Pakistan low carbon analysis:
Waste sector

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Contents

ABBREVIATIONS

BOD	Biochemical Oxygen Demand
CFM	Cubic Feet per Minute
COD	Chemical Oxygen Demand
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
IRRC	Integrated Resource Recovery Centres
MCF	Methane Correction Factor
MSW	Municipal Solid Waste
NAMA	Nationally Appropriate Mitigation Action
NMVOCs	Non-Methane Volatile Organic Compounds
NOx	Nitrogen Oxides
PAK-EPA	Pakistan Environmental Protection Agency
PPP	Public-Private Partnership s
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SWDS	Solid Waste Disposal Sites
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
MW	Megawatt
N_2O	Nitrous Oxide
USD	United States Dollar

1 INTRODUCTION

This chapter is part of a larger analysis of low-carbon development options in Pakistan, which covers a variety of mitigation sectors. The holistic, sectoral analysis aims to inform Pakistan's policy makers and provides the evidence base for prioritising low-carbon development options and developing proposals for Nationally Appropriate Mitigation Actions (NAMAs) and REDD+ (Reducing Emissions from Deforestation and Forest Degradation) actions.

The analysis includes a preliminary greenhouse gas (GHG) emissions inventory and reference case projecting GHG emissions to 2030 for the entire Pakistani economy and by sector. The analysis then demonstrates how low-carbon development options can bend down emissions from the proposed reference case in each sector. Recognising Pakistan's development priorities and plans, the analysis also considers how the various options can contribute to sustainable development. The overall work concludes with the identification of priority actions to enable low-carbon development.

This chapter analyses low-carbon development options for electricity and fossil fuel energy demand in the waste sector in Pakistan and is one of seven sectoral chapters developed as part of the overall low-carbon scenario analysis.

Stakeholder consultation was undertaken with sectoral experts on these options for the purpose of seeking feedback the results and identifying additional areas for GHG mitigation. This stakeholder consultation was led by the Centre for Climate Research and Development supported by the International Institute for Sustainable Development (IISD) and PITCO.

2 WASTE SECTOR: BACKGROUND

In most developed and developing countries with increasing populations, prosperity and urbanisation, it remains a major challenge for municipalities to collect, recycle, treat and dispose of increasing quantities of solid waste and wastewater. A cornerstone of sustainable development is the establishment of affordable, effective and truly sustainable waste management practices. It must be further emphasised that multiple public health, safety and environmental benefits accrue from effective waste management practices which concurrently reduce GHG emissions and improve the quality of life, promote public health, prevent water and soil contamination, conserve natural resources and provide renewable energy benefits.

The major GHG emissions from the waste sector are landfill methane (CH_4) and, secondarily, wastewater CH_4 and nitrous oxide (N_2O). In addition, the incineration of fossil carbon results in minor emissions of carbon dioxide (CO_2) (Bogner, 2007, p. 588).

2.1 Sector Context

Municipal Solid Waste
Municipal solid waste comes from the residential and commercial sector, and typically includes elements such as food waste, garden and park waste, paper and cardboard, wood, textiles, diapers, rubber and leather, plastics, metal, glass (and pottery and china), as well as other elements such as ash, dirt, dust, soil or electronic waste. This section first explains what emissions are associated to the management of municipal solid waste, and then explains how it is stored or disposed of.

Municipal solid waste produces a number of greenhouse gasses: CH_4, CO2, Non-methane volatile organic compounds (NMVOCs), N_2O, nitrogen oxides (NO_x), carbon monoxide (CO), but only CH_4 and carbon dioxide CO_2 are considered in this work. This is because N_2O emissions are negligible, and because NMVOCs, NO_x and CO fall outside of the scope of this work: Their monitoring is performed under other guidelines/conventions than the Intergovernmental Panel on Climate Change (IPCC) and there is less clarity on how exactly they should be treated. This is however a necessary point of attention that should be addressed in future work, as such gasses can contribute significantly to the greenhouse effect (IPCC, 2006).

CH_4 and CO_2 come from the organic material (for example glucose) present in the waste is digested (basically, eaten) by microorganisms (bacteria or fungi). There are essentially two types of processes: aerobic digestion and anaerobic digestion. The difference between the two is the source of oxygen that is available for the microorganisms.

- Aerobic digestion uses gaseous oxygen present in the air. In terms of greenhouse gasses, it only produces CO_2. It also produces compost (which is used as a soil conditioner, i.e. to improve the soil's physical quantities, most notably its nutrition for plants) and heat.
- Anaerobic digestion uses non-gaseous oxygen (for example oxygen present in the waste (organic material) itself). In terms of greenhouse gasses, it only produces both CO_2 and CH_4. It also produces a soil conditioner (digestate), and trace levels of hydrogen sulphide.

(Shammas and Wang, 2007)

Note that while CO_2 is mentioned here, its net emissions are actually accounted for under the Agriculture, Forestry and Other Land Use sector (IPCC, 2006).

The IPCC guidelines have four categories for the treatment of municipal solid waste:

1) **Solid Waste Disposal Sites (SWDS):** This corresponds to sending waste to sites and storing it there. The proportion of anaerobic reactions is called the Methane Correction Factor (MCF). Managed anaerobic sites (meaning that they have at least one of the following: cover material, mechanical compacting, levelling of the waste) only have anaerobic reactions and have an MCF of 1. Managed semi-aerobic sites use systems to place the waste and introduce air into layers (for example with a gas ventilation system, or permeable cover material) have an MCF of 0.5, or 50 per cent of anaerobic reactions. The MCF of unmanaged systems will depend on their depth, since shallower systems have a bigger proportion of their waste (the surface) exposed to the ambient air than deep

systems. The IPCC gives an MCF factor of 0.8 (80% anaerobic reactions) for deep systems (>5m) and an MCF factor of 0.4 (40% anaerobic reactions) for shallow systems (<5m). We assume that 70 per cent of the collected waste is disposed in unmanaged shallow landfills, while the remaining 30 per cent goes to unmanaged deep landfills. The management of waste dumping sites is still in its early phases in Pakistan (PAK-EPA, 2005) and most dump sites lack the facilities they would need to be managed. There has, however been some progress with the building of waste management infrastructure that can enable practices that would reduce emissions, for example in Lahore (DAWN, 2014; ESMAP, 2010; DAWN, 2016; PPI, 2016).

