Development of a Framework for Assessing Sustainability Benefits of Landfill Gas Clean Development Mechanism (CDM) Projects

By

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ABSTRACT

The twin objectives of the Clean Development Mechanism (CDM) are to assist developing country host nations in achieving sustainable development, and to assist developed countries in meeting their greenhouse gases (GHG) emission reduction targets. This is achieved through implementing GHG abatement projects in developing countries. There has been increased attention in the contribution of CDM projects to sustainable development in host nations. Previous research has suggested that, when left to market forces, the CDM does not contribute effectively to sustainable development. One likely reason is that host nations define and evaluate projects contribution to sustainable development. This has led to a “race to bottom” with regard to setting sustainability standards triggered by a concern that project developers prioritise CDM investments in countries with lower sustainability standards. Researchers have identified the need for an international standard for assessing sustainable development benefits of CDM projects. The main aim of this research was to develop an international level framework for assessing sustainable development benefits of CDM projects with a specific focus on landfill gas (LFG) projects.

An in-depth literature review was carried out to establish the link between sustainable development benefits of CDM projects in general, and LFG CDM projects in particular. A case study methodology was used to develop an understanding of landfill management practices at three existing landfill sites both in developed (n=1) and developing countries (n=2). The results from the literature review and case studies were utilized to develop the framework for assessing sustainable development benefits of LFG CDM projects. The developed framework comprises three sustainable development dimensions and 12 criteria with 16 matching indicators. Such a project specific assessment framework has not previously been developed. The results from the validation of the framework suggested that technology transfer is the most likely benefit of any LFG CDM project while balance of payments is the least likely benefit. The proposed framework can be utilised at two stages in a CDM project lifecycle. It can be used as: (i) a template to guide host nations’ Designated National Authorities (DNAs) on how to review projects before issuing Letters of Approval (LoA); and (ii) Designated Operating Entities (DOEs) can also use the developed framework to validate and verify that sustainable development benefits stated in project proposals have been realised at the project level.

Key words: Clean Development Mechanism (CDM), landfill gas, sustainable development, Kyoto Protocol

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

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DEDICATION

- To my late parents, whose prayers were to see not only me as their last born child to succeed in life, but all their children.

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ABBREVIATIONS

BOD:	Biochemical Oxygen Demand
BoP:	Balance of Payments
CDM:	Clean Development Mechanism
CERs:	Certified Emission Reductions
COD:	Chemical Oxygen Demand
DANIDA:	Danish International Development Agency
DNA:	Designated National Authority
DOE:	Designated Operating Entity
DME:	Department of Minerals and Energy
DWAF:	Department of Water Affairs and Forestry
EB:	Executive Board
EC:	European Community
EEC:	European Economic Community
EPA:	Environmental Protection Agency
EU:	European Union
FML:	Flexible Membrane Liner
FOD:	First Order Decay
GHG:	Greenhouse Gas
HDPE:	High Density Polyethylene
HFCs:	Hydrofluorocarbons
IPCC:	Inter governmental Panel on Climate Change
ISWA:	International Solid Waste Association
KP:	Kyoto Protocol
LFG:	Landfill Gas
LoA:	Letter of Approval
MATA-CDM:	Multi-Attribute Assessment -CDM
MCA:	Multi-Criteria Analysis

MoE:	Ministry of Economy
MEDEP:	Ministry of Energy, Development and Environmental Protection
MENR:	Ministry of Ecology and Natural Resources
MEP:	Ministry of Environment Protection
MEPNR:	Ministry of Environment Protection and Natural Resources
MNP:	Ministry of Nature Protection
MSTI:	Ministry of Science, Technology and Innovation
MSW:	Municipal Solid Waste
MW:	Mega watts
NDRC:	National Development and Reform Commission (NDRC)
PDD:	Project Design Document
PVC:	Poly Vinyl Chloride
QUEROLS:	Quantified Emission Limitation & Reduction Commitments
RCRA:	Resource Conservation and Recovery Act
SA:	South Africa
SD:	Sustainable Development
UK:	United Kingdom
UN:	United Nations
UNCED:	United Nations Conference on Environment and Development
UNCHE:	United Nations Conference on Human Environment
UNEP:	United Nations Environment Programme
UNESCAP:	United Nations Economic and Social Commission for Asia and the Pacific
UNFCCC:	United Nations Framework Convention on Climate Change
USA:	United States of America
USEPA:	United States Environmental Protection Agency
WCED:	World Conservation on Environment and Development

GLOSSARY

Additionality: The effect of the CDM project activity to reduce anthropogenic GHG emissions below the level that would have occurred in the absence of the CDM project activity.

Annex 1 countries: A group of countries included in Annex I (as amended in 1998) to the UNFCCC, including all the OECD countries and economies in transition.

CDM Executive Board: The CDM EB supervises the CDM under the authority and guidance of the Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol (COP/MOP).

CDM project participant: A Party involved in a CDM project with letter of approval (LoA) from a Kyoto Protocol Party.

CERs: A type of emissions unit (or carbon credits) issued by the CDM Executive Board for emission reductions achieved by CDM projects and verified by a DOE under the rules of the Kyoto Protocol.

Clean Development Mechanism: A Kyoto Protocol mechanism that aims to help developed countries listed in Annex 1 to cost-effectively meet part of their emission reduction targets under the Protocol, and to assist the Protocol's developing country Parties in achieving sustainable development.

DNA: The DNA is the authority in the host country in charge of reviewing and approving CDM projects. The DNA has to issue a Letter of Approval (LoA) to project participants confirming that the project contributes to sustainable development in the host country.

DOE: An independent auditor accredited by the CDM Executive Board (CDM EB) to validate project proposals or verify whether implemented projects have achieved planned greenhouse gas emission reductions.

Economic Benefits: Benefits that provides financial returns to entities, results in positive impact on balance of payments, and transfers new technology.

Environmental Benefits: Benefits that leads to reductions in air, land and water pollution, conserves local resources, and provides health and other environmental benefits.

GHG: A gas in the atmosphere that absorbs and emits radiation within the thermal infrared range.

Hazardous landfill: A landfill which contains hazardous primarily hazardous waste.

Host country or nation: A country where a CDM project is implemented

Kyoto Protocol: A Protocol to the UNFCCC adopted at the third Conference of the Parties (COP 3) in Kyoto, Japan in 1997.

The Protocol sets binding commitments to developed countries and economies in transition, listed in Annex B, to reduce their GHG emissions by an average of 5.2 per cent on 1990 levels (the first commitment period, 2008 - 2012) and an average of 18 per cent on 1990 levels (the second commitment period, 2013 – 2020) .

Kyoto GHGs: These are the seven greenhouse gases that are eligible for reduction under the Kyoto Protocol comprising of Carbon dioxide (CO_2), Methane (CH_4, Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulphur hexafluoride (SF), and Nitrogen trifluoride (NF_3),

Landfill Aftercare: The management of a closed landfill (typically monitoring, maintenance, and treatment of emissions) until no more measures are necessary (landfill aftercare = landfill post-closure care).

Landfill closure: The point where the landfill has reached the layout according to the aftercare requirements (i.e., installation of top cover) and is transferred to the aftercare period.

Landfill gas CDM projects: CDM projects at landfill sites that collect, treat and/or utilise the landfill gas generated by the biodegradation of the landfilled solid waste. In this study, the terms "landfill gas CDM projects" and "CDM projects at landfill sites" refer to these types of projects.

Landfill gas: A gas generated by the decomposition of biodegradable waste that has been landfilled and predominantly comprises of methane and carbon dioxide gases with some trace compounds.

Landfill operational period: The time period during which waste is deposited at the landfill.

Landfill owner or operator: The individual who owns or has operated the landfill and is responsible for landfill management (landfill owner = landfill operator).

Landfill stability or compatibility: A status when no further management is required and occurs when concentrations of potential concern have reached levels that are no longer detrimental to human health and the environment.

Landfill: The disposal of waste into or onto land

Leachate: A liquid generated in a landfill that contains dissolved and/or suspended contaminants from the deposited waste.

Letter of Approval: A letter written by a developing country host nation DNA confirming that the proposed project activity contributes to sustainable development in the country.

MSW landfill: A landfill which contains primarily municipal solid waste (MSW). In developing countries, such landfills may contain hazardous waste as well due to lack of segregation of waste types prior to disposal (disposal of co-mingled waste).

Non-Annex 1 countries: The countries that have ratified or acceded to the UNFCCC but are not included in Annex I.

Open dumping: An uncovered site used for disposal of waste without environmental controls.

Sanitary landfill: A type of landfill where waste is isolated from the environment until it is safe.

Social Benefits: Benefits that improve the quality of life, alleviates poverty and improves equity.

Sustainable Development: A type of development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs.

Sustainable Landfill: Landfill practice that protects human health and the environment, minimises the burden on future generations, and a practices that conserves natural resources.

CHAPTER 1 : INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Landfill remains the dominant option for waste management in many parts of the world (US EPA, 2012a). The comparatively high costs of other waste management alternatives such as incineration and gasification, particularly in developing countries, is one of the reasons for the heavy reliance on this management option (Laner et al., 2011). Although the use of landfill as the main waste management option is declining in Europe due to increasing regulation, landfill will continue to play a role in disposing of residue wastes in future waste management systems (AGMA, 2012). Even proponents of zero waste acknowledge that landfill may ultimately be the best option for certain types of waste (Williams and Curran, 2010). In 2009, 80 % of the generated municipal solid waste (MSW) in China was landfilled (Dong, 2011) and over 90 % in South Africa in 2011 (DEA, 2012). This contrasts markedly with Europe (EU27) where 34 % was sent to landfill in 2012 with Germany having the lowest rate of less than 0.5 % (Eurostat, 2014).

Globally, landfills are the third largest anthropogenic sources of methane (CH_4) (US EPA, 2012a) – a greenhouse gas (GHG) with a global warming potential (GWP) that is 25 times the global warming potential of carbon dioxide (CO_2) over a 100 year time horizon (IPCC, 2007). Landfill gas (LFG) comprises of methane and carbon dioxide gas with some organic trace compounds (Reinhart and Townsend, 1997). This gas has the potential to impact locally on the health and safety of communities. In the absence of proper gas management (e.g., venting, flaring, and energy generation), LFG can lead to explosions if concentrations rise to 5-15 % by volume in atmospheric air (Munawar and Fellner, 2013). The organic trace compounds in LFG can cause local as well as global environmental problems (e.g., unpleasant odours, ozone depletion or smog due to ground level ozone nitrogen-oxide reactions) (Barker, 2008). The other main emission of concern from landfills is leachate (Randerson et al., 2010). This is a liquid produced by the organic decomposition and compaction of wet refuse, with the infiltration of rain water/snow (Agamuthu, 2013). The major impacts associated with leachate are the pollution of both ground and surface water. Historically, the risk of groundwater pollution from landfill leachate was the most severe environmental impact because policies and regulations did not require the installation of engineered liners and leachate collection and treatment systems (Kjeldsen et al., 2002). Most landfill sites were developed on a 'dilute and attenuation' basis. As biochemical processes in landfills continue for many years and even decades after closure, negative impacts continue to occur beyond the site closure (Stief, 2001).

Over the last 15 years, increased awareness of environmental impacts associated with landfills has led to the introduction of legislation targeting waste management in developed countries. These regulations dictate the design, operation, and management of landfills. For instance, the European Union (EU) Waste Framework Directive (75/44/EEC) as amended by 2008/98/EC relates to the protection of the environment from the harmful effects of waste disposal on landfills. In particular, the directive encourages the recovery and use of waste in order to conserve natural resources. The introduction of other legislation such as the Landfill Directive (1999/31/EC), which aims to achieve sustainable landfilling by permitting the landfill disposal of predominantly inorganic wastes, and the Restriction of Hazardous Substances (2002/95/EC) has resulted in operational and management practices becoming progressively more stringent (Morris and Crest, 2011). Within the EU, all modern landfills are now fully engineered and require: (i) containment systems; (ii) facilities for collection and treatment of LFG and leachates; (iii) control systems with monitoring; and (iv) end of life maintenance programmes (aftercare).

In the spirit of the Brundtland report (WCED, 1987), inter-generation equity requires that today's landfills should not leave environmental legacies for future generations. It is generally accepted that sustainable development should "meet the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Therefore, every generation should endeavor to solve its own problems: a maximum of 30 years is assumed as a period for each generation (Scharff, 2006). Regulations in the developed world now specify a minimum period of "aftercare" once a landfill site ceases to operate. Within the EU, the Landfill Directive (1999/31/EC) specifies a 30 year aftercare period (which equates to a generation) as a basis for the build-up of financial provisions and monitoring unless the period is shortened or extended by the regulatory agency on a site-specific basis. Similarly, in the US, Subtitle D of the Resource Conservation and Recovery Act (RCRA) (USEPA, 1991) specifies a 30 year aftercare period as a basis for the build-up of financial provisions.

Although, landfill remains the dominant waste management option in the developing world, policies, regulations and technologies required to mitigate their impact often do not exist. Consequently, many sites remain poorly managed and operated, which leads to serious negative impacts on both human health and the environment. A projection by the United

States Environment Protection Agency (US EPA, 2006) suggested that Africa followed by China will have the highest MSW emissions by 2020.

It is a combination of financial and technical barriers which makes it difficult for many landfill operators to install and maintain adequate control systems (UNESCAP, 2007). For example, in many African countries, there is a combination of factors influencing the operation of landfills. The reasons are either: (i) inadequate technical skills and infrastructure; (ii) insufficient legislation on the treatment of waste; (iii) little or no enforcement where it does exist; or (iv) where there is enforcement, they frequently do not prescribe any aftercare. This results in closed landfill sites being left unmanaged with passive gas venting and dispersion of leachate into the surrounding environment.

Albeit at a slow pace, improved waste management practices are being implemented in some developing countries such as China, South Africa, and in Latin America (US EPA, 2012b). These countries have initiated plans to properly site, design, and construct landfills in line with new landfill guidelines that have been prepared. Currently, China has regulations in place to deal with the management of landfills (Standard for Pollution Control on the Landfill Site of Municipal Solid Waste (GB 16889-2008)). The standard stipulates requirements for the siting, design and construction, conditions for wastes eligible for landfill and pollution control and monitoring during operation, close down and post maintenance of municipal solid waste landfill sites. As a result of these new regulations, a number of landfill sites have been commissioned in China with design standards and construction on par with international standards (Haiyun, 2008).

South Africa is one African country that has put in place specific legislation for managing waste disposal sites and minimum regulatory requirements for the management of waste disposal sites through the *"Minimum Requirements for Waste Disposal by Landfill"* (DWAF, 1998). The minimum requirements have the following objectives: (i) to improve the standard of waste disposal; (ii) to provide guidelines for environmentally acceptable waste disposal for a spectrum of landfill sizes and types; and (iii) to provide a framework of minimum waste disposal standards within which to work and upon which to build. All new landfills must comply with the minimum requirements while existing ones must close if they fail to do so within an agreed period. All landfill sites closed after August 1990, when the permitting system came into force, are subject to the minimum requirements. Depending on their potential environmental impact, landfill sites closed prior to August 1990 may be required to be rehabilitated in terms of the minimum requirements. Although, the period is not stated, aftercare of landfill sites that had ceased operations is a requirement under the new legislation. The aftercare stipulated states that “ongoing inspections and maintenance are required after site closure to ensure that problems do not continue unidentified and unabated and that the End-use-Design is properly implemented.” Within Zambia, although legislation exists that directly relates to waste disposal, there is none that refers to landfills. Consequently, many landfill sites are operated as ‘open dumps’ or semi - managed dumpsites with associated environmental, health, and safety issues.

As developing countries shift from open dumping towards more managed landfill practices (Agamuthu, 2013), an environment is created that becomes more anaerobic within the waste. This increases the production of methane gas from the landfill site (Cooper, 2012; UNEP, 2010). Emission mitigation of the generated methane gas at these managed disposal sites presents an opportunity for developing countries to both earn revenue and access advanced landfill technology. This has the potential to allow improvements in the way landfill sites are managed and operated. This opportunity exists through market mechanisms such as the Clean Development Mechanism (CDM). The CDM has been defined in Article 12 of the Kyoto Protocol (KP) (UN, 1998) and aims to achieve two objectives: (i) to help developed countries listed in Annex 1 of the KP to cost-effectively meet part of their emission reduction targets under the Protocol; and (ii) to assist non-Annex I Parties (developing countries) in achieving sustainable development (SD). Using the CDM, landfill operators in developing countries have recognized the benefits associated with implementing landfill gas mitigation CDM projects at their sites. Since 2001, when the rules for implementing the KP were adopted (Marrakech Accords, 2001) and since Russia’s ratification allowing the entry into force of the Protocol on 16th February 2005 (UNFCCC, 2014), landfill gas CDM projects have been implemented in developing country host nations. The Nova Gerar LFG CDM project in Brazil was the first project to be registered in 2004 (UNFCCC, 2004). As of 1st March, 2014, landfill gas projects accounted for 5 % of the 7, 500 registered CDM projects (UNEP Risoe Centre, 2014b).

It should be noted that the CDM has not been without its challenges (Gillenwater and Seres, 2011). Concerns have been raised regarding the contribution of CDM projects, including landfill gas, to the host nations’ sustainable development (Subbarao and Lloyd, 2011). Although, CDM projects aim to bring dual benefits in terms of climate change mitigation and sustainable development in recipient countries, trade–offs exist between these two objectives. This has manifested itself in the dominance of cost-efficient GHG emission reductions (Torvanger et al., 2012). While over 200 methodologies (UNEP Risoe Centre, 2014a) have been developed for determining, reporting, monitoring, and verifying GHG emission reductions for various CDM projects, none exist for determining and monitoring sustainable development (Shishlov and Bellassen, 2012; Wang et al., 2013). The widely used checklist approach based on congruence with existing sustainable development national policies for approving CDM projects has been critiqued by some researchers (Figueres, 2004; Kolshus et al., 2001). They have argued that the use of existing policies that are not climate friendly (e.g., programs that support the exploitation of non-renewable resources such as fossil fuels) has been instrumental for the minimal achievement of sustainable development benefits by CDM projects at an operational level. This has led to a call by many researchers for an international standard or framework for assessing CDM projects' contribution to sustainable development (Olsen and Fenhann, 2008; Sutter, 2003; Thorne and La Rovere, 1999).

1.2 RESEARCH AIMS, OBJECTIVES AND QUESTIONS

To address the identified gap in literature, research aims, objectives and questions have been developed. The three research aims are:

(i) To critically evaluate the role of landfill in waste management and assess existing landfill management practices during operation and aftercare in both developed and developing countries;

(ii) To review and evaluate existing methodologies for assessing sustainable development benefits of CDM projects; and

(iii) To develop a framework for assessing sustainable development benefits of LFG CDM projects.

Specific objectives are:

(i) To assess and report on existing landfill management practices during operation and aftercare in both developed and developing countries;

(ii) To assess the main factors affecting the management of landfills including aftercare in developed and developing countries;

(iii) To assess the potential sustainable development benefits of implementing LFG CDM projects at landfill sites in developing countries;

(iv) To ascertain and report on existing sustainability methodologies used by developing country host nations' designated national authorities (DNAs) in approving CDM projects;

(v) To validate the developed framework (for uptake by both DNAs and DOEs) by using it to assess the achievement of sustainable development benefits by LFG CDM projects registered with the CDM Executive Board (EB).

The relationship between research aims, subordinate objectives, and research questions is shown in Table 1.1. The research questions set the boundaries for the research study and determine the appropriate methods to be used in the collection and analysis of data (Corbin and Strauss, 2008).

Table 1.1: Research Aims, Objectives and Questions

Research Aims	Research Objectives	Research Questions (RQs)
(i) To critically evaluate the role of landfill in waste management and assess existing landfill management practices during operation and aftercare in both developed and developing countries	(i) Assess and report on existing landfill management practices during operation and aftercare in both developed and developing countries	**RQ1:** What role does landfill play in the management of solid waste and what are the main factors affecting their management including aftercare in both developed and developing countries?
	(ii) Assess the main factors affecting the management of landfills including aftercare in developed and developing countries	
	(iii) Assess the potential benefits of implementing LFG CDM projects at landfill sites in developing countries	**RQ2**: Can LFG CDM projects play a beneficial role in the management of landfill sites during both the operation and aftercare periods in developing countries?
(ii) To review and evaluate existing methodologies for assessing sustainable development benefits of CDM projects	(iv) Ascertain and report on existing sustainability methodologies used by developing country host nations' designated national authorities (DNAs) in approving CDM projects	**RQ3:** Are existing sustainable development criteria or methodologies used by developing countries DNAs adequate?
(iii) To develop a framework for assessing sustainable development benefits of LFG CDM projects	(v) Validate the developed framework (for uptake by both DNAs and DOEs) by using it to assess the achievement of sustainable development benefits by LFG CDM projects registered with the CDM Executive Board	**RQ4:** Is there a need to address current approaches on how LFG CDM projects are assessed with regard to their contribution to sustainable development in host nations?
		RQ5: Are registered LFGCDM projects achieving sustainable development benefits in host nations as claimed in their project design documents (PDDs)?

1.2.1 Research Programme

The research programme comprised five stages as shown in Figure 1.1. The five research stages and the research approaches adopted to address the objectives of each stage are explained in Chapter 3 of the thesis.

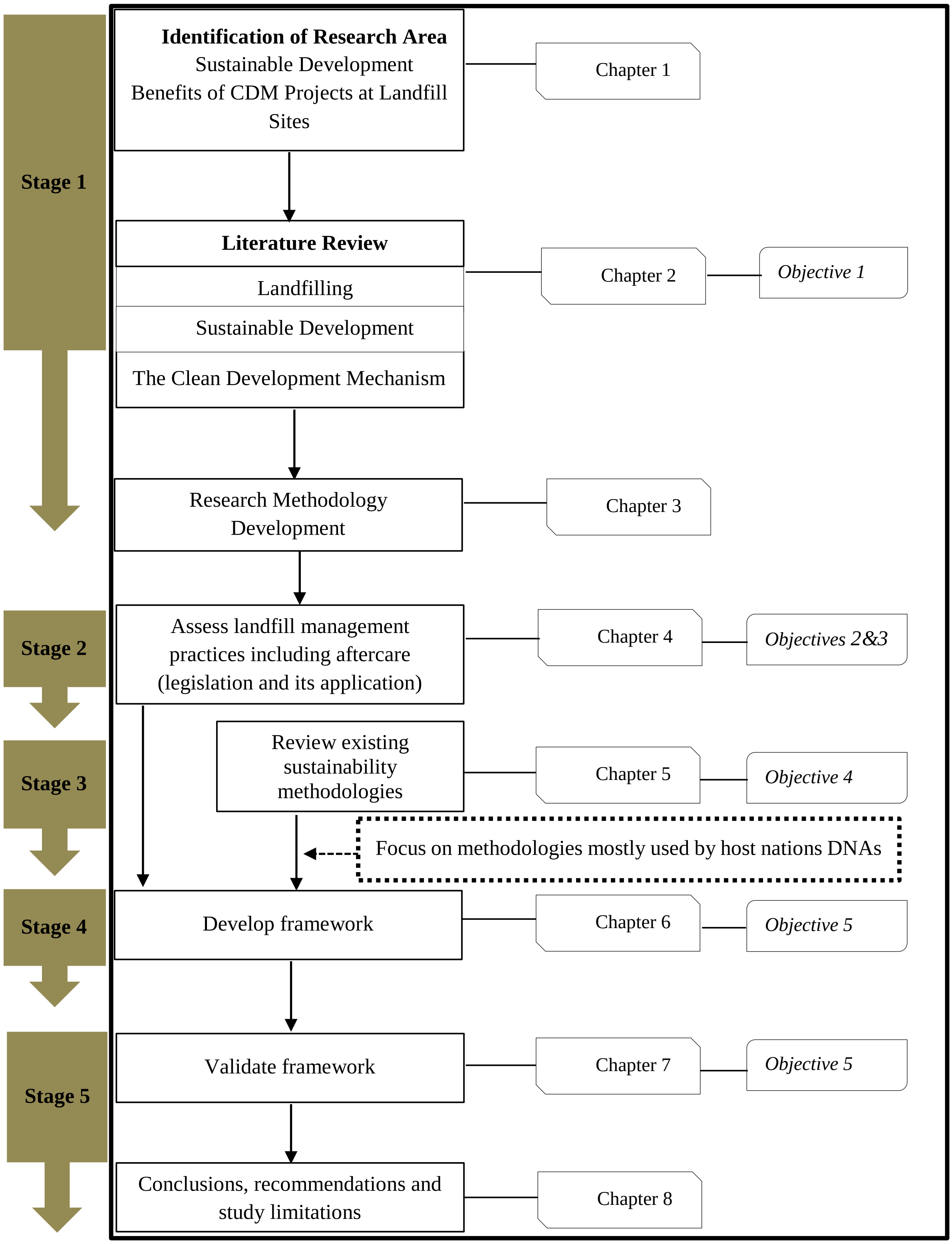


Figure 1.1: Research Flow and Outputs

1.3 SCOPE OF THE RESEARCH STUDY

As mentioned in section 1.1, the CDM aims to assist developed countries listed in Annex 1 of the Kyoto Protocol to cost-effectively meet part of their emission reduction targets. It also aims to assist developing countries without Kyoto targets in achieving sustainable development (SD). According to the UNEP Risoe Centre (2014), there are 26 projects types that are eligible under the CDM. These project types can reduce or avoid emissions of the seven Kyoto GHGs below the level projected in the absence of a CDM project. These projects are further subdivided into project sub-types. The focus of this study is on sustainable development benefits of landfill gas CDM project types. The landfill gas CDM project type category includes composting, incineration, gasification, and combustion of municipal solid waste (MSW). Other potential project categories such as re-use and recycling do not yet have approved CDM methodologies to value their GHG emission savings (Couth and Trois, 2012). However, since waste disposal to landfill remains the dominant waste management option in most developing countries (section 1.1), this study is concerned only with landfill gas CDM projects that involve the collection, treatment and/or utilization (flaring or energy generation) of the landfill gas generated by the biodegradation of solid waste that has been disposed of at a landfill.

1.4 STRUCTURE OF THE THESIS

This thesis consists of nine chapters which are summarised as follows:

- **Chapter 1** provides the introduction to the thesis. It gives the background and justification for selecting the particular research topic for this study. This chapter lays out the research questions and the aim and objectives of the research. An outline of the research flow throughout the five stages of the research study is presented.

- **Chapter 2** provides a review of the literature on the focus areas of the research consisting of landfill, sustainable development, and the Clean Development Mechanism. A review of the role of landfill in waste management is provided along with the different landfill definitions and classifications that have been given by various researchers. A review of the origins of sustainable development is presented along with the prevailing confusion around the use of the concept. Finally, a background to the CDM and its role in climate change mitigation is given and so is the relationship between CDM projects and sustainable developments of projects at landfill sites is given. The chapter addresses the first research aim, objective one, and research question (RQ) number one.

- **Chapter 3** presents the research methodology used to achieve the aim and objectives stated in section 1.2. The philosophical stance of the researcher is explained in this chapter. An overview of different research approaches and methods used throughout the research process along with the rationale for their selection are given.

- **Chapter 4** presents findings in relation to existing landfill legislation and its application by observing management practices at existing landfill sites in both developed and developing countries. It also presents findings in relation to the potential sustainability benefits that can be accrued by implementing CDM projects at sites in developing countries. This chapter addresses objectives one and two, and research questions one and two (section 1.2).

- **Chapter 5** presents the findings from a review of sustainability methodologies used by host nations DNAs in approving CDM projects. These findings are utilised in the development of a framework for assessing sustainable development benefits of CDM projects at landfill sites. This chapter addresses the second research aim, objective four, and research question three.

- **Chapter 6** presents the developed framework based on the findings from previous stages of the research. This is the third and main output of the research and fulfils research objective five and research question number five.

- **Chapter 7** validates the developed framework by using it to assess the achievement of sustainable development benefits of landfill CDM projects registered with the CDM Board. The framework was validated by using PDDs and survey responses from project developers as sources of information. The chapter addresses research objective five and research question five.

- **Chapter 8** is a discussion of the findings from all five stages of the research study.

- **Chapter 9** presents the conclusions of the research. Recommendations for further research are also presented in this chapter.

CHAPTER 2 : LITERATURE REVIEW

2.1 INTRODUCTION

The management of solid waste is important to the protection of human health and the environment (Wilson et al., 2001). It is an area of concern both in the developed and developing world. At a global level, the decay of solid waste contributes 5 % of emitted greenhouse gases (gases that contribute to global warming) (UNEP, 2013). At a local level, uncollected solid waste may attract rodents and vector insects for which it provides food and shelter (UNEP, 2005b). These can transmit various pathogenic agents that can lead to public health impacts such as respiratory ailments, diarrhea and dengue fever (World Bank, 2012). Apart from contributing to flooding in cities due to blockage of drainage systems, uncollected solid waste may contribute to the deterioration of the local environmental quality in the form of foul odours and unsightliness (UNEP, 2005b).

Prior to the 19th century, the amount of waste generated both in developed and developing countries was relatively insignificant and could easily be dealt with due to low population density and low levels of exploitation of natural resources (Hester and Harrison, 2001). However, since the 19th century (Westlake, 1995), the growth in population, industrialization, urbanisation, and prosperity have all contributed to high levels of exploitation of natural resources and the rise in the amounts of waste being generated. For example, Williams (2013) reported that on average, we have used resources eight times faster since 1900. This has also led to an increase in waste complexity and hazardousness (UNEP, 2013). In 2012, the World Bank (2012) estimated that world cities generated approximately 1.3 billion tonnes of solid waste and suggested that this figure would increase to 2.2 billion by 2025. Over the next twenty years, waste generation rates are forecast to double in developing countries due to the burgeoning middle class (US EPA, 2012a; World Bank, 2012). It is therefore, of utmost importance that appropriate waste management options are adopted for these rapidly increasing urban populations.

This research focuses on landfill as a waste management option and the assessment of sustainable development (SD) benefits of landfill gas Clean Development Mechanism (CDM) projects in particular. Accordingly, the research draws from three main bodies of literature: (i) literature on landfill; (ii) literature on the CDM as it relates to landfill gas projects; and (iii) literature on sustainable development (SD) as it relates to landfill gas CDM projects. The chapter introduces elements and concepts that feature in the research study, which all fall within the life-cycle of landfills in most developed and developing countries (Figures 2.1 and 2.2). It fulfils Objective 1 and Research Question 1 of this research (see Table 1.1).

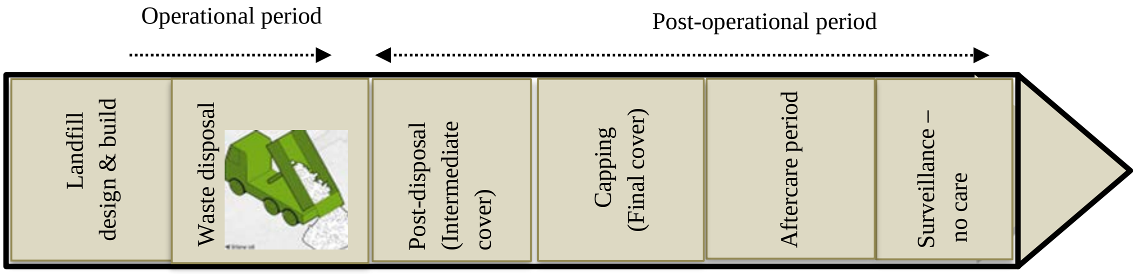


Figure 2.1: Landfill Life Cycle in Most Developed Countries (e.g., EU)

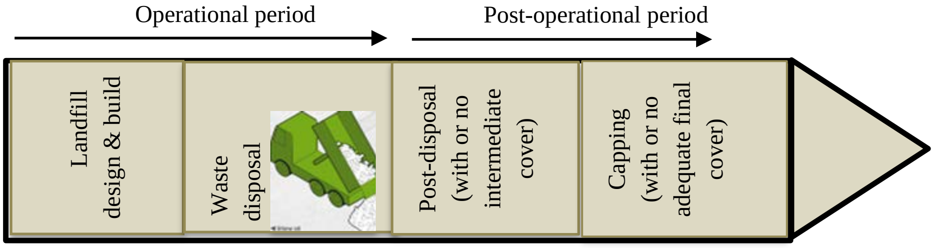


Figure 2.2: Landfill Life Cycle in Most Developing Countries (e.g., Zambia)

2.2 LANDFILL AND ITS ROLE IN WASTE MANAGEMENT

Landfill has played an important role in the management of solid waste and is likely to continue to be an important component of most waste management systems (EPA, 2010). Through landfill, the exposure of humans and the environment to the detrimental effects of solid waste is reduced (UNEP, 2005b). Although the implementation of the waste management hierarchy (Figure 2.3) in most developed countries has resulted in significant diversion of waste, landfill is still the most favored management option in the developing world. Landfill continues to play a key role in almost all solid waste management systems. It is the final repository of any city's waste after all other management options have been exercised (EPA, 2010; US EPA, 2012a; Williams, 2014). For example, final residues such as bottom and fly ash from waste incineration plants are still required to be disposed of in specific hazardous landfills. Landfill also acts as 'safety net' for other waste management options that may be experiencing temporary or permanent lack of capacity (Scharff, 2006).

In the event of temporary or insufficient capacity, landfills can reduce solid waste from being exposed to society.

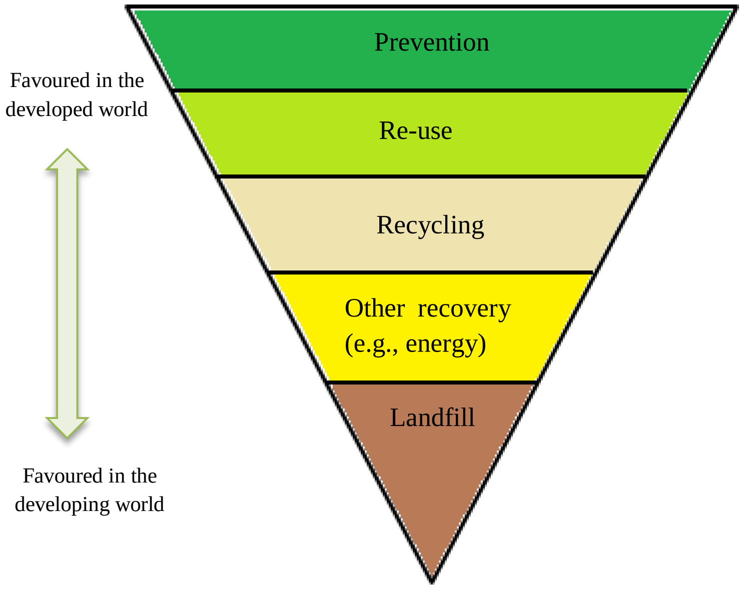


Figure 2.3: Waste Management Hierarchy

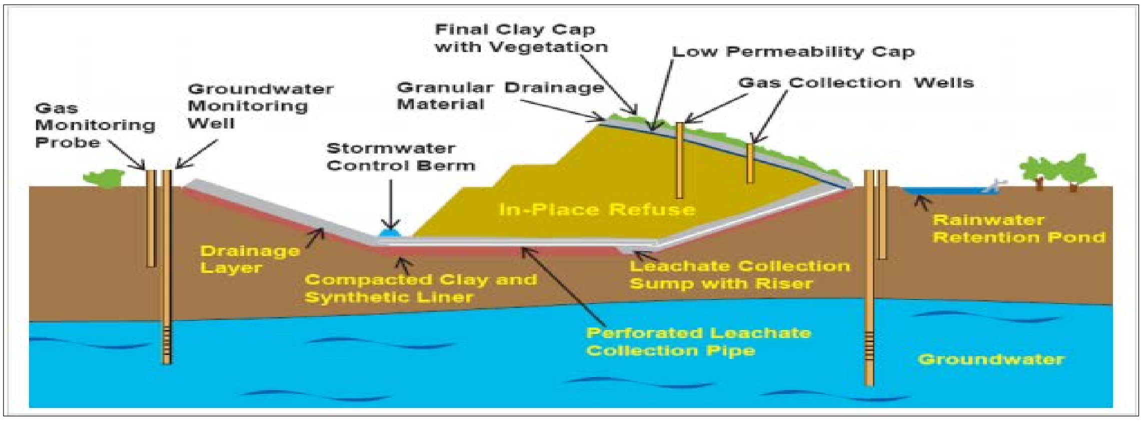
2.2.1 Definition of Landfill

The term ‘landfill’ has many definitions. Table 2.1 shows some of the definitions found in the literature. The different definitions have one thing in common - they call for the isolation of waste from the environment (Government Engineering, 2006). The main differences in the definitions are associated with the degree of isolation and the means of achieving it as well as the required monitoring and closure of the landfill and its maintenance during both the operational and aftercare periods (UNEP, 2005b). The degree of isolation required by legislation in developed countries (e.g., EU Landfill Directive of 1999) is usually much more stringent than would be practical in most developing countries.

