transport	Waste Burning	Landfills & LFG Combustion	Organics Management	Waste Handling Equipment	Waste Combustion	Total
2020	3,000	22,227	52,932	912	12,479	0	91,550
2021	4,760	22,671	54,619	930	10,622	0	93,602
2022	4,855	8,259	56,289	949	10,834	0	81,186
2023	4,952	0	58,045	2,406	6,332	12,273	84,007
2024	5,051	0	54,623	2,454	6,458	12,518	81,105
2025	5,152	0	53,652	2,503	6,587	12,769	80,664
2026	5,255	0	52,999	2,553	6,719	13,024	80,551
2027	5,360	0	52,615	2,604	6,854	13,285	80,718
2028	5,468	0	52,459	2,656	6,991	13,550	81,124
2029	5,577	0	52,497	2,709	7,131	13,821	81,735
2030	5,688	0	52,700	2,763	7,273	14,098	82,523
2031	5,802	0	53,045	2,819	7,419	14,380	83,464
2032	5,918	0	53,512	2,875	7,567	14,667	84,540
2033	6,037	0	33,134	2,932	7,718	14,961	64,782
2034	6,157	0	32,540	2,991	7,873	15,260	64,821
2035	6,281	0	32,090	3,051	8,030	15,565	65,017
2036	6,406	0	31,765	3,112	8,191	15,876	65,351
2037	6,534	0	31,546	3,174	8,355	16,194	65,803
2038	6,665	0	31,418	3,238	8,522	16,518	66,361
2039	6,798	0	31,370	3,302	8,692	16,848	67,011
2040	6,934	0	31,391	3,368	8,866	17,185	67,745
2041	7,073	0	31,472	3,436	9,043	17,529	68,553
2042	7,214	0	31,606	3,505	9,224	17,879	69,428
2043	7,359	0	31,787	3,575	9,409	18,237	70,366
2044	7,506	0	32,011	3,646	9,597	18,602	71,361
2045	7,656	0	32,272	3,719	9,789	18,974	72,410
2046	7,809	0	32,568	3,793	9,984	19,353	73,509
2047	7,965	0	32,896	3,869	10,184	19,740	74,655
2048	8,125	0	33,252	3,947	10,388	20,135	75,847
2049	8,287	0	33,636	4,026	10,596	20,538	77,083
2050	8,453	0	34,046	4,106	10,807	20,949	78,361

Table 7: Total Emissions Changes from BAU (Metric Tons CO_2e)				
Year	Site Remediation	Remediate & New LF	Remediate, New LF & Ph1 Diversion	Remediate, New LF & Ph2 Diversion
2020	0	0	0	0
2021	898	-2,107	-407	-407
2022	-13,949	-17,015	-15,281	-15,281
2023	-14,130	-25,681	-25,310	-14,921
2024	-15,815	-26,847	-29,090	-20,295
2025	-15,522	-26,132	-30,655	-23,223
2026	-15,309	-25,581	-32,105	-25,842
2027	-15,165	-25,170	-33,460	-28,205
2028	-15,080	-24,876	-34,740	-30,356
2029	-15,046	-51,208	-35,958	-32,331
2030	-15,054	-54,058	-37,128	-34,161
2031	-15,100	-56,736	-62,171	-35,874
2032	-14,877	-59,129	-65,004	-37,346
2033	-14,719	-61,426	-67,709	-59,708
2034	-14,618	-63,646	-70,310	-62,330
2035	-14,565	-65,805	-72,829	-64,850
2036	-25,450	-67,917	-75,283	-67,288
2037	-24,896	-69,995	-77,689	-69,662
2038	-49,352	-72,048	-80,058	-71,986
2039	-53,520	-74,085	-82,402	-74,274
2040	-57,343	-76,113	-84,729	-76,534
2041	-60,881	-78,139	-87,048	-78,777
2042	-64,184	-80,167	-89,366	-81,010
2043	-67,296	-82,202	-91,688	-83,240
2044	-70,250	-84,249	-94,020	-85,471
2045	-73,078	-86,311	-96,366	-87,710
2046	-75,805	-88,391	-98,729	-89,961
2047	-78,451	-90,493	-101,114	-92,227
2048	-81,035	-92,617	-103,524	-94,511
2049	-83,571	-94,767	-105,960	-96,817
2050	-86,073	-96,945	-108,426	-99,148

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