2) **Biological treatment:** This includes composting and managed anaerobic digestion (where methane is recovered). Composting mostly has aerobic reactions, but also has some anaerobic ones. Note that composting also produces amounts of methane and nitrous oxide if not properly managed, but the amounts produced are typically small.
3) **Incineration and open burning:** Waste can be burned, either to produce energy (in which case it belongs to the energy sector) or not (in which case it belongs to the waste sector). There are three GHGs that are produced:
    a. CO_2, which contrary to the case for digestion belongs to the waste sector
    b. CH_4, which is a result of incomplete combustion
    c. N_2O, which appears at low combustion temperatures (500-950 °C).
4) **Unspecified:** This includes recycling as well as waste that does not belong to any of the above categories. It is often waste that is not brought for treatment or disposal at a site. As such, it mostly decomposes aerobically and does not produce any methane. As mentioned above, CO_2 emissions from decomposition do not belong to the waste sector, so this category does not add to emissions from the waste sector.

The key to determine emissions is to know the proportions of each system. Incineration of waste does not seem to occur significantly in Pakistan, and composting is also apparently very small, and the unspecified category does not contribute to the waste sector. This means that (almost) all the emissions come from the proportion of waste that is sent to SWDSs. The baseline model assumes that 50% of MSW goes to SWDSs, based on the fact that solid waste collection by government owned and operated services in Pakistan's cities averages 50 per cent of waste quantities generated (compared to 75 per cent needed to keep cities relatively clean). This amount is larger in cities such as Lahore, where 76 per cent was collected in 2011 (Masood, 2011), than in rural areas, with variations from zero per cent in low-income rural areas up to 90 per cent in high-income urban areas (PAK-EPA, 2015; PAK-EPA, 2005).

Industrial Solid waste

While industrial solid waste has some common elements with Municipal Solid Waste (MSW) (such as paper from office activities, and food from catering), it is very different from MSW, both in terms of the type of components that are present and in terms of the proportions of each component. It includes the results of industrial activity, which vary strongly from industry to industry. Some of that waste is hazardous and cannot be treated together with MSW, while the non-hazardous part (food and paper, for example) can be handled together with MSW.

Unfortunately, no data was available for industrial solid waste, so it does not feature in this work. This is could be considered as a possibility for future work.

Wastewater

To understand emissions from the treatment of wastewater, it is useful to divide them by source and resulting type of emissions. There are essentially two categories.

The first type is, as for solid waste, organic matter. Microorganisms digest it and produce CH_4 in anaerobic reaction (when no gaseous oxygen is available) and CO_2 in both anaerobic and aerobic reactions. As explained above, the latter gas does not count towards emissions from the waste sector. The main parameters that come in play to determine the amount of CH_4 that is emitted are the following:

i. **The amount of organic matter that can be digested by microorganisms.** This can be given by two quantities: Biochemical Oxygen Demand (BOD) or Chemical Oxygen Demand (COD). BOD measures the level of biodegradable organic matter. COD is less specific, as it measures everything that can be chemically oxidised. The difference is important for this work, because BOD data is available for domestic wastewater, while COD data is available for industrial wastewater. As such, the data below makes the distinction between domestic and industrial wastewater. This can be useful for designing policies applying to either sector.
ii. **The temperature of the wastewater.** Methanogens (microorganisms that digest organic matter into methane (and other things) become active at 15°C. Below that temperature, the organic matter undergoes sedimentation (they will accumulate at the bottom of the water).
iii. **The type of treatment system.** This will determine if anaerobic reactions occur or not. Mixing (i.e., water not being stagnant) or aeration of the water reduces the likelihood of anaerobic reactions to occur. Shallow lagoons have few anaerobic reactions, while deeper ones (>2-3m) have many of such reactions. Closed, underground sewers do not produce emissions, while open sewers do, especially when stagnant or overloaded.

(IPCC, 2006)

The other type of source is nitrogen components, such as urea, nitrate, and protein, which can be degraded into N_2O. These components come from human waste. Their amount is related to the amount of food (protein) consumed by people. The manner in which the wastewater is treated strongly influences the occurrence of such processes. The process that is the most likely to release significant amounts of nitrous oxide is the discharge of wastewater into rivers, lakes and estuaries. They can also occur in wastewater treatment plants (but in smaller amounts) (IPCC, 2006).

Wastewater in Pakistan is essentially untreated and discharged directly to a sewer system, a natural drain or water body, a nearby field or an internal septic tank, without provisions for reuse for agricultural or municipal uses (it is however used directly for irrigation for its added value as a fertiliser). Treatment only occurs in Islamabad and Karachi, and for very small amounts between 1-8 per cent of urban wastewater are treated, depending amongst others on the capacity at which existing installations are working). More facilities were built, but they are either under-loaded or abandoned, as they lack associated sewerage networks. The existing facilities are only primary treatment ones, where gross, suspended and floating solids are removed by mechanical means (a screening trap in the water). Secondary treatment, where microbes consume some of the organic matter, and tertiary treatments, chemicals and specific equipment, that are used to produce > 99% impurity-free water for drinking are essentially absent. Industrial wastewater is also essentially untreated, with a few exceptions, mostly for export industries that feel pressure for international customers and the fertiliser industry. The main reason for this is the lack of incentives for industries to treat their wastewater (Zia, 2012; World Bank Group, 2015).

2.2 Structure

The main entity taking care of waste issues at the national level is the Environment Protection Agency (PAK-EPA), which used to be a part of the (former) Ministry of Environment, but is now an agency on its own at the moment.

The waste relevant parts of the Pakistan Environmental Protection Act of 1997, which establishes that the PAK-EPA shall:

- Assist the local councils, local authorities, Government Agencies and other persons to implement schemes for the proper disposal of wastes so as to ensure compliance with the standards established by it.
- Take samples of any materials, products, articles or substances or of the effluents, wastes or air pollutants being discharged or emitted or of air, water or land in the vicinity of the discharge or emission.
- Prohibit emissions or discharge of any effluent or waste or air pollutant or noise in an amount, concentration or level that is in excess of the National Environmental Quality Standards.
- Prohibit the import of hazardous waste

(PAK-EPA, 2015; National Assembly of Pakistan, 1997)

The actual management of waste occurs at the municipal level. They spend a considerable portion of their budgets on solid waste management, but receive limited tax revenue in return, in insufficient amounts to meet their operation and maintenance costs. This is one of the main reasons why they cannot afford the latest techniques and equipment that would make solid waste management a profitable and environmentally friendly enterprise (PAK-EPA, 2005).