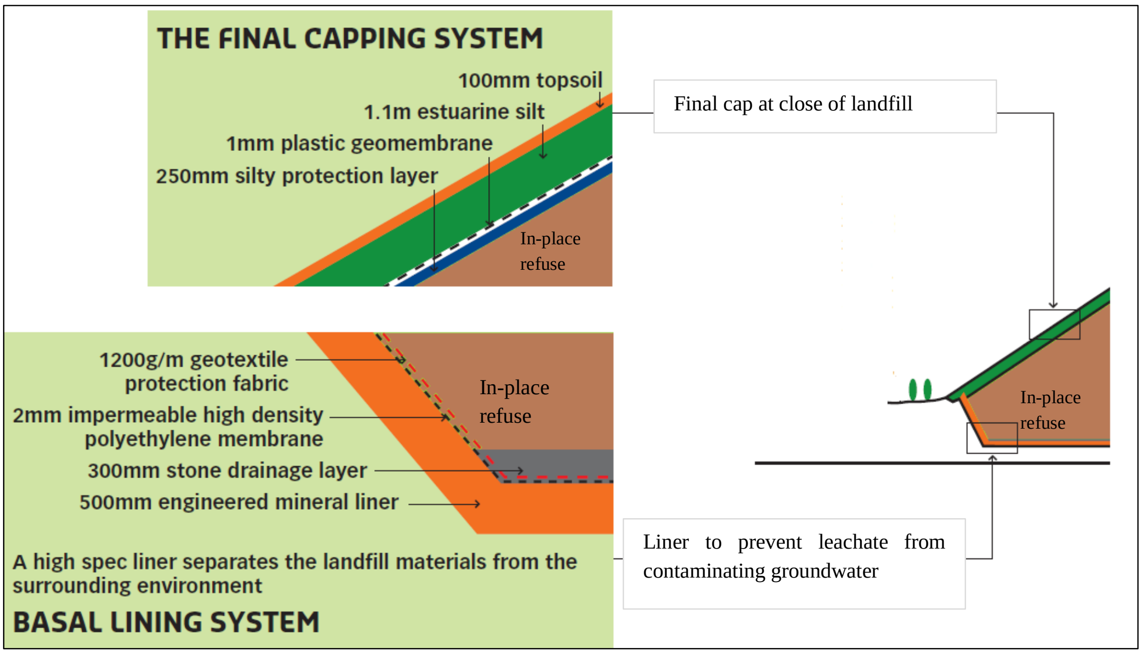
Table 2.1: Definitions of Landfill

Reference	Definition
Tammemagi (1999)	‘A confined and centralised location where collected waste materials are disposed of’
Skitt (1992)	‘The engineered deposit of waste onto and into land in such a way that pollution or harm to the environment is prevented and, through restoration, land provided which, may be used for another purpose’
CEC (1999)	‘A waste disposal site for the deposit of waste onto or into land’
EPA (2006)	‘An engineering method of disposing of solid waste on land’

Sanitary landfills are the primary solid waste disposal option in most developed countries designed and engineered to contain waste until it is stabilised biologically, chemically and physically (US EPA, 2012a). According to UNEP (2005b), for a landfill to be designated sanitary, the following three general but basic practices must be met: (i) compaction of the waste; (ii) daily cover application (with soil or other material) to remove it from the influence of the outside environment; and (iii) control and prevention of negative impacts on public health and the environment (e.g., odours, dust, surface and groundwater contamination etc.). When it closes, it must be capped. The main aim of sanitary landfills is to reduce the release of pollutants into the environment. Figure 2.4 shows the basic requirement of a sanitary landfill.



(a) Components of a Sanitary landfill



(b) Sanitary landfill containment system (bottom & top liners) as required under EU regulations

Figure 2.4: Aspects of a Sanitary Landfill (Adapted from US EPA, 2012 and SITA, 2009)

However, economic and technological constraints makes meeting all aspects of sanitary landfill requirements impractical in most developing countries. Most disposal sites in these countries are operated as uncontrolled open dumps. Joseph et al. (2000) defined an open dump as a “land disposal site at which solid wastes are disposed of in a manner, which does not protect the environment, is susceptible to open burning, and exposed to elements such as disease vectors and scavengers.” Such sites are often poor in terms of environmental performance and can pose public health concerns through emissions of air pollutants and leaching of waste constituents can pollute ground and surface water (US EPA, 2012a). Figure 2.5 is an example of an uncontrolled landfill site with waste pickers in Zambia.

Figure 2.5: Waste Pickers at Chunga (Open Dump) in Lusaka, Zambia (Author, 2013)

2.2.2 Landfill Classifications

Although the classification of landfills is in most cases based on the type of waste they accept (Williams, 2005), many countries such as Japan, Brazil, South Africa, and the EU classify them differently. Table 2.2 shows the different classifications. In the EU, Article 4 of the EU Landfill Directive (1999/31/EC) classifies landfills into three categories:

(i) Non-hazardous waste landfills;
(ii) Hazardous waste landfills; and
(iii) Inert or non-hazardous waste landfills.

Non-hazardous also known as municipal solid waste (MSW) landfills accept waste commonly known as rubbish, trash or garbage that consists of our everyday items that we use and throw away. These types of wastes come from homes, schools, and businesses and are collected by, or for, the local municipality. Hazardous waste landfills receive waste that pose substantial or potential threats to public health and the environment and include wastes such as contaminated soils and asbestos (EA, 2010). Inert waste landfills receive stabilised wastes such as construction and demolition (C&D) debris and do not generally require the same degree of engineering as hazardous and nonhazardous waste landfills since they are unlikely to react with other wastes (EA, 2010). In Japan, the Waste Management and Public Cleansing Law (Waste Management Law) of 2000 classifies landfills into three categories:

(i) Isolated;
(ii) Leachate controlled; and
(iii) Non-leachate controlled.

Isolated landfills are used for the disposal of hazardous industrial wastes. Leachate-controlled landfills are used for the disposal of both municipal and industrial wastes other than hazardous and stable wastes. Non-leachate-controlled landfills are used for the disposal of stable wastes such as waste plastics, rubber scrap, metal scrap, waste glass, ceramics, and demolition waste. In Brazil, the Technical Standard NBR 10004/2004 classifies landfills into two categories:

(i) Class I (hazardous waste); and
(ii) Class II (non-hazardous waste)

Class I is applied to landfills that accepts wastes with characteristics like dangerousness, flammability, corrosivity, reactivity, toxicity and pathogenicity, providing risks to public health and the environment. Class II landfills have two sub-classes – Class IIA (non-inert) and IIB (inert). Class IIA (non-inert) landfills accepts wastes, which are soluble in water and have biodegradability and combustibility properties. Waste types that do not cause alterations in the parameters of appearance, colour, turbidity, hardness and taste when in contact with water are sent to Class IIB (inert) landfills. In South Africa, the "Minimum Requirements for Waste Disposal by Landfill" classifies landfills into two categories:

(i) General waste; and
(ii) Hazardous waste landfills.

General waste landfills accepts wastes that do not pose a significant threat to public health or the environment if properly managed and these include domestic, commercial, certain industrial wastes and construction and demolition rubble. Hazardous landfills accept wastes with the potential to cause significant adverse effects on public health and the environment even in low concentrations because of their inherent toxicological, chemical and physical characteristics.

Table 2.2: Examples of Landfill Classification in Different Regions/Countries

Region/Country	Landfill Classification
European Union	▪ Non-hazardous; ▪ Hazardous; and ▪ Inert or non-hazardous waste landfills
Japan	▪ Municipal; and ▪ Industrial waste landfills
Brazil	▪ Class I (hazardous waste); and ▪ Class II (non-hazardous waste) Class IIA (non-inert); and Class IIB (inert)
South Africa	▪ General waste; and ▪ Hazardous waste landfills

2.2.3 Landfill Designs

Although designs may vary, modern landfills employ engineered containment systems that aim to minimise negative impacts on human health and the environment (Brindley, 2012; Hughes et al., 2005). The containment system comprises of barriers or liners installed at the bottom, sides and when a site is closed, a top liner is installed.

2.2.3.1 Bottom Containment Systems/Liners

The design of a bottom containment system depends on the type of waste (i.e., inert, non-hazardous, and hazardous) permitted on a landfill. The containment system must provide sufficient attenuation to prevent potential risks to soil and groundwater (Environment Agency, 2010). According to Hughes et al. (2005), containment systems can be described as single, composite, or double liners. Single liners consist of any of the following:

(i) A layer of compacted clay;
(ii) A geo-synthetic clay layer consisting of a thin clay layer (four to six millimetres) between two layers of a geotextile; or
(iii) A geo-membrane (specialised plastic sheeting).

Above the liner would be a durable cloth like protective layer called geotextile that prevents material of one layer from mixing with the adjacent layer (Figure 2.6). The geotextile layer also protects the liner from puncture and filters fine suspended solids (Williams, 2005). Single liners are cheap to build and are mostly used in landfills where inert materials such as construction and demolition (C&D) debris are deposited (Hughes et al., 2005). Composite liners consists of a clay liner in combination with a geo-membrane liner called a flexible membrane liner (FML) or high density polyethylene (HDPE). This type of barrier system is more effective at limiting leachate migration into the subsoil than a single clay or geo-membrane layer (Hughes et al., 2005). Subtitle D of the US Resource Conservation and Recovery Act (RCRA) (US EPA, 1991) - the principal federal law that governs the disposal of municipal solid waste and non-hazardous waste - requires composite liners as a minimum for all landfills. In Europe, the EU Landfill Directive requires a composite liner consisting of a clay layer (40 to 80 cm thickness) and a geo-membrane or flexible membrane liner (FML) constructed from various plastic materials, including polyvinylchloride (PVC) and high density polyethylene (HDPE) (Munawar and Fellner, 2013).

Double liners consists of either two single liners, two composite liners, or a combination of a single and a composite liner. The upper (primary) liner is usually meant for collecting leachate, while the lower (secondary) liner is used for detecting any leakage of leachate and as a backup to the primary liner (Hughes et al., 2005). Subtitle C of the US Resource Conservation and Recovery Act (RCRA) (1991) – the principal federal law that governs the disposal of hazardous waste - requires double liners for all hazardous waste landfills.

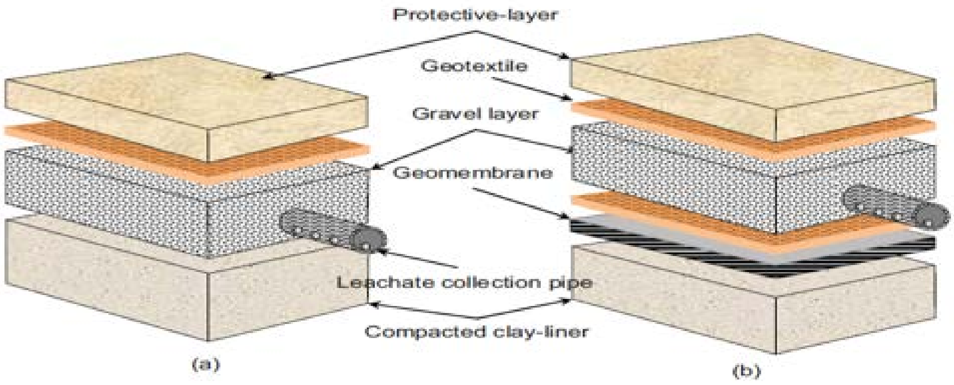


Figure 2.6: Schematic Diagram of Baseline Systems (a) Single-Liner, and (b) Composite Lining System (Munawar and Fellner, 2013)

2.2.3.2 Bottom Drainage System

Bottom lining systems are mostly overlain by a layer of coarse material (e.g., gravel), which act as leachate collection systems (Figure 2.7). At local points within the leachate collection system, drainage pipes are installed. According to Munawar and Fellner (2013), leachate collection systems must be placed at a minimum depth of 50 cm with a hydraulic conductivity of above 10^{-3} m/s and a base slope of at least 2 %. This creates sufficient water drainage capacity at the landfill bottom. Insufficient drainage can lead to water saturated waste zones (backwater) at the landfill bottom leading to mechanical failure (waste slide).

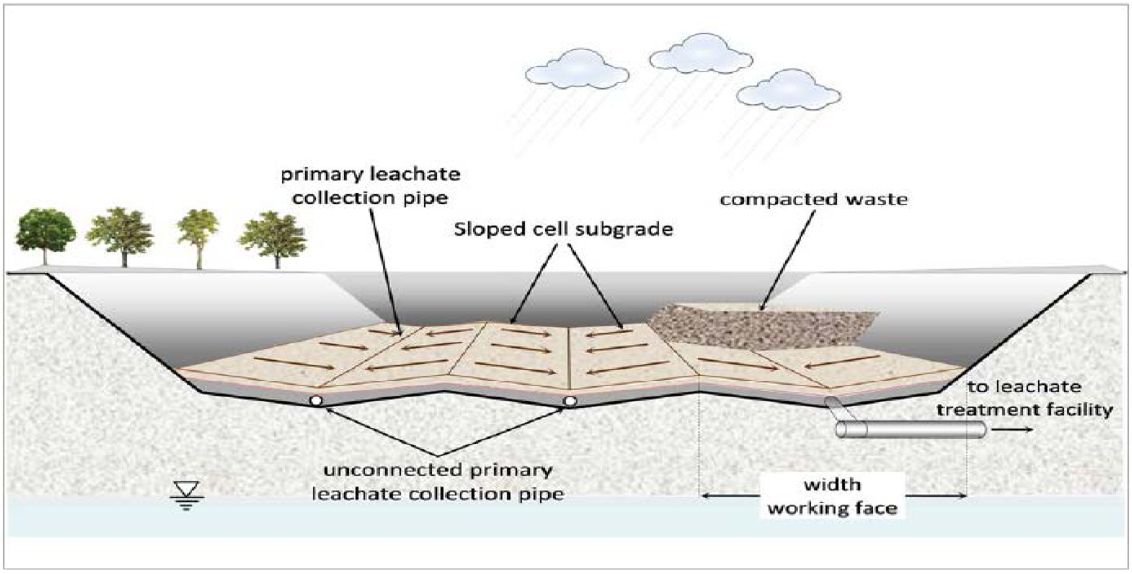


Figure 2.7: Schematic Diagram "Saw-Tooth" Configuration of Leachate System (Munawar and Fellner, 2013)

2.2.4 Landfill Processes and Emissions

Once solid waste has been placed in a landfill, it is subject to a range of biological and physical - chemical processes that lead to its degradation (Williams, 2005). The metabolism during the operation period and post operation period (after landfill closure) is determined by the bio-chemical degradation of organic matter that results in the production of landfill gas (LFG) and potentially organically polluted leachate. Cellulose and hemi-cellulose are the major biodegradable constituents in municipal solid waste (MSW) (Barlaz et al., 2002). It should, however, be noted that differences in composition are expected between developed and developing countries. For example, the EU Landfill Directive (CEC, 1999) targets has provided a good framework for member countries to landfill less biodegradable municipal waste. In contrast, large quantities of biodegradable waste are sent to landfill in developing countries where such restrictions do not exist.

2.2.4.1 Phases of landfill degradation

Figure 2.8 (Laner, 2011), which has been developed from the first description of landfill phases by Farquhar and Rovers (1973), shows the composition of landfill gas (top) and leachate (bottom) as the solid waste decomposes in a landfill.

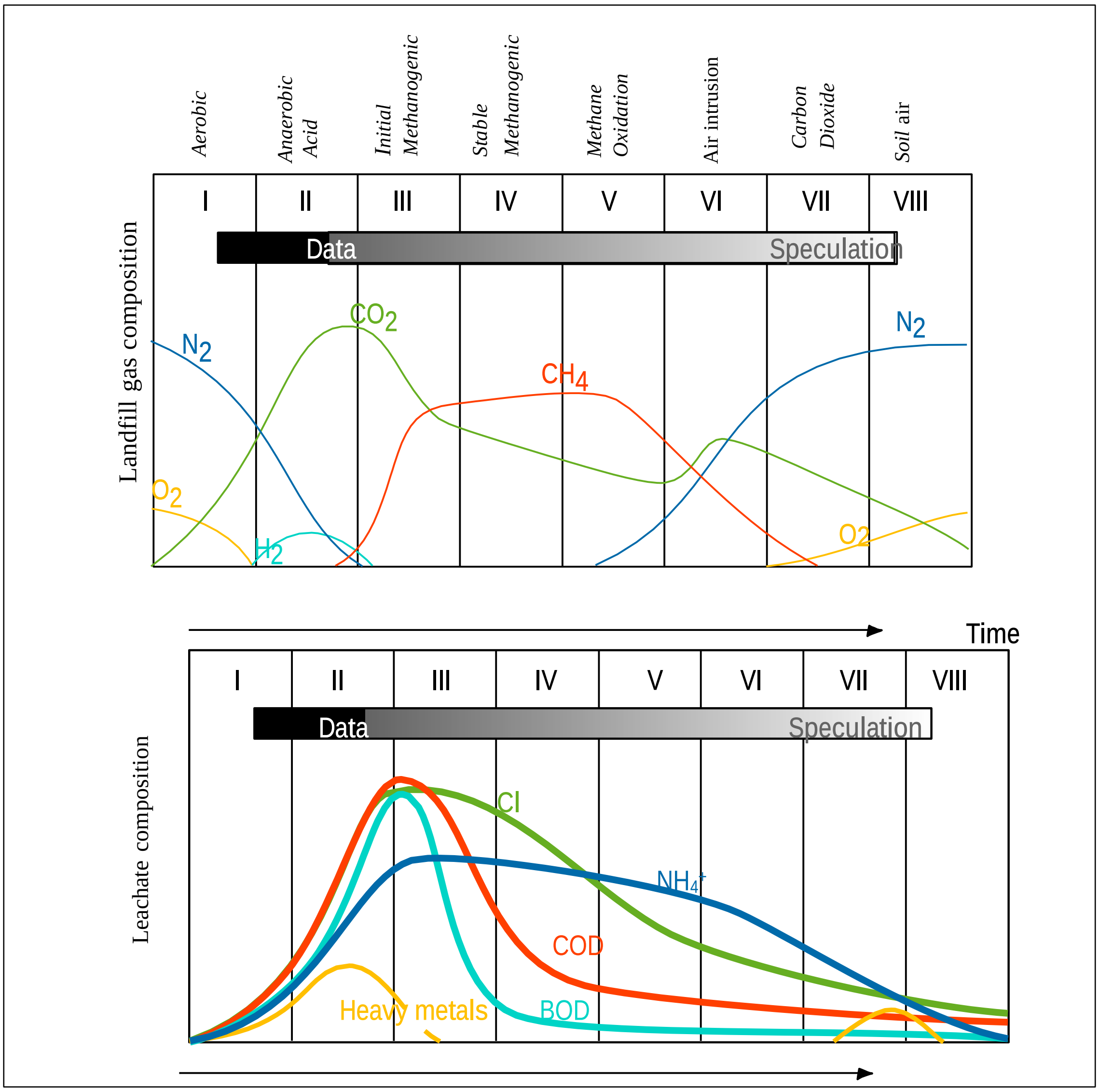


Figure 2.8: Characteristics of Landfill Gas Emissions (Top) and Leachate Emissions (Bottom) for an Idealised Landfill (Adapted from Laner, 2011)

During the initial aerobic phase (Phase I), oxygen entrained in solid waste at disposal is depleted by aerobic microbes resulting in the production of simpler hydrocarbons like sugars, amino acids and fatty acids (Figure 2.9). Carbon dioxide, water, and heat are also generated leading to temperature increases of up to 70-90 ^{0}C (McBean et al., 1995). Since there is no replenishment of oxygen once the waste has been covered, the aerobic phase lasts only for days to weeks (Barlaz, 2002). The leachate produced at this stage results from the release of moisture during compaction by heavy duty equipment and infiltration of precipitation. In phase II, different micro-organisms that can tolerate reduced oxygen conditions (facultative anaerobes) become dominant (Williams, 2005). There is an imbalance between the activities of hydrolytic bacteria, which converts cellulose and hemicellulose to soluble intermediates, and those of the acetogenic and methanogenic bacteria that work together to convert these intermediates to CH_4 and CO_2 (Barlaz et al., 2002). Organic acids are produced in large quantities leading to the lowering of the system's pH, and there is little solid decomposition (Tammemagi, 1999). The low pH results in the concentrations of chloride and ammonium ions to be high in the leachate (see leachate composition Figure 2.7). There is also a high chemical oxygen demand (COD), which is attributed to the presence of carboxylic acids. According to Adams and Clark (2009), phase II lasts between two weeks and six months. Methane production begins in the third phase (Phase III) when significant decomposition of cellulose and hemicellulose commences. The onset of this phase is likely associated with the system's pH becoming sufficiently neutralised for at least limited growth of methanogenic bacteria (Barlaz et al., 2002). Methanogenic bacteria converts the acids that accumulated in the acid phase into methane and carbon dioxide. In the fourth phase (Phase IV), the rate of cellulose and hemi-cellulose hydrolysis determines the rate of methane production and any accumulated carboxylic acids are depleted. The pH meanwhile continues to increase and the little COD present in the leachate is mostly recalcitrant compounds such as humic and fulvic acids (Barlaz et al., 1994 cited in Kjeldsen et al., 2002).

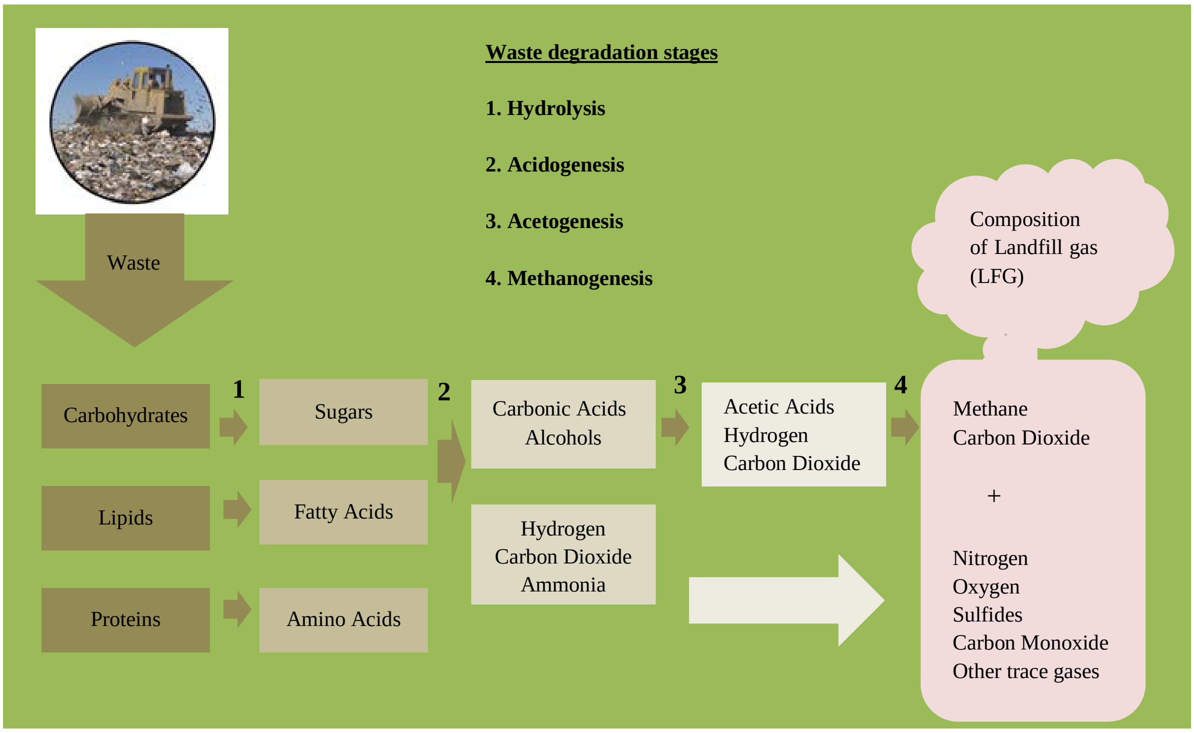


Figure 2.9: Landfill Waste Degradation Stages

2.2.5 Landfill Management

The behaviour of landfills is a fundamentally important issue because of the potential threat that they pose to human health and the environment (Laner, 2011b). Morris et al. (2011) lists the main aspects that require management at a landfill as leachate, landfill gas, and final cover.

2.2.5.1 Leachate

A major concern associated with landfills is that chemically hazardous materials that are in the waste body can be mobilised by the infiltration of liquids (e.g., rainwater) to form leachate (Howard et al., 1996). Landfill leachate in industrialised countries has been found to contain large amounts of hazardous compounds (Oman and Junestedt, 2008). Although it is expected to vary, the composition of landfill leachate from developing countries is not completely known due to lack of adequate published data. However, pollutants such as heavy metals and nutrients (nitrogen and phosphorous) have been reported (Aluko et al., 2003; Blight et al., 1999; Borzacconi et al., 1999). Recently, Munawar and Fellner (2013) reported that the quality of leachate from developing tropical countries was comparable to those generated in most affluent countries (characterised by high contents of organic pollutants, ammonium and soluble salts). They further reported that the concentration of pollutants increases during the dry season (less dilution of leachate by rainwater) and decreases during the wet season. The volume and chemical character of leachate varies considerably but contributory factors include:

- The physical and chemical composition of the waste;
- Waste density;
- Waste placement sequence and depth;
- Climatic conditions (moisture loading and temperature); and
- The final cover (cap) applied.

Although it is acknowledged that no typical leachate exists, evidence based on various studies suggests that many leachate constituents reflect the composition of a common waste type and occur within relatively consistent ranges of concentration at many landfill sites. Based on various studies and reports, Kjeldsen et al. (2002) generated a range of general parameters for leachate from MSW landfills (Table 2.3).

Table 2.3: Composition of Leachate (Values in mg/l unless stated) (Kjeldsen et al., 2002)

Parameter	Range
pH	4.5-9
Specific Conductivity (µScm^{-1})	2500-35000
Total Solids	2000-60000
Organic Matter	
Total Organic Carbon (TOC)	30-29000
Bio-chemical Oxygen Demand (BOD_5)	20-57000
Chemical Oxygen Demand (COD)	140-152000
BOD_5 /COD (ratio)	0.02-0.80
Organic nitrogen	14-2500
Inorganic Macro-components	
Total phosphorous	0.1-23
Chloride	150-4500
Sulphate	8-7750
Hydrogen bicarbonate	610-7320
Sodium	70-7700
Potassium	50-3700
Ammonium-N	50-2200
Calcium	10-7200
Magnesium	30-15000
Iron	3-5500
Manganese	0.03-1400
Silica	4-70
Heavy Metals	
Arsenic	0.01-1
Cadmium	0.0001-0.4
Chromium	0.02-1.5
Cobalt	0.005-1.5
Copper	0.005-10
Lead	0.001-5
Mercury	0.00005-0.16
Nickel	0.015-13
Zinc	0.03-1000

The appropriate leachate management measures identified by the International Solid Waste Association (ISWA)’s Working Group on Landfill (ISWA, 2010) includes the following:

- Adoption of best practice landfill design
- Minimisation/control of liquid entering the waste mass (installation of top cover)
- Installation and operation of an engineered leachate collection and extraction system
- Installation and operation of a leachate treatment system(onsite or offsite)

The above controls aim to achieve minimum build-up of leachate within the waste body and on the bottom liner system, which reduces the potential for surface and groundwater contamination.

2.2.5.2 Landfill gas

Landfill gas is generated from municipal solid waste (MSW) with significant quantities of biodegradable materials (Williams, 2005). The rate at which it is produced is a function of the type of solid waste involved (e.g., rapidly decomposing food wastes vs long lasting paper or other organic wastes). Although the main gases are methane and carbon dioxide, landfill gas contains a wide range of other gases found in trace amounts (Table 2.4). Methane and carbon dioxide are both greenhouse gases that contribute to global climate change (IPCC, 2007). Methane is, however, the gas of major concern from landfills because of its high global warming potential (GWP) – an index representing the combined effect of the differing times GHGs remain in the atmosphere and their relative effectiveness in absorbing outgoing infrared radiation (UNFCCC, 2015). Methane is 25 times more potent than carbon dioxide over a time horizon of 100 years (IPCC, 2007). Globally, landfills are the third largest contributors of methane emissions (Reinhart et al., 2012). Apart from its high global warming potential, methane has several health and safety issues. At concentrations between 5-15 % v/v in air, it is flammable and explosive (Agamuthu, 2013). If landfill gas is not properly monitored and controlled, it can give rise to flammability, toxicity, asphyxiation and other hazards such as vegetation dieback (EPA, 1997). Trace gases may also include harmful and toxic compounds such as vinyl chloride, benzene, toluene, xylene, perchloroethlyene, carbonyl sulphide, siloxanes and various other chlorinated and fluorinated hydrocarbons while others such as mercaptans are responsible for the distinctive vinegary smells associated with landfill sites (ISWA, 2010).

Table 2.4: Landfill Gas Composition (ISWA, 2010)

LFG Constituent	Concentration (%)
Methane (CH_4)	40 to 60 %
Carbon Dioxide (CO_2)	35 to 45 %
Oxygen (O_2)	<1 to 5 %
Nitrogen (N_2)	<1 to 10 %
Hydrogen (H_2)	<1 to 3 %
Water Vapour (H_2O)	1 to 5 %
Trace Constituents	< 1 to 3 %

2.2.5.2.1 Available Technologies for Controlling Landfill Gas Emissions

According to the US EPA (2011), the available landfill gas control technologies can be divided into three categories: (i) landfill gas collection systems; (ii) landfill gas control devices; and (iii) increased methane oxidation.

Landfill gas collection systems – The collection efficiency of landfill gas is contingent upon landfill design and the manner in which a landfill is operated and maintained (US EPA, 2011). Active and passive systems are the two types of landfill gas collection systems. Active systems use mechanical blowers or compressors to create a vacuum that optimizes landfill gas collection. Passive systems intercept landfill gas migration and the collected gas is vented to the atmosphere. This system relies on the natural pressure gradient between the waste mass and the atmosphere to move gas to collection systems.

Landfill gas control devices – After collection, landfill gas may be controlled and/or treated for sale or use as an energy source such as electricity generation, steam, and heat for drying leachate. Combustion of landfill gas is the most common method used to reduce its associated hazards. Devices for combustion include flares, electricity generation units (e.g., reciprocating engines, gas turbines), and energy recovery technologies (e.g., boilers). Combustion converts the methane gas to biogenic carbon dioxide, which has a lower global warming potential (US EPA, 2011).

Increase of Methane Oxidation – The technologies to increase methane oxidation rate include biocovers and biofiltration beds. These technologies convert methane into carbon dioxide, water, and biomass by methanogenic bacteria. Methanotrophic bacteria possess the methane mono-oxygenese enzyme that enables them to use methane as a source of energy and as a carbon source.

2.2.5.3 Landfill Cover System

The application of cover to a landfill surface is one of the management aspects required to protect human health and the environment from the negative impacts of landfilling (Environmental Agency, 2010). The objectives of applying landfill cover as identified by the UK’s Environmental Agency (2010) are:

- Prevent windblown litter
- Prevent odours causing a problem off site

- Avoid attracting scavenging birds to the site or the air space above it
- Deter other forms of scavenging
- Prevent flies from infesting
- Minimise the risk of fire on or within the site
- Aesthetic issues

Public health may be affected by the spread of disease, vermin or other infestations if a site is not covered. Furthermore, in the absence of cover, public health can be affected by the spread of odours from waste or its decomposition products. For example, Tsang (2012) reported that a waste disposal company in south-west England that did not apply adequate cover was ordered to pay £58,000 in fines and damages for allowing odour from a landfill to cause nuisance to the local community. Landfill cover consists of three types: (i) daily; (ii) intermediate or temporary; and (iii) final cover. Daily cover is generally applied to the working face of an active site. This maybe continuous as filling takes place; at the end of each working day; or occasionally in the case of a tipping face. Daily covers, however, don't minimise rainfall ingress to a site, though some cover materials maybe effective in this respect. After a landfill or part of it (single landfill cell) has reached its final capacity, the waste is first covered by an intermediate or temporary cover, which is insensitive to settlements of the landfill surface. The reduction of water infiltration can be accomplished by intermediate cover material with high water retention capacity (e.g. compost material), by profiling the surface (establishing a relatively large slope of 5-10 %), and/or vegetation (Munawar and Fellner, 2013). After 5 to 20 years, depending on settlement developments at a landfill site, the intermediate cover should be replaced by a final cover, which further reduces the amount of water infiltrating into the waste.

2.2.6 Landfill Aftercare

The nature of landfill processes entails that they can remain active for many years and continue to pose a threat even after they have ceased accepting waste. Freeze and Cherry (1979) for example reported that landfills developed by the Roman Empire over 2,000 years ago were still generating leachate. Belevi and Baccini (1989) also reported that the heavy metal lead was expected to be leached from Swiss landfills for over 1,000 years. Landfill management should therefore, be prolonged beyond closure until they are stable or compatible with the environment. Landfill stability or compatibility is attained when no further management is required and occurs when concentrations of constituents of potential concern (e.g., leachate and landfill gas) have reached levels that no longer have a detrimental effect; accepting that total containment and zero emission is unrealistic (Hall et al., 2005; Morris, 2012). The management of landfills beyond closure is called aftercare. Landfill aftercare is necessary for monitoring and managing the following:

(i) Landfill gas (LFG) (volume and composition);
(ii) Leachate (volume and composition);
(iii) Groundwater (composition);
(iv) Settlement (landfill bottom and surface);
(v) Biological degradation processes in the landfill body;
(vi) Efficiency of bottom liner and cover systems; and
(vii) Efficiency of the “water budget layer” (re-vegetation layer, top soil layer).