3 DEVELOPMENT PRIORITIES OF PAKISTAN

The main documents setting powers, objectives and functions for the government to act on waste matters are the Pakistan Environmental Protection Act (PEPA) of 1997 (PAK-EPA, 2015; National Assembly of Pakistan, 1997), and the National Environment Policy of 2005 (Ministry of Environment, 2005). These powers, objectives, and functions include the following:

- Enforcing quality standards and monitoring and reporting systems
- Introducing a discharge licensing system for the industry
- Make installation of wastewater treatment plants an integral part of all sewage schemes
- Devise and implement a National Sanitation Policy (Ministry of Environment, 2006) that:
    - Provides a broad framework and policy guidelines to enhance and support sanitation coverage.
    - Primarily focuses on the safe disposal of excreta from dwelling units and work places by using sanitary latrines and includes the creation of an open defecation free environment along with the safe disposal of liquid wastes, together with the promotion of health and hygiene practices in the country.
    - Meet the Millennium Development Goals of dividing the number of people without sustainable access to improved sanitation by half in 2015, reaching 100 per cent access to improved sanitation by 2025.
    - Initiate research and pilot projects for developing sustainable models for the safe disposal of liquid, solid, municipal, industrial, and agricultural waste.
    - Establishes a National Sanitation Policy Implementation Committee comprising representatives of the public and private sector, as well as Civil Society Organisations.
- Devising and implementing master plans for treatment of municipal and industrial wastewater in urban and rural areas.
- Develop strategies for the integrated management of waste at national, provincial and local levels
- Encourage reduction, reduction and reuse of waste.

4 REFERENCE CASE

Through the processes of disposal, treatment and recycling different types of waste can produce greenhouse gas emissions. The most important gas produced in this source category is methane (CH_4). Two major sources of this type of CH_4 production are solid waste disposal to land and wastewater treatment. In each case, methanogenic bacteria break down organic matter in the waste to produce CH_4. The breakdown of human sewage can also lead to significant amounts of N_2O emissions. The waste sector is the smallest of all the categories of emissions, currently contributing approximately 2% of total greenhouse gas emissions.

4.1 Methodology

An emissions reference case for the waste sector was developed by using a number of Tier 1 approaches from the IPCC 2006 Guidelines for methane emissions from domestic and industrial wastewater treatment and N2O emissions from human sewage and CO2, CH4 and N2O emissions from waste incineration. The calculation of methane emissions from Solid Waste Disposal Sites (SWDS) was completed using the Tier 2 First Order Decay Model methodology from the 2006

IPCC Guidelines. The FOD method produces a time-dependent emission profile that better reflects the true pattern of the degradation process over time.

The default IPCC parameters identified in Table 1 were used in the spreadsheet model to estimate the methane generation potential.

Table 1: Waste model IPCC default values

Default IPCC parameter	Default values used in model
Methane Correction Factor (MCF)	0.4, Un-managed shallow
	0.8, Un-managed deep
Methane Recovery Factor	0
Fraction of DOC dissimilated	0.5
Methane Generation Rate Constants (yr^{-1})	0.085, Food Waste, Sewage sludge
Default for and Dry Tropical climate zone	0.065, Garden, Textiles, Disposable nappies
	0.045, Paper
	0.025, Wood and straw
Delay time (months)	6
Fraction of methane (F) in developed gas	0.5

4.2 Data, Assumptions & Uncertainty

Waste disposal rates are based on estimates prepared by PAK-EPA (Pakistan Environmental Protection Agency, 2005). The percentage of solid waste generated and sent to solid waste disposal sites is assumed to be 60 per cent (Zuberi J. S. and Ali S. F., 2014, GCISC, 2015). Table 2 below summarises the urban population, waste generation rate and total solid waste produced and sent to landfill for the period between 1970 and 2030.

Table 2: Urban solid waste generation summary (1970 to 2030)

Year	Population	Waste per capita	Total MSW	% to SWDS
	millions	kg/cap/yr	Gg	%
1970	14.7	164.3	2,413	60%
1971	15.3	164.3	2,507	60%
1972	16.6	164.3	2,726	60%
1973	16.6	164.3	2,727	60%
1974	16.6	164.3	2,728	60%
1975	16.6	164.3	2,730	60%
1976	16.6	164.3	2,731	60%
1977	16.6	164.3	2,732	60%
1978	16.6	164.3	2,734	60%

Year	Population	Waste per capita	Total MSW	% to SWDS
	millions	kg/cap/yr	Gg	%
2001	47.5	164.3	7,802	60%
2002	48.3	164.3	7,927	60%
2003	50.0	164.3	8,208	60%
2004	51.3	164.3	8,431	60%
2005	53.9	164.3	8,856	60%
2006	55.8	164.3	9,165	60%
2007	57.7	164.3	9,481	60%
2008	59.7	164.3	9,802	60%
2009	61.9	164.3	10,162	60%

1979	16.7	164.3	2,735	60%	**2010**	61.9	164.3	10,162	60%
1980	16.7	164.3	2,736	60%	**2011**	67.6	164.3	11,095	60%
1981	23.8	164.3	3,916	60%	**2012**	69.9	164.3	11,476	60%
1982	23.9	164.3	3,918	60%	**2013**	72.3	164.3	11,871	60%
1983	23.9	164.3	3,920	60%	**2014**	74.7	164.3	12,275	60%
1984	23.9	164.3	3,922	60%	**2015**	77.3	164.3	12,689	60%
1985	23.9	164.3	3,924	60%	**2016**	79.8	164.3	13,113	60%
1986	23.9	164.3	3,925	60%	**2017**	82.5	164.3	13,546	60%
1987	23.9	164.3	3,927	60%	**2018**	85.2	164.3	13,989	60%
1988	23.9	164.3	3,929	60%	**2019**	87.9	164.3	14,442	60%
1989	23.9	164.3	3,931	60%	**2020**	90.7	164.3	14,905	60%
1990	23.9	164.3	3,933	60%	**2021**	93.6	164.3	15,378	60%
1991	34.7	164.3	5,693	60%	**2022**	96.6	164.3	15,862	60%
1992	35.8	164.3	5,879	60%	**2023**	99.6	164.3	16,355	60%
1993	37.1	164.3	6,085	60%	**2024**	102.6	164.3	16,859	60%
1994	37.1	164.3	6,088	60%	**2025**	105.8	164.3	17,373	60%
1995	37.1	164.3	6,091	60%	**2026**	109.0	164.3	17,897	60%
1996	40.8	164.3	6,705	60%	**2027**	112.2	164.3	18,432	60%
1997	42.1	164.3	6,918	60%	**2028**	115.5	164.3	18,978	60%
1998	40.0	164.3	6,572	60%	**2029**	118.9	164.3	19,533	60%
1999	44.8	164.3	7,355	60%	**2030**	122.4	164.3	20,100	60%
2000	46.1	164.3	7,577	60%					

The composition of waste impacts the amount of organic material that is available for anaerobic decay and therefore the projected methane emissions released. The waste composition used in the modeling is presented in Table3. This waste composition reflects the composition of the waste that is collected and is based on the draft Guidelines for Solid Waste Management (Pakistan Environmental Protection Agency, 2005).