From a technical and operational perspective, aftercare is the continuation of landfill management activities carried out during the operation period (Scharff et al., 2013). The only difference is that aftercare has to be financed differently as landfills no longer generate income to finance management activities. However, one of the challenges facing regulatory agencies in particular, and the waste management industry in general, is determining when to end or complete aftercare. Scharff et al. (2011) defined aftercare completion as the moment at which responsibility for the remaining risk associated with a landfill is transferred from the operator to society. While regulations and/or guidelines in most developed countries stipulate that aftercare should continue for at least 30 years following closure (e.g., RCRA, 1991), this timeframe was only developed as a basis for calculating financial security (Marcoux et al., 2008). Landfill aftercare depends on site-specific circumstances. The starting point for aftercare depends on each country’s regulatory definition of landfill closure, which varies considerably among countries. For example, in the United Kingdom (UK), aftercare does not start when a site is ‘closed’ (when it has stopped accepting waste) but starts after ‘definite closure’, i.e. when the regulatory agency has agreed that a site is definitely closed (EA, 2009). In France, aftercare starts once the disposal of waste at the site comes to an end while in the Netherlands, aftercare commences after final capping of a landfill site (Marcoux et al., 2008). For this reason, the EU Landfill Directive (CEC, 1999) has delegated powers to competent authorities to determine when to end aftercare. Article 13(d) of the EU Landfill Directive (CEC, 1999) states that “for as long as the competent authority considers that a landfill is likely to cause a hazard to the environment…., the operator of the site shall be responsible for monitoring and analysing landfill gas and leachate… and groundwater regime in the vicinity of the site….” The Directive does not provide guidance on when and how to end aftercare. Accordingly, aftercare cannot be ended until the regulatory agency can be convinced that the landfill is no longer causing a hazard.

2.2.6.1 Range of Aftercare Periods

According to Laner et al. (2012), several alternatives exist for the long-term management of landfills and these include:

(i) Termination of aftercare after a specified time;
(ii) Perpetual or eternal care;
(iii) Termination when specific endpoint criteria have been reached (e.g. for leachate, gas, and waste settlement); and
(iv) Complete waste stabilization before aftercare termination.

Termination after a specified timeframe - This alternative describes a situation where landfill aftercare is carried out for a predetermined period after which, the owner is released from the responsibility of managing the site. This period could be 30 years or any other time as specified by legislation. The advantage with this alternative is that it is predictable and the owner/operator knows what is required for what period of time (Laner et al., 2012). However, the alternative leaves society, through public institutions, to be responsible for problems that may arise in future. This is because termination after a predetermined time period does not address biological, chemical or physical status of a landfill and its potential threat to human health and the environment.

Perpetual care - If termination after a pre-determined period of time is at one extreme, then eternal care would be the other extreme (Laner et al., 2012). In this alternative, a landfill owner's responsibility to monitor and maintain the site never ends. The main advantage with this alternative is that it removes uncertainty for both the landfill owner and the regulatory authority. The owner knows what is required in advance and the authorities have no need to assess and evaluate the status of the landfill over time. This alternative has been adopted in the Netherlands (Tsang, 2012). Since 1996, the Netherlands has mandated 'eternal' aftercare where after capping, landfill owners/operators transfer the responsibility for aftercare to local authorities. According to the Dutch system, the maintenance and periodic replacement of the impermeable top cover, which should be a composite system, is the most important aftercare cost. The final amount required for aftercare that must be contributed by each landfill operator is determined based on an assessment of the environmental protection measures after construction of the top cover. The responsibility for aftercare is then transferred to the authorities and the landfill owner is discharged from all aftercare obligations. The logic behind this alternative is that while landfill operators, who in most cases are private entities can go under through bankruptcy, governments through regional authorities cannot. While this alternative offers maximum protection, it does so without regard to costs. Scharff et al. (2011) argued that it is not an efficient way of using societal resources if funds are spent to protect against insignificant risks. Furthermore, global volatilities such as wars and stock market crashes can mean accumulated sums for aftercare losing their value over time (Tsang, 2012).

Termination after reaching specific end points – This alternative manages a landfill until it is stable with respect to specific endpoints (e.g., leachate, solids, gas, and geotechnical aspects). Reinhart and Townsend (1997) have suggested that stability with respect to leachate is attained when a BOD/COD ratio of less than 0.1 has been reached. A BOD/COD ratio is a good indicator of organic matter degradation in a landfill (Lee and Nikraz, 2014). However, although this is necessary, it is an insufficient criterion to prove that the waste has biodegraded because of the manner in which landfills are filled (fresher waste at the top, and that leachate is collected from the bottom of the landfill). As the leachate from freshly filled waste, which may be in the acidic phase of decomposition, percolates through well decomposed waste, it would reflect the composition of well decomposed waste because the high BOD of acid phase leachate will be consumed as it passes through the well decomposed waste, which is carbon limited. As such, leachate with a low BOD/COD ratio does not imply that all the waste is well decomposed. Furthermore, leachate criterion do not address metals, ammonia or other compounds (Laner et al., 2012). With respect to solids, Kelly et al. (2006) have suggested a cellulose plus hemicellulose to lignin (CH/L) ratio of less than 0.1 as an indicator for well degraded waste. According to Laner et al. (2012), a performance criterion for gas, such as required by Wisconsin Department of Natural Resources (2007), may be more realistic as a standard could be set to require that landfill gas production rate decrease to a rate at which it can be attenuated in a biofilter or biocover.

Complete stabilisation - In this alternative, a landfill is monitored until it is completely stable with respect to biological and physical–chemical characteristics of the waste mass. The assumption is that at the point of complete waste stabilization, a failure of a containment system would not result in negative impacts as the waste would not pose a threat. The main advantage with this alternative is that it makes sure that a landfill is not only biologically stable but that it does not get reactivated in future as a result of unfavourable circumstances (Heyer et al., 2007). While desirable, other authors have argued that complete waste stabilisation is not practical, particularly for landfills with a large fraction of biodegradable waste (Morris and Barlaz, 2008; Morris, 2008). While physical stability may be easier to address as post-closure settlement could be monitored until there is no risk from a geotechnical perspective, chemical stability would be difficult to address. For example, ammonia presents long-term potential problems in that there is no mechanism for its transformation under anaerobic conditions in landfills (Laner et al., 2012). In addition, there may be chemicals that have yet to be identified in leachate because landfills represent an accumulation of society's waste (Öman and Junestedt, 2008). Marcoux et al. (2008) reported that Germany issued a draft integrated landfill directive (BMU, 2007) that bases aftercare completion on the level of complete stabilisation. According to the Germany Directive, aftercare completion is reached when the state of a landfill meets the following criteria:

(i) Transformation and degradation processes within the deposited waste must largely be completed;
(ii) Generation of landfill gas should not occur or should be sufficiently low such that active gas extraction is not necessary;
(iii) The rate of landfill settlement should have decreased to a level where future damage of the top cover system due to settlement must be excluded. This should be demonstrated by 10 years of settlement data;
(iv) The cover system should be functional and stable, and should not be impaired by planned after-use of the site;
(v) Leachate discharged into surface and groundwater should comply with the stipulated levels in the German Ordinance; and
(vi) Leachate released to subsurface will not cause a violation of site-specific groundwater trigger values.

2.3 SUSTAINABLE DEVELOPMENT – A REVIEW

2.3.1 Origins and Policy Developments

Environmental problems such as ozone depletion, groundwater depletion and pollution, deforestation, desertification, and species extinction began to be recognised by national governments in the 1970s (Tammemagi, 1999). The United Nations Conference on Human Environment (UNCHE) (also known as the Stockholm Conference) held in 1972 articulated this concern and established the United Nations Environment Program (UNEP). The responsibility of UNEP was to build environmental awareness and stewardship. It was at this conference that the concept of “sustainable development” first received major international recognition (SDC, 2011). Although the term was not explicitly referred to during the conference, the international community nevertheless agreed to the notion that development and the environment, which until then were addressed as separate issues could be managed in a mutually beneficial way (SDC, 2011).

The concept was popularised 15 years later in 1987 by the World Commission on Environment and Development (WCED) through their report “Our Common Future” (WCED, 1987). The report is also known as the Brundtland Report named after its chair and former prime minister of Norway, Gro Harlem Brundtland. The WCED was established by the United Nations General Assembly in 1983 with a mandate of looking at the numerous concerns that had been raised in previous decades on how development was affecting the environment (Carson, 1962; Hardin, 1968; Meadows et al., 1972; The Ecologist Magazine, 1972). Generally, concerns related to negative impacts human activities were having on the planet and that the existing patterns of growth and development would be unsustainable if they were not checked (SDC, 2011).

The Brundtland Commission Report included the 'classic' definition of sustainable development as *"development which meets the needs of the present without compromising the ability of future generations to meet their own needs"* (WCED, 1987). While imprecisely defined, the concept of sustainable development was welcomed by leaders with environmental concerns since it seemed to put a natural limit on economic development strategies (Pubantz and Moore, 2008). The concept introduced the idea of inter-generational equity as a standard for national and international development and activities that related to the environment (Kates et al., 2005; Pubantz and Moore, 2008). In 1988, the Brundtland Commission Report was supported by more than 50 world leaders (Tammemagi, 1999) and the concept of sustainable development formed the basis of the United Nations Conference on Environment and Development (UNCED), also known as the Earth Summit held in 1992 in Rio de Janeiro, Brazil. The Earth Summit supported the concept of sustainable development and adopted Agenda 21, which called on countries to develop national sustainable strategies. Many initiatives for moving towards a more sustainable pattern of development were initiated. International protocols such as ISO 14000 – a standard that require companies to develop and incorporate environmental management systems were some of the outcomes of the Earth Summit initiatives (Tammemagi, 1999).

In 2002, a second World Summit on sustainable development was held in Johannesburg, South Africa to assess progress since the Rio Earth Summit and re-affirmed the commitment to sustainable development (UN, 2002). Three outcomes were delivered at this Summit: (i) a political declaration; (ii) a plan of implementation; and (iii) a range of partnership initiatives (UN, 2002). Among the key commitments from the Johannesburg Summit made by national governments, UN agencies, multilateral financial institutions and other major groups were the sustainable consumption and production of goods and services, water and sanitation, and energy. In 2012, 20 years after the first meeting, a third international conference on sustainable development was held in Rio de Janeiro, Brazil. The United Nations Conference on Sustainable Development (UNCSD), also known as Rio+20 was aimed at reconciling the economic and environmental goals of the global community (UN, 2012). The conference had three objectives:

(i) Securing renewed political commitment for sustainable development;
(ii) Assessing the progress and implementation gaps in meeting previous commitments; and
(iii) Addressing new and emerging challenges

The main outcome of the conference was a non-binding document called "The Future We Want." Head of states of the 192 governments in attendance renewed their political commitment to sustainable development by declaring their commitment to the promotion of a sustainable future.

2.3.2 Meaning of "Sustainable Development"

In the years following the Brundtland Commission's Report, sustainable development as a concept became the cornerstone of many government policies (Tammemagi, 1999). At the same time, a debate about the concept's actual meaning began. A striking characteristic of the concept put forward by sceptics was that the concept could mean "*all things to all people*" (UNECE, 2004). Environmental activists felt that the concept was not strong enough to provide guidance for action and accused governments of cosmetic environmentalism under the umbrella of sustainable development. Another argument that emerged related to the dominance of environmentally centred action at the expense of economic and social pillars of the concept. Although the economic pillar has to be integrated as a whole, sceptics argued that the concept does not give any guidance on how to arbitrate between the "*unavoidable conflicting objectives of economic profitability, social justice and ecological equilibrium*"

(UNECE, 2004). At the political level, the argument that emerged was that sustainable development depends on its capacity to deal or respond to a country's social problems (UNECE, 2004). However, measurement of the social pillar is complex (Colantonio, 2007; Murphy, 2012). According to Littig and Griessler (2005), the selection of social measure indicators is often a function of power rather than policy coherence. This is because influential groups are more likely to have their concerns included in the indicator sets for measuring the social pillar. Ultimately, social indicators reflect different socio-cultural priorities (Oman and Spangenberg, 2002) that are often picked for political rather than scientific reasons (Fahey, 1995).

The ambiguity of the Brundtland Report standard definition has allowed people with different perspectives to articulate and promote their own alternative definition of sustainable development (CEE, 2007). As noted by Kates et al. (2005), this has led some scholars to refer to sustainable development as an oxymoron – fundamentally contradictory and irreconcilable. As a concept, sustainable development remains open, dynamic, and an evolving idea that can be adapted to fit different situations and contexts across space and time. Against this background, the U.S. National Academy of Science conducted a study that sought to bring some order to the broad literature on the concept of sustainable development (NRC, 1999). The study focused on the seemingly inherent distinction between what was sought to be "sustained", what was sought to be "developed" and the relationship between the two, and the time horizon of the future. Under the heading "what is to be sustained," three major categories were identified: (i) Nature; (ii) Life Support Systems; and (iii) Community – as well as intermediate categories for each, such as earth, ecosystem services, and cultures (Figure 2.10). Drawing from the surveyed literature, the study found that emphasis was placed more on life support systems, which defined nature or the environment as a source of services for humankind (ecosystem services). Similarly, the study found three quite distinct ideas about "what is to be developed":

(i) People;
(ii) Economy; and
(iii) Society.

The study found that the early literature focused on economic development mainly because of employment, consumption, and wealth creation that were provided by productive sectors. Attention has however, recently shifted to human development, including an emphasis on values and goals, like increased life expectancy, education, equity, and opportunity. The study also identified calls to develop society that emphasized the values of security and well-being of national states, regions, and institutions and the social capital of relationships and community ties. Although there were extremes of “sustain only” to “develop mostly”, the study concluded that there was agreement generally that sustainable development implies linking what is to be sustained with what is to be developed. The time period for sustainable development that has been ambiguously described as “now and in the future” has been interpreted differently by many. It has been interpreted by some from as little as a generation to forever (Kates et al., 2005).

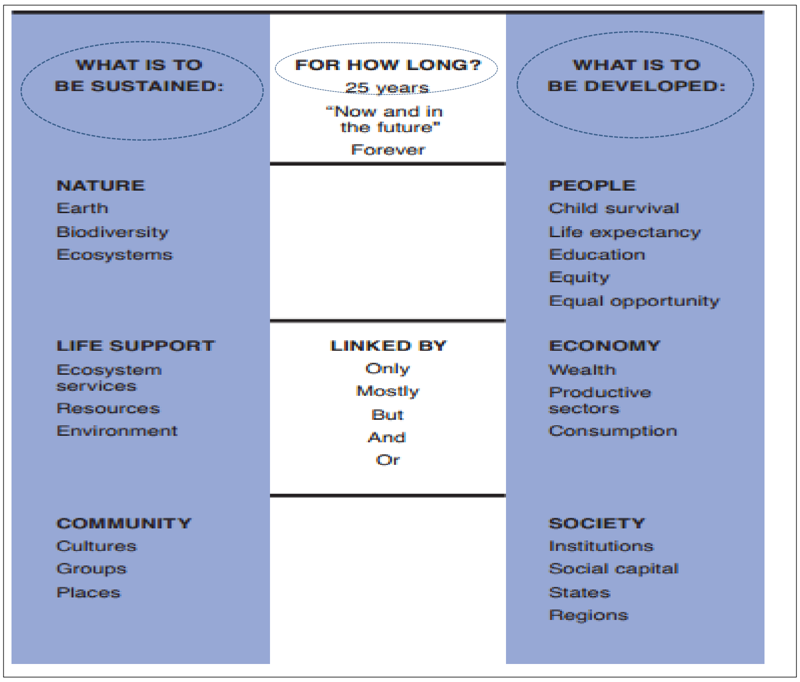


Figure 2.10: Definitions of Sustainable Development (US National Research Council, 1999)

The World Summit on Sustainable Development (WSSD) in 2002 expanded the standard definition of sustainable development with the widely used three pillars of economic, social (society), and environmental (Figure 2.11). At this Summit, a *“collective responsibility to advance and strengthen the interdependent and mutually reinforcing pillars of sustainable development – economic development, social development, and environmental protection at local, national, regional, and global levels”* (UN, 2002) was declared. This declaration addressed the concern over the limits of the framework on environment and development. Before this Summit, development was widely viewed as economic development – a narrow definition that obscured human development, equity, and social justice (Kates et al., 2005).

The three pillars or three dimensions of “sustainable development” were reiterated in the outcome of the Rio+20 Conference held in 2012.

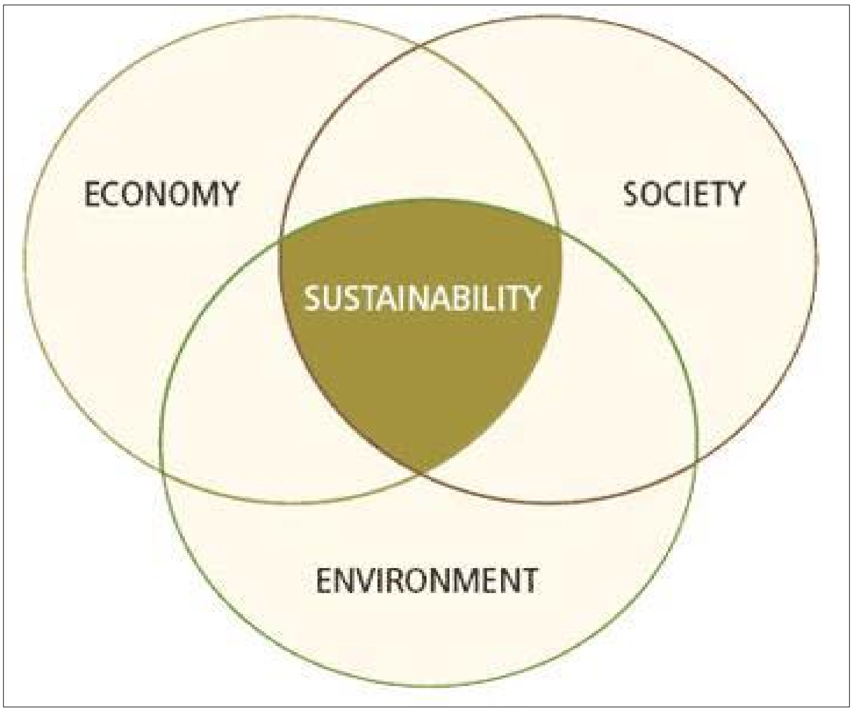


Figure 2.11: Dimensions of Sustainable Development (CEE, 2007)

2.3.3 Landfill and Sustainable Development

According to Tammemagi (1999), sustainable development in landfill requires that we do not allow the landfill practices of this generation to adversely affect the quality of life of the next generation. A society that strives to achieve sustainable development must therefore, practice sustainable methods of landfilling. These methods must be sustainable in all aspects from design, operation, and control of emissions to completion of aftercare (Reinhart et al., 2012). Although sustainable development as a concept is increasingly being embraced by the waste management industry, the concept has no internationally accepted definition (Scharff, 2006). Crest et al. (2010) attributed this to the differences in opinions on how different groups (e.g., waste management industry, regulators, and the general public) define sustainable landfill and/or the metrics that characterise landfill sustainability. Very often, terms such as landfill stability, landfill completion, and landfill final storage have been used in discussions that refer to landfill sustainability (Scharff, 2006). Table 2.5 shows some of the definitions put across by different groups for sustainable landfill.

Table 2.5: Definitions of Landfill Sustainability

Reference	Definition of sustainable landfill
Scharff (2006)	A landfill is ‘functionally stable’ if the waste mass and its post-closure do not pose a threat to human health and the environment. The definition assesses stability (sustainability) by consideration of leachate quality; gas composition and production, cover, side-slope and liner design, site geology and hydrogeology, climate, potential receiving bodies, and other factors deemed relevant on a site-specific basis
United Kingdom’s Environment Agency (2005)	A “landfill completion” is attained when the contents have stabilised physically, chemically and biologically to an extent where there is no pollution risk posed when left undisturbed. At completion, active aftercare pollution controls and monitoring are not required
Hjelmar and Bjerre (2005)	A landfill “final storage” is defined as a situation where active environmental protection measures are no longer necessary and emissions from leachate and landfill gas are acceptable in the surrounding environment
Lagerkvist et al. (1997)	A sustainable landfill is defined as the safe transfer of materials from society to nature with the following specific goals: o Providing system components that provide significant redundancy of environmental safeguards; o Providing effective protection of human health and environment during the operation and aftercare period and beyond; and o Allowing for responsible and beneficial end use of the landfill site during and after care completion of aftercare.
Stegmann et al. (2003)	A landfill is considered “stable” and aftercare phase may end when the emission potential is that low that the actual emissions do not harm the environment

A general consent that emerges from the definitions in Table 2.5 is that a sustainable landfill is one that within a limited period of time should reach a state where the undisturbed contents no longer pose a threat to human health and the environment. At that point, aftercare or post closure care can be stopped. Tammemagi (1999), however, viewed the concept of sustainable development to be mostly applied at the “front end” (production of goods) and not at the “back end” (disposal of wastes) of the industrial cycle. He highlighted three major reasons why sustainable development should also be applied at the “back end”:

- Firstly, sustainable development cannot be attained if leaking landfills were allowed to degrade surface water and ground water – some of mankind's basic and valuable natural resources;
- Secondly, sustainable development cannot be achieved if the space occupied by thousands of landfills were not re-used for other productive uses, such as agriculture and urban development; and
- Lastly, he noted that there would be no sustainable development if legacies of leaking landfills were left to our grandchildren to deal with.

From the underlying principle of sustainable development, he came up with three specific principles for a sustainable landfill as follows: (i) it should protect human health and the environment; (ii) it should minimise the burden on future generations; and (iii) it should conserve natural resources (see Figure 2.12).

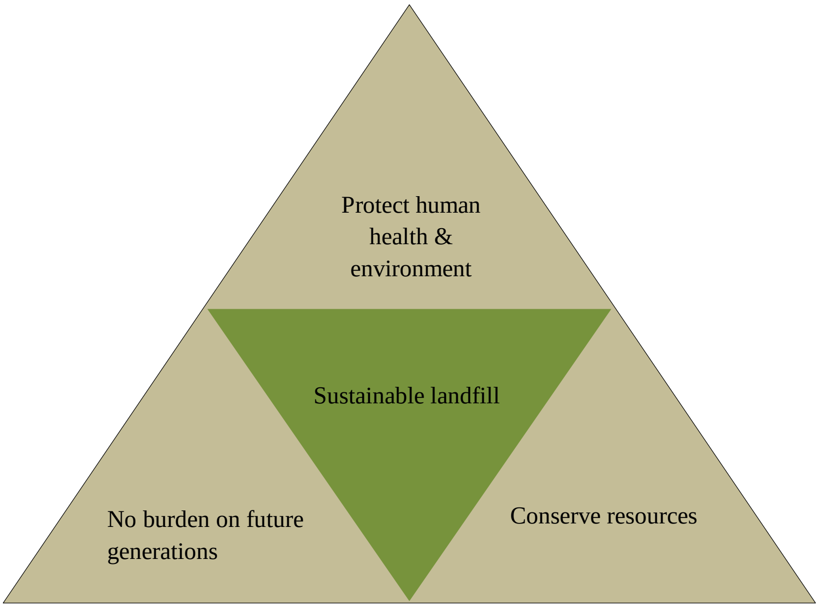


Figure 2.12: Sustainable Landfill (Adapted from Tammemagi, 1999)

2.3.3.1 Protection of Human Health and the Environment

The disposal of waste must be done in a manner that does not pose a risk to human health and the environment, either now or in the future. Some of the constraints placed by this principle includes the siting and designing of landfills, and the form of the placed waste. According to Tammemagi (1999), landfills must be designed in such a way that the leakage of leachate into groundwater and the emission of landfill gases into the atmosphere are eliminated or reduced to levels where they can be assimilated safely by the natural environment. One standard practice has been the enclosing of a landfill with an impermeable membrane. However, although impermeable membranes are necessary, they are often inadequate and will not protect human health and the environment for long periods (Lee and Jones, 2004). Liners may hold for decades and even centuries but will inevitably fail at some point in time (Scharff, 2006). Once this happens, bio-chemical processes, which are the driving forces for landfill emissions will start thereby causing negative impacts on both human health and the environment. In such a scenario, potential negative effects would be postponed for future generations to deal with – a scenario that is against the definition of sustainable development.

A sustainable example of protecting human health and the environment from the negative effects of landfill is the current EU Directive on landfill (CEC, 1999). In addition to setting minimum standards for location and design, the EU Directive on landfill permits the landfill disposal of predominantly inorganic wastes (inert wastes) through extensive mechanical and biological pre-treatment of the biodegradable wastes prior to disposal. With this approach, even if liners fail in future, there will be no active wastes to trigger reactions that would lead to emissions. According to the EU Landfill Directive (1999/31/EC), landfills for inert waste do not require isolation or aftercare as their wastes are considered acceptable.

2.3.3.2 Minimise Burden on Future Generations

From the Bruntland Report (WCED, 1987), every generation should solve its own problems and very often, a period of 30 years has been suggested as a generation (Kattenberg et al., 2013; Scharff, 2006). Although some countries such as the Netherlands require eternal care of closed landfill sites (Laner et al., 2012), many national regulations now require aftercare for at least 30-50 years after closure (Crest et al., 2010). Given the Bruntland Report's interpretation of sustainability, such aftercare periods cannot be considered sustainable as they are required for longer than a generation. Landfills should, therefore, be designed and operated in a way that does not place a burden on future generations (Reinhart et al., 2012; Tammemagi, 1999). Various methods have been proposed to stimulate landfill processes that accelerates stabilisation of the waste within a generation. One operation approach that has been suggested is the bioreactor landfill. Bogner et al. (2007) reported that many developed countries such as the US, Canada, Australia and New Zealand were studying and considering implementing "bioreactor" landfills as a way of compressing the time period to within a decade for reducing the emission potential of landfills and to decrease the aftercare period. Since biodegradation of the organic material in landfills is the most important process as it leads to the mobilisation of key pollutants, bioreactor landfills enhances this process. By recirculating leachate or any other liquids on the waste body, biodegradation is enhanced leading to emission reductions within a generation due to the quick flushing out of contaminants (Scharff, 2006). Kattenberg et al. (2013) reported that the need to minimise the burden on future generations has led the Dutch Parliament to approve a Decree allowing research on sustainable landfill management at full-scale for a period of ten years. The research, which will start in 2014 aims to investigate whether long-term treatment of the waste body by leachate irrigation and re-circulation, and/or subsequent aeration over a period of ten years would be sufficient to reduce the remaining emission potential in a landfill to a level that does not pose an undesired risk to the environment.

2.3.3.3 Conserve Resources

This principle places two constraints on landfill. Firstly, landfill should not consume non-renewable resources (Tammemagi, 1999). Particularly, the principle recognises land as a valuable natural resource that must be protected. In the context of today's urban developments and growing land pressure, land occupied by closed non-hazardous landfills offer potential for productive re-use (Crest et al., 2010). Several factors, however, may limit their re-use potential and these could include significant settlement due to ongoing biochemical reactions in the waste body, and the emissions of leachate and landfill gas. Operating a landfill as a bioreactor could enhance stabilisation both in terms of emissions and settlement. This sustainable way of landfill operation can open sites for alternative uses within a generation. For example, Hudgins et al. (2011) reported that by recirculating leachate onto the waste body for 18 months at the 6.5 ha Baker Place Road landfill in Columbia County, Georgia (USA), the biodegradation rate increased by 50 %, leachate BOD fell by 65 %, methane production decreased by 90 %, and non-methane organic compounds (NMOC) levels declined by 75 %. Secondly, the principle requires that all useful resources be extracted from the waste prior to disposal (Tammemagi, 1999). The extraction of useful resources from solid waste minimises the amount of solid waste requiring disposal. This ultimately leads to a reduction in the amount of space that would be required for a landfill site. For example, Yamatomi et al. (2003) reported that due to restrictions on the availability of land space, only six percent of the generated MSW in Japan was landfilled in the year 2000. Seventy seven percent was incinerated while the rest was used as resources and for other purposes. In Scotland, new regulations (Zero Waste Regulations) aimed at helping the country become one of the most resource efficient nations in Europe have been passed (SEPA, 2013). Some of the provisions under these regulations include:

(i) Requirements for businesses to present metal, plastic, glass, paper and card for separate collection from 1 January 2014;

(ii) A ban on any metal, plastic, glass, paper, card and food collected separately for recycling from going to incineration or landfill from 1 January 2014;

(iii) Requirements for local authorities to provide a minimum recycling service to householders; and

(iv) A ban on biodegradable municipal waste going to landfill from 1 January 2021.

2.4 THE CLEAN DEVELOPMENT MECHANISM (CDM)

2.4.1 Background

As with sustainable development, the debate on climate change, which is defined as the long-term shift in the statistics of the weather (NOAA, 2007), emerged in research and policy in the late 1980s (Olsen, 2007). It came about due to the increase in scientific evidence on how human interference was affecting the global climate system and growing public concern about the environment (UNEP, 2004a). Although both concepts gained prominence at the same time and dealt with human impacts on the environment, they remained divided for a long period of time. The climate change debate is more natural science driven while the sustainable development debate is more social and human science oriented (Olsen, 2007). In 1988, a conference organised by the World Meteorological Organisation (WMO) - The World Conference on the Changing Atmosphere: Implications for Global Security (the Toronto Conference) held in Toronto, Canada called for specific actions to be taken in order to reduce the impending crisis caused by the pollution of the atmosphere (WMO, 1989; Zillman, 2009). In particular, the conference called for the development of a comprehensive global convention as a framework for protocols on the protection of the atmosphere (WMO, 1989). This call led to the establishment of the Inter-governmental Panel on Climate Change (IPCC) formed in 1988 by the United Nations Environment Programme (UNEP) and the WMO (UNEP, 2004a). The IPCC was tasked with assessing the state of scientific knowledge concerning climate change, evaluating its potential environmental and socio-economic impacts (WMO, 1989).

The IPCC's First Assessment Report (AR1) in 1990 concluded that the growing accumulation of human-made greenhouse gases (GHGs) in the atmosphere would *"enhance the greenhouse effect, resulting on average in an additional warming of the earth's surface by the next century, unless measures were adopted to limit emissions"* (IPCC, 1990). The UN General

Assembly responded to the report's concerns by launching negotiations for a UN Framework Convention on Climate Change (UNFCCC). The UNFCCC was agreed during the UN Conference on Environment and Development (UNCED) (Earth Summit) in 1992 and entered into force on 21 March 1994 and has a membership of 194 (IISD, 2014). The operationalization of the UNFCCC marked the beginning of an international political response to climate change and was strengthened in 1997 by the adoption of the Kyoto Protocol (KP) (UN, 1998). The Kyoto Protocol to the UNFCCC was a milestone in global efforts to protect the environment and achieve sustainable development. For the first time, industrialised countries and economies in transition to a market economy committed to achieve GHG emission reduction targets. These countries, known as Annex 1 parties under the UNFCCC, accepted legally-binding targets to limit their overall emissions of the GHGs by at least 5% below 1990 levels in 2008-2012 (first commitment period), with specific targets varying from country to country (IISD, 2014). For the first commitment period (2008-2012), the Kyoto Protocol recognised a 'basket' of six greenhouse gases namely: (i) carbon dioxide (CO_2); (ii) methane (CH_4); (iii) nitrous oxide (N_2O); (iv) hydrofluorocarbons (HFCs); (v) perfluorocarbons (PFCs); and (vi) sulphur hexafluoride (SF_6) each with a different impact on the global climate (UNEP, 2007). Following the adoption of a second commitment period (2013-2020), the target for GHG emission reductions was increased to 18% below 1990 levels and nitrogen trifluoride (NF_3) was added to the 'basket' of GHG gases (UNFCCC, 2012b) (Table 2.6).

Table 2.6: Kyoto Protocol Gases and Respective GWPs (Adapted from IPCC, 1995)

Greenhouse Gases (GHGs)	Global warming potential(GWP) over 100 years
Carbon dioxide (CO_2)	1
Methane (CH_4)	25
Nitrous oxide (N_2O)	310
Hydrofluorocarbons (HFCs),	150-11,700
Perfluorocarbons (PFCs)	6,500-9,200
Sulphur hexafluoride (SF_6)	23,900
Nitrogen trifluoride (NF_3)	17, 2000

As it does not matter where emission reductions are achieved, the Kyoto Protocol also broke new ground with its innovative "cooperative mechanisms" (UNEP, 2004a). To help developed countries curb the emissions and meet Kyoto targets, and to encourage the private sector and developing countries to contribute to GHG emission reduction efforts, the Kyoto Protocol introduced three innovative market-based mechanisms namely:

(i) International Emissions Trading (IET) – allows the international transfer of national allocations of emissions rights between industrialised countries with emission reduction targets;

(ii) Clean Development Mechanism (CDM) – allows the implementation of emission reduction projects in developing countries without Kyoto targets (‘Non-Annex I countries’) that generate emission reductions (carbon credits) that can be used towards compliance by Annex I countries; and

(iii) Joint Implementation (JI) – allows the implementation of emission reduction projects in Annex I countries that generate carbon credits that can be used towards compliance by other Annex I countries.

The CDM is similar to JI, except that its emission reduction projects are hosted in developing countries, which do not have targets under the Protocol. The three market mechanisms enables the transfer of GHG emissions known as “allowances,” each worth one ton of carbon dioxide equivalent (CO_2–eq.) from one country to another while keeping the total amount of allowable emissions constant (Gillenwater and Seres, 2011). In the emission calculation, all results must be converted into CO_2–equivalents (UNEP, 2004c). This is done by multiplying the emissions by the Global Warming Potential (GWP) in Table 2.6. Carbon dioxide equivalent is a measure used to compare the emissions from various greenhouse gases based upon their GWP. For example, the global warming potential for methane over 100 years is 25. This means that emissions of one million metric tons of methane is equivalent to emissions of 25 million metric tons of carbon dioxide.

2.4.2 The Clean Development Mechanism

The CDM is the only international offset program in existence today that involves developing countries in GHG emission reductions (Goodward and Kelly, 2010). Its objectives are stated in Article 12 of the Kyoto Protocol (UN, 1998):

(i) To assist Parties not included in Annex I (i.e., developing countries) in achieving sustainable development and in contributing to the ultimate objective of the UNFCCC as stated in Article 2 - *“stabilisation of greenhouse gas concentrations* *in the atmosphere at a level that would prevent dangerous anthropogenic interference with the system"* (UNFCCC, 1992); and

(ii) To assist parties included in Annex I (i.e., developed countries) in achieving compliance with their quantified emission limitation and reduction commitments (QUEROLS) of greenhouse gases.

According to Sutter and Parreno (2007), the CDM's twin objectives were inherited from two main instruments. The sustainable development objectives came from the proposed Clean Development Fund (CDF) while the objective of cost-efficient emission reductions came from the concept of Joint Implementation (JI). It was the consequence of this amalgam that led to the CDM's twin objectives (Sutter and Parreno, 2007). Other authors however, claim that the mechanism's dual objectives are a reflection of a compromise over political differences between the "north and south" on the framing of climate change and sustainable development as an environmental or a developmental problem (Olsen et al., 2011).