Table 3: Composition of wastes in Pakistan

Type	Composition (%)
Plastic and Rubber	5.3%
Metals	0.4%
Paper	2.6%
Cardboard	1.7%
Textiles / Rags	5.5%
Glass	1.4%
Bones	2.3%

Food	17.3%
Animal	3.8%
Green Waste	13.4%
Wood	1.5%
Fines	39.3%
Stones	5.2%
TOTAL	**100%**

Wastewater can be a source of methane if treated or disposed of anaerobically. The emission factors and parameters used to calculate methane emissions from domestic wastewater are presented in Table 4 and Table 5.

Table 4: Wastewater treatment systems and associated methane correction factors

Treatment System	Urban – Low (80% urban population)	Urban – High (20% urban population)	Rural	MCF
Septic	14%	18%	0%	50%
Latrine	10%	10%	47%	10%
Other	3%	3%	0%	10%
Sewer	53%	53%	10%	13%
None	20%	20%	43%	0%

Source: (IPCC, 2006).

Table 5: emission factors and parameters to calculate ch₄ domestic wastewater emissions

Parameter	Description	Value	Data Source
BOD	Kg BOD/1000 persons/yr	14,600	(IPCC, 1996 Default parameter)
EF	Kg CH_4 / kg BOD	0.25	(IPCC, 1996 Default parameter)

The activity data, emission factors and parameters used to calculate methane emissions from industrial wastewater are presented in Table 6

Table 6: activity data, emission factors and parameters to calculate ch₄ industrial wastewater emissions

Parameter	Description	Value	Data Source
Wastewater Volume	M3/yr (2000 adjusted by industrial GDP growth rate for other years)	344,000,000	(Zia & Murtaza, 2012)
Average COD/m3	Kg COD/m3	4.24	(Zia & Murtaza, 2012) (IPCC, and (IPCC, 2006 default parameters)
EF	Kg CH_4 / kg COD	0.25	(IPCC, 1996 Default parameter)
MCF	(dimensionless)	0.1	(IPCC, 2006 default parameter)

The activity data, emission factors and parameters used to calculate N_2O emissions from industrial wastewater are presented in7.

Table 7: activity data, emission factors and parameters to calculate N_2O emissions from human sewage

Parameter	Description	Value	Data Source
Population	Persons (2010 adjusted for every inventory year)	177.1 million	Pakistan Economic Survey
Per capita Protein consumption	g/person/day (2013)	65.49	(FAOSTAT Database, 2015)
Fraction of nitrogen in protein	kg N/kg protein	0.16	(IPCC, 2006 default parameter)
Emission Factor	kg N2O-N/kg sewage-N produced	0.005	(IPCC, 2006 default parameter)

The waste sector contributes to less than 5 per cent of total emissions. Domestic and industrial wastewater is the largest source of overall emissions. With industrial wastewater expected to grow at a substantially higher rate than other waste emission sources.

The uncertainty of these emissions is large. The necessary activity data to describe the volumes of solid waste and wastewater generated are not collected and reported on a regular basis. There is also considerable uncertainty around the proportion of solid waste and wastewater organic matter that is broken down anaerobically to produce CH_4. These MCFs have uncertainties of more than ±100 per cent.

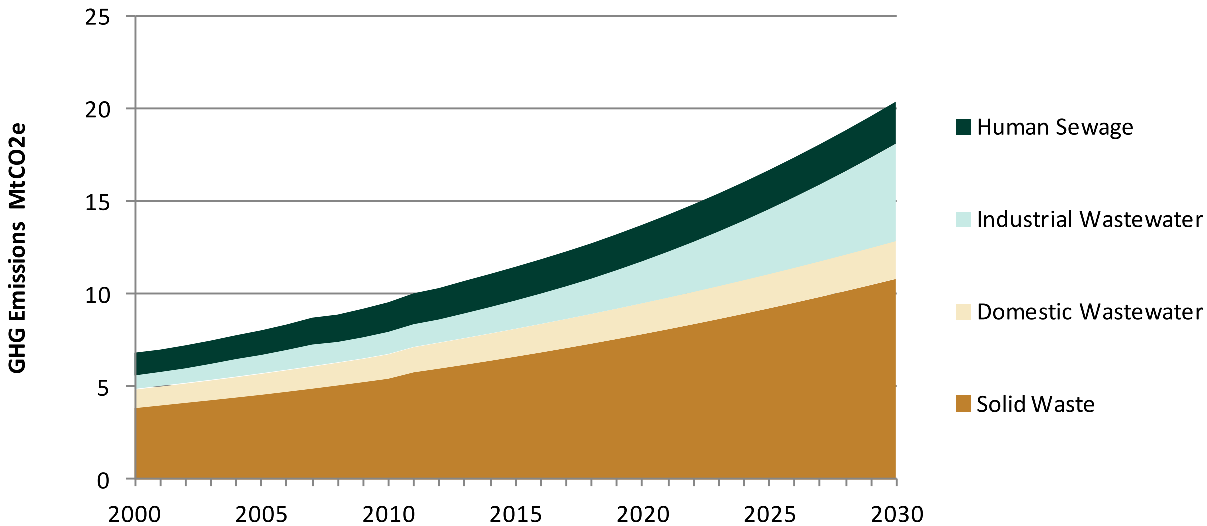
Major data gaps in the waste sector that need to be addressed:

1. **Use of higher-quality existing methane correction factors (MCF)**. Methane correction factors used for wastewater are primarily estimated to be related to untreated sea, river or lake discharge. These MCF values are estimated to be vary in the range between 0 and 0.2 (IPCC, 2006).
2. **Estimates of volumes of Industrial Wastewater Produced**. Estimates were taken from an old source that dates back to the year 2000 (Zia & Murtaza, 2012). This source references the original data source as the Pakistan Water Sector Strategy (PWSS, 2002).
3. **Estimates of volume of Solid Waste sent to Disposal Sites**. Estimates are available from various documents that project that in urban cities between 40 per cent and 60 per cent of waste is collected and put in disposal sites. Estimates of total municipal solid waste were taken from GCISC inventory (GCISC, 21015). These figures likely include all industrial solid waste. This figure is highly uncertain and may not account for sites that are too shallow and unmanaged to be considered disposal sites.

4.3 Greenhouse Gas Emissions Reference Case

Total projected GHG emissions from the waste sector by source are indicated in Figure 1. It is interesting to note that the ranking of these categories is projected to change quite dramatically. Industrial wastewater is projected to go from being the lowest emitter to being the highest emitter.

Figure 1: Projected greenhouse gas emissions in WASTE sector (Mt CO_2e)



5 LOW CARBON SCENCARIO ANALYSIS

The low-carbon scenario analysis consists of identifying low-carbon development options, and calculating the mitigation potential against the reference case. The resulting wedge analysis demonstrates the emissions reductions potential by low-carbon technology in the sector.

5.1 Choice of Abatement Options

Two options were chosen, both in the MSW sector, namely composting MSW, and landfill gas utilisation (the recovery (and combustion) of methane from landfill gas). No options were made for wastewater.

The reason why no wastewater options have been considered is that they are were judged to be unlikely to occur in the short term. There is essentially no wastewater treatment infrastructure present. The priority is to build some kind of infrastructure, not to extract some value or reduce emissions out of it. This is in contrast with MSW, which has some revenue streams such as scavenging to recover elements that can be resold or reused. Even if these revenues might sometimes be small and insufficient, they are a possible driver for the implementation of new processes and technology. The benefits of emission reduction or a better environment (which have economic counterparts) can then act as a catalyser. This kind of situation is not likely to occur in the coming years in Pakistan for wastewater (but could in principle, thanks to the possible extraction of fertilisers from wastewater).

Table 8: Rejected options for waste

Rejected options	Reasons for rejection
Changing diets of Pakistani citizens to reduce protein intake	• Controversial • Pakistan has a much lower consumption of protein per capita than the world average. It is also lower than the average in the developing world, and similar to Sub-Saharan Africa (FAO, 2015) (ChartsBin, 2011). Attempting to reduce it would strongly go against the development goals of Pakistan.
Wastewater treatment options	• No infrastructure to build on • No incentives • Priority is on getting some kind of treatment first
Waste to energy	• Requires large investments and operation and maintenance costs. • Much less scalable than composting or landfill gas: One needs to build a relatively large facility whose capacity cannot easily be increased or decreased according to the amount of waste: One would need to build a whole new facility (or at least another feed train). This is also a problem if the waste supply changes with time (seasonal or year-on-year). Facilities in the Netherlands have to rely on waste import from the UK to be viable. • Requires waste with a large and constant calorific value in order for the operations to produce sufficient energy, in a reliable fashion. Waste in developing countries does not have such properties, as it has high moisture content. (UNEP, 2013)

5.2 Calculation of Abatement Potentials

The calculation of abatement for the options considered here is relatively straightforward. We assume that each option shifts a certain percentage of the collected solid waste from its current path (where it has a given emission factor) and brings it towards the treatment at hand (e.g. compost landfill gas utilisation). This volume, multiplied by the difference in emission factors gives us the emission savings. We also chose to build up the volumes linearly between a start and an end year for lack of a more appropriate approach at this stage (2016 is the first year where an option is active, 2030 is when it reaches its selected potential, for both options).

5.3 Investment Costs

The costs of the options were based on a literature search of existing projects and studies with a focus on projects that take into account the characteristics of Pakistan (for example planned or existing projects). These costs were scaled up according to the projected volumes. As such, these are investment costs only, and do not include any analysis of the economic value of side products generated (compost and heat, essentially). These would need to be balanced against operational costs to see if the operation of the facilities would be profitable. We did not perform such a full analysis of this, as there was a lack of detailed available information about both the value of the benefits of compost and heat on the market and operational costs in Pakistan.

6 LOW CARBON DEVELOPMENT OPTIONS

The waste sector in Pakistan offers a number of low-carbon development options relating to landfill gas utilisation and compost. This section provides some context for the options that could be quantitatively measured. Following the context, the different options are examined for their mitigation potential, costs and other development benefits.

6.1 Context

Landfill gas utilisation

This option is about collecting landfill gas (a mix of CH_4 and CO_2). The most common way to do this involves drilling vertical wells in the waste and connecting those wellheads to lateral piping that transports the gas to a collection header using a blower or vacuum induction system. Horizontal wells are also possible, as combinations of both. As the warm gas travels to the collection system, water condensates and needs to be removed. A blower pulls the gas from the collection wells into the collection header and conveys the gas to downstream treatment and energy recovery systems. Flaring systems are also needed for safety reasons (in case too much gas is suddenly produced, for example). The gas can then be treated (removing excess moisture, particulates and other impurities). The costs of that processing depend on the gas purity requirements of the end use applications, which can be electricity generation, or direct use as a fuel for heating (US EPA, 2015; Masood F., 2013).

The most important element is to have a managed sanitary landfill. This is needed to even consider collecting landfill gas. The first such installation in Pakistan started operations in April 2016 on the Lakhodair site in Lahore (DAWN, 2016). There also needs to be a proper, large-scale waste collection system in place. As mentioned in Section 2.1 Sector Context, there is some collection going on, especially in cities, but it is still globally too low (50 per cent on average, while at least 75 per cent would be needed to keep cities clean to a minimum). Some cities (such as Lahore, at 76 per cent) fare better than others. The reason for this need is to ensure sufficient end product (natural gas for heat and/or electricity) to cover operational expenses and recoup the investment cost.

Compost

This option is about composting collected municipal solid waste in facilities connected to landfills, such as the facility built in the Mahmood Booti dumpsite in Lahore (ESMAP, 2010), not about composting in households to reduce the amount of waste (Masood, 2011). While the latter would have some clear benefits (reduction of amounts of processed waste, no need to build large facilities), it would not be easy to implement, as not all households would have the possibility or the willingness to do it (for example in apartments). An intermediary solution could be to incite households to sort food waste from the rest, in order for separate waste streams to be collected. This would enhance the quality of the compost produced by central processing facilities. Note that such a scenario would also change the emission factors for the production of compost. The abatement potential presented below is based on a scenario where unsorted waste is composted (which is reflected in the assumed emission factors). A potential extension of this work could be to have a scenario where a portion of food waste is collected separately after households separate their waste.

Similarly, to landfill gas composting would require proper processing installations and a large enough stream of waste to produce enough compost and offer fertilizer to the market in amounts large enough to cover operational costs and recoup investments.

In addition to the Mahmood Booti site in Lahore mentioned above, a few pilots have started/are being considered in the cities of Islamabad/Rawalpindi, Karachi and Mardan. They are however much smaller than the Lahore facility mention above: 2-10 tonnes per day for a facility that started operating in Islamabad in September 2015 versus 1000 tonnes per day at the Mahmood Booti site (UN Habitat, 2015 September).

6.2 Scenarios

Landfill gas utilisation

The volume of methane that is avoided is determined by the product of two parameters: How much waste goes to facilities that recover methane, and what percentage of the methane emitted at these facilities is recovered.