2.4.2.1 CDM and Sustainable Development

The CDM's requirement to contribute to host nations sustainable development was a key condition put forward by developing countries when agreeing to the Kyoto Protocol in 1997 (Vasa and Neuhoff, 2011). This was to be achieved by promoting environmentally friendly technologies from industrialised country governments and businesses (UNEP, 2004b). The funding through CDM projects was also expected to assist developing countries reach some of their economic, social, and environmental objectives like clean air and water, improved land use, employment generation, poverty alleviation, reduced dependence on imported fossil fuels (UNEP, 2004a) among many others. However, although the methodological literature seems to agree that sustainable development should encompass at least three dimensions namely the social, the economic and the environmental (Kolshus et al., 2003), sustainable development remains undefined under the CDM (Wang et al., 2013). There is no universally accepted approach or methodology applicable for assessing the sustainability impacts of CDM projects regardless of project type and location (Olsen, 2007). The CDM modalities and procedures, which were only agreed four years after the adoption of the Kyoto Protocol (Marrakech Accords, 2001) did not specifically define what sustainable development meant in the context of the CDM but instead transferred the onus of doing this to developing country host nations (Subbarao and Lloyd, 2011). Voigt (2008) attributed this to the argument by developing countries that setting such a definition would impinge on their national sovereignty. There is therefore, no common guideline for sustainable development criteria and it is up to developing countries' host nations to determine their own criteria and assessment process (UNEP, 2004). According to Olsen (2007), the widely used criteria, which were also reiterated in the outcome of the Rio+ 20 conference (UN, 2012) comprise of three dimensions:

- Social criteria - the project should improve the quality of life, alleviates poverty, and improves equity;
- Economic criteria - the project provides financial returns to local entities, results in positive impact on balance of payments (BoP), and transfers new technology; and
- Environmental criteria – the project reduces greenhouse gas emissions and the use of fossil fuels, conserves local resources, reduces pressure on the local environment, provides health and other environmental benefits, and meets energy and environmental policies.

Other studies on the sustainable development criteria set by most developing country host nations have also identified these three as the most frequently used dimensions (TERI, 2012; Tewari, 2012).

2.4.2.1.1 Existing Methodologies for Assessing Sustainable Development

Some researchers (e.g., Olhoff et al., 2004; Sutter, 2003) have divided the existing methodologies for sustainability assessment into different approaches of which, checklists and multi-criteria are commonly used by host nations (Olsen, 2007). Though rarely used due to its stringency, the Gold Standard is the other methodology used for assessing sustainability of CDM projects.

Checklist Approaches - The sustainability assessment in a checklist approach is done qualitatively by people, usually appointed from different government ministries/departments, in the institutional framework of a host nation DNA. According to Olsen et al. (2008), the approach is simple to use as the project design document (PDD) is usually the basis for assessing a proposed project's contribution to sustainable development. The approach is easily adaptable to host country priorities of sustainable development such as congruence with existing national policies. This approach has, however, been critiqued by Figueres (2004). In her assessment of DNAs in Latin America and the Caribbean, she argued that existing policies were not climate friendly and thus the goal of achieving sustainable development was minimised at the project implementation level. She further argued that the narrow focus of checklist approaches on projects' compatibility with existing national environmental and development priorities as opposed to developing new sustainable development policies at sector and policy levels was insufficient to initiate 'sectoral transformation' towards the decarbonisation of economies.'

Multi-Criteria Assessment Approaches - According to Olhoff et al. (2004), the basis of multi-criteria approaches is the need to make decisions based on multiple factors and types of information. In multi-criteria approaches, qualitative and quantitative data can be combined and the relative significance of all the factors is weighed to arrive at a single measure for sustainability. Olsen and Fenhann (2008) reported that the most elaborated approach is the Multi-Attribute Assessment methodology (MATA-CDM) developed by Sutter (2003). The MATA-CDM approach generates a holistic overview assessment of sustainability benefits of CDM projects rather than a strictly scientific evaluation of single parameters (Sutter, 2007). By drawing from various disciplines, it assists decision makers by being accurate while at the same time being practical. The aim of MATA-CDM is to assign a value to each project, which determines its utility in terms of contributing to sustainable development in a host country. The utility U of a project Pi can be calculated with the central equation of MATA-CDM (Sutter, 2003). The equation is the basis of the five steps that have to be conducted for the application of MATA-CDM. Figure 2.12 shows the equation and the five steps that are applied through the MATA-CDM and these are:

(i) ***Identification of sustainability criteria***: the overall target of a "contribution to sustainable development in a host country" is divided into a hierarchical set of criteria (sub-targets);

(ii) ***Defining indicators:*** The criteria are associated with indicators, which can be applied on a project level. Indicators can either be quantitative or qualitative. The scales of these indicators, including maximum and minimum values, are identified;

(iii) ***Weighting the criteria:*** The criteria are weighted in order to determine their relative importance;

(iv) ***Assessment of the CDM projects:*** The criteria are applied on CDM project proposals. The respective scorings of the projects can be displayed in a matrix; and

(i) ***Aggregation and interpretation of results:*** Results are aggregated and uncertainty is identified. Rules are defined, based on which the results lead to an approval or a rejection of the project proposal.

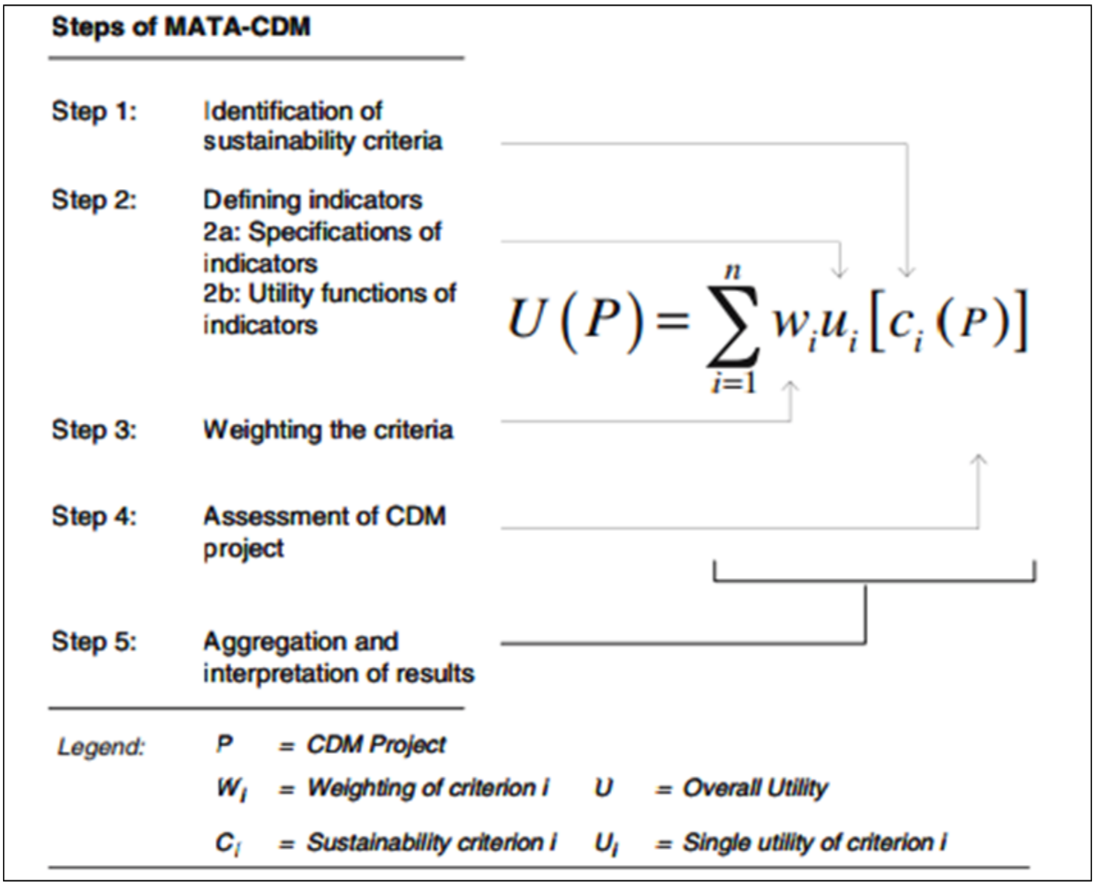


Figure 2.13: MATA-CDM Step and Central Equation to Compute Overall Utility of CDM Projects (Sutter, 2003)

The Gold Standard – The Gold Standard was developed in 2003 by a group of non-governmental organizations comprising the World Wide Fund for Nature (WWF), SouthSouthNorth, and Helio International to address observed shortcomings of CDM projects (Killick, 2012). The voluntary standard is an effective tool for creating high-quality emission reduction projects that promote sustainable development and benefit local communities (The Gold Standard, 2006). Projects with a Gold Standard status are rewarded for their efforts by an ability to obtain higher CER prices. The Gold Standard label is applicable to both the projects (upon completion of validation) as well as the credits (CERs) produced by Gold Standard labelled projects (upon verification). This enables project owners to both market a project before achieving the actual emissions reductions, as well as to credibly demonstrate the achievement of the promised reductions that were stated in the PDD. For a project to qualify to be certified with a Gold Standard label, it must meet strict guidelines. With the stricter guidelines, it was hoped that these premium projects would achieve genuine sustainability benefits and emissions reductions – the two objectives of the CDM. To encourage best practice CDM projects, the Gold Standard employs three main screens:

(i) Firstly, because the Gold Standard aims at achieving greater sustainability benefits, only renewable energy and energy efficiency projects qualify for registration with the Gold Standard;

(ii) Secondly, the Gold Standard carries out its own, more conservative, assessment of a project's additionality – a check of whether emission reductions would have taken place anyway even in the absence of a CDM project; and

(iii) Finally, all projects applying for registration with the Gold Standard are required to submit a 'sustainability matrix'- a checklist approach requiring project developers to state what impact their project will have on a range of environmental, social, and economic indicators (Bumpus and Cole, 2010). Negative scores are not permitted on any sustainable development indicator, and a net positive score must be attained to achieve Gold Standard (Killick, 2012).

The Gold Standard builds upon the requirements in the PDD template. The Standard sets out a code of best practice on many issues in the PDD and incorporates a small number of extra screens necessary to deliver real contributions to sustainable development in host countries plus long term benefits to the climate. For example, only two project categories are eligible under the Gold Standard and these are renewable energy, and energy efficiency projects (Gold Standard, 2006). Furthermore, all the impacts identified during the environmental impact assessment (EIA) must not have a negative score. To minimise extra costs, the extra screens can be completed and validated as part of regular CDM procedures mandated by the CDM Executive Board.

2.4.2.2 CDM and GHG Emission Reductions

Although it does not matter from an environmental perspective where GHGs emission reductions occur, the location of such emission reductions matters (Gillenwater and Seres, 2011). The location has economic implications because countries and companies face different costs. The CDM therefore, gives developed countries and their private sector companies the opportunity to reduce emissions in developing countries where the cost is lowest (Mckinsey, 2009). The offset credits called certified emission reductions credits (CERs) can then count towards their own domestic emission reduction targets (Figure 2.13). In return, developing countries are expected to benefit from the implementation of environmentally benign projects through technology transfer and financial investments (Subbarao and Lloyd, 2011).

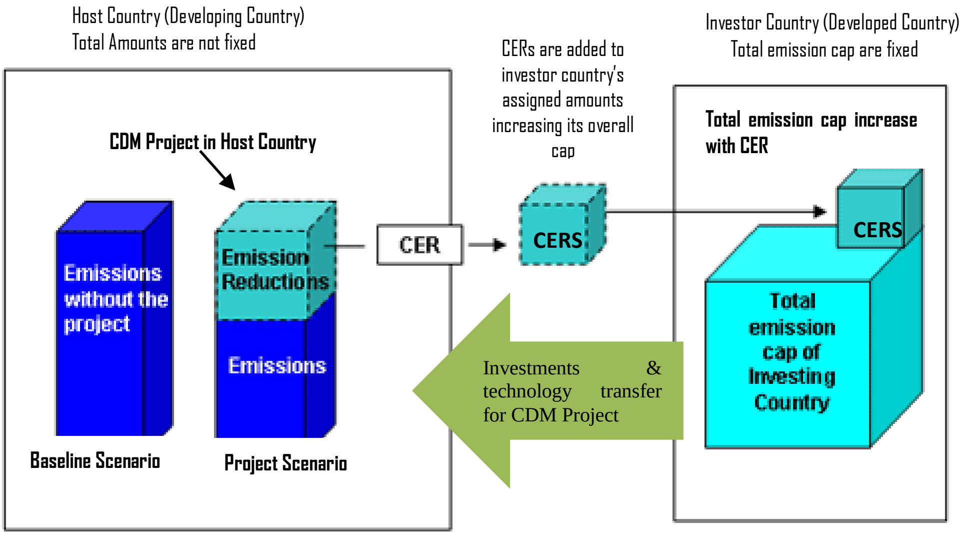


Figure 2.14: Basic Scheme of a CDM Project (Adapted from Shishlov and Bellassen, 2012)

In order to survive an "environmental integrity check" (the ability to reach its objective and purpose), the CDM project's GHG emission reductions should be real, measurable and additional to any that would have occurred anyway (Voigt, 2008). Article 12(5) (c) of the Kyoto Protocol states that GHGs emission reductions shall be certified based on reductions that are additional to any that would have taken place in the absence of a CDM project. This was reinforced later by Decision 3/CMP.1, paragraph 43 of the modalities and procedures (UNFCCC, 2006b), which states that, *"a CDM project is additional if anthropogenic emissions of GHGs by sources are reduced below those that would have occurred in the absence of a registered CDM project activity."* Although additionality (i.e., the extent to which the value of expected revenue caused the CDM project to be implemented) is one of the critical criteria for offset quality, it is difficult to determine. To mitigate this, over 200 methodologies have been developed for determining, reporting, monitoring and verifying emission reductions in various sectors (UNEP Risoe Centre, 2014a). Decision 3/CMP.1, Annex, paragraph 44 of the modalities and procedures requires all CDM projects to fulfil two types of methodologies:

(i) Baseline; and
(ii) Monitoring methodologies.

A baseline methodology estimates the emissions that would have been created as a result of not implementing a CDM project activity (baseline scenario) (UNEP, 2005a). A monitoring methodology is a means of calculating the actual GHGs emission reductions from the project, taking into account any emissions from sources within the project boundary (Curnow, 2014). The first step in determining project additionality is establishing a credible baseline – a scenario that predicts GHGs emissions that would have occurred in the absence of a CDM project. A project's net GHG emission reductions are measured against this baseline. If the baseline emissions and the resulting emissions from a proposed project are the same, then there are no "additional" emission reductions. Similarly, if the proposed project results in an increase in GHGs emissions relative to the baseline, then such as a project is not "additional." When identifying baseline scenarios, all existing policies and regulations must be taken into account. For example, if there is a regulatory requirement in place that requires the implementation of the changes described in a proposed project, then such a project would not be regarded "additional" as GHG emission reductions would eventually be achieved through the enforcement of that law.

2.4.3 Participation and Eligible Projects under CDM

The general eligibility criteria for participation in the CDM are set out in the CDM modalities and procedures Decision 3/CMP.1, Annex, paragraphs 28-30 (UNFCCC, 2006b) and requires that:

- The host country is a Party to the Kyoto Protocol;
- It is participating voluntarily in the project activity; and
- It has designated a national authority (DNA) for the CDM

Furthermore, developed country Parties must meet several stipulations such as establishing an assigned amounts under Article 3 of the Kyoto Protocol, a national system for the estimation of greenhouse gases, a national registry, an annual inventory and an accounting system for the sale and purchase of GHGs emission reductions. According to Decision 1/CMP.2, paragraph 28 (UNFCCC, 2007), the CDM modalities and procedures recognises three project types (Table 2.8). The project types are reviewed at least once a year and are updated as and when need arises (Curnow, 2014).

Table 2.8: CDM Project Types and Categories (Curnow, 2014)

Project Types	Project Categories
Type (i): Renewable energy projects	A. Electricity generation by the user/household
	B. Mechanical energy for the user/enterprise
	C. Thermal energy for the user
	D. Electricity generation for a system
Type (ii): Energy efficiency improvement projects	E. Supply-side energy efficiency improvements – transmission and distribution activities
	F. Supply- side energy efficiency improvements - generation
	G. Demand-side energy efficiency programmes for specific technologies
	H. Energy efficiency and fuel switching measures for industrial facilities
	I. Energy efficiency and fuel switching measures for buildings
Type (iii): Other project activities	J. Agriculture
	K. Switching fossil fuels
	L. Emission reductions in the transport sector
	M. Methane recovery

2.4.4 Governance of the CDM

As set out in Article 12 (4) of the Kyoto Protocol (UN, 1998), the CDM Executive Board (EB) is the chief regulatory body for the CDM. The ten-member Board oversees the entire CDM process from project evaluation to the issuance of offset credits (UNEP, 2004c). The EB is charged with the responsibility of accrediting organisations known as designated operational entities (DOEs) or auditors whose work is to validate proposed CDM projects, verify the resulting emission reductions, and certify those emissions as CERs before issuing them. Another key task of the EB is the maintenance of a CDM registry and to manage an account for CERs for each developing country party hosting a CDM project. A process has been established by the Board in which proposed projects are reviewed at least twice before a decision is made (Gillenwater and Seres, 2011).

2.4.4.1 Project Design, Validation, Registration, and Issuance of CERs

The first step in the CDM project cycle is the identification and formulation of a potential CDM project by preparing a standardised proposal called a Project Design Document (PDD) (Figure 2.14). Along with the validation report from the Designated Operational Entity (DOE) and a Letter of Approval (LoA) from the host nation’s Designated National Authority (DNA), the PDD is a key document required in the validation and registration of a CDM project. It is the basis for decision making by host nations prior to issuing a LoA. Section A.2 of the PDD template (UNFCCC, 2006a) requires a project developer to describe activities in terms of its contribution to host nation’s sustainable development. The other information required in the PDD includes the type of technologies to be employed (Section A.4.3), a calculation of the projected emissions with and without the project, and the approved methodologies to be used for monitoring and quantifying emission reductions from the project (Section B). Project developers have an option of either proposing a new methodology or choosing from the many approved methodologies in the CDM library. Newly proposed methodologies are subject to a review process before final approval (Gillenwater and Seres, 2011). Project participants must choose whether the crediting period (i.e., length of the CDM project) is 10 years without renewal or 7 years with a possibility to be renewed twice (a maximum of 21 years).

Once a PDD is completed, it is submitted to a host nation’s DNA, which is the focal point for CDM projects. The DNA reviews the project and assesses whether it will contribute to its national sustainable development goals. If it does, the DNA issues a LoA and the PDD must then be “validated” by a DOE. If the DOE is satisfied that the proposed project meets all the CDM’s requirements and is technically sound, the proposal is subjected to a thirty-day public comment period where stakeholders provide their input. After this period, the DOE submits a validation report certifying that the proposed project is ready for formal review and registration by the EB. With the support of the secretariat, the EB assesses the proposal and validation report submitted by the DOE and can either: (i) reject the project; (ii) call for it to be improved and re-submitted; and/or (iii) approve it for registration.

A CDM project can either be bilateral or unilateral. Until a LoA is issued by the host nation to a buyer country, the project is unilateral (Olsen and Fenhann, 2008).When a LoA is issued to a buyer country by the host nation, the project is considered bilateral.

After a project has been operating and monitored for some time (months or years), the project developer is required to hire another accredited DOE (different from the one hired earlier for the validation phase) to verify the amount of GHG emission reductions achieved. The second DOE’s verification report and the project’s monitoring reports are submitted to the EB for approval. If both reports are approved, the EB will issue project participants the CERs achieved during that period. Project participants must continue to submit monitoring and verification (audit) reports and credits will be issued for the duration of its crediting period (UNEP, 2004c).

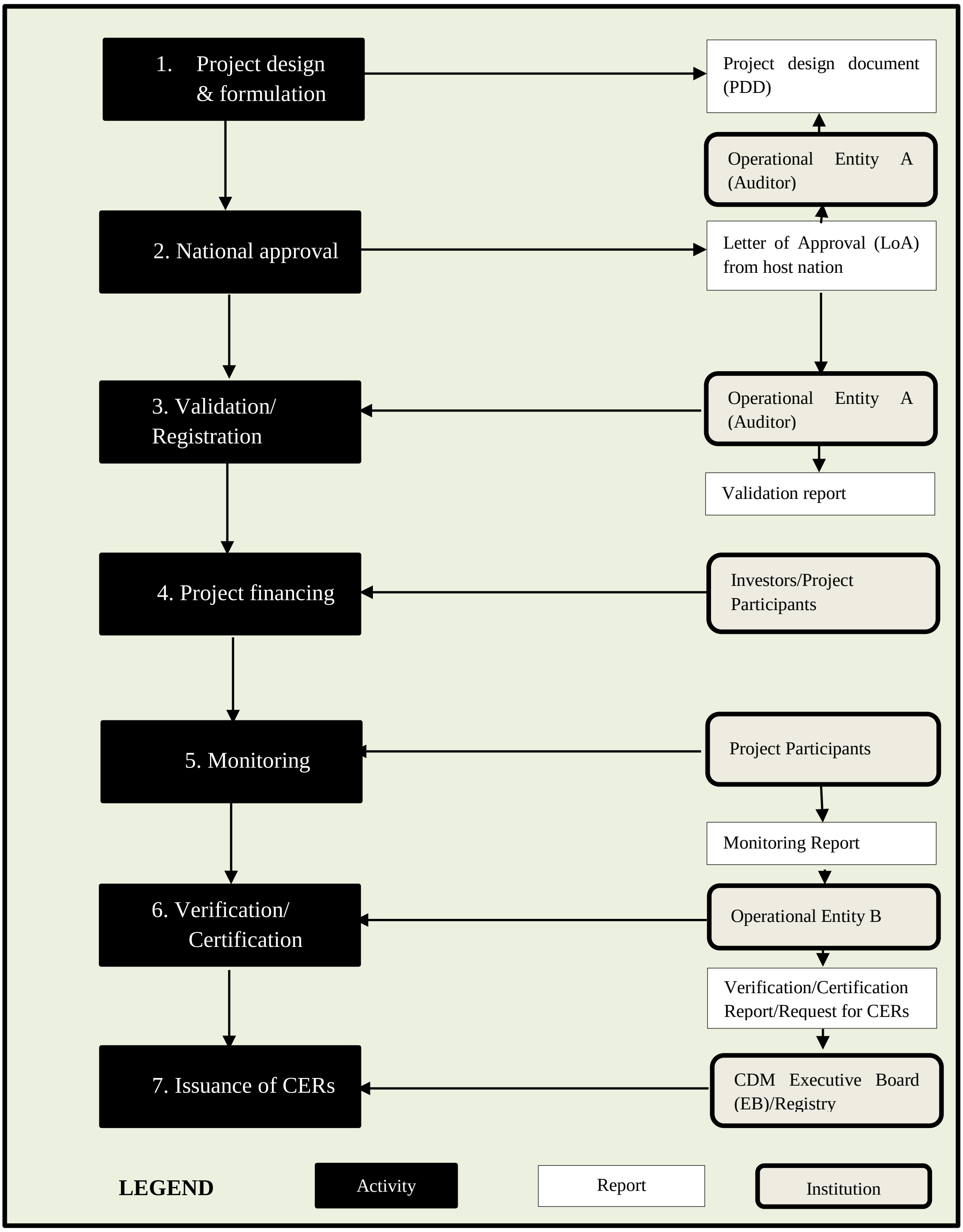


Figure 2.15: CDM Project Cycle (Adapted from UNDP, 2010)

2.4.5 Waste Management and the Clean Development Mechanism

Municipal solid waste (MSW), particularly in developing countries, contains large fractions of organic waste (UNEP Risoe, 2010). The anaerobic degradation of the organic fraction of MSW in landfills generates methane (Trois and Couth, 2012). Using the CDM, the volume of landfill methane emissions can significantly be avoided or reduced. According to the UNEP Risoe Centre (2010), the four waste management project categories eligible under the CDM are: (i) composting; (ii) gasification; (iii) incineration; and (iv) landfills.

2.4.5.1 Composting CDM Projects

The volume of methane produced from landfill sites can be reduced by composting of MSW prior to disposal (Trois and Couth, 2012). By changing the way organic waste is stored and decomposed (from anaerobic to aerobic conditions), composting avoids the production of methane (UNEP Risoe, 2010). Apart from avoiding methane production, there are many benefits of composting organic waste over disposal to landfill. By composting organic waste, hazards and adverse environmental impacts such as noxious odours, leachate production and potential contamination of surface and groundwater, visual intrusion, and litter nuisance that arise from the degradation of landfilled organic waste can be avoided (Trois and Couth, 2012). A study by Trois and Couth (2012) showed that GHG emissions related to composting of organic waste (i.e., use of electricity and fuels in plant operations, and methane and nitrous oxide emissions from composting process) are outweighed by GHG emission savings (methane emissions) from organic waste that would otherwise have been disposed to landfill. Furthermore, composting of wet biogenic waste avoids carbon emissions associated with landfill. Trois and Couth suggested that theoretically, 98 % of the GHG emissions can be avoided by composting whereas only 50 % of the emissions from landfill can be captured. A similar study by Seng et.al (2013) on the benefit of municipal organic-waste composting over landfill in Cambodia showed that GHG emissions could be reduced by a minimum of 13 % and a maximum of 65 % over a period of 17 years. The study also showed that the life of a landfill can be extended by a minimum of six months and a maximum of four years due to volume reductions (recycling of organic fractions) over the same period. At the same time, benefit is gained from the compost product, which can be used as fertilizer in agricultural production. Compost applied to land contributes to GHG emission reductions by replacing emissions that would have been generated by the production of inorganic fertilizers and application (nitrous oxide). Applying compost on land reduces the need for pesticides because of its suppressive effect on plant pathogens (Abbasi et al., 2002; Hoitink and Fahy, 1986). The application of compost on land also reduces tillage (improves soil structure and reduces erosion) and irrigation (increases water retention of soil) (Trois and Couth, 2012). However, the contamination of agricultural soil with heavy metals, which can endanger human health are some of the fears of using composted waste materials (Vilella, 2012). For this reason, there is legislation for the quality of MSW compost that can be applied to land in most developed countries. Compost from MSW in the EU must comply with PAS 100: 2011

Specification for compost material (BSI, 2011). The specification only allows the application of compost from source segregated biowaste. Such standards, however, do not exist in most developing countries.

2.4.5.2 Gasification CDM Projects

Gasification is one way of utilizing the energy content in solid waste. The process involves the reaction of carbonaceous feedstock with an oxygen-containing reagent, usually oxygen, air, steam or carbon dioxide, generally at temperatures in excess of 800 °C (Zafar, 2009). The main product is a syngas, which contains carbon monoxide, hydrogen and methane. Unlike composting that avoids gas (methane) development, organic matter may be gasified for the development of methane gas, which can be used in gas engines or for cooking in households. Pre-processing of MSW is necessary and the degree of pre-processing to convert waste into a suitable feed material is a major criterion because unsorted MSW is not suitable for most thermal technologies (UNEP Risoe, 2010). Municipal solid waste gasification projects under the CDM directly displace GHG emissions that would have been generated from anaerobic degradation of organic waste in landfills (Purohit, 2009). Eliminating such emissions and producing energy has the potential to generate large amounts of CERs. Apart from avoiding GHG emissions, gasification has several advantages over the traditional combustion processes for MSW treatment. Since it takes place in a low oxygen environment, the formation of dioxins and of large quantities of SOx and NOx are limited. Gasification generates a fuel gas that can be integrated with combined cycle turbines, reciprocating engines and, potentially, with fuel cells that convert fuel energy to electricity more efficiently than conventional steam boilers (Zafar, 2009).

However, the diffusion of MSW gasification projects has been low. A study by Purohit (2009) showed that the few projects that have been installed in India are attributed to government subsidies and not market forces. An earlier study by Purohit and Michaelowa (2007) showed that if the diffusion of MSW gasification projects were driven by market forces instead of subsidies, the cumulative capacity of installations in India would have been three times the actual level. According to Purohit and Michaelowa (2007), the high investment cost associated with gasification infrastructure is one of the major barriers for the diffusion of MSW gasification projects. The CDM, could therefore, be used as a tool to foster their diffusion. The high investment cost associated with these projects can easily make such projects pass the CDM's additionality test.

2.4.5.3 Incineration CDM Projects

Incineration can reduce GHG emissions by diverting organic contents in MSW from disposal to landfills where anaerobic processes would have led to the generation of methane gas. Electricity can be generated using heat that is a by-product of the incineration process. This electricity can be fed into the national Power Grid. Thus, in addition to directly eliminating methane emissions, a MSW incineration CDM project displaces fossil fuel-based electricity generation that would have emitted additional carbon dioxide. Moreover, incineration does not require complex pre-separation and pre-treatment steps.

However, Vilella (2012) has argued that incinerators do not always replace fossil fuels in energy generation, but often require them alongside MSW. Municipal waste, particularly in developing countries, is high in moisture and often will not burn without the addition of auxiliary fuel. According to CDM rules, waste incineration allows up to 50 % of the generated energy to come from auxiliary fossil fuel (Rand et al., 2005 cited in Vilella, 2012). According to Vilella (2012), incineration of such wet wastes with added fossil fuel does nothing to abate climate change and has serious implications for the CDM’s environmental integrity. Vilella further argued that incinerators lack pollution control because under the CDM, approval conditions for such projects do not impose toxic emissions limits nor do they require monitoring of incinerator pollution.

2.4.5.4 Landfill CDM Projects

Methane emissions from landfills represent the largest source of GHGs from the waste sector (Bogner et al., 2007). While these emissions are projected to decrease by 31 % in OECD countries by the year 2020 compared to 1990 levels (Rogger et al., 2010), an exponential increase in emissions is expected from non-OECD countries (UNEP, 2010). Using current trends, estimates by Monni et al. (2006) showed that non-OECD countries will have a relative share of 64 % of the global landfill methane emissions by the year 2030 (Figure 2.15). A UNEP (2010) report attributed this increase to the high amounts of biodegradable waste landfilled, growth in population, expansion in waste collection services, and improved landfill management practices in most developing countries.

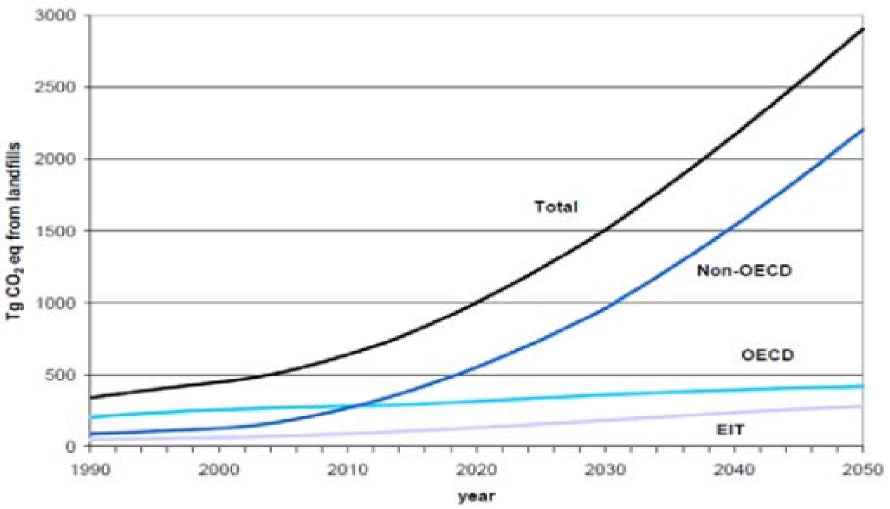


Figure 2.16: Methane Emissions from Different Regions (Monni et al., 2006)

Although improved landfill management has many benefits, care is required to avoid the associated dis-benefit of increased methane emissions (UNEP, 2010). Sustainable waste management involving waste minimisation, recycling/reuse, treatment, and finally disposal to landfill, is a generally accepted hierarchy in the developed world. However, this may not be feasible in many parts of the developing world due to economic constraints (Reinhart et al., 2012). Economic and industrial development plays an important role in solid waste management because an enhanced economy can allow more funds to be allocated to solid waste management on a sustainable basis (Pepper and Brebbie, 2012). However, developing countries are by definition weak economically (IMF, 2011), and hence have insufficient funds for sustainable development of their waste management systems (Pepper and Brebbie, 2012). The CDM provides an opportunity for developing countries to not only reduce methane emissions contained in landfill gas, but to also improve landfill site operations (Barker, 2008). The CDM enables landfill operators to access environmentally friendly technologies for capturing and treating methane in landfill gas, which ordinarily requires significant investment and expertise to implement. In addition to reducing GHG emissions, the treatment of trace components in landfill gas that are responsible for nuisance odours, and other health risks contributes to improvements in the local environment. The CDM also provides an opportunity for landfill operators to generate additional revenue through the sale of CERs achieved from methane emission reductions and when possible, through energy generation. The additional revenue can assist operators in the management of their landfill sites both during the operational and after-care period. Other socio-economic benefits of landfill gas CDM projects include short and long-term employment opportunities for local people required during construction of landfill gas infrastructure (UN, 2007). It has also been shown that landfill gas projects can easily pass the CDM additionality test (EPRI, 2011). This is because most related legislations in many developing countries do not require the capture and treatment of landfill gas and even where such legislation exists, implementation is sparse due to lack of funds (Tbilisi City Municipality, 2007). Landfill gas CDM projects achieve GHG emission reductions in the following two ways:

(i) By flaring methane contained in landfill gas and converting it into carbon dioxide thereby reducing its global warming potential from 25 to 1 (Peterson et al., 2008). Although both methane and carbon dioxide are greenhouse gases (GHG), the GHG accounting system (IPCC, 1996) does not include carbon dioxide emitted from biogenic sources. This is because during plant growth, carbon is taken up and incorporated into plants and that the same amount of carbon is emitted when plants decompose in a landfill (US EPA, 2014; Gourc et al., 2011); and/or

(ii) By using it to generate energy such as electricity using gas engines (EPRI, 2011).

The carbon dioxide fraction of landfill gas is classified as carbon neutral because it is derived from organic biomass. Equally, the carbon dioxide by-product from the flaring of methane in landfill gas and/or that used for energy generation is likewise considered to be carbon neutral (Peterson et al., 2008).

All CDM projects use models to estimate GHG emission reductions. A methodology for estimating methane emissions from landfills is well established. The first order decay model (FOD) version 06.00 (UNFCCC, 2011b) provides landfill project developers with default waste decay rate values for four types of waste of varying degradability depending on climatic conditions (i.e., temperature and precipitation) (EPRI, 2011). The model also corrects for the level of management and the depth of the landfill, which affects anaerobic conditions. Equation 4 is the FOD model formula and Table 2.9 shows the default values or parameters for the non- monitored parameters required to be used in the model.

$$BE_{CH4,SWDS,y} = \varphi.(1-f).GWP_{CH_4}(1-OX).\frac{16}{12}.F.DOC_f.MCF.\sum_{x=1}^{y}\sum_{j}W_{j,x}.DOC_j.e^{-k_j(y-x)}.(1-e^{-k_j})$$

Equation 2.1: First Order Decay (FOD) Equation

Where,

BECH4, SWDS,y = Baseline methane emissions occurring in year y generated from waste disposal at the landfill during a time period ending in year y (t CO_2e/yr)

X = Year during the crediting period: x runs from the first year when landfill site started receiving waste to the year y for which avoided emissions are calculated (x=y)

Y = Year of the crediting period for which methane emissions are calculated (y is a consecutive period of 12 months)

DOC_f = Fraction of degradable organic carbon (DOC) that decomposes in the landfill for year y (weight fraction)

Wj,x = Amount of solid waste type j disposed of in the landfill in year x(t)

φy = Model correction factor to account for model uncertainties for year y

f = Fraction of methane captured and/or flared at the landfill

$GWPCH_4$ = Methane global warming potential

OX = Oxidation factor (reflecting amount of methane from landfill oxidised in the soil cover material)

F = Fraction of methane in the landfill gas (LFG)

MCFy = Methane correction factor for year y

DOC_j = Fraction of degradable organic carbon in the waste type j (weight fraction)

Kj = Decay rate for the waste type j (1/yr)

j = Types of residual waste or type of waste in the municipal solid waste (MSW)

16/12 = Conversion factor for Carbon (C) to Methane (CH_4)

Table 2.9: Default Parameters Not Monitored (Adapted from UNFCCC, 2011)

<table>
<tr><th>Data/Parameter:</th><th>Value(s) Applied</th></tr>
<tr><td>φ</td><td>0.9</td></tr>
<tr><td>OX</td><td>Use 0.1 for managed solid waste disposal sites that are covered with oxidizing material such as soil or compost. Use 0 for other types of solid waste disposal sites</td></tr>
<tr><td>F</td><td>0.5</td></tr>
<tr><td>DOC_f</td><td>0.5</td></tr>
<tr><td>MCF</td><td>Use the following for MCF:
• 1.0 for anaerobic managed solid waste disposal sites. These must have controlled placement of waste (i.e., waste directed to specific deposition areas, a degree of control of scavenging and a degree of control of fires) and will include at least one of the following: (i) cover material; (ii) mechanical compacting; or (iii) leveling of the waste;
• 0.5 for semi-aerobic managed solid waste disposal sites. These must have controlled placement of waste and will include all of the following structures for introducing air to waste layer: (i) permeable cover material; (ii) leachate drainage system; (iii) regulating pondage; and (iv) gas ventilation system;
• 0.8 for unmanaged solid waste disposal sites – deep and/or with high water table. This comprises all solid waste disposal sites (SWDS) not meeting the criteria of managed SWDS and which have depths of greater than or equal to 5 meters and/or high water table at near ground level. Latter situation corresponds to filling inland water, such as pond, river or wetland, by waste; and
• 0.4 for unmanaged-shallow SWDS. This comprises all SWDS not meeting the criteria of managed SWDS and which have depths of less than 5 meters.</td></tr>
<tr><td>DOC_j</td><td>Apply the following values for the different waste types <i>j:</i>
<table>
<tr><th>Waste type <i>j</i></th><th>DOC_j (% wet waste)</th><th>DOC_j (% dry waste)</th></tr>
<tr><td>Wood and wood products</td><td>43</td><td>50</td></tr>
<tr><td>Pulp, paper and cardboard (other than sludge)</td><td>40</td><td>44</td></tr>
<tr><td>Food, food waste, beverages and tobacco (other than sludge)</td><td>15</td><td>38</td></tr>
<tr><td>Textiles</td><td>24</td><td>30</td></tr>
<tr><td>Garden, yard and park waste</td><td>20</td><td>49</td></tr>
<tr><td>Glass, plastic, metal, other inert waste</td><td>0</td><td>0</td></tr>
</table></td></tr>
<tr><td>k_j</td><td>
<table>
<tr><th colspan="2">Waste type <i>j</i></th><th colspan="2">Boreal and Temperate (MAT≤ 20^0C)</th><th colspan="2">Tropical (MAT>20^0C)</th></tr>
<tr><td rowspan="2">Slowly degrading</td><td>Pulp, paper, cardboard (other sludge), textiles0.07</td><td>0.04</td><td>0.06</td><td>0.045</td><td>0.07</td></tr>
<tr><td>Wood, wood products and straw</td><td>0.02</td><td>0.03</td><td>0.025</td><td>0.035</td></tr>
<tr><td>Moderately degrading</td><td>Other (non-food) organic putrescible garden and park waste</td><td>0.05</td><td>0.10</td><td>0.065</td><td>0.17</td></tr>
<tr><td>Rapidly degrading</td><td>Food, food waste, sewage sludge, beverages and tobacco</td><td>0.06</td><td>0.185</td><td>0.085</td><td>0.40</td></tr>
</table></td></tr>
</table>

N.B: MAT – Mean annual temperature, MAP – Mean annual precipitation

2.5 SUMMARY

While landfill remains the dominant waste management option in the developing world, most disposal sites in these countries are operated as uncontrolled open dumpsites. Apart from the absence of adequate policies and regulations, economic and technological constraints make meeting all aspects of sanitary requirements impractical in most developing countries. The absence of these policies and regulations coupled with the disposal of waste, which is predominantly organic, presents an opportunity for landfill operators to both earn additional revenue and access advanced landfill technology through the CDM. The absence of policies and regulations makes landfill projects easily pass the CDM additionality test. Through its sustainable development objective, the CDM has the potential to allow improvements in the way landfill sites are managed and operated. However, further scrutiny revealed that there is no universally accepted approach or methodology applicable for assessing sustainability benefits of CDM projects regardless of project type and location. The CDM modalities and procedures do not define what sustainable development means in the context of the CDM. Instead, it transferred the onus to developing countries' host nations because of the argument by developing countries that setting such a definition would impinge on their national sovereignty. It is therefore, up to developing countries CDM project host nations to determine their own criteria and assessment process. Although various methodologies have been adopted, checklist and multi-criteria approaches are predominantly used by developing countries host nations for sustainability assessment. With different type of projects, it is expected that differences arise when it comes to selection of specific criteria and indicators for sustainability measurements. However, the two approaches are applied without taking into consideration the different project types.

CHAPTER 3 : RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter presents the research methodology used to achieve the aims and objectives of the study. The chapter establishes the philosophical orientation of the research and discusses in detail the chosen strategies of inquiry. The research design consists of five stages: (i) literature review; (ii) assessment of landfill management practices including aftercare (legislation and its application) at existing landfill sites in developed and developing countries (using case studies); (iii) review and evaluation of sustainable development methodologies used by host nations' DNAs with highest number of registered landfill gas CDM projects in the five regions of Africa, Asia and Pacific, Latin America, the Middle East, and Europe and Central Asia; (iv) development of a framework for assessing sustainable development benefits of CDM projects at landfill sites; and (v) validation of the developed framework to illustrate its applicability.

3.2 RESEARCH DESIGN

The research design for this study is both descriptive and explanatory in nature. Although usually dismissed as 'mere description', good description is fundamental to any research because it adds to our existing knowledge by provoking the 'why' questions of explanatory research (De Vaus, 2001). Explanatory research looks for explanations of the nature of certain relationships; it focuses on the 'why' questions (De Vaus, 2001). The 'why' questions can be answered by developing causal explanations, which argue that phenomenon Y is affected by factor X. The research study seeks to provide descriptions and explanations of landfill management including aftercare that will be observed at landfill sites in both developed and developing countries. Furthermore, the research seeks to answer some research questions frequently asked by 'What?' and 'How?' questions. Blaikie (2010) stated that, in social research, 'what' questions require answers that describe the state or status of a concept. The 'how' questions are concerned with interventions. This research intends to answer 'what' questions that are concerned with knowledge, such as, what are the factors affecting the management of landfills including aftercare both in developed and developing countries?' Why questions are concerned with, why is the CDM not equally achieving its dual objectives as stated in Article 12 of the Kyoto Protocol? Lastly, how questions are concerned with, how can landfill management including aftercare be improved in developing countries in view of the existing inadequate legislation requirements (Diaz, 2011) to manage landfill emissions such as leachate and landfill gas? According to Denscombe (2010), a key decision when undertaking social research is that researchers should be able to answer some fundamental questions in relation to their research. The fundamental questions include those mentioned above. The adopted research design in this study serves as a framework that directs how the study has been conducted from the research aims and objectives (section 1.2) to the concluding chapter (Chapter 9).

3.3 THEORIES ADOPTED IN RESEARCH STUDY

According to Thomas (2010), researchers base their work on certain philosophical perspectives, which may be based on a single or more paradigms. The choice of a philosophical perspective usually depends on the kind of work involved. The philosophical assumptions underlying this research study comes mainly from the pragmatic paradigm. The study also adopts elements of the other two perspectives – positivists and constructivists. Pragmatist supporters acknowledge that discoveries about reality cannot be separated from the perspective of the researcher (Wahyuni, 2012). They believe that positivists (who look for explanations of behaviour and not meaning) and constructivists (where meaning is constructed and constantly re-constructed through experience resulting in many different interpretations) are not mutually exclusive. Their emphasis is on what works best to address a research problem. The pragmatic viewpoint provides a useful foundation to gain insight into the concept of sustainable development in general, and as it relates to landfill gas CDM projects in particular. Ontologically (nature of knowledge) reality is viewed to be complex, which undergoes change as well as periods of permanence (Corbin and Strauss, 2008). This is particularly true in relation to sustainable development, which is rife with complexities and ambiguities (see section 2.3.2). Sustainable development was coined at the international level in order to launch discussions over relationships between development and environment among a series of stakeholders (Wallenborn, 2008). However, sustainable development is not defined under the CDM (UNFCCC, 2012a). This responsibility was delegated to developing country host nations DNAs (see section 2.4.2.1). Fien (2010) has argued against having an agreed definition because the concept concerns a process of change, which is heavily reliant upon local contexts, needs and interests. This however, has resulted in the concept to be interpreted differently (multiple realities) by different stakeholders who include developing country host nations DNAs and project developers. For example, developing countries DNA have different definitions and interpretations of sustainable development because of the differences in their sovereign requirements (Monceau and Brohe, 2011). This in turn has led to different actions at the project implementation level. For example, social sustainability benefits aspects required by the Philippines DNA include the provision of education and training, provision of resources and services for disadvantaged groups, and the improvement of local participation in project CDM activities while public participation and the provision of healthcare are the social requirements by the Thailand DNA (Monceau and Brohe, 2011). In terms of an epistemological approach (development of knowledge), this research assumes that reality can only be created through interaction between the researcher and the research participants who in this case are developers of CDM projects at landfill sites. In order to gather adequate information/data from the developers, they must be treated as human beings whose ideas and opinions are based on their perspective of the research problem. This is because they are the ones experiencing and labelling the 'reality' that is being investigated.

3.4 RESEARCH APPROACH

The epistemological and ontological assumptions for this research calls for an approach that is capable of capturing adequate information. This could be facilitated by a qualitative research approach "because qualitative investigation understands the complex world of human experience and behaviour from the point-of-view of those involved in the situation of interest" (Krauss, 2005). Krauss further added that "a major point most qualitative researchers tout as a major epistemological advantage of what they do is that, it allows them to grasp the point of view of participants." They see quantitative research as limited in nature because it looks only at a small portion of reality that cannot be split without losing the importance of the whole phenomenon. Qualitative research on the other hand is based on multiple realities constructed by human beings experiencing a phenomenon of interest. In the context of this research study, the human beings constructing realities are the developers of landfill gas CDM projects while the phenomenon of interest are the sustainability benefits achieved by implementing such projects.

However, apart from collecting qualitative data e.g., observation, interviews, documents and listening to stories from participants (landfill operators/owners), this study also required quantitative data. In order to assess/determine the potential sustainability benefits that can be achieved by implementing landfill gas CDM projects in developing countries in view of the inadequate legislations for managing various landfill emissions such as leachate and landfill gas, the potential GHG emission reductions (in tonnes) were required to be calculated based on the type and amount of waste arisings at landfill sites. Taking the above into consideration, neither a quantitative nor qualitative research approach would achieve the research aims and objectives as stated in section 1.2. However, by combining the two, the inflexibility of one research approach was compensated by the flexibility of the other. A mixed methods approach was therefore, found to be the most suitable for this study.

3.5 RESEARCH FRAMEWORK

In this study, a research or conceptual framework (Miles and Huberman, 1994) is used to explain the main areas that were studied, which included legislation requirements for landfill management both in developed and developing countries, and methodologies mostly used by developing country host nations when assessing sustainable development benefits of CDM projects. As stated by Maxwell (2013), the most important thing to understand about a conceptual framework is that, “it is primarily a conception of what is out there that you plan to study, and of what is going on with these things and why, a tentative *theory* of the phenomena that you are investigating.” The theory informs the rest of the research design i.e., it helps to assess and refine goals, develop realistic and relevant research questions, select appropriate methods, and identify potential validity threats to research conclusions.

As described in section 3.4, the research design for this study is analyzed largely through qualitative methods with a small component of quantitative methods. Qualitative researchers usually analyze their data inductively (Thomas, 2010). In research studies such as this one, which are descriptive and interpretive, the researcher, analyses, interprets and theorizes about the phenomenon against the backdrop of a framework. Figure 3.1 shows the research framework for this study, which consisted of five key stages that are discussed below.

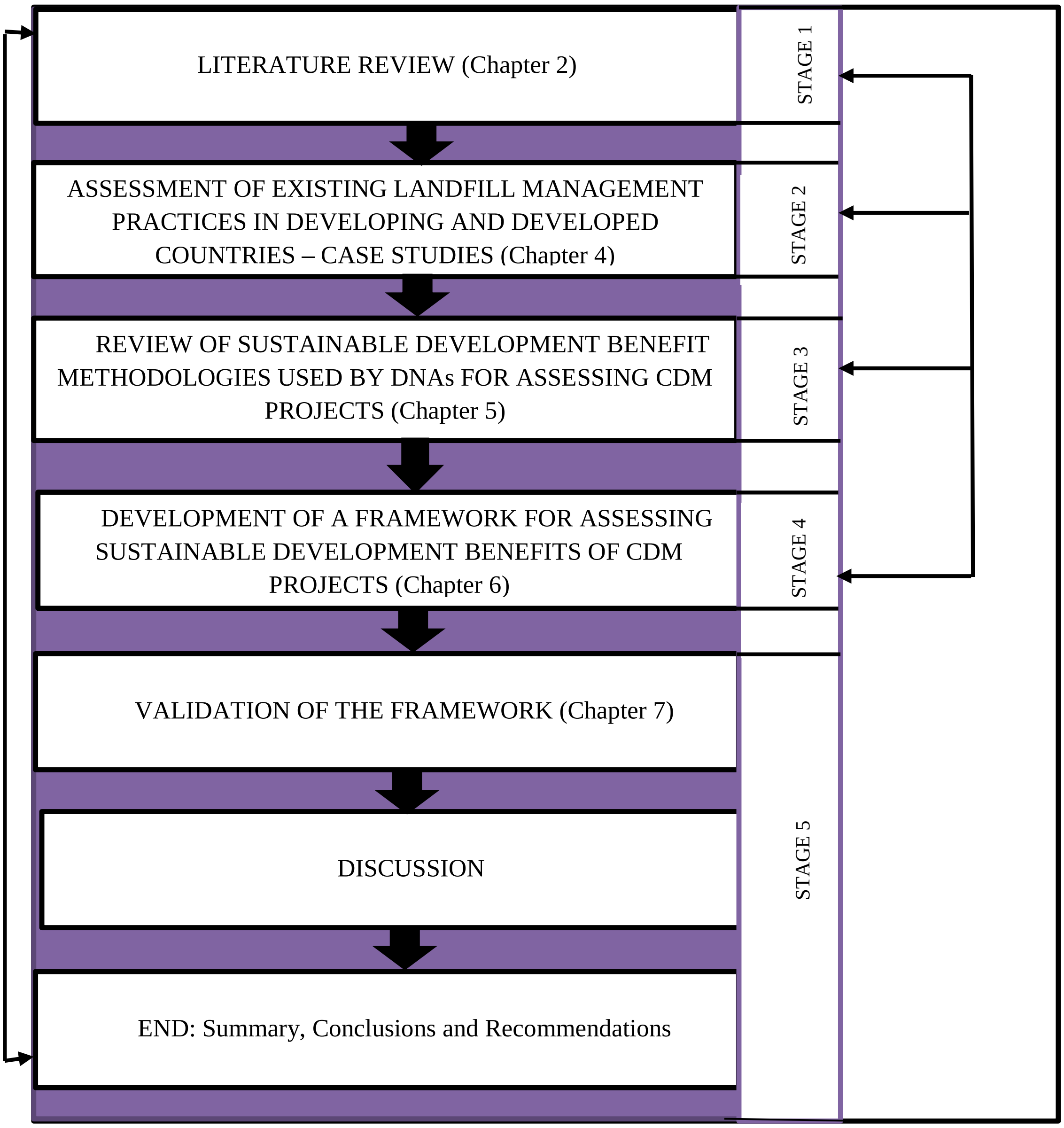


Figure 3.1: Research Framework

3.6 STAGE 1: LITERATURE REVIEW

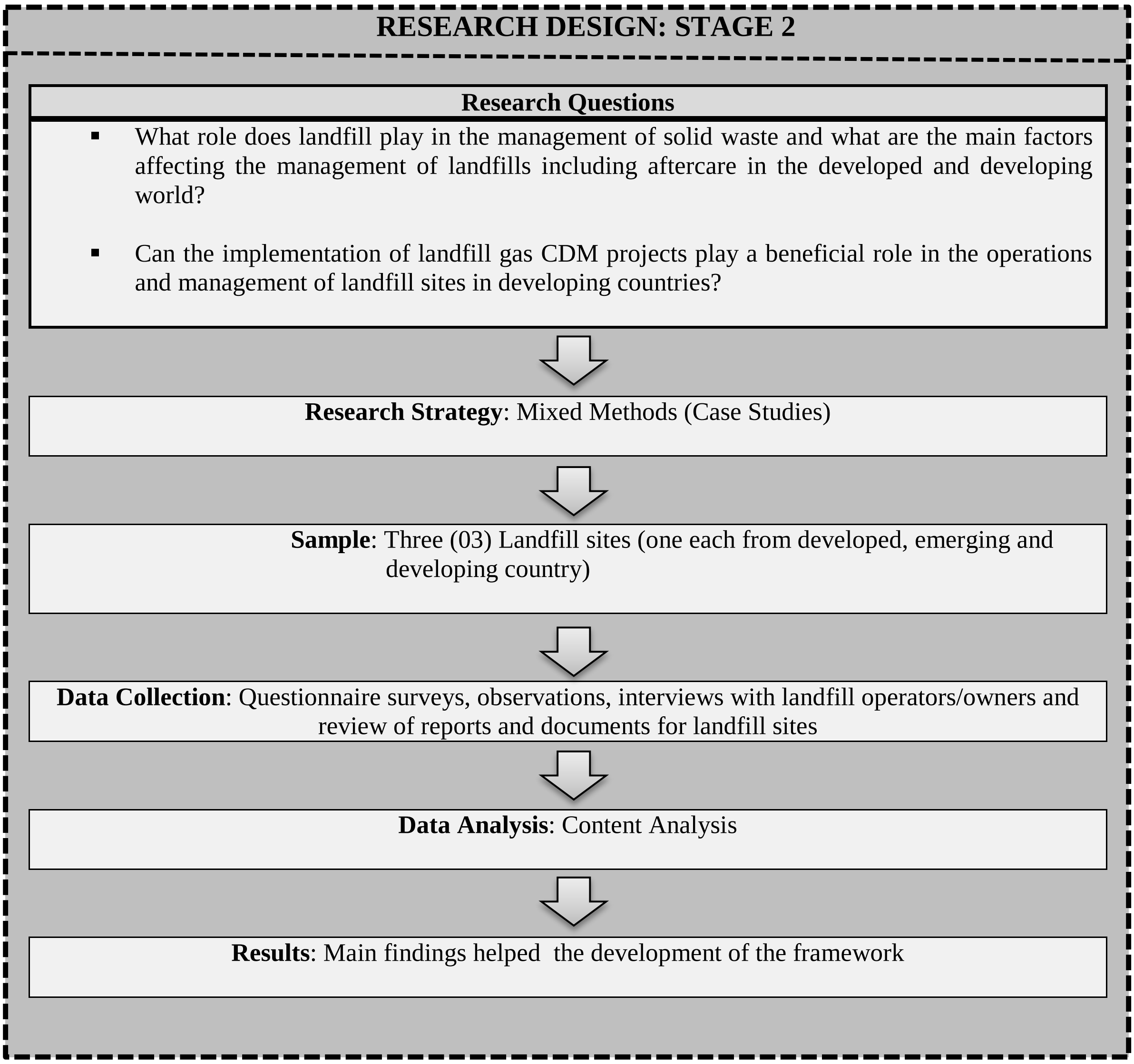
Stage one of this research process deals with the literature review for the study. A literature review gave the research study a theoretical basis and helped to determine its nature. As alluded by Boots and Beile (2005), a literature review is not just a search for information but includes the identification and articulation of relationships between the literature and one’s field of research. An initial review of literature was carried out covering the three main focus areas of the study. This helped to understand the research problem and identify the gaps in literature. The literature review covered a variety of sources relevant to the research study and these included:

- Books
- Journal articles
- Conference proceedings
- Reports (from government, non-governmental organizations, and multilateral agencies such as UNEP, UNDP, UNFCCC and World Bank)
- Sustainable development criteria used by developing country host nations
- Policy and legislation documents governing landfill management both in the developed and developing world
- Web sites
- Electronic research data bases
- Key word searches using internet search engines such as Google scholar

All the relevant references from the literature reviewed were saved and stored in Reference Manager bibliographical software.

3.7 STAGE 2: ASSESSMENT OF LANDFILL MANAGEMENT AND OPERATIONAL PRACTICES IN DEVELOPED AND DEVELOPING COUNTRIES – CASE STUDIES (UNITED KINGDOM (UK), SOUTH AFRICA AND ZAMBIA)

Stage two of this research process deals with the assessment of existing landfill operations and management practices both in the developed and developing world. As shown in Figure 3.2, it was undertaken to answer research questions 2 and 3 given in section 1.2.



RESEARCH DESIGN: STAGE 2

Research Questions

- What role does landfill play in the management of solid waste and what are the main factors affecting the management of landfills including aftercare in the developed and developing world?
- Can the implementation of landfill gas CDM projects play a beneficial role in the operations and management of landfill sites in developing countries?

Research Strategy: Mixed Methods (Case Studies)

Sample: Three (03) Landfill sites (one each from developed, emerging and developing country)

Data Collection: Questionnaire surveys, observations, interviews with landfill operators/owners and review of reports and documents for landfill sites

Data Analysis: Content Analysis

Results: Main findings helped the development of the framework

Figure 3.2: Research Design – Stage 2

3.7.1 Rationale for Inclusion of Developed Countries.

Although CDM projects can only be implemented in developing countries (Article 12 of the Kyoto Protocol), it was important in this study that operations and management practices at landfill sites in developed countries were looked at for the following two reasons. Firstly, while the CDM's primary goal is to save abatement costs for developed countries, it is also considered as a means of boosting technology transfer and diffusion from developed to developing countries. If the technology used in a CDM project has to be imported, the project leads, de facto, to the transfer of technology (Dechezlepretre et al., 2008). Furthermore, section A.4 of the Project Design Document (PDD) template (UNFCCC, 2006a) i.e., technical description of the project activity, requires CDM project developers to include a description of whether or not the technologies proposed in a particular project are environmentally friendly. In the context of this study, sustainable development benefits of landfill gas CDM projects can be realised through the transfer of landfill gas technologies from developed countries where a range of technologies that can collect, treat, and utilise landfill gas exist and are considered mature (Barker, 2013; EPRI, 2011). Against this background, in developing a framework for assessing sustainable development benefits of landfill gas CDM Projects, it was necessary that such technologies and associated sustainability benefits were observed at existing landfill sites in developed countries. Secondly, it was important to observe and learn how management of landfills including aftercare was achieved in developed countries in view of the existing regulatory requirements for managing different landfill emissions such as landfill gas and leachate both during operation and aftercare period.

3.7.3.5 Number and Type of Case Studies Selected

In order to answer the two research questions (Figure 3.2), three case studies were selected and used in this research stage. Case study selection was based on a number of considerations that included availability of resources, timeframe of the research study, and the nature of information that was required to be collected. Three cases were selected to represent the three categories of countries (developing, emerging and developed) as classified by the International Monetary Fund (IMF) based on their level of development (IMF, 2011). Developing countries are nations with underdeveloped industrial base, and low human development index (HDI) while emerging countries are those progressing towards advanced economies but do not yet have the level of market efficiency to be on par with advanced economies (Investopedia, 2015). Developed countries have highly developed economies and advanced technological infrastructure (Investopedia, 2015). The three case studies helped in establishing cross-case conclusions during the data analysis stage.

Accordingly, a single landfill site in the United Kingdom (UK), South Africa, and Zambia, representing developed, emerging, and developing countries, respectively, were selected. The sites were identified by locating existing landfill sites and their operators/owners in the three countries after which emails were sent to operators/owners requesting for permission to use their sites for the research. Once a no objection feedback was received, a landfill site was selected and confirmed for use in the research. In obtaining final ethical approval (Appendix 1), conditions for this research study required confidentiality of the data collected from the landfill sites. Therefore, the country location for the case study sites are mentioned in the study but the city/town and name of the landfill sites are withheld. For ease of reference, each landfill case study was assigned a code as shown in Table 3.2. Although Chapter four of the thesis provides further detail with the three case studies, a brief description of the reasons for their selection is given below.

Table 3.1: Codes Assigned to Case Studies

Case Study	Code Assigned
UK Landfill Case Study	Landfill A
South Africa Landfill Case Study	Landfill B
Zambia Landfill Case Study	Landfill C

UK Landfill Case Study – Landfill A: The choice of Landfill A was based on the following:

(i) It is located in a developed country where stringent landfill regulations are in existence. Furthermore, it is one of the few landfill sites in the UK that has been subjected to a number of policy and legislation changes from the time waste disposal commenced in 1986 when cell construction was based on 'dilute and attenuation' basis, to now when regulations require stringent design of control systems. The control systems are a requirement under the EU Landfill Directive (1999/31/EC) and are aimed at reducing environmental impacts of landfilling; and

(ii) The site comprises both active and closed landfill cells, which require management. Information acquired on the way these areas are managed may be used in the development of a framework for assessing sustainable development benefits of CDM projects at landfill sites in developing countries.

South Africa Landfill Case Study – Landfill B: The choice of Landfill B was based on the following:

(i) It is located in an emerging developing country that has put in place regulations for the management of landfill sites. Information related to how the regulations impacted on the operations and management of the landfill site may be used in the development of a framework for assessing sustainability benefits of landfill gas CDM projects; and

(ii) It was the first landfill site in Africa – the poorest region in the world (World Bank, 2013) - to be registered, verified and issued with CERs by the CDM Board as a landfill gas CDM project. As a registered CDM landfill site, it was expected that the twin objectives of the CDM (i.e., GHG emission reductions and achievement of sustainable development) were being met. It was therefore, important to learn and observe how these were being achieved at the site. Furthermore, it was important to assess the additional benefits that had been brought to the landfill sites by implementing a CDM landfill project at the site.

Zambia Landfill Case Study – Landfill C: Landfill site C was chosen based on the following:

(i) Preliminary investigations conducted by the researcher showed that the site was poorly managed despite having been constructed based on sanitary principles by an international donor agency called the Danish International Development Agency (DANIDA); and

(ii) It is located in a developing country where almost all the collected waste goes to the landfill site. The collected waste is predominantly organic (biodegradable), which apart from presenting negative effects both on human health and the environment, presents an opportunity for implementing landfill gas CDM projects that would generate additional revenue and lead to other co-benefits other than just mitigating landfill gas emissions.

3.8 STAGE 3: REVIEW AND EVALUATION OF SUSTAINABLE DEVELOPMENT METHODOLOGIES USED BY DEVELOPING COUNTRY HOST NATIONS TO APPROVE CDM PROJECTS

The third stage of this research process concentrated on reviewing and evaluating existing sustainable development benefit methodologies used by developing country host nations' DNAs for approving CDM projects. The review and evaluation was based on two data sources:

(i) Sustainability criteria as defined/provided in developing countries DNA websites; and

(ii) Relevant sources of literature such as studies on existing methodologies.

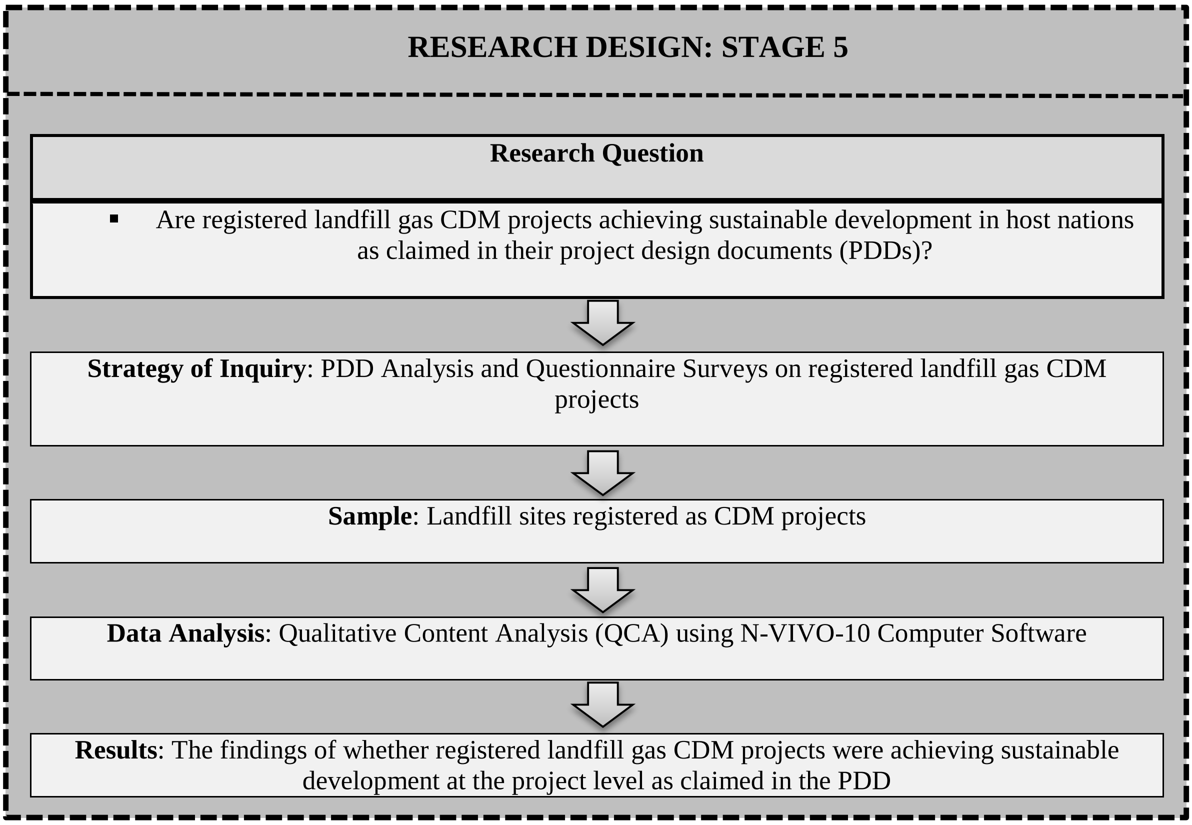
Since the focus of the study was on sustainable development benefits of the CDM as it relates to projects at landfill sites, emphasis was placed on developing country host nations' DNAs with the highest number of CDM projects at landfill sites registered with the CDM Executive Board in the five regions of Africa, Asia and Pacific, Europe and Central Asia, Latin America, and the Middle East.

3.9 STAGE 4: DEVELOPMENT OF A FRAMEWORK FOR SUSTAINABLE DEVELOPMENT (SD) BENEFITS OF LANDFILL GAS CDM PROJECTS

The findings from stages 1, 2 and 3 of the research established the need for developing a framework for assessing sustainable development benefits of CDM projects at landfill sites. This allowed for the use of a multi-strategy triangulation approach utilising the literature review, assessment of existing landfill management practices in both developed and developing countries, and the review of sustainable development criteria methodologies used by DNAs. This approach allowed findings to be cross-checked" (Bryman, 2001). Flick (2005) recommended this approach in complex studies because it reflects and explains issues more accurately than any single measure and gives several combined methods equal relevance. Furthermore, triangulation allows a researcher to have greater confidence in the research findings than if a single method was used (Clarke and Dawson, 1999). The in-depth understanding of these findings was used to develop the proposed framework for assessing sustainability benefits of landfill gas CDM projects. The developed framework is presented in Chapter Six.

3.10 STAGE 5: VALIDATION OF THE DEVELOPED FRAMEWORK

In this research study, validation is defined as a process used to confirm the suitability of the developed framework for its intended use. The framework is intended to be used by both host nations DNAs when granting letters of approval (LoA) and third party UNFCCC agencies (DOEs) when validating and verifying projects before recommending for registration and issuance of CERs, respectively. According to Huber (2007), validation results can be used to judge the quality, reliability and consistency of findings from a developed method. Validation of the framework was done by applying it to assess the achievement of sustainable development by LFG CDM projects that were registered with the CDM Executive Board. This stage of the research was undertaken to answer research question RQ6 given in Section 1.2 (i.e., are registered LFG CDM projects achieving sustainable development benefits in host nations as claimed in their project design documents?) The research design for this stage is shown in Figure 3.3.


RESEARCH DESIGN: STAGE 5

Research Question

- Are registered landfill gas CDM projects achieving sustainable development in host nations as claimed in their project design documents (PDDs)?

Strategy of Inquiry: PDD Analysis and Questionnaire Surveys on registered landfill gas CDM projects

Sample: Landfill sites registered as CDM projects

Data Analysis: Qualitative Content Analysis (QCA) using N-VIVO-10 Computer Software

Results: The findings of whether registered landfill gas CDM projects were achieving sustainable development at the project level as claimed in the PDD

Figure 3.3: Research Design – Stage 5

3.10.1 Data-sets Used for Framework Validation

Project Design Documents for LFG CDM projects that have been registered with the CDM Executive Board were chosen as the basis for validating the framework. According to Bowen (2009), the quality of documents and evidence they contain should be the main concern when selecting documents for documentary analysis. Section A.2 of the PDD template (UNFCCC, 2006a) requires project developers to describe project activities in terms of their purpose and contribution to sustainable development. Furthermore, a PDD can be considered authentic and credible because it is a key document involved in the validation and registration of a CDM project activity (see section 2.4.4.1). It is one of the three documents required for a CDM project to be registered, along with the validation report from a designated operational entity (DOE) and a letter of approval (LoA) from the host nation DNA. The choice of PDDs for approved LFG CDM projects only as opposed to all PDDs for projects that were in the CDM ‘pipeline’ (i.e., including non-registered projects) is based on the following three premises:

(i) They have been approved by DNAs host nations (i.e., issued with LoAs);
(ii) They have been assessed by UNFCCC's accredited agencies (DOEs); and
(iii) They have been registered with the UNFCCC's CDM Executive Board.

Acknowledging the existing weaknesses in DNA criteria used for assessing sustainable development (Rindefjall et al., 2010), it is expected that, in addition to achieving GHG emission reductions, sustainable development benefits are achieved in project host nations by such projects.

However, in spite of the many advantages associated with PDDs, the data/information they contain may not be accurate. The description of a project's contribution to sustainable development in PDDs reflects only 'potential' and not 'real and measured' benefits since they are prepared before project implementation. There is therefore, a tendency by project developers to put forward projects that are likely to meet eligibility criteria set by host nations' DNAs in order to get letters of approval (Subbarao and Lloyd, 2011; UNFCCC, 2012a). For this reason, Killick (2012) recommended the use of additional sources of evidence when using PDDs as sources of inquiry. In view of the above inadequacies with PDDs, a questionnaire survey based on the developed framework was developed (Appendix 4) and administered to landfill operators of LFG CDM projects registered with the CDM Executive Board. Responses from the questionnaire survey were used as an additional source of data to validate the framework.