The volume that goes through landfill gas utilisation facilities is directly related to the amount of such facilities, and to their individual capacities. Pakistan's first sanitary landfill (Lakhodair dump site in Lahore), has started operating is expected to be able to process about 2000 tonnes per day of waste, or 0.73 million tonnes per year (DAWN, 2014; DAWN, 2016). This is about 12 per cent of the currently collected MSW, and about 7.25 per cent of the projected 2030 volume. Note that this does not include landfill gas utilisation infrastructure, and that this is not strictly necessary for landfill gas collection, but that it is a proxy indicator that shows landfills are managed. The scenario here is that, in addition to the Lahore facility, three other facilities are built in Karachi, Faisalabad, and Rawalpindi (the other three members of the four most populated cities). We assume that the sizes of these facilities are proportional to the populations of these cities. The population of the four largest cities (Karachi, Lahore, Faisalabad, and Rawalpindi) is about 3.5 times the population of Lahore (Pakistan Bureau of Statistics, 1998). This means that the four facilities would process about **25 per cent**[1] of collected waste.

The recovery rate of methane can vary quite strongly from site to site, with the US EPA citing a variation between 50 and 95 per cent, and an average of 75 per cent, which is what we assumed (US EPA, 2015). The product of this recovery rate and of the percentage of collected waste that goes through landfill gas processing facilities gives a **volume factor of 19 per cent.**

Burning CH_4 means that it will be replaced by CO_2. There are two effects that play into changing the GHG emissions. The first is that one molecule of CO_2 has a greater mass than one molecule of CH_4. Both have one carbon atom, with a molecular mass of 12, but the two oxygen atoms have a molecular weight of 16 each, so a total of 44, versus 16 for CH_4 (each hydrogen atom has a molecular mass of one). The second is the fact that CH_4 has a larger global warming potential (GWP) than CO_2. The value of this GWP factor depends on the time horizon we look at. For a 100-year time horizon, the GWP of CH_4 is 21 times the one of CO_2. This means that the emissions factor of this option is 44/ (21*16) = **0.13 times the baseline emission factor**.

Compost

The Mahmood Booti Lahore facility is expected to reach a processing volume of up to 1'500 tonnes per day, which is about 550'000 tonnes per year, or a bit less than 10 per cent of the currently collected waste in Pakistan and about 5 per cent of the expected volume of collected waste in 2030. Here, we assume a similar scenario to the landfill gas scenario, namely that the four largest cities get an installation similar to Mahmood Booti, proportional to their population. Together, these four installations (which include Mahmood Booti) represent about 3.5 times the capacity of Mahmood Booti, or a **volume factor of 19 per cent[2].**

The emission factor given by the IPCC is 4g CH_4/kg wet waste, compared to 13.95 g CH_4/kg wet waste in the baseline. The 4g CH_4/kg needs to be corrected by a factor that takes into account the removal of inert waste in the composting process. The proportion of inert waste is 58 per cent, so the percentage of waste that will be composted (and for which the factor 4g CH_4/kg applies) is 42 per cent, leading to a factor of 1.68g CH_4/kg (on a total mass basis, i.e., the same as the basis for the 13.95 g CH_4/kg wet waste factor). Note that the factor in the baseline changes with time (it increases by about 3 per cent between 2013 and 2030), so we took an average of the factor across the 2013-2030 period. This change reflects the fact the change in composition of the waste due to decomposition of the accumulated waste. This means that the **emission factor of composting is 12 per cent of the emission factor of the baseline** (unmanaged landfills).

[1] 3.5*7.25%~25%

[2] There is no need to introduce a recover rate, as compost is processed differently from landfill gas.

6.3 Mitigation Potentials

Figure 2 and Table 9 show the potential savings for each option. The two options are relatively close in size, with landfill gas utilisation being a bit lower, due to lower assumed volumes (with relatively similar emission factors).

A few caveats should be taken: First, these options are quite ambitious and would require other motivations (such as reduced local pollution) to be enacted. Second, they were considered individually. In practice, it might be an either/or choice for economic reasons (capital and resources available for such matters are limited). In case both are used, there should be an assessment of the overlap between the two, as they might happen at the same facilities. In that case, the savings would not be additive: one option would remove (most of) the methane the other option would not be able to remove anymore.

Figure 2: Waste sector baseline and savings

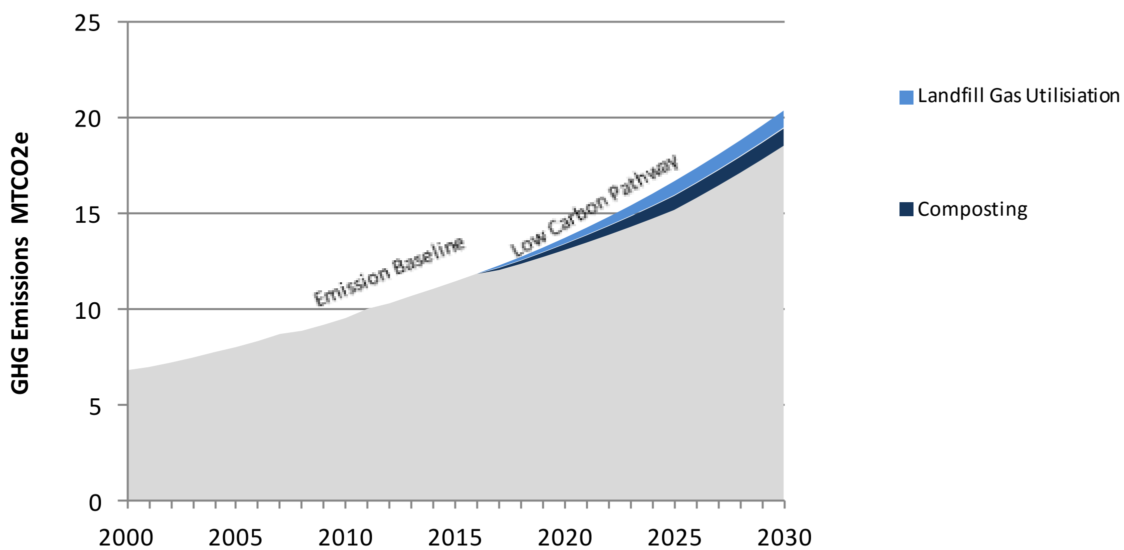


Table 9: Waste sector baseline and savings

	2025 savings (million tonnes CO2e)	2025 savings (% of baseline)	2030 savings (million tonnes CO2e)	2030 savings (% of baseline)
Compost	0.738	4.0%	0.90	4.4%
Landfill gas utilisation	0.721	3.3%	0.88	4.3%

6.4 Costs

Landfill gas utilisation

To estimate the costs, we simply scale up the costs of the Lakhodair facility in Lahore in the same way we scaled up the volumes treated: We assume that the other three cities in the top four of Pakistani cities by population (Karachi, Faisalabad, and Rawalpindi) also build similar facilities, proportional to their populations. As seen above, the population of the top four cities is about 3.5 times the population of Lahore (see 6.2 Scenarios). The Lakhodair facility cost PKR 7 billion, or about USD 70 million (DAWN, 2014). This means that the total investment costs for the four facilities (Karachi, Lahore, Faisalabad, and Rawalpindi) would be about USD 245 million.