3.10.2 Validation Method - Qualitative Analysis of PDDs and Surveys Responses

The computer assisted qualitative data analysis software (CAQDAS) program Nvivo 10 (QSR International, 2009), developed for qualitative text analysis was used to analyse the PDDs and the questionnaire survey responses. There were a range of benefits offered to the researcher by using CAQDAS. One benefit that was particularly useful is that, new opportunities are offered in the process of analysing data, which are helpful in the development of explanations (Managabeira, 1995). For example, using the tools in Nvivo and by teasing out themes from the data, the sustainable development dimensions were visually shown as parent nodes while the sustainability benefits under each dimension were shown as daughter nodes. This helped in explaining the sustainability benefits that can be obtained under each dimension by implementing a landfill gas CDM project. Using Nvivo, results from data analysis can also be visualised using graphs and/or tree maps. Tree maps display a hierarchy of structured data results (Shneiderman and Plaisant, 2009).

Text analysis of PDDs and questionnaire surveys responses and ‘coding’ of the sustainable development benefits patterns and aspects (predetermined categories) mentioned in the two data sources was done using the various sustainable development criteria in the developed framework (see Chapter 6). Both PDDs, in pdf format, that were downloaded from the UNFCCC homepage (UNFCCC, 2014) and questionnaire survey responses (MS Word) were imported and stored as folders according to region location of projects into Nvivo 10 sources’ internals for coding (Figure 3.4).

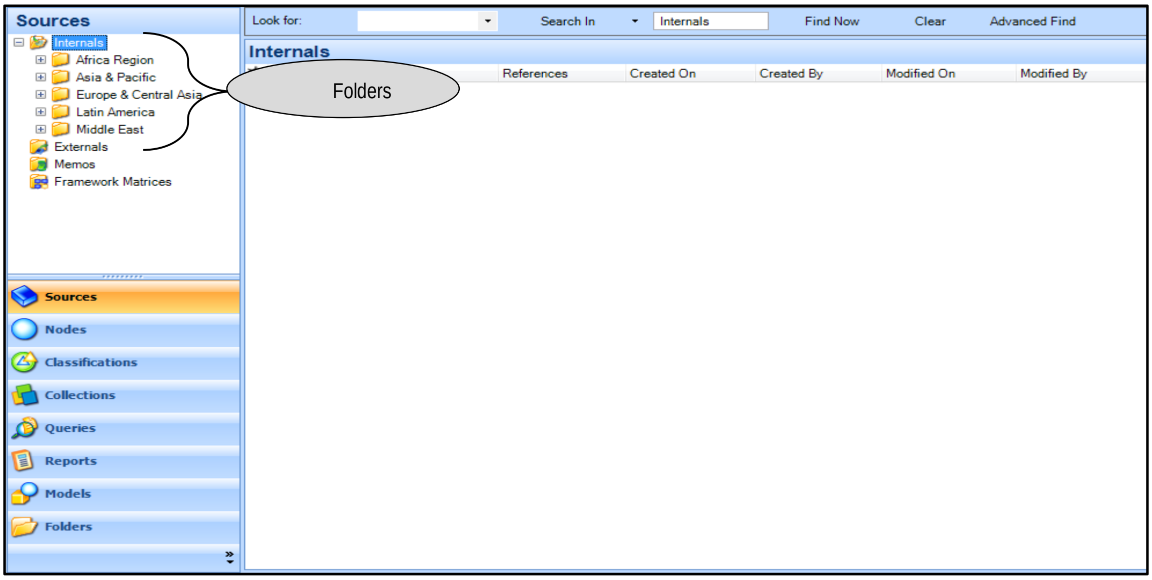
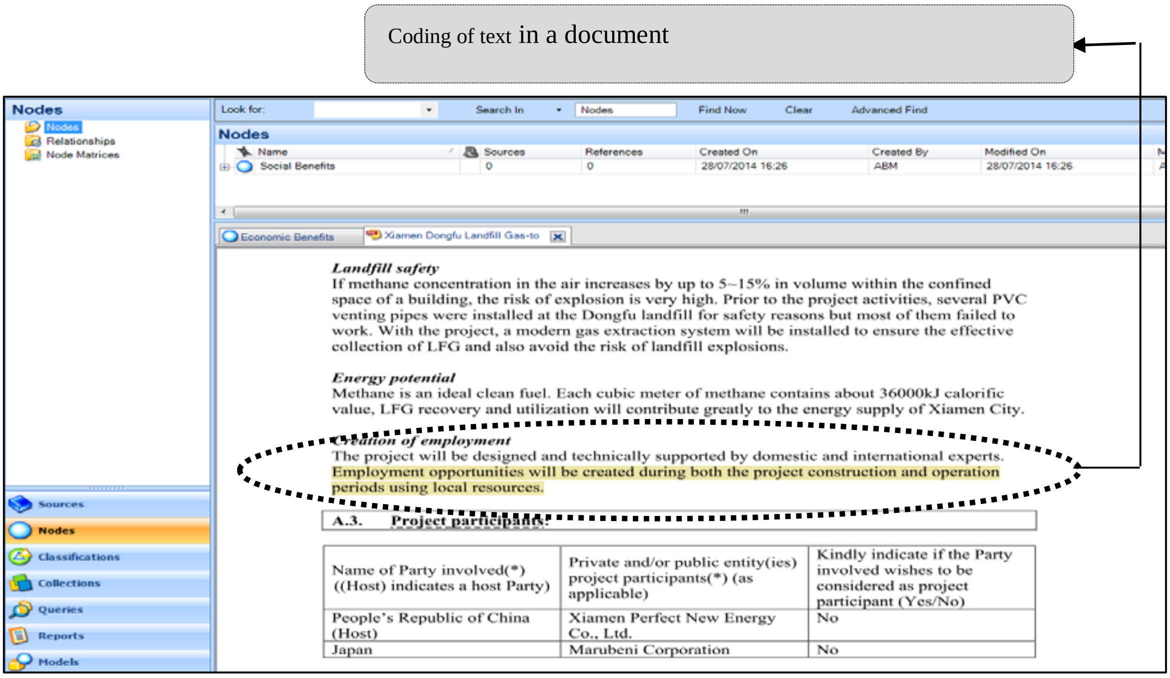


Figure 3.4: Folders Saved and Stored into Nvivo's Internals

Coding – is a term used in Nvivo for gathering material about a related topic or subject in a text and store it in a container called node. In this study, a ‘Yes’ (if there was a positive contribution to sustainable development in the text) or ‘No’ (if there was a negative or no contribution to sustainable development) ‘decision’ was made for each of the sustainable development criteria in the developed framework. If a positive contribution was found, the text that indicated or showed that contribution was appropriately coded and stored in the appropriate node (economic, environmental or social) as shown in Figures 3.5 and 3.6. Nvivo was useful in this study in that, the coding process was transparent and was always possible to back-track the coding decisions made since the text bites for the two data sources (PDDs and surveys) were easily accessible in the software program.


Coding of text in a document

Nodes

Name	Sources	References	Created On	Created By	Modified On
Social Benefits	0	0	28/07/2014 16:26	ABM	28/07/2014 16:26

Landfill safety

If methane concentration in the air increases by up to 5~15% in volume within the confined space of a building, the risk of explosion is very high. Prior to the project activities, several PVC venting pipes were installed at the Dongfu landfill for safety reasons but most of them failed to work. With the project, a modern gas extraction system will be installed to ensure the effective collection of LFG and also avoid the risk of landfill explosions.

Energy potential

Methane is an ideal clean fuel. Each cubic meter of methane contains about 36000kJ calorific value, LFG recovery and utilization will contribute greatly to the energy supply of Xiamen City.

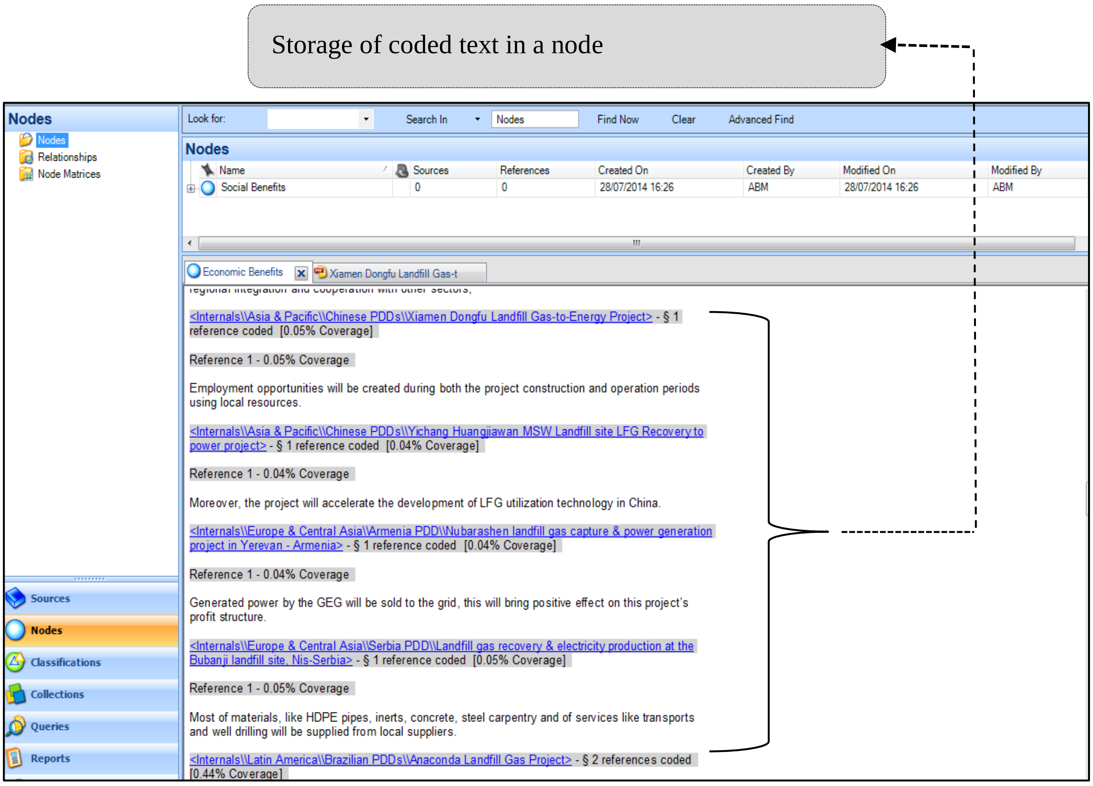
Creation of employment

The project will be designed and technically supported by domestic and international experts. Employment opportunities will be created during both the project construction and operation periods using local resources.

A.3. Project participants:

Name of Party involved(*) ((Host) indicates a host Party)	Private and/or public entity(ies) project participants(*) (as applicable)	Kindly indicate if the Party involved wishes to be considered as project participant (Yes/No)
People's Republic of China (Host)	Xiamen Perfect New Energy Co., Ltd.	No
Japan	Marubeni Corporation	No

Figure 3.5: Coding of Text in a PDD Indicating Positive Contribution to Employment Criterion


Storage of coded text in a node

Nodes

Name	Sources	References	Created On	Created By	Modified On	Modified By
Social Benefits	0	0	28/07/2014 16:26	ABM	28/07/2014 16:26	ABM

regional integration and cooperation with other sectors;

<Internals\\Asia & Pacific\\Chinese PDDs\\Xiamen Dongfu Landfill Gas-to-Energy Project> - § 1 reference coded [0.05% Coverage]

Reference 1 - 0.05% Coverage

Employment opportunities will be created during both the project construction and operation periods using local resources.

<Internals\\Asia & Pacific\\Chinese PDDs\\Yichang Huangjiawan MSW Landfill site LFG Recovery to power project> - § 1 reference coded [0.04% Coverage]

Reference 1 - 0.04% Coverage

Moreover, the project will accelerate the development of LFG utilization technology in China.

<Internals\\Europe & Central Asia\\Armenia PDD\\Nubarashen landfill gas capture & power generation project in Yerevan - Armenia> - § 1 reference coded [0.04% Coverage]

Reference 1 - 0.04% Coverage

Generated power by the GEG will be sold to the grid, this will bring positive effect on this project's profit structure.

<Internals\\Europe & Central Asia\\Serbia PDD\\Landfill gas recovery & electricity production at the Bubanji landfill site, Nis-Serbia> - § 1 reference coded [0.05% Coverage]

Reference 1 - 0.05% Coverage

Most of materials, like HDPE pipes, inerts, concrete, steel carpentry and of services like transports and well drilling will be supplied from local suppliers.

<Internals\\Latin America\\Brazilian PDDs\\Anaconda Landfill Gas Project> - § 2 references coded [0.44% Coverage]

Figure 3.6: Storage of Coded Text Indicating Contribution to Employment in a Node (Economic benefit container)

3.10.2.1 Quantitative Data Analysis

Although the developed framework is qualitative in nature, decisions at the national approval stage (i.e., issuance of LoA) and at the validation and verification stages can be made based on the weights or scores of sustainable development criteria (benefits), which is quantitative. This will be applied at the project level. However, in this study, Nvivo was used to assess the sustainability benefits of more than one LFG CDM project registered with the CDM Executive Board in a qualitative way and therefore, presents findings at aggregated rather than project level. This is because of the large number of projects that were required to be assessed. While the software program is not demanding in terms of data requirements, it is limited in its scope to describe *how* projects contribute to sustainable development (i.e., distribution of benefits in the three dimensions) and not by how much. Though coding of sustainability patterns and aspects in PDD and survey texts were done at project level, the findings are only presented at an aggregated level. The number of sustainable development benefits was a proxy measure of the maximum possible sustainability contribution (Olsen and Fenhann, 2008) by a CDM project. The more sustainable development benefits a project had, the higher the possible maximum magnitude of sustainability benefits and vice versa (Olsen and Fenhann, 2008). For example, if a project had 12 sustainable development benefits, it is likely that these would give a higher contribution to sustainable development than a project with only two or three sustainable development benefits. However, a project with few sustainable development benefits could still have a higher impact than a project with many sustainable development benefits, if the scale and magnitudes of the few benefits were high and seen to be important locally and nationally.

Quantitative data generated from both questionnaire survey responses and PDDs is captured and analysed using Statistical Package for Social Scientists (SPSS) software. This software allowed the defining of variables and the entering of data, which then generated statistical components of recorded information (see section 7.2.1). Tree maps are also used to visualise the distribution of benefits in each dimension.

CHAPTER 4 : LANDFILL MANAGEMENT PRACTICES (LEGISLATION AND ITS APPLICATION) AT EXISTING LANDFILL SITES IN DEVELOPED AND DEVELOPING COUNTRIES - CASE STUDIES (UNITED KINGDOM, SOUTH AFRICA, AND ZAMBIA)

4.1 INTRODUCTION

This chapter presents findings in relation to existing management and operational practices at landfill sites in both developed and developing countries. The findings have been derived using selected landfill case study sites. The criteria used in selecting the case study sites are described in Chapter 3. The case study sites were visited by the researcher and observations were made of existing site management practices and technologies. The information from this chapter was used to develop the framework for the assessment of sustainability benefits of landfill gas CDM projects. The chapter addresses research objectives one, two and three and research questions one and two given in Section 1.2.

4.2 LANDFILL CASE STUDIES

Data from case study landfill sites were collected using semi-structured interviews, observations, and documents. The questionnaire used in the semi-structured interviews is in Appendix 2. Visits to the three case study landfill sites were undertaken by the researcher between 14th June, 2013 and 17th July, 2013. A total of three site visits were made to Landfill A (14th, 25th, and 28th June, 2013). Two visits were made to Landfill B (10th and 11th July, 2013) while one visit was made to Landfill C (17th July, 2013).

4.2.1 UK Landfill Case Study – Landfill A

Landfill A is located in the United Kingdom - a developed country with stringent regulations governing landfill management. The 9.2 ha conventional landfill site is operated strictly in accordance with the EU Landfill Directive (1999/31/EC). The EU Landfill Directive introduced requirements for member states to reduce the amount of biodegradable wastes disposed of untreated to landfills. This restriction aims to prevent and reduce as far as possible negative effects on the environment, in particular the pollution of surface and groundwater, soil and air as well as any resulting risk to human health. Furthermore, the Landfill Directive requires high standards of engineering and operational practices consistent with best modern practices. Unauthorized entry to the landfill site is prohibited. This is achieved by a fence that has been constructed around the site and a gated entrance. The landfill site is split into four phases (Figure 4.1). Phases 1 to 3 are complete (closed), capped, and currently undergoing aftercare. Current disposal activity is confined to Phase 4, which is divided into smaller cells.

Landfill A accepts a wide range of wastes including domestic, commercial, industrial and special wastes including hazardous (i.e., asbestos) and low level radioactive wastes (LLW), which are disposed of separately. Over 90 % of waste disposal at the site is residual waste collected from households and businesses. The low level radioactive waste makes up less than 10 % of the total waste. The effect of the EU Landfill Directive, which bans the disposal of liquid wastes and sets targets for member states to reduce the amounts of biodegradable waste sent for disposal (e.g., UK targets are 75 %, 50 % and 35 % of 1995 levels for the years 2010, 2013, and 2020, respectively) is visible at Landfill A. The quantities of waste landfilled have declined from 800,000 tons when the site opened in 1986 to 100,000 tons in 2012 and only 50,000 tons were expected to be disposed of at the end of 2013 (Walker, 2013 Pers. Comm., 14th June).

Figure 4.1: Aerial View of Landfill A

Engineering Designs (Containment System) - A key engineering requirement under the EU Landfill Directive is a geological barrier for all landfills. This is required up the landfill sides as well as across the base and must provide sufficient attenuation to prevent potential risks to soil and groundwater. When operations have ceased, a final cap is required to be installed at the top of a landfill (Figure 4.2).The EU Landfill Directive further requires that a landfill site be situated and designed so as to meet the necessary conditions for preventing pollution of soil, surface and groundwater and ensuring efficient collection of leachate as and when required. As shown in Table 4.1, the changes in EU landfill legislation can be seen from the way the top and bottom compartments (liners) for Phases 1-3 and Phase 4 have been designed. Phases 1 -3 were developed on a ‘dilute and attenuation' basis comprising earthen material (clay) as the only bottom liner (barrier). At the time of construction, it was generally believed that attenuation and buffering capacity of the natural barrier (i.e. geologic conditions) was sufficient to prevent seepage of leachate into groundwater. This understanding may have led regulations not to require the installation of low permeability barriers. However, Phase 4 (active area of landfill), which is more recent and subject to existing EU legislation, has been developed on a full containment basis with composite lining and leachate collection systems. In addition to liner requirements at the bottom, a 10 m deep slurry wall encapsulation has been built around Phase 4, which in addition to accepting general wastes, accepts low level radioactive-waste (LLW). The slurry wall prevents the flow of contaminants into and from the landfill site. As shown in Table 4.1, a low-permeability top cover (final cap) is now required at all modern landfills after closure.

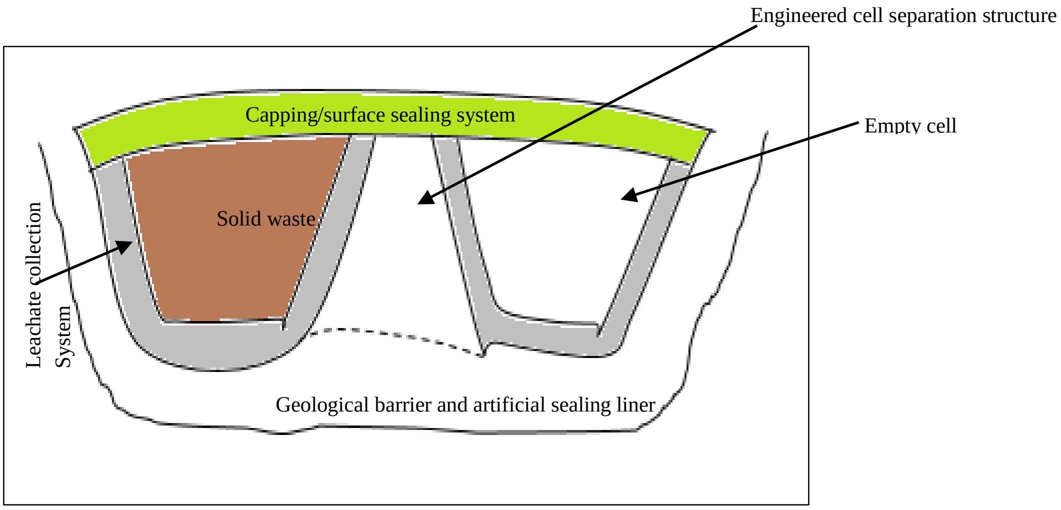


Figure 4.2: Sketch of a Containment System Requirement under EU Regulations (Adapted from EA, 2009)

Table 4.1: Design of Top and Bottom Containment Systems at Landfill A

Landfill Phase (Area of landfill)	**Landfill Base(Liners)**	**Landfill Final Cover**
Phase 1-3 **(Closed cells)**	Low permeability earthen barrier	100 mm top soil 1.1 m estuarine silt 1 mm plastic geomembrane 250 mm silty protection layer
Phase 4 **(Active cells)**	300 mm stone drainage layer 1200 g/m geotextile material 2 mm impermeable HDP membrane 500 mm engineered mineral liner	100 mm topsoil 1.1 m estuarine silt 1 mm plastic geomembrane 250 mm silty protection layers

Waste Disposal Process - The landfill operator/owner operates a tracking system that enables the identification of areas within a landfill cell where a particular waste load will/has been disposed of. Waste disposal is confined to active tipping areas of Phase 4. Inert material is used as daily cover to prevent odour, windblown litter and particulates, and scavenging by birds. Waste accumulation at the site is only permitted for a maximum of 14 days before disposal. The accumulated waste is subject to conditions requiring containment against weather; any accumulated waste is covered by a mat. Low level radioactive wastes (LLW), which come packaged in sealed containers are disposed of by digging a trench into conventional wastes that have already been disposed of. After disposal, the container is covered with approximately 50 cm of non-radioactive materials and approximately 150 cm of non-radioactive cover is placed on top the same day of disposal.

Landfill Gas Management and Monitoring - Landfill gas management is a requirement under the EU Landfill Directive. Annex 1 Paragraph 4.1 of the Directive requires that appropriate measures be taken to control the accumulation and migration of landfill gas. These measures include the requirement to collect and treat the gas through the production of energy and where this is not possible, the gas must be flared. Landfill gas at the landfill site is collected and transported to a treatment facility by a network of gas pipes that have been installed (Figure 4.3). The collected gas is treated by generating approximately 2.8 MW of electricity using CAT engines. The generated electricity is fed into the local electricity grid. The absence of odours at the landfill site is attributed to existing good management (collection and treatment) of landfill gas, which is a requirement under the EU Landfill Directive. Furthermore, in accordance with the issued permit, landfill gas monitoring is carried out on a monthly basis. The trigger levels have been set at 1.0 (% v/v) for methane and 6.1 (% v/v) carbon dioxide.

Figure 4.3: Gas collection pipe at landfill A (Author, 2013)

Leachate and Water Management - It is a requirement under the EU Landfill Directive to sample and collect the generated leachate at representative points within a landfill site. Leachate sampling and measurement (volume & composition) must be determined separately where leachate is discharged from the site. Furthermore, the EU Landfill Directive requires surface water to be monitored at not less than two points: (i) upstream; and (ii) downstream of a landfill. The above management requirements are being met at Landfill A. Leachate arisings are collected and pumped into two lagoons where methane is removed by air-stripping (bubbling air). The methane stripped leachate is sent to a nearby wastewater treatment plant for further treatment before it is discharged into the environment. Groundwater is monitored on a monthly basis both upstream and downstream of the landfill site while surface water is monitored at three points: (i) upstream; (ii) downstream; and (iii) at the outfall. Ammoniacal nitrogen is the surface water determinant parameter whose trigger level has been set at 5.31 mg/l.

Aftercare Management - Article 13 of the Landfill Directive requires member states to undertake aftercare of closed landfills. The Directive has given powers to national regulatory agencies to determine the aftercare period on a site specific basis. In accordance with this requirement, Phases 1 to 3 at Landfill A have all been rehabilitated/restored and were now being used as pasture land for sheep while parts of Phase 4 that had closed have been rehabilitated and were undergoing aftercare. The components being managed during the aftercare period include landfill gas, leachate, and top cover.

4.2.2 South Africa Landfill Case Study – Landfill B

Landfill B is located in South Africa - an emerging developing country in Africa. The 28 ha valley landfill site was opened in 1997 and was the first African landfill site to be registered as a CDM project (Couth et al., 2011). The landfill site is fenced, guarded and is well screened from the public by natural topography and established growth of large trees in the peripheral buffer zone (Figure 4.4). Apart from being the first landfill site in South Africa to go through an Environmental Impact Assessment (EIA) after legislation came into force in 1996, it is the only operational landfill in Africa to have achieved national conservancy status (Parkin, 2013 Pers. Comm., 10th July).

Figure 4.4: Aerial View of Landfill B

Engineering Design (Containment Systems) – Based on waste types, the legislation in South Africa (Minimum Requirements) classifies or grades landfills into either general or hazardous waste landfills. Landfills are also classified as either significant or sporadic leachate landfills. Significant leachate landfills generate leachate either seasonal or continuous throughout the year due to climatic conditions and/or waste with high moisture content. Sporadic leachate landfills are located in arid climates and leachate results from exceptional circumstances, such as a succession of excessive wet periods. Once a landfill has been placed in a particular class (grade), only requirements (operations and management) appropriate to that class need to be met. In this way the legislation ensures environmental acceptability for a full spectrum of landfills from a small communal operation to a regional hazardous waste landfill in a cost-effective way. However, regardless of class or grading, as a minimum, all landfills are required to have an acceptable physical separation between the proposed waste body and the wet season high elevation of the groundwater. The minimum permissible separation distance is 2 m (Figure 4.5). As a precaution measure, the legislation requires minimal liners (compacted layer of re-worked in-situ soil with minimum thickness of 150 mm) at landfill sites that do not generate significant leachate. For landfill sites that generate significant leachate, it is a requirement that a substantial liner (composite or double liner) and leachate management system are installed. The lining system must be additional to the separation comprising soil or rock between the wet season high elevation of the ground water and the landfill. Landfill B is a significant leachate landfill and because of this, the bottom liner consists of a stabilised sand layer onto which a geo-membrane (FPP – Flexible Poly Propylene) liner and geo-grid is placed (Table 4.2). A stabilised sand protection layer is constructed on the liner/geo-grid and crushed dump rock aggregate is placed on this protection layer to facilitate the collection and removal of leachate. In the valley bottom areas of the landfill, an additional component (composite) is added to the barrier system described above.

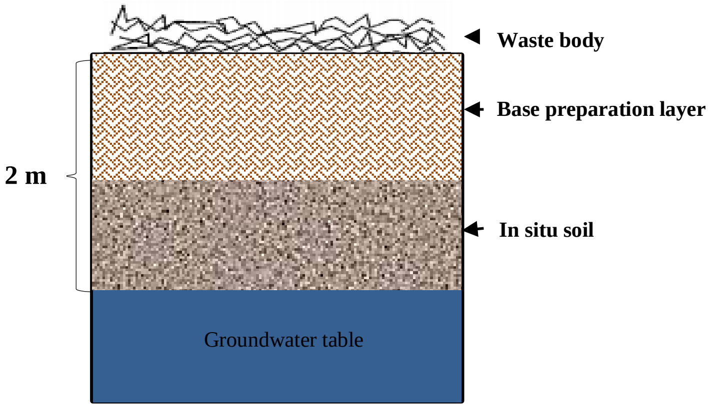


Figure 4.5: Minimum Permissible Separation Distance between Waste Body and Groundwater Table

Table 4.2: Design of Containment System at Landfill B

Landfill Bottom System	Landfill Final Cover System
↑ Rock aggregates	↑ Topsoil
Stabilised sand protection layer	Inert material
1.5 m geomembrane(FPP)	1.5 m geomembrane(FPP)
Stabilised sand(clay)	Sand layer

Waste Disposal Process - Landfill B receives on average 450 tons/day of mixed waste comprising general municipal solid waste, garden waste, and construction and demolition (C&D) debris. Approximately 60 % of the waste is biodegradable (i.e., paper and cardboard, and putrescibles). The lack of a requirement to segregate waste prior to disposal presents an opportunity for hazardous waste to be present in the waste streams received and ultimately landfilled at the site. All the received waste is weighed and disposal is confined to the tipping face(s) of active cells. To prevent odour, windblown litter and particulates, and scavenging, inert material (e.g., soil) is used as daily cover material. The site is free of waste pickers.

Landfill Gas (LFG) Management - South Africa's landfill legislation is not prescriptive on landfill gas management. Permit holders of large landfills are however, required to carry out gas monitoring and report to relevant authorities if landfill gas levels exceeds 1 % v/v in air. Large landfills are also required to implement venting systems if methane concentrations exceeds 5% v/v in air. In the absence of legislative requirements to manage landfill gas, the existing management of landfill gas at Landfill B is mainly attributed to the implemented CDM project (Parkin, 2013 Pers. Comm., 10th July). The extracted landfill gas from both active and closed cells is treated by generating electricity (approximately 1MW) that is fed into the grid using GC Jenbacher engines – a technology that was installed with the CDM project. The excess gas is sent to a flare unit where methane is treated (combustion) by converting it into biogenic carbon dioxide, which is neutral in terms of GHG emissions. By displacing electricity from the grid, the project reduces GHG emissions and particulates related to coal-fired power production. It has also reduced the adverse impacts related to the transportation of coal and coal-mining (dust and acid mine drainage). According to Parkin (2013 Pers. Comm., 10th July), economic, environmental, and social benefits that have arisen at Landfill B following the implementation of the CDM project include:

- Acquisition of landfill gas technology (GC Jenbacher engines for generating electricity, and gas extraction and flaring unit);
- Reduction in site odours due to the treatment of landfill gas (flaring and energy generation). The CDM project has contributed to improvements in local air quality by reducing the amount of landfill gas released into the atmosphere, and thus reducing the risk of dangerous methane gas concentrations;
- Employment creation at the CDM project (11 permanent and 250 part time during construction of CDM project facilities); and

- Generation of additional revenue from the sale of CERs (US$223,000 generated, US$324,000 pending, and approximately R7.65 million (US$0.8m) in electricity savings).

According to the World Bank (2015), Landfill B has served as a pioneer for other CDM landfill gas capture and landfill gas-to-energy projects. The methodology for GHG accounting from use or flaring of landfill gas was developed specifically for this project. Prior to this project, there was no approved methodology for accounting for GHG emissions generated by landfills. The initial methodology used at Landfill B has served as a basis for the development of a UNFCCC consolidated methodology for "Flaring or use of landfill gas", which is now used worldwide (World Bank, 2015). As a result of the implemented CDM project, Landfill B has won numerous awards worldwide. For example, in August 2012, KPMG named the Project as the only one of six African infrastructure projects among its list of "100 most innovative and inspiring urban infrastructure projects in the world". In 2009, the project won the Honorary Energy Globe Award for Sustainability and in 2008, Landfill B won the Dubai International Award for Best Practices to Improve the Living Environment.

Leachate and Water Management - South Africa has no standard leachate management system. The climatic water balance determines whether a landfill is located in an area that will generate significant leachate or not and hence determines the leachate management system to be installed. According to the Minimum Requirements (Regulations), landfills that generate significant leachate must be managed by means of a leachate collection and treatment system. Significant leachate landfills are required to be managed by means of an adequate leachate management system while sporadic leachate landfills do not warrant such a management system. In terms of treatment, the leachate composition determines the most appropriate method for treatment. This could be on-site, chemical, physical or biological treatment, and/or off-site treatment. Since Landfill B is regarded as a significant leachate landfill site, it is equipped with an adequate leachate management system. All gas capturing wells installed under the CDM project are equipped with leachate collection systems, which contributes to the protection of both surface and groundwater. Leachate arisings are pumped into a treatment plant comprising one Sequencing Batch Reactor (SBR) unit constructed of reinforced concrete. The leachate plant also comprises a lined reed bed, which provides final 'polishing treatment' for the removal of residual bio-chemical oxygen demand (BOD), chemical oxygen demand (COD) and solids. The treated effluent from the SBR is used for dust suppression and any excess is sent to the reed bed. The effluent from the reed bed is used for irrigation of vegetated areas within the conservancy area of the landfill.

After-care Management - In order to render a landfill site suitable for its proposed end-use, Section 12 of the Minimum Requirements (DWAF, 1998) requires that closure of a site be preceded by rehabilitation. It is further required that after-care management of a site be undertaken once operations have ceased. However, the period for which financial provisions should be made for the aftercare period is not stated. All closed cells at Landfill B have been rehabilitated and capped with final cover (Figure 4.6).


Rehabilitated and capped cell

Figure 4.6: One of the Rehabilitated and Capped Cell at Landfill B (Author, 2013)

4.2.3 Zambia Landfill Case Study – Landfill C

Landfill C is located in Zambia - a developing country where management of waste that is collected is predominantly by landfill. The 24 ha landfill site was built with financial support from the Danish Government through the Danish International Development Agency (DANIDA). The site comprises a 1.8 ha closed area and a 5 ha active area (Figure 4.7). The non-engineered closed area accumulated waste between the years 2001-2006 while the 5 ha active area has been in operation since 2007.

Figure 4.7: Aerial View of Landfill C

Engineering Design (Containment Systems) - The Waste Management (Licensing of Transporters of Wastes and Waste Disposal Sites) Regulations, 1993 (SI No 71 of 1993) do not specify requirements for the design of landfill containment systems (i.e., bottom liners and top covers). As a result, the design of containment systems at the landfill site are different. At the bottom of the 1.8 ha closed area, an earthen barrier (clay) was installed as the only liner while the 5 ha active area has been equipped with a composite lining system comprising a clay liner and a High Density Poly-Ethylene (HDPE) membrane (Table 4.3). The modern design at the base of the 5 ha active area is attributed to the external assistance received from DANIDA who may have followed internationally recognised best practice in landfill designs as regulations do not specify requirements for bottom liners.

Table 4.3: Design of Barrier Systems at Landfill C

Landfill Area	Bottom System	Cover Material
1.8 ha closed area	Clay liner	Thin loamy soils(final cover)
5 ha active area	↑ Drainage layer HDPE membrane Stabilized clay	No daily cover applied

Waste Disposal Process - Section 6(2) of the Waste Management Regulations gives conditions under which landfill operations must be carried out and these include:

(i) Requirement to enclose and secure sites from scavenging;

(ii) Avoiding pollution of surface and groundwater;

(iii) Avoiding emissions of bad smells; and

(iv) Preventing breeding of rats, mosquitoes or other vermin at the site.

Although the active area of the landfill site was designed and built to be operated as a sanitary landfill, existing operations and management practices were below sanitary requirements. The tipping face was very wide with no daily cover application. This has resulted in the dispersion of waste over large areas within the landfill. Furthermore, despite legislative requirements to enclose and secure disposal sites from scavenging, Landfill C has waste pickers, almost on a daily basis, who carry out their activities (pickings) throughout the landfill site including the active tipping face (Figure 4.8).

Figure 4.8: Waste Pickers (Scavengers) at Landfill C (Author, 2013)

Landfill Gas (LFG) Management - Other than the requirement to provide ventilation, regulations do not require landfill operators to capture and treat landfill gas (LFG) generated on site. As a result, there is no landfill gas management at the site. Due to the absence of landfill gas management, landfill fires are prevalent at the landfill site. Some of these fires are deliberately started by waste pickers in their search for valuable materials such as ferrous metals.

Leachate and Water Management - According to the design, leachate from the active landfill area is designed to flow under gravity to the lowest part of the landfill via a collector into leachate ponds. However, it was observed during the visit that leachate levels in the landfill area were high (almost overflowing from the pond); an indication that the drainage system may not be functioning properly. There is a likelihood that the leachate collection system may have been blocked as a result of scavenging activities by waste pickers who excavate through the waste body to expose buried valuable materials (Mulwanda, 2013 Pers. Comm., 17th July). The design of the leachate treatment system was to recycle it back onto the waste body. This however, was not happening and during the rainy season, leachate rich ponds were allowed to overflow into the surrounding environment. Furthermore, despite the installation of monitoring boreholes during construction, groundwater was not being monitored due to budgetary constraints faced by the operator (Mulwanda, 2013 Pers. Comm., 17th July).

After-care Management – The regulations do not specify the period for aftercare. Aftercare of closed areas (cells) is therefore, non-existent. The 1.8 ha closed area was not undergoing any aftercare. Apart from a thin layer of soil that was applied when operations stopped, no final top cover was applied. This has resulted in the formation of gullies due to mudslides, particularly during the rainy season.

4.2.3.1 Potential of Implementing a CDM project at Landfill C

In view of the existing poor operations and management practices at Landfill C, the potential of implementing a CDM project was investigated. As shown from Landfill B, implementing a CDM project can result in positive social, environmental, and economic benefits.

Methodology Used - Data was gathered through interviews with site operators and analysis of waste arising reports/documents. Baseline greenhouse gases (GHGs) emissions from the site were estimated using the Clean Development Mechanism (CDM) Board approved First Order Decay (FOD) equation model for emissions from solid waste disposal sites (equation 1 section 2.4.5.4). Based on waste records both at the closed 1.8 ha area and the active 5 ha area, cumulative totals for the landfilled waste were generated. Using this data, projections were made for waste quantities to be landfilled up to 2020 (estimated end year of CDM project) in the 5 ha active area (Table 4.4). The waste composition fractions used in the calculations are based on the waste characterization study of 2002 for the city where Landfill C is located conducted by the Lusaka City Council (LCC, 2002). Using this information, different waste composition fractions for the collected data on landfilled waste both at the closed and active areas of the landfill site were generated (Table 4.5). Since both the closed and active areas where the CDM project could potentially be implemented already contained wastes that had partially decayed, the GHG emission reduction calculations had to consider the ages of these waste types prior to commencement of a CDM project. The mean age ("ā") of the waste types *j* at the beginning of the CDM project in both areas was estimated as the weighted average age (UNFCCC, 2009) considering the yearly amount of wastes disposed of since the two areas started accepting waste up to closure in case of the 1.8 ha area, and up to the year prior to commencing the CDM project in case of the 5 ha active area. The mean age of the waste was calculated using equation 2 below:

$$\bar{a} = \frac{1.A_1+2.A_2+3A_3+\ldots..+a.A_a}{A_1+A_2+A_3\ldots+A_a}$$

Equation 4.1: Mean Age of Waste (UNFCCC, 2009)

Where:

$\bar{a}$ weighted mean age of the wastes present in both the closed and the active areas of the landfill prior to start of the CDM project.

a Years before project start, starting in the first year of the waste disposal (a=1) up to the maximal age of the wastes contained in the cells at commencement of the CDM project.

Aa The amount of waste deposited in each year “a”.

In this way, baseline GHG emissions at any year “y” during the crediting period were calculated using the FOD Model. However, the exponential term for the FOD Model i.e., “exp [-k_j. (y-k)]” was corrected for the mean age of the wastes in both areas and was substituted by “exp [-k_j.(y-k+$\bar{a}$)]”. Table 4.6 shows the model parameters used in the calculations and gives reasons for their use while Table 4.7 is the waste data applied in the baseline emission calculations/estimations. Since only biodegradable materials contribute to GHG generations in disposal sites, baseline emissions and ultimately GHG emission reductions were calculated based on organics, rags (textiles), and paper fractions of the landfilled waste.

Table 4.4: Landfilled Waste Figures at Landfill C

Landfill Area	Year	Daily waste disposal (tons)	Yearly disposals (tons)	Cumulative totals (tons)
1.8 ha closed area (Actual)	2001	106	38,171	38,171
	2002	122	44,000	82,171
	2003	138	49,829	132,000
	2004	155	55,658	187,658
	2005	171	61,487	249,145
	2006	187	67,316	316,462
5 ha active area (Actual)	2007	203	73,080	73,080
	2008	220	79,200	152,280
	2009	247	88,890	241,170
	2010	274	98,596	339,766
	2011	301	108,360	448,126
	2012	300	108,000	556,126
5 ha active area (Projections)	2013	315	113,400	669,526
	2014	330	118,800	788,326
	2015	335	120,600	908,926
	2016	355	127,800	1,036,726
	2017	365	131,400	1,168,126
	2018	375	135,000	1,303,126
	2019	400	144,000	1,447,126
	2020	405	145,800	1,592,926

Table 4.5: Waste Figures and Fraction Composition at Landfill C

Landfill Area	Year	Paper (8.9 %)	Fe (0.9 %)	Non-Fe (0.7 %)	Plastic (7.1 %)	Glass (2.0 %)	Rags (1.3 %)	Organics (40.4 %)	Soil/ashes (38.6 %)
1.8 ha closed area (Actual)	2001	3,397	382	267	2,710	763	496	15,421	14,734
	2002	3,916	440	308	3,124	880	572	17,776	16,984
	2003	4,435	498	349	3,538	997	648	20,131	19,234
	2004	4,954	557	390	3,952	1,113	724	22,486	21,484
	2005	5,472	615	430	4,366	1,230	799	24,841	23,734
	2006	5,991	673	471	4,779	1,346	875	27,196	25,984
5 ha active area (Actual)	2007	6,504	658	512	5,89	1,462	950	29,524	28,209
	2008	7,049	792	554	5,623	1,584	1,030	31,997	30,571
	2009	7,912	889	622	6,312	1,778	1,156	35,915	34,315
	2010	8,775	986	690	7,000	1,972	1,282	39,833	38,058
	2011	9,644	1,083	758	7,689	2,166	1,408	43,751	41,801
	2012	9,612	972	767	7,668	2,160	1,404	43,632	41,688
5 ha active area (Estimations)	2013	10,093	1,021	794	8,051	2,268	1,474	45,814	43,772
	2014	10,573	1,069	832	8,435	2,376	1,544	47,995	45,857
	2015	10,733	1,085	844	8,563	2,412	1,568	48,722	46,552
	2016	11,374	1,150	895	9,074	2,556	1,661	51,631	49,331
	2017	11,695	1,183	920	9,329	2,628	1,708	53,086	50,720
	2018	12,015	1,215	945	9,585	2,700	1,755	54,540	52,110
	2019	12,816	1,296	1,008	10,224	2,880	1,872	58,176	55,584
	2020	12,976	1,312	1,021	10,352	2,916	1,895	58,903	56,279

Table 4.6: Model Values and Parameters Used

Parameter	Value Applied	Reasons
OX	0	Two default values are provided by the UNFCCC (see Table 2.9). Managed solid waste disposal sites covered with oxidising material such as compost are required to use a value of 0.1 while a value of 0 is recommended for other types of solid waste disposal sites. Being a semi-managed solid waste disposal site with only a thin soil cover, a value of 0 has been applied at the 5ha active area
F	0.5	Fraction of methane in landfill gas (i.e., 50 %)
DOC_f	0.5	Fractions of degradable components (organics, rags and paper)in waste (Default values given by the model)
MCF	1	Default value for anaerobic solid waste disposal site (UNFCCC, 2011)
K_j	See table 4.7	Decay rate for waste type $_j$ provided by the tool
DOC_j	See table 4.7	Fractions of degradable organic carbon (by weight) in the waste type $_j$ as provided by the tool.
f	0	No regulatory requirement for capturing landfill gas.
GWP_{CH4}	25	Taken from IPCC(2007)
X	2001-2006	Disposal period for 1.8ha closed area
	2007-2020	Disposal period for 5ha active area
$W_{j,x}$	See table 4.7	Amount of waste type j disposed of in closed area and projections of waste to be disposed of in the active area in the year x
ā	See table 4.7	Mean age of waste type *j* contained in closed and active areas of the landfill site prior to CDM project commencement

Table 4.7: Data Parameters Applied for Calculating Baseline Emissions

Waste Category	A	B	C
1.8ha Closed Area			
	Food (organics)	Paper	Textiles (rags)
$W_{j,x}$	127,851	28,165	4,114
DOC_j	0.15	0.4	0.24
K_j	0.185	0.06	0.06
ā	3.8	3.8	3.8
Active Area			
	Food (organics)	Paper	Textiles (rags)
$W_{j,x\ (year1)}$	318,484	70,161	10,248
$W_{j,x\ (year2)}$	367,206	80,894	11,816
$W_{j,x\ (year3)}$	418,837	92,269	13,477
$W_{j,x\ (year4)}$	471,923	103,963	15,186
$W_{j,x\ (year5)}$	526,463	115,978	16,941
$W_{j,x\ (year6)}$	584,639	128,794	18,813
$W_{j,x\ (year7)}$	643,542	141,770	20,708
DOC_j	0.15	0.4	0.24
K_j	0.185	0.06	0.06
ā	4.3	4.3	4.3

4.2.3.2 Results - Potential Benefits of Implementing a CDM Project at Landfill C

Environmental and Social Benefits - The estimated baseline GHG emission reductions that would be achieved by implementing a CDM project at Landfill C over a 7 year (Minimum) crediting period is 1,160,000 tCO_2eq. Table 4.8 and Figure 4.9 shows that more than 80 % of these emissions would come from the 5 ha active area of the landfill site. Greenhouse gas emissions from landfills, particularly those in tropical regions like Zambia occur in the early stages when biogenic carbon contents are still available (EPRI, 2011). Once a landfill has been closed and no more biogenic carbon is added, emissions start to decline exponentially. The estimation shows that most of the GHG emissions at the closed area of the landfill have already occurred. Apart from mitigating the emissions of methane contained in landfill gas, implementing a CDM project would contribute to health and safety by reducing and/or eliminating existing fires, noxious gases and odours because the landfill gas will be collected and treated by the CDM project infrastructure. Waste pickers could be incorporated and employed to operate and maintain the CDM project infrastructure thereby generating skills, which could be useful beyond the CDM project duration. As shown at Landfill B (section 4.2.2), a total of 260 new jobs were generated by the implemented CDM project both during the construction and operation period.

Table 4.8: Potential GHG Emission Reductions at Landfill C

Crediting Period	$BE_{CH4,SWDS,y}$ (tCO_2eq/year)		Total CO_2eq
	1.8 ha closed area	5 ha active area	
Year 1	28,800	97,700	126,500
Year 2	26,000	112,600	138,600
Year 3	22,200	128,400	150,600
Year 4	19,000	144,700	163,700
Year 5	16,300	161,400	177,700
Year 6	14,000	179,200	193,300
Year 7	12,090	197,300	209,400
Total	**139,000**	**1,000,000**	**1,160,000**

Economic Benefits - The average price of CERs during the Kyoto Protocol's first commitment period (2008-2012) was estimated around €14.90/ tCO_2eq (CDM Policy Dialogue, 2012). The CER prices declined from €20 in 2008 to around €0.40 in 2013 (EUETS, 2013; Lang, 2013). The collapse in price has been attributed to the low demand partly due to the non-ratification of the Kyoto Protocol by major emitters such as the United States of America (USA) (Koch et al., 2014). Using a conservative CER price of €0.40 for the 7 year duration of a CDM project, the potential revenue from the sale of 1,160,000 tCO_2eq would be €464,000. This translates to an additional 18 % to the gate fee revenues generated by the operator (Table 4.9).

Table 4.9: Potential Additional Revenue (Conservative CER Price) by implementing a CDM Project at Landfill C

Crediting Period	Income now(€)/yr. without CDM project (status quo)	Potential additional Revenue(€)/yr. with LFG CDM Project @ €0.40/CER
Year 1	332,600	50,600
Year 2	337,700	55,500
Year 3	357,800	60,300
Year 4	367,900	65,500
Year 5	378,000	71,100
Year 6	403,200	77,300
Year 7	408,240	84,000
Total	2,585,500	464,000

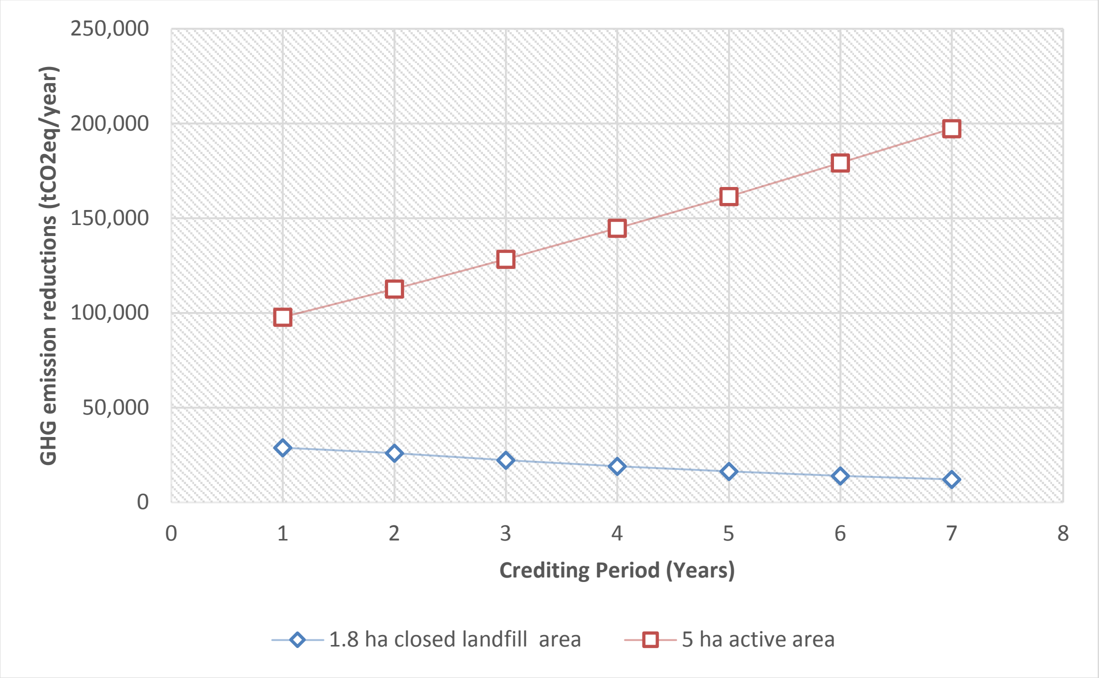


Figure 4.9: Trend in GHG emission reductions at active and closed areas of the landfill site

Although the CER revenue may appear insufficient to cover the investment cost, there are other benefits that can be accrued, which can offset the investment cost. For example, Phase 1 of a LFG CDM project at the Loma Los Colorados landfill in Chile cost the developer US$ 3 million (Global Methane Initiative, 2012). However, over the 10 year crediting period, the expected benefits excluding revenue from CER sales, were expected to outweigh the cost of investment and these benefits include:

- Reduction of approximately 582,400 tonnes of CO_2eq emissions annually;
- Mitigating slope stability and fire issues, as well as odours and LFG migration in surrounding neighbourhoods;
- Minimizing air pollution, eliminating emissions of non-methane organic compounds, among other pollutants;
- Provision of renewable energy for 200,000 people;
- Provision of economical renewable energy to the grid; and
- Diversifies energy generation in the country, improving energy security.

4.3 SUMMARY

The case study findings have shown that the enactment of legislation aimed at reducing negative effects of landfill on the environment in the EU (developed region) has been responsible for the existing good management and operational practices at Landfill A. To protect surface and groundwater, the EU Landfill Directive requires that containment systems (liner) be constructed at the bottom of a landfill and when a landfill operations cease, a similar liner is required at the top (final capping). To further reduce negative impacts on water, soil and air from landfill, the EU Landfill Directive requires member states to reduce the amounts of biodegradable wastes sent to landfill. Furthermore, operators are required to manage landfill gas and leachate – the two major emission pathways for pollutants from landfills. In addition, the EU Directive requires operators to undertake aftercare for landfill sites or part of a landfill that had ceased accepting waste for a period determined by the regulatory agency on a site specific basis. These regulations are enforced by regulatory agencies.

In contrast, landfill regulations are inadequate in both South Africa and Zambia. Regulations in both countries are not prescriptive on landfill gas management. In the absence of this requirement, the findings from Landfill B have shown that implementing a CDM project has been responsible for not only the existing good management of landfill gas but has also brought other economic, environmental and social benefits that includes:

- Acquisition of landfill gas technology (GC Jenbacher engines for generating electricity, and gas extraction and flaring unit);
- Reduction in site odours;
- Global environmental benefits - GHG emission reductions;
- Employment creation at the CDM project;
- Surface and groundwater management/monitoring
- Generation of additional revenue from the sale of CERs

At Landfill C in Zambia where regulations also do not require landfill gas management and where there is no CDM project being implemented, the landfill is operated as a semi-managed dumpsite associated with a lot of negative impacts such landfill gas emissions. Mitigating these emissions by implementing a CDM project presents an opportunity for the operator to earn additional revenue and access advanced landfill technology that can assist in the management and operations of the landfill site. As shown at Landfill B, implementing a landfill gas CDM project brings additional local benefits other than GHG emission reductions. The incorporation of engineered designs that occur in parallel with landfill gas collection infrastructure could lead to the upgrading of the landfill site from a semi-managed dumpsite into a sanitary landfill. Furthermore, operational practices like unloading of waste at the tipping face, daily cover application, and compaction that are pre-requisites for anaerobic conditions required for landfill gas generation for CDM projects could help reduce odours, limit presence of fires, and discourage the existing scavenging activities by both humans and animals. The CDM project could also generate employment opportunities for waste pickers both during the construction and operation period.

CHAPTER 5 : SUSTAINABILITY CRITERIA USED BY HOST NATIONS DNAS WITH HIGHEST NUMBER OF REGISTERED LANDFILL GAS CDM PROJECTS

5.1 INTRODUCTION

Although general methodologies for assessing sustainable development under the CDM have been described (see section 2.4.2.1.1), this chapter gives an insight into the existing methodologies for sustainability assessment used by DNAs with the highest number of registered landfill gas CDM projects in the five regions of Africa, Asia & Pacific, Latin America, the Middle East, and Europe and Central Asia (section 3.10.1). The information is utilised in developing a framework for assessing sustainable development benefits of landfill gas CDM projects. Overall, the chapter provides information required in addressing objective four and answers research question three of this research.

5.2 METHODOLOGY

The evaluation is based on two data sources: (i) Host nations' DNA sustainability criteria as defined/provided in their websites; and/or (ii) DNA criteria and related sustainability requirements published/provided in literature. According to the CDM rules (Marrakech, 2001), establishment of a DNA is one of the requirements for participation by a Party in the CDM. Each host nation DNA is required to develop criteria for assessing CDM projects' contribution to sustainable development. The UNFCCC website (https://cdm.unfccc.int/DNA/index.html) contains a list of all country DNAs. The nine country DNAs used in the study were checked for their sustainable development criteria. However, three of the nine DNAs criteria could not be accessed because the websites were either not working or the criteria were not published/uploaded on their websites. The three are China, Serbia, and Azerbaijan (Table 5.1). Therefore, literature containing references to their criteria was used as an additional source of information for the evaluation.

Table 5.1: Names of Country DNAs and their Websites

Region	Country	DNA	Does the website exist? (Yes or No)	SD criteria published in the website (Yes or No)	DNA website (URL)
Africa	South Africa	Department of Energy (DoE)	Yes	Yes	http://www.energy.gov.za/files/
Asia and Pacific	China	National Development and Reform Commission (NDRC)	Yes	No	http://en.ndrc.gov.cn/mfod/200812/t20081218_252201.html
Europe and Central Asia	Armenia	Ministry of Nature Protection (MNP)	Yes	Yes	http://www.nature-ic.am/en/Projects_Approval_Criteria
	Azerbaijan	Ministry of Ecology and Natural Resources (MENR)	Yes	No	http://www.eco.gov.az/en/ozon.php
	Georgia	Ministry of Environment Protection and Natural Resources (MEPNR)	Yes	Yes	http://moe.gov.ge/index.php?sec_id=123&lang_id=ENG
	Serbia	Ministry of Energy, Development and Environmental Protection (MEDEP)	Website not working	Website not working	http://www.ekoplan.gov.rs/DNA/index_en.html
	Uzbekistan	Ministry of Economy (MoE)	Yes	Yes	http://mineeconomy.uz/cdmfiles/Resolution_9_2007_eng.pdf
Latin America	Brazil	Ministry of Science, Technology and Innovation (MSTI)	Yes	Yes	http://www.mct.gov.br/index.php/content/view/327850.html
The Middle East	Israel	Ministry of Environment Protection (MEP)	Yes	Yes	http://www.sviva.gov.il/

5.3 CRITERIA USED FOR SUSTAINABILITY ASSESSMENT

All nine DNAs adopted the checklist method based on economic, environmental, and social dimensions (Table 5.2) to assess sustainability. However, the definition of criteria differs from country to country. For example, the Chinese DNA uses criteria that discriminates between CDM projects based on project types (Olsen and Fenhann, 2008). The criteria favours project types in the Government’s priority areas of energy efficiency, renewable energy, and methane capture/avoidance (NDRC, 2005). These projects are not only seen to support domestic environmental and energy policies but have higher sustainability benefits. China is also unique amongst the nine CDM host countries in that the DNA’s sustainable development criteria imposes restrictions on CDM projects (Kinkead, 2012). The restrictions include: (i) a floor price for CERs; (ii) a levy of between 2 % and 65 % on CER revenue; and (iii) a requirement that project entities must be under Chinese control. According to Kinkead, the Chinese criteria requires that a CER Purchase Agreement be submitted as part of the sustainable development approval. Since CER prices reflect incremental costs of CDM projects, including investment and operation/maintenance costs (Hodes and Kamel, 2007), projects with CERs lower than the floor price are rejected by the Chinese DNA. Since 2008, the floor price had been kept stable at 8 euros and was only lowered to 7 euros in 2012 as a response to CERs record low prices (Kinkead, 2012). The floor price is aimed at preventing ‘cheap’ Chinese CERs from flooding the market and lowering the global CER prices because China accounts for 60 % of the issued CERs for CDM projects (Fenhann and Antonsen, 2015). Projects with higher sustainable development benefits are subject to the lowest CER levy of 2 % (NDRC, 2005). In contrast, CERs from chemical gas-based CDM projects such as nitrous oxide (N_2O) and hydrofluorocarbons (HFCs) with few inherent sustainability benefits are negatively discriminated against by higher levies of 30 % and 65 %, respectively. As a result of these measures, over 90 % of the registered CDM projects in China are in priority sectors encouraged by the Government (Figure 5.1). The collected levies from all CDM projects are pooled in a clean development fund for supporting sustainable development initiatives in other areas such as improving energy efficiency and environmental protection in general.

Table 5.2: Sustainable Development Criteria Used by DNAs

	COUNTRY DNAs								
	China	**Brazil**	**Israel**	**South Africa**	**Armenia**	**Azerbaijan**	**Georgia**	**Serbia**	**Uzbekistan**
Sustainable Development Criteria	Checklist for economic, environmental, and social benefits but discriminates by project type: ▪ Priority areas: EE, RE, CH$_4$ ▪ Gas based approach: 2 % tax on CERs from priority areas, 30 % for N$_2$O and 65 % for HFCs and PFCs	Checklist economic, environmental, and social benefits but based on congruence with existing national SD policies	Checklist for: ▪ Economic and technology ▪ Social, and ▪ Environmental development	Checklist for: ▪ Economic ▪ Social, and ▪ Environmental development	Checklist for: ▪ Economic ▪ Social, and ▪ Environmental development ▪ Political development	Checklist for: ▪ Economic ▪ Social, and ▪ Environmental development	Checklist for: ▪ Economic ▪ Social, and ▪ Environmental criteria	Checklist for: ▪ Economic ▪ Social, and ▪ Environmental development	Checklist for: ▪ Economic ▪ Social, and ▪ Environmental development
Additional Requirements	▪ At least 51% Chinese ownership of CDM project ▪ CER sales belong to the Chinese Government and project developers ▪ Revenue sharing by other entities forbidden ▪ DNA supervises implementation of CDM project ▪ Project developer required to submit project implementation and monitoring reports to DNA ▪ Sustainable development benefits statements mentioned in PDDs verified by DNA to ensure that desired local benefits are achieved	▪ Submission of validation report in Portuguese before LoA is issued ▪ Documentation for stakeholder consultation ▪ Commitment to report on CERs produced ▪ Requirement for PDD to be validated by a designated operating entity (DOE) prior to submission to the DNA for approval	▪ None	▪ Requirement for PDD to be validated by a designated operating entity (DOE) prior to submission to the DNA for approval	▪ Requirement for participation of stakeholders throughout the CDM project cycle	▪ None	▪ Requirement for participation of stakeholders throughout the CDM project cycle	▪ Requirement for participation of stakeholders throughout the CDM project cycle	▪ None

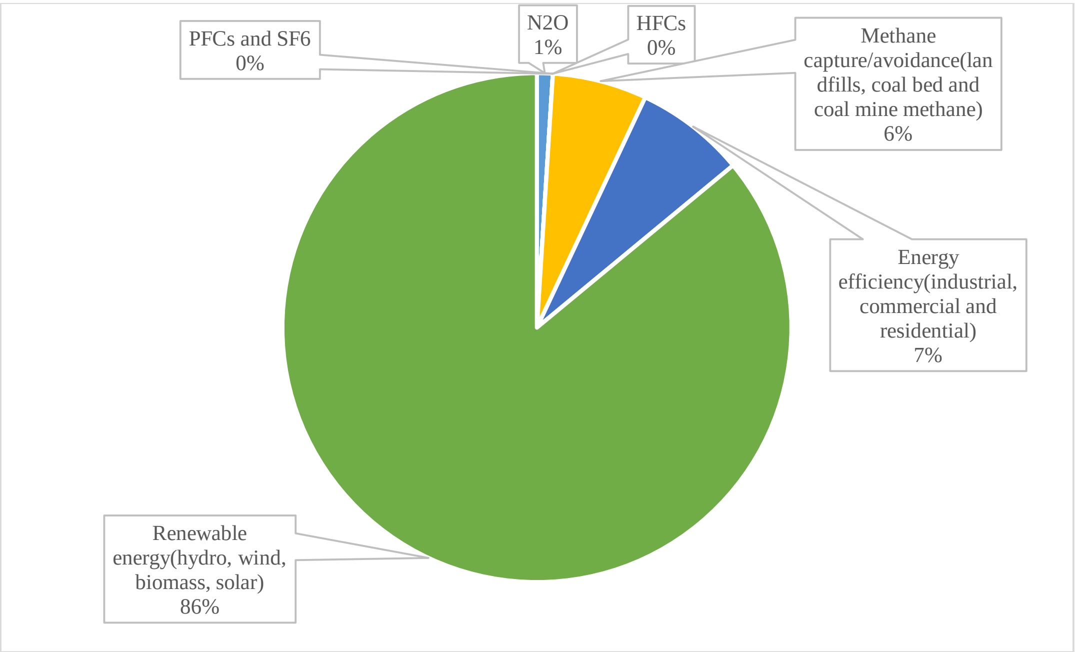


Figure 5.1: Number of Registered Projects in China by Project Type (Adapted from UNEP Risoe, 2012)

China’s sustainability criteria also requires at least 51 % Chinese partnership in all CDM projects. In practice, this means that for any CDM project to be implemented, it must either be a Chinese domestic entity or a joint venture in which the foreign shareholding is no more than 49 %. China’s CDM laws and regulations (NDRC, 2005) further stipulate that:

(i) The DNA supervises the implementation of a CDM project to improve implementation quality;

(ii) The CDM project developer submits project implementation and monitoring reports during project implementation; and

(iii) The DNA records the CERs issued by the CDM.

In the approval process, DNA members from provincial areas where a CDM project is located are kept informed of project progress by making regular inspections at the project. A link therefore, exists between the national DNA office and its provincial arms. For example, during the approval process, the national DNA office invites officials from the provincial office for comments about a proposed CDM project’s contribution to sustainable development under local conditions and to verify statements made in the Project Design

Document (PDD). This approach enables the monitoring of projects more closely and ensures that the Government’s desired local benefits are achieved by CDM projects. These approaches are aimed at protecting Chinese interests and promoting equitable sharing of the benefits obtained from selling CERs.

The Brazilian DNA define their sustainable development criteria along economic, environmental, and social dimensions (MSTI, 2007). However, Olsen and Fenhann (2008) reported that these are based on congruence with existing national policies as a qualitative threshold that CDM projects must at least meet. In addition to the economic, environmental, and social dimension, the Armenian DNA has included political development in their criteria for sustainability assessment (MNP, 2013). Other than the economic, environmental, and social dimensions and the administrative requirements, the other six DNAs make no further requirements in their criteria. In terms of approach, all nine DNAs use a checklist of criteria/indicators under each dimension. For each of the sub-criteria, it is imperative that the project describes possible effects including mitigation measures in the case of negative impacts arising. The Georgian DNA criteria gives an elaborate scoring for sustainable development indicators under a set of criteria for each dimension (MEPNR, 2005).

5.4 ASSESSMENT BASED ON ECONOMIC BENEFITS

Although there are variations among the DNA criteria, all DNAs (100 %) require CDM projects to contribute towards the creation/generation of new employment opportunities (Table 5.3). The Brazilian DNA criteria is more stringent by requiring specific information about the actual number of direct and indirect jobs that will be created by a CDM project (Olsen and Fenhann, 2008). The South African and Serbian DNAs requires that the nature/quality of jobs to be created by a project are stated in the PDD (CDM Policy Dialogue, 2012). While the other eight DNAs are less explicit in stating the location where capacity should be developed, the South African criteria specifies that the capacity of the community near the CDM project site should be developed (DME, 2004).

As shown in Table 5.3, technological benefits are treated as economic benefits by all the DNAs and all require projects to contribute towards the transfer of cleaner, efficient, and environmentally friendly technologies. While there are variations in the definitions of technology benefits provided by DNAs, the Georgian DNA is more explicit by assigning scores to each criteria (MEPNR, 2005). The South African and Brazilian DNAs evaluates the employed technology's potential for reproduction or a CDM project's impact on the uptake of such technologies within the country.

5.5 ASSESSMENT BASED ON ENVIRONMENTAL BENEFITS

Tewari (2012) classified environmental benefits of CDM projects into the following:

(i) GHG reductions achieved;
(ii) Impact on the environment and resources; and
(iii) Contribution to sustainability of resources.

However, variations exist in the environmental indicators used by DNAs. For example, the Chinese DNA uses four indicators: (i) levels of CO_2 reduction in the local area; (ii) GHGs emission reduction benefit; (iii) improve air quality; and (iv) increase efficiency in utilisation of resources (Gallardo and Anderson, 2004). The Armenian DNA uses three indicators: (i) improvement of air (including GHG emission reduction) and water quality; (ii) efficient utilisation of natural resources; and (iii) biodiversity protection. Sustainability of resources like water, forests, and other non-renewable resources are criteria given special mention by the DNAs of South Africa, Serbia, Georgia, and Uzbekistan. For example, the Georgian criteria requires CDM projects to contribute to a more sustainable use of natural resources (MEPNR, 2007). Furthermore, the criteria requires that landfill aesthetics should include screening of daily operations from roads or nearby residents by berms, planting of trees, or other landscaping.

All nine DNAs consider the GHG reduction potential of a CDM project to be one of its environmental benefits (Table 5.4). In addition, the Georgian DNA considers a CDM project to have positive environmental benefits if project implementation contributes to the country's obligation to other global environmental conventions and agreements apart from those on climate change (MEPNR, 2005).

5.6 ASSESSMENT BASED ON SOCIAL BENEFITS

As with the economic and environmental benefits, a list of social benefits indicators is considered sufficient since there is no agreed list of indicators for CDM projects (UNFCCC, 2012).The improvement of quality of life for the local community is listed in all nine DNA criteria (Table 5.5). Sixty percent of the DNAs require CDM projects to include developmental activities that will support the local communities. For example, the Brazilian DNA criteria states that a developer must " assess direct and indirect effects on the quality of life of low –income populations, noting the socio-economic benefits provided by the project in relation to the reference scenario" (MSTI, 2007). The Armenian DNA lists creation of new jobs for local people, improvements in the quality of services, and capacity development as social indicators.

The requirement for stakeholders' participation throughout the project cycle – from consultation during project design to utilisation of local resources and manpower during project implementation is listed by three of the nine DANs (i.e., Armenia, Georgia and Serbia). The six DNAs of South Africa, Serbia, Georgia, Armenia, Uzbekistan, and Israel give impetus to the ability of a CDM project to generate technical skills and knowledge in the local community. This is to be achieved by the provision of training, which could be in the form of 'on-the job' training or any other form that must be provided by the developer to the local people employed at the CDM project. For example, the Armenian DNA requires that the capacity of local people employed at the project must be developed. The Georgian DNA criteria gives a maximum score of (+2) for a project that contributes to a substantial increase in the intellectual capacity of local people employed at the project (MEPNR, 2005). The South African DNA requires projects to enhance social equity, especially in terms of gender and racial equality in employment generated (DME, 2004). Since criteria are based on congruence with existing national sustainable development policies, linkages with socio-economic development of other sectors and regions within the country are mentioned as social benefits by the Brazilian DNA.