The US EPA provides a number of examples of investment costs for a 3MW facility (excluding the collection facilities). They vary between 5 and 8 million USD. The also provide a table that relates the gas flow (in cubic feet per minute (CFM)) to the engine size, with about 2.5 kW/CFM. They also mention that a 40-acre system produces about 600 CFM. Our scenario assumes a similar surface (38 acres[3]), so this means that we would need 600*2.5=1'500 kW in total power (from several turbines), or about half the 3MW they use for economic assessments. This means that the costs for electricity generation would be about 2.5-4 million USD. This is highly simplified, but gives an indication of investment costs. Directly using the gas for heating highly depends on the length of the pipelines required for the gas, but appears to be about half the costs for electricity, for similarly sized projects. An actual assessment would highly depend on the circumstances of the project and would require specific calculations (US EPA, 2015).

Compost

Here, we again scale up the costs of the Lahore in the same way we scaled up the volumes treated. The investment costs of the Lahore facility are 5.52 million USD (ESMAP, 2010). This means that the total investment costs for the four facilities (Karachi, Lahore, Faisalabad, and Rawalpindi) would be about USD 19 million.

While costs of operation were not available, the Lahore case contains a number of interesting pieces of information that indicate that composting has a good business case and can be self-sufficient. The Lahore project is actually a public-private partnership (PPP) between Saif Holdings Limited (SHL), one of the largest industrial conglomerates in the country, and the City District Government of Lahore (CDGL) (The World Bank Group, 2016). This joint venture is called Lahore Compost Limited and sells the compost as a fertiliser under the name of Zameen Dost, with strong marketing efforts[4], indicating that sales are a key focus of the joint venture and that they are

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[3] Based on the same growth as above and the fact that The Lakhodair in Karachi is 11 acres (1 acre= 4046.856 square meters) (DAWN, 2014)

[4] See their website: http://www.lahorecompost.com/ . Another thing to note is that Zameen Dost means "Land Friend/Lover". This pun is used in advertisements: https://www.youtube.com/watch?v=kZ-8SXDN4a8 . Other advertisements use songs: https://www.youtube.com/watch?v=8YZo29w8WAg or https://www.youtube.com/watch?v=-2c4jDvstik

probably profitable. Detailed prices were not available, but a search on Alibaba[5] shows a page claiming that the company can provide 150 tonnes per day, at USD 61 per tonne (for orders of at least 40 tonnes, so not necessarily for end customers), indicating a potential revenue of 150*61=USD 9150 per day, or about USD 3.3 million per year. Such figures would cover the investment costs quoted above in a bit more than 1.5 years. Operational costs and actual sales instead of production capacity would increase this time somewhat, but this is a good indication that the project is viable in its form.

6.5 Development Benefits

Many developing countries struggle to develop costly waste management systems and municipal authorities are often unable to provide efficient collection and sustainable disposal services. Unmanaged landfills and open dumping of waste in streets, however, bear serious environmental and health hazards, particularly in densely populated urban areas, including diseases, odour, groundwater pollution and exposure to hazardous substances (UNESCAP, 2015; World Bank, 2015). Without waste separation and treatment, valuable resources from waste are lost. In many developing countries, urban solid waste management and the recovery of waste with economic value is an informal sector relying on waste pickers and collectors. More efficient waste management systems and the recovery of energy from waste can lead to job creation and improve energy security, and can yield long-term macroeconomic benefits and an increase in GDP (see an integrated solid waste management case study from Brazil, in (World Bank, 2014)). Composting of household waste in combination with improved recycling and sanitary landfill might provide the highest environmental and socio-economic benefits (Rajeev K. Singh, 2014).

Capturing **landfill gas** allows communities to use this local energy source, while reducing air pollution and other environmental benefits and generating economic opportunities. Economic benefits can include fuel cost savings, job creation in construction and operation, as well as improved economic development near landfills. Environmental and social benefits include safer landfills with reduced odours and air pollution. Moreover, waste resources can be captured to provide access to a reliable local fuel source that may displace fossil fuel use for landfill operations, for electricity production or heating (US EPA, 2008; US EPA, 2006).

The high percentage of organic waste in municipal solid waste streams presents a considerable opportunity of turning waste in a valorised resource (UNESCAP, 2015). **Composting** can have important environmental and agricultural benefits when applied to the soil, increasing nutrients and moisture, improving plant quality and soil structure (UNESCAP, 2013). Using compost reduces the need for chemical fertiliser, while increasing crop yields, hence reducing farmers' expenses and benefitting both the environment and food security (UNESCAP, 2015). Recycling of organic waste in a decentralised and pro-poor manner can provide important livelihood opportunities for rural communities by creating formal job opportunities at better working

[5] https://www.alibaba.com/product-detail/Zameen-Dost_119419833.html

conditions, reduce the spread of vectors, diseases and odours and improve hygiene, reducing cost of landfilling and improving crop yields through organic fertiliser (UNESCAP, 2013). Experience from community-led waste management projects show that composting systems can empower communities and women in particular, who often make up the largest group of waste pickers and benefit from better working conditions, a formal income and better health (UNFCCC, 2005).

Experience from decentralised and integrated resource recovery centres (IRRCs) show that "every ton of CO2e reduced composting projects in developing countries can generate co-benefits in a range between USD 93.82 and USD 184.21 [excluding benefits] related to public health arising from avoided pollution and spread of diseases" (UNESCAP, 2015) These social, economic and environmental benefits include job creation and additional income for waste pickers employed in compost plants, many of which are women; municipal cost savings related to avoided landfilling; savings in chemical fertiliser use (25 per cent reduction), savings in fertiliser subsidies, and increased crop yields (UNESCAP, 2015: 25). The first Pakistani IRRC promoted by the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) was launched in September 2015 in Islamabad and will undoubtedly generate similar co-benefits (see Table 10).

Table **10**: Co-benefits of waste options

Legend: ● Highly positive; ◓ Positive; ▬ Neutral / Minor impact; ◡ Negative; ◓◡ Uncertain / policy specific; * Indirect	Climate			Economic			Social				Environment	
	Abatement potential	Abatement cost (2020	Climate resilience	GDP / macroeconomic	Energy security	End-user impact (cost	Employment	Working conditions	Health	Gender equality	Reduced air pollution	Waste stream (water /solid)
Landfill gas Collecting landfill gas for energy use by drilling vertical wells			Neutral / Minor impact	Neutral / Minor impact	Positive	Positive	Positive	Neutral / Minor impact	Positive *	Neutral / Minor impact	Positive	Highly positive
Compost Composting collected municipal solid waste in facilities connected to landfills			Neutral / Minor impact	Positive	Neutral / Minor impact	Highly positive	Highly positive	Positive	Positive	Positive	Positive	Highly positive

6.6 Climate Resilience Impacts

The main element to consider for these options to be safe from the impact of climate change is that the facilities they are located at should not be in (future) flood zones.

7 POTENTIAL POLICY MEASURES AND INSTRUMENTS

Figure 3: Elements needed for successful landfill gas or compost projects

The two selected options are relatively similar in terms of what they need and of how they can be organised. Their requirements can essentially be placed into three categories, as illustrated in Figure 3. First they need to **secure** a **supply** of waste through sorting and collecting. Second, they need to **finance** their **infrastructure**, namely sanitary landfills and their supporting infrastructure such as sorting installations and gas pipelines for distribution. Third, they need to **conquer** the **market** to generate revenue to support their operational costs and recover the investment in infrastructure. This mix of roles and focuses means that one interesting possibility to organise the chosen options is to create PPPs in the form of joint ventures such as Lahore Compost Limited, as already discussed in Section 6.4 Costs. Having such a partnership would increase the chances of raising the capital necessary to finance the infrastructure. It would also allow the parties to focus on the elements they can deliver best. Securing the supply requires a large-scale, sustained effort that needs to reach millions of households for many years, which makes local governmental organisations a good fit as a task leader. In contrast, the market for products (fertiliser, heat, electricity) requires competing against many established players and requires a certain degree of reactivity and flexibility. As such, private companies are a good fit to take the lead. Both these leading roles can be supplemented by a supporting role from the other party: Private parties can also participate in awareness efforts (for example by emphasising the origin of their products) and government institutions help set up the right market conditions for the generated products.

7.1 Secure supply

To secure a steady and large volume of supply, one needs to ensure that the collection rates of municipal solid waste increase from their current levels. This involves both actions from households and companies that should throw their waste into proper collection facilities, as well as from collecting organisations that need to collect the waste and deliver it at processing facilities. Financial actions can be to allow different tipping fees (i.e. the fee that the waste producer pays to the waste management company). This would make it financially interesting to bring waste to compost or landfill gas treatment facilities (UNESCAP, 2015).

For compost, the waste also needs to be sorted. Recyclable elements such as glass, metals, plastics and (clean) paper are valuable on their own and should not be composted[6]. This separation can either happen at the household level (with separate bins for waste), or in a central facility. The choice between sorting at a household level or centrally is not a straightforward one and depends on the local situation. Some of the elements to take into account are the composition off the waste (share of recyclable elements and of elements suitable for compost), the level of knowledge and willingness to comply of households, as well as the collection network configuration (density of possible sorting hubs, for example) (Richard, 1996).

In the case where sorting at the household level is chosen, some actions around awareness need to be taken. Households need to know that they are expected to separate waste, they need to know how to separate waste (which things go into which bins), they need convenient ways to sort their waste (accessible bins that are regularly emptied to avoid situations where people cannot deposit paper because the bins for paper are already full), and they need to be shown the benefits of separating waste (lower fees for them, a better local environment, attractive products generated). The degree of effort needed and chances of success are a key element to decide where the separation needs to take place (see above). If this effort is too large compared to the benefits of sorting at the collection point[7], then separation should happen at a central facility.

These elements (awareness, knowledge, convenience of infrastructure, and willingness to cooperate) need to be present anyway in order to increase collection rates, but they each have lower thresholds for simple collection than for sorting at the collection point. As for collecting organisations (which also include individuals making a living of collecting waste), they can be financially incentivised to deliver waste to the compost or landfill gas by getting more interesting prices than other options they might have. These interesting prices would be supported by the end products that bring in the revenue (fertiliser, heat, electricity).

7.2 Finance infrastructure

As previously mentioned, they key missing element for the options mentioned here is to have proper waste management, namely sanitary landfills. The key challenge here is to secure relatively large amounts of investments, as each facility would need to have a relatively large scale to be profitable.

Having a proper assessment of the amount of waste that will be collected is an important aspect to decide on the size of the treatment facility, as too large a facility would require importing waste

[6] Some elements do not contain organic matter and would not increase compost yield anyway
[7] In some cases, there can be no benefits and separation at a central facility can be better regardless of issues of getting households to properly sort their waste, as was discussed in the previous paragraph

from other locations, while a too small facility would fail to capture all the potential value of the waste stream an might not be profitable (Richard, 1996).

The key solution to this issue is to ensure that the value of these facilities is clear, especially in terms of potential revenues. Having a good potential business case in place will help bring various partners (private sector, but also possibly international players) on board to build the necessary infrastructure.

7.3 Conquer market

One of the identified causes for the failure of compost plants is the lack of attention given to marketing the end product (UNESCAP, 2013). As was explained in Section 6.4 Costs, Lahore Compost Limited actually made considerable marketing efforts. This is a good indication that partnering with private companies can help solve some of the issues landfill gas and compost installations might face to produce a profit. Such a partnership ensures that the end products (fertiliser, heat, electricity) benefit from all the tools (marketing, flexibility in pricing) as their widespread competition does. Public entities also have a role here: They can ensure that the generated products enter the market with favourable conditions. Concretely, this can mean the creation of feed-in tariffs, i.e. a requirement for utilities to purchase the electricity produced at the site, with long-term contracts that reflect the production costs for electricity from waste. Setting these tariffs at the right (UNESCAP, 2015).

A specific decision that needs to be made for compost is regulating its quality. This will balance the amount of contaminants that are allowed in the compost (and the associated environmental impact) versus an increased yield, since setting higher quality standards would mean rejecting more of the collected waste, thereby reducing revenue. This decision needs to take into account characteristics such as the waste composition, the business case for the compost facilities, and the possibility of taking mitigation measures (such as recycling and removing toxic products form the waste stream) (Richard, 1996). This decision about quality can also be turned into an advantage for compost-based fertilisers, as federal and local government entities could introduce standards, quotas, or procurement criteria (i.e. they would require that sustainable fertilisers are used for products they purchase) for sustainable fertilisers such as compost-based ones (IEA, 2009).

8 CONCLUSIONS

Composting waste and reclaiming landfill gas have the potential to save about 0.75 million tonnes CO_{2e} per year by 2030. This potential can only be reached with a great effort that would represent a dramatic change of what waste management is in Pakistan. This is particularly challenging, given the lack of current waste management in Pakistan. For this reason, it is important not to consider the options solely as ways of reducing greenhouse gas emissions. Rather, they should be viewed as an extra benefit of an effort that would bring a better environment to Pakistani citizens, with great health benefits, some good side economic benefits brought by compost and landfill gas.

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