Table 5.3: Summary of Sustainability Indicators for the Economic Dimension Benefits Listed/Provided in the DNA Criteria

CRITERIA	**INDICATORS**	**REGIONS AND COUNTRY DNAs**									**Percentage (%) Number of DNAs requiring indicator to be fulfilled**
		AFRICA	**ASIA & PACIFIC**	**EUROPE & CENTRAL ASIA**					**MIDDLE EAST**	**LATIN AMERICA**	
		South Africa	China	Armenia	Azerbaijan	Georgia	Serbia	Uzbekistan	Israel	Brazil	
Economic Dimension Benefits	**1.Additional investment**	✓	✓	✓			✓			✓	60 %
	2. Employment generation	✓	✓	✓	✓	✓	✓	✓	✓	✓	100 %
	2.1 Number of jobs created for local people									✓	11 %
	2.2 Quality of jobs created	✓					✓				22 %
	3. Income generation		✓								11 %
	4. **Contribution to sustainability of balance of payments by:**										
	4.1 Attraction of foreign direct investment	✓	✓	✓		✓	✓				
	4.2 Contribution to macro-economic sustainability					✓					11 %
	5. Clean energy development										
	5.1 Development of clean energy (renewable sources)	✓	✓	✓		✓	✓				60 %
Economic Dimension – Technology Transfer Benefits	**1. Contribution towards improvement/transfer of technologies that are:**										
	1.1 Cleaner, efficient and environmentally friendly	✓	✓	✓	✓	✓	✓	✓	✓	✓	100 %
	2.Technological sustainability										
	2.1 Indigenous technology development					✓				✓	22 %
	2.2 Replication and demonstrating potential of project	✓								✓	22 %
	2.3 Capacity and skills development/transfer of know-how	✓							✓		22 %

Table 5.4: Summary of Sustainability Indicators for the Environmental Dimension Benefits Listed/Provided in the DNA Criteria

CRITERIA	INDICATORS	REGIONS AND COUNTRY DNAs									Percentage (%) Number of DNAs requiring indicator to be fulfilled
		AFRICA	**ASIA & PACIFIC**	**EUROPE & CENTRAL ASIA**					**MIDDLE EAST**	**LATIN AMERICA**	
		South Africa	China	Armenia	Azerbaijan	Georgia	Serbia	Uzbekistan	Israel	Brazil	
Environmental Dimension Benefits	**1.GHG emission reduction**	✓	✓	✓	✓	✓	✓	✓	✓	✓	100 %
	2. Impact on environment: general							✓	✓	✓	30 %
	3. Impact on environment: specific										
	3.1 Impact on air, water and land resources	✓	✓	✓	✓	✓	✓			✓	80 %
	3.2 Impact on solid waste generation or disposal	✓				✓				✓	30
	3.3 Impact on conservation/promotion of biodiversity (generic, species and ecosystem) and ecosystems	✓	✓	✓	✓	✓	✓			✓	80 %
	4. Contribution to resource sustainability (Efficient usage of resources and access of resources by local community)	✓	✓	✓	✓	✓	✓	✓	✓		90 %
	5. Contribution of project to other global conventions and agreements (e.g., MDGs, Biodiversity, Desertification etc.)					✓					10 %
	6. Other impacts (Noise, safety, aesthetic, landscape, heat, odour and electromagnetic radiation)	✓				✓					20 %

Table 5.5: Summary of Sustainability Indicators for the Social Dimension Benefits Listed/Provided in the DNA Criteria

CRITERIA	INDICATORS	REGIONS AND COUNTRY DNAs									Percentage (%) Number of DNAs requiring indicator to be fulfilled
		AFRICA	**ASIA & PACIFIC**	**EUROPE & CENTRAL ASIA**					**MIDDLE EAST**	**LATIN AMERICA**	
		South Africa	China	Armenia	Azerbaijan	Georgia	Serbia	Uzbekistan	Israel	Brazil	
Social Dimension Benefits	**1.Contribution to national, provincial and local development and other priority sectors**	✓	✓			✓	✓				40 %
	2. Quality of life of local community (e.g., health, poverty alleviation, improvement of labour conditions)	✓	✓	✓	✓	✓	✓	✓	✓	✓	100 %
	3. Poverty reduction	✓	✓				✓				30 %
	4. Impact on human health (e.g., health of community in project area and occupational health and safety measures)		✓				✓	✓		✓	40 %
	5. Inclusion of developmental activities to support local communities (e.g., healthcare, public infrastructure etc.)	✓	✓				✓		✓	✓	60 %
	6. Accessibility of local public services	✓				✓					20 %
	7. Community participation in project			✓		✓	✓				30 %
	5. Capacity/skill/knowledge development	✓		✓		✓	✓		✓		60 %
	6. Removal of social disparities and enhancing public awareness (climates change &use of resources)	✓						✓			20 %

5.6 SUMMARY

Under the current rules of the CDM (Marrakech Accords, 2001), a list of sustainability benefit indicators selected by a host country DNA is deemed sufficient criteria since there is no agreed approach for assessing sustainable development benefits of CDM projects. Although the definition of criteria differs from country to country, the checklist approach is used by all the nine DNAs reviewed in the study. Apart from the Georgian DNA that includes political development in the criteria, all the eight DNAs define their criteria along economic, environmental, and social dimensions. The review has suggested weaknesses in the criteria adopted for assessing sustainability benefits by DNAs. Apart from the Chinese DNA, no other host nation's DNA criteria requires that sustainable development benefits as described in PDDs are monitored to verify that they are achieved at the project implementation level. There is no follow up over time by DNAs to ensure that claims in the PDD are achieved at the project level. Relevant literature sources have however, shown that China's DNA is the only one that has put in place stringent measures to ensure that the CDM delivers equally on its dual objectives. The CDM rules in China require that the DNA supervises the implementation of projects in order to ensure that sustainable development benefits stated in the PDD are realised. Furthermore, China is the only country that has put in place measures aimed at encouraging the implementation of CDM projects with higher sustainability benefits. For example, only 2 % tax on CERs is levied on projects with higher sustainability benefits while projects with lower sustainable development benefits, that tend to generate larger volumes of CERs at relatively low production, are discriminated against by imposing higher levies (e.g., 32 % and 65 % levy is applied on CERs from N_2O, and HFCs and PFCs, respectively). Low sustainability criteria set by most DNAs could be attributed to developing country host nations being more concerned with attracting CDM projects and their revenues.

CHAPTER 6 : DEVELOPMENT OF A FRAMEWORK FOR ASSESSING SUSTAINABLE DEVELOPMENT BENEFITS OF CDM PROJECTS AT LANDFILL SITES

6.1 INTRODUCTION

The main focus of this research, as stated in section 1.2, is to develop a framework for assessing sustainable development benefits of CDM projects at landfill sites. This chapter fulfils objective five of the research. Information from previous chapters (i.e., literature review, landfill case studies, and existing methodologies used by host nations DNAs for approving CDM projects) is utilised to develop the framework.

6.2 ASSESSING THE NEED FOR A FRAMEWORK

Although the CDM continues to drive low carbon transformations in developing countries (Bumpus, 2012), uncertainty prevails as to whether it is delivering equally on its twin objectives. Sutter (2003) attributed this to project developers who prioritise cost-efficiency over sustainability. Economically, this makes sense as there is no extra monetary remuneration for projects that have additional sustainable development benefits; with the partial exception of the Gold Standard (see section 2.4.2.1.1) and a few scattered national initiatives such as those developed by the Chinese DNA (see section 5.2). As sustainable development benefits do not have a monetary value in the carbon market, the tendency by project developers has been to priorities achieving cost-effective reductions of greenhouse gases (Subbarao and Lloyd, 2011). According to Article 12 of the Kyoto Protocol, achievement of sustainable development objective is of equal importance as emission reduction of GHGs. However, while project specific methodologies have been developed for determining, reporting, monitoring and verifying GHG emission reductions (e.g., FOD model for landfill gas CDM projects), explicit criteria that ensures that sustainable development benefits, as described in PDDs, are monitored on an equal basis with GHG emission reductions, have not been established at an international level. Gillenwater and Seres (2011) for example, observed that, although there was a requirement under the CDM to include an explanation in PDDs (section A.2) on how a project will contribute to sustainable development, it should be noted that few, if any, projects are being rejected by host nations DNAs (Monceau and Brohe, 2011). This suggests that sustainability criteria set by developing country host nations' DNAs are insufficient. It is also well documented that a highly competitive supply side of CDM projects combined with the devolution of approval powers to developing country host nations DNAs has led to less demanding (less stringent) sustainability assessment criteria as countries compete to attract CDM projects (Kolshus et al., 2001; Sutter, 2003). As a result, neither Annex-1 countries (developed countries) nor non-Annex-1 countries (developing countries) have direct incentives to enforce high sustainability standards. In the absence of an international framework or standard, developing countries may continue to provide easy and rapid approval of CDM projects thereby creating a disincentive towards high sustainability standards (Olsen, 2008). Furthermore, as part of their validation report for assessing CDM projects, the UNFCCC accredited agencies (the DOEs) include a checklist of questions on a project's contribution to sustainable development. Validation is achieved through interviews with project stakeholders. However, when DOEs need to verify a project's achievement of GHG emission reductions, the contribution or achievement of sustainable development is not included in the assessment since it is not required at the international level. Once a LoA is given, the project goes ahead without verifying the achievement of the PDD claims. Thus a project, which fails to deliver sustainability benefits described in its PDD will not be sanctioned at the validation (prior to registration) or verification (prior to issuance of CERs) stages by the DOE (Boyd et al., 2009).

It is therefore, clear that until more specific assessment criteria are developed at the international level, assessing the contribution of CDM projects to sustainable development in developing country host nations will be difficult. As with GHG reductions methodologies, such criteria/methodologies should be clear, project specific and easily understood by stakeholders.

6.3 THE PROPOSED FRAMEWORK FOR ASSESSING SUSTAINABLE DEVELOPMENT BENEFITS OF CDM PROJECTS AT LANDFILL SITES

This section presents the proposed framework that has been developed. In developing the framework, the view by selected authors (Subbarao and Lloyd, 2011; Olsen and Fenhann, 2008) who argued that CDM projects benefits should be termed as 'development benefits' rather than 'sustainable development benefits' in the sense that they are not long lasting was considered. While this argument is valid, and to avoid the contention that development cannot be sustained forever (New Economics Foundation (NEF), 2010); the framework has been developed using the term 'sustainable development benefits' because this is the terminology required to be used in all CDM proposal documents (PDDs) by the CDM Board. Acknowledging that there is no 'right' way or agreed basis for determining sustainable development under the CDM, a conceptual framework has been proposed as shown in Figure 6.1. The choice of dimensions for the framework is based on the widely agreed definition for sustainable development, which was also reiterated in the outcome of the United Nations' Rio + 20 conference (UN, 2012). The mutually reinforcing dimensions are:

(i) Economic development;
(ii) Social development; and
(iii) Environmental protection.

Finding and selecting appropriate criteria (i.e., principle or standard of judging) for each dimension was a challenge because of the correlation or cross linkages of benefits among the three dimensions. For example, economic benefits often bring about welfare improvements due to new employment opportunities created by the CDM project at a landfill site. Similarly, environmental benefits such as use of renewable energy (from landfill gas) can lead to health and safety improvements as well as improved access to energy. The conceptual framework shows the main benefits under each of the three dimensions. The cross linked benefits are also shown below the main benefits with broken lines. The framework's selected criteria are specified and supplemented with clearly defined and assessable indicators. The indicators measure the extent to which a CDM project meets sustainable development criteria. Although, the choice of criteria in the developed framework is informed by existing methodologies used by developing country host nations, it builds on existing terminologies for sustainability assessment such as the checklist and multi-criteria assessments (section 2.4.2.1.1). The criteria are specific to CDM projects at landfill sites. The choice of criteria and indicators have been developed based on the following:

(i) Interrogation of information on landfill operations and management practices gathered from the literature;
(ii) Observations made and information gathered from landfill case study sites; and
(iii) Review of sustainable development criteria used by host nations' DNAs

The development and choice of criteria and indicators (Table 6.1) was an iterative process between reading of relevant literature, observations made and information gathered from landfill case study sites, and conducting of text analysis of sustainable development criteria used by the nine host country DNAs selected for the study. The nature of landfill processes and associated impacts entails that there are overlaps on the potential sustainability benefits between criteria and indicators. For example, the application of daily cover and waste compaction could account for both air criterion (air pollution prevention) through reduced odours, wind-blown litter and smoke generation, as well as health and safety criterion (disease and accident prevention) through reduced nauseous odours and risks of fires and explosions. To avoid these overlaps between criteria due to double counting of benefits (Thokala, 2015), delimitations of each criterion are applied (Table 6.2). Since the framework has been developed to assess how landfill gas CDM projects should (or are) contribute (contributing) to sustainable development, characteristics that are common to all CDM projects (Table 6.3) are not included in the framework. As shown in Table 6.1, the proposed framework has 12 sustainability benefits (criteria) with 16 matching indicators, which can be scored/weighted. As such, any proposed landfill gas CDM project should potentially achieve 12 sustainability benefits at the project level.

6.3.1 Weighting of Criteria and Indicators

As noted by Ireland's Department of Finance and Personnel (DFP) (2015), it is generally adequate to 'list and/or describe' approaches without necessarily using weighting scores. Where weighted scores are employed, the rationale for each weight and score must be explained. According to the UNFCCC (2012), on a project-by-project basis, two types of assessment of the contribution of the CDM to sustainable development are possible. The two are:

(i) How a CDM project contributes to sustainable development; and
(ii) How much a CDM project contributes to sustainable development?

To determine how a CDM project contributes to sustainable development requires only a list of indicators against which a project is assessed to show the nature of its contribution (UNFCCC, 2012). In contrast, determining how much a CDM project contributes to sustainable development requires a list of indicators – a quantitative or qualitative measure for each indicator that can be used to score the project, and weights that allow the scores for different indicators to be aggregated into an overall measure of the extent of the contribution (Olsen and Fenhann, 2008).

The developed framework is a checklist of criteria (benefits) and indicators that can be weighted. A weighting and scoring method has been adopted in the developed framework because it will assist both the DNAs and DOEs in reflecting how much a CDM project will or is contributing to specific benefits. For example, a CDM project that provides employment opportunities (employment criteria) for the local people during both the construction and implementation phases must not be scored equally with a project that only provides employment during the construction or implementation stages. It is acknowledged that numeric values (weights) to judgements should not be arbitrary or subjective, but should reflect expert views supported by objective information (Thokala, 2015; DFP, 2014). The numeric values (weights) in the developed framework are based on the Georgian DNA criteria. The Georgian DNA criteria was developed after extensive stakeholder consultation (Shvangiradze, 2005). Of the nine DNAs used in the study (Chapter 5), it is more detailed with respect to assigning numeric values to the benefits. The values range from +4 (maximum benefit) to -4 (minimum benefit). To reduce the range of variations, the developed framework has adopted a maximum score or weight of +2 and a minimum of -1 for each specified indicator. A zero (0) score suggests that the CDM project does not have any effect on that indicator (status quo i.e., project is non additional to that indicator) while a negative score suggests that the CDM project leads to a detrimental effect for that indicator (e.g., not providing alternative sources of livelihood to waste pickers that have been removed from a landfill or leading to job losses that existed prior to the project).

The importance of sustainability benefits at national and local level is context specific depending on stakeholder perspectives. A benefit that might be important to one nation or community may not be so to another. For example, the substitution of fossil fuel (e.g. coal) with LFG (renewable) can have different Balance of Payments (BoP) benefits/impacts between a country that relies on fossil fuel imports and one that has its own fossil fuel reserves. Savings will be achieved through import reduction for the former and provide no savings for the latter. Consequently, the extent of weighting or scoring each specified indicator (i.e., high/medium/low) in the developed framework has been left to individual host nations' DNAs to determine. This is in line with the Marrakech Accords (2001), which gives powers to developing country host nations to define and evaluate CDM projects' contribution to sustainable development. However, it is proposed that for a project to be issued with a letter of approval at the national level, and to pass the DOE validation and verification stages, an average score of 'medium to high' (1-2) should be achieved. This is because CDM projects that have average scores of low (0) and negative (-1) are considered to be non-additional and detrimental, respectively.

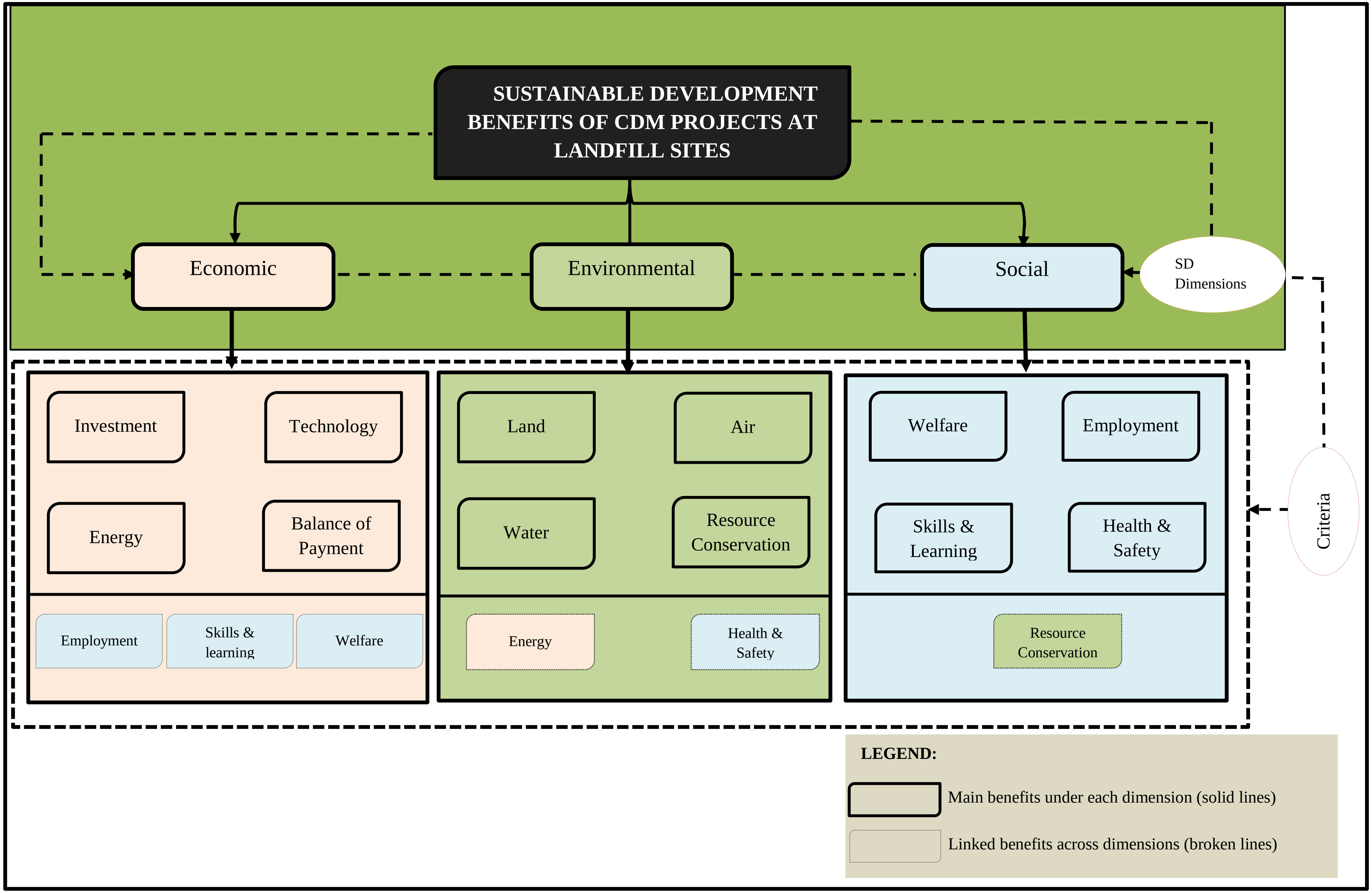


Figure 6.1: Proposed Conceptual Framework for Assessing Sustainable Development Benefits of CDM Projects at Landfill Sites

Table 6.1: Framework for Assessing Sustainable Development Benefits of CDM Projects at Landfill Sites

SD DIMENSION	CRITERIA	INDICATORS	INDICATOR SPECIFICATIONS	WEIGHTING
Environmental Benefits	Air	Air pollution prevention	▪ Reduced odours (not cause nuisance odour) during both the operational and post operational period by collection /capturing and treatment of LFG (through flaring or using it to generate energy (electricity)) (Yes/No)	Yes (+2) No (0)
			▪ Reduced particulate matter (wind-blown litter and dust) to PM$_{2.5}$ level of 25 µ/m^3 24 – hour mean (WHO, 2005) during operational period through compaction and/or by re-circulating leachate (Yes/No)	
	Water	Water pollution prevention	▪ Reduced risk of surface and groundwater contamination through provision/installation of containment (top & bottom liners), leachate collection and treatment systems (Yes/No)	Yes (+2) No (0)
			▪ Reduced risk of groundwater contamination through the installation of monitoring boreholes around the site for detection of leachate that maybe caused by failure of containment system (bottom liners) (Yes/No)	
			▪ Reduced leachate generation by keeping size of “working face” minimal (4 m width (ISWA, 2010) to reduce surface area, and by good waste compaction to reduce leachate generating rates (increase surface runoff) (Yes/No)	
	Land	Land contamination prevention.	▪ Reduced risk of land contamination through provision of storm drains around the site to capture storm water and/or mudslide from the site (Yes/No)	Yes (+2) No (0)
		Reduce land disturbance	▪ Reduced/minimise land disturbance/degradation by unloading waste in small designated (working faces) areas followed by compaction (increase waste density) within the site. Small working faces could save amount of daily cover used, which could be extracted elsewhere leading to land disturbance there (Yes/No)	
			▪ Reduced/minimise land disturbance (aesthetic) during both the operational and post-operational period by the application of daily, intermediate, and final cover material (Yes/No)	
	Resource Conservation	Recycling/Separation of valuable materials	▪ Reduced resource wastage through diversion of valuable materials from landfill. This could be done by separation of high value waste materials like plastics and ferrous metals prior to disposal through provision of recycling facilities (Yes/No)	Yes (+2) No (0)
			▪ Substitution of usage of finite (non-renewable) resources such as fossil fuels with renewable resources such landfill gas (Yes/No)	
Social Benefits	Health and Safety	Disease prevention	▪ Reduced presence of vermin and waste pickers by activities such as compaction, daily cover application and landfilling of waste at designated tipping areas (Yes/No)	Yes (+2) No (0)
		Accidents Prevention	▪ Reduced risk of fires and explosions by the collection and treatment of landfill gas (Yes/No)	
			▪ Reduced risk of settlement, landfill slides and erosion by compaction, and having stable slopes (benches) (should not be steeper than 3:1(US EPA, 2012a)) (Yes/No)	
			▪ Prevent illegal waste picking (scavenging) through restricted entrance to the site (i.e., entry should be through guarded gate) (Yes/No)	
			▪ Availability of lighting at site during dark hours (Yes/No)	
	Employment	New jobs	▪ Number of jobs generated for local people by LFG CDM project as a percentage of total workforce (low (0 % to 25 %) /medium (25 % to 50 %)/ high (above 50 %))	Low (0) Medium (+1) High (+2) Negative effect (-1) Skilled (+2) Unskilled (+1) Short-term (+1) Long-term (+2) Yes (+2) No (0)
			▪ Continuity of generated jobs (short term (construction or project implementation stage only)/long-term (jobs running beyond the two stages))	
			▪ Type of jobs created (skilled (with certificate/diploma/degree) /unskilled (with no certificates)) ▪ Other jobs generated as a result of implementing a LFG CDM project (e.g., supply of commodities) (Yes/No) ▪ Leads to job losses (negative effect)	
	Skills transfer/ Learning	Job training	▪ Job related training attributed to LFG CDM project implementation (low/medium/high)	Low (0) Medium (+1) High (+2)
		Education services	▪ Provision of education and further training other than job related training for employees or members of the community (e.g., provision of bursaries) (low (non) /medium (certificates/diplomas) /high (degrees))	
	Welfare	Improved living and working conditions	▪ Improvement of local living and working conditions including safety, poverty alleviation through e.g., employment of local people who previously depended on scavenging/waste picking at the landfill site and providing them with adequate personal protective equipment (PPEs) (low/medium/high)	Low (0) Medium (+1) High (+2)
Economic Benefits	Energy	Access to energy	▪ Improved access to energy through the production of renewable energy from LFG (Yes/No)	Yes (+2) No (0)
	Investment	New Infrastructure	▪ New infrastructure in the area (e.g., energy generation and transmission facilities) attributed to CDM project at landfill site (Yes/No)	Yes (+2) No (0)
	Balance of Payments (BoP)	Reduction in foreign dependency.	▪ Energy production in the country based on renewable energy (LFG) replacing imported fossil fuels (Yes/No)	Yes (+2) No (0)
	Technology	Technology transfer	▪ Development, use, improvement and/or diffusion of new, local or foreign technology attributed to the implementation of LFG CDM project (Yes/No)	Yes (+2) No (0)

Table 6.2: Delimitation of the SD Criteria

SD Criteria	Description of benefits not included in criteria
Air	▪ Reductions in GHG (methane) is not included as this defines all landfill gas CDM projects ▪ Avoided or reduced smoke from the landfill is counted as a health and safety benefit
	▪ Although cover application (temporary and final) can reduce dust and wind-blown litter during both the operation and post-operation period, it is regarded as a land benefit (aesthetic)
Welfare	▪ Employment opportunities generated by the CDM project is counted as an employment benefit
	▪ Recycling/separation of valuable materials is counted as a resource conservation benefit
Health	▪ Reduction in site odour is counted as an air quality benefit

Table 6.3: Common Characteristics of all CDM Projects

1.	Reduction in emission reduction of any of the seven Kyoto Protocol GHGs: CO_2, CH_4,HFCs, PFCs, N_2O, SF_6 and NF_3
2.	Regulatory additionality (i.e., project implemented due to absence of regulatory requirement in host nation)
3.	Generation of revenue for project developers through the sale of CERs

6.3.1 Descriptions of Criteria in the Developed Framework

This section sets out how sustainable development benefits in the three dimensions should be achieved or accounted for using the 12 criteria in the developed framework.

6.3.1.1 Environmental Benefits

Air - Landfill operations and management practices should be conducted in such a way that negative impacts on air such as odour, windblown litter, dust, and noxious gases from landfill fires are minimised. To control odour, windblown litter, and dust, the following measures must be in place at a LFG CDM project:

- Cover the waste and ensure it remains covered in all areas except at the active tipping face. In addition to cover application, windblown litter and dust can further be minimised by compaction using equipment such as bulldozers or steel-wheeled compactors, which ensures that material capable of being windblown is compacted and worked into the waste surface; and

- The active tipping face should be kept as small as practically possible. This reduces the surface area from which particulates and other air impacts can be generated.

Water – Leachate constituents (i.e., dissolved and suspended) have the potential to cause surface and groundwater contamination. As such, other than installing and operating a leachate collection and treatment system at a landfill site, measures such as compaction and installation of top covers that reduce its generation must be put in place. This will minimise its build-up within the waste mass and on the liner system thereby reducing the potential for surface and groundwater contamination. Operational practices such as keeping the size of the "working face" minimal (to reduce surface area), compaction, and covering of completed cells reduce the infiltration of liquids that contribute to leachate generation. Compaction and cover application increases run-off away from active areas that have the potential to generate leachate. Furthermore, compaction and cover application reduces waste settlement, which also reduces the potential for depressions in the active area. Depressions can lead to ponding of water and this allows precipitation to infiltrate into the waste mass. Installation of containment systems (top and bottom liners) as well as leachate collection and treatment systems prevents the contamination of surface and groundwater from leachate constituents.

Land - Land contamination can be minimised through the provision of storm drains around a landfill site. This captures storm water and/or mudslides that may contain contaminants. Land disturbance can also be minimised by keeping the working face to a minimum. As a general guide for minimising visual impacts on a landfill area, ISWA (2010) recommends that a working face should not be more than 600 m^2.

Resource Conservation – This criterion refers to the conservation of natural resources at a landfill site. This could be achieved by diverting valuable materials like metals and plastics that are within the waste streams or allowing organised waste pickers to collect them prior to disposal. The replacement of non-renewable (fossil fuel) with the energy generated from landfill gas can contribute to resource conservation.

6.3.1.2 Economic Benefits

Energy Production – This benefit arises when a CDM project at a landfill site contributes to improved access to energy through the generation and supply of renewable energy from landfill gas. The energy could be utilised in the generation of electricity - for boilers or heat generated to assist in treating leachate (evaporation).

Investment – As a minimum, a CDM project at a landfill site must collect and treat the methane gas contained in landfill gas thereby, mitigating the impact of greenhouse gas emissions. To do this, any CDM is (as a minimum requirement) expected to invest in some form of gas collection and flaring infrastructure (collection pipes and flare). Therefore, investment can only be qualified as a benefit for a project if additional infrastructure/equipment, other than the above mentioned minimum, is brought to a landfill site by a CDM project developer. For example, this could include infrastructure for energy generation and/or distribution.

Technology transfer - Technology transfer is one benefit that is difficult to define. According to the Intergovernmental Panel on Climate Change (IPCC) (2000), technology transfer is a broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders. Therefore, in this study, technology transfer for a CDM project is only seen to exist if the import of equipment at a landfill site is accompanied with some form of training (flow of know-how and experience) for the people who will be using or operating the CDM equipment/infrastructure.

Balance of Payments (BoP) - This benefit is counted as positive if imported fossil fuels are replaced with renewable energy leading to reductions in foreign exchange expenditure.

6.3.1.2 Social Benefits

Health and Safety – This benefit at a landfill site can lead to disease and accident prevention. A CDM project should therefore, result in a reduction and/or elimination of vermin and waste pickers if they ever existed before project implementation by engaging them as employees to operate and/or manage the CDM infrastructure. This could be achieved by daily cover application and waste compaction to avoid exposure of landfilled waste. The landfilling of waste at designated tipping areas can reduce the dispersion of waste across the landfill area. Explosions and fires can be prevented by daily cover application, compaction, collection and treatment of landfill gas. The risks of settlement, landfill slides and erosion can be prevented or minimised by having stable slopes (benching), which should not be steeper than 3:1 (US EPA, 2012).

Employment – This benefit relates to a CDM project generating additional new jobs to those that existed at a landfill site prior to its implementation. The jobs could be temporary – generated during the construction of the CDM infrastructure or permanent – operating and managing the CDM infrastructure.

Welfare – The creation of employment opportunities that helps alleviate poverty for the local people, particularly vulnerable groups such as women and youths could account for this benefit. Furthermore, improvement in local living and working conditions attributed to the CDM project could account for this benefit.

Skills transfer and learning – Job related trainings, provision of education and any other form of skills enhancement attributed to the CDM project could account for this benefit.

6.3.2 Use of the Proposed Framework

The developed framework is meant to be used by the two institutions involved in approving CDM projects and in the issuance of CERs: (i) developing country host nations DNAs; and (ii) UNFCCC accredited agencies (the designated operating entities (DOEs)). Figure 6.2 shows the two stages in the CDM project process at which the two institutions can use the framework. Although, the approval by host nations' DNAs takes place before a project is implemented and therefore, before the stated sustainability benefits can be achieved; the PDD, (which is the basis for decision making used by all host nation's DNAs (Olsen and Fenhann, 2008)) should address the majority of the sustainability benefits in the developed framework. The 'potential' sustainability benefits as required by Section A.2 of the PDD template should include the 12 benefits in the developed framework. This is because, regardless of host nation, the components that require management at a landfill site are the same. What differs are the levels of management (refer to Chapter 4). Similarly, when DOEs are verifying a project's achievement of GHG emission reductions prior to making a recommendation for the issuance of CERs; they can use the developed framework as a means of validating the achievement of sustainable development benefits that were stated in a project's PDD when it was issued with a LoA by a host nation DNA. This will ensure that CDM projects deliver equally on its twin objectives as stated in Article 12 of the Kyoto Protocol.

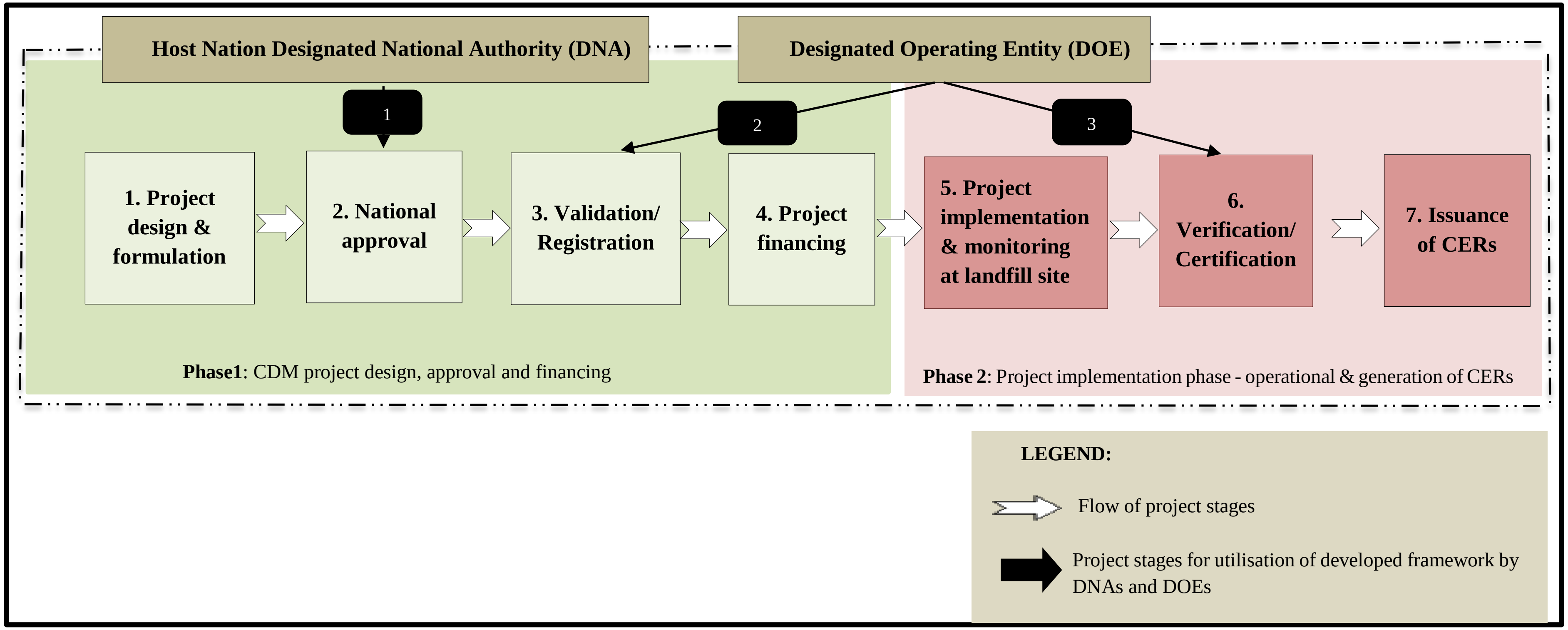


Figure 6.2: CDM Project Stages at which the Developed Framework can be used by DNAs and DOEs

6.4 SUMMARY

This chapter addressed Research Objective five presented in section 1.2 by developing a framework for assessing sustainable development benefits of CDM projects at landfill sites. The developed framework addresses the non-availability of criteria/methodologies for assessing sustainable development benefits of CDM projects. The proposed framework comprises three sustainable development dimensions: (i) economic; (ii) environmental; and (iii) social. The framework has 12 criteria with 16 indicators. In essence, any proposed CDM project at a landfill site should ‘potentially’ generate 12 sustainability benefits across the three sustainability dimensions. The weighting or scoring of indicators (i.e., high/medium/low) has been left to individual host nation DNA because the relative importance of benefits at national and local level is important and context specific depending on stakeholder’s perspectives. However, as an acceptable level, for a project to be issued with a letter of approval at the national level, and to pass the validation stage, an average weight of medium to high (1-2) must be achieved for the specified indicators. This is because a scores of zero (0) and negative (-1) scores reflect projects that are non-additional and detrimental, respectively.

CHAPTER 7 : VALIDATION OF THE DEVELOPED FRAMEWORK

7.1 INTRODUCTION

Chapter six dealt with the development of a framework for assessing sustainable development benefits of landfill gas CDM projects. This chapter validates the developed framework by using it to assess whether registered LFG CDM projects are achieving sustainable development benefits in host nations. The purpose of the validation exercise is to test the suitability of the developed framework for use at approval, validation and verification stages by DNAs and DOEs, respectively.

7.1 Methodology

7.1.1 Number of Projects Used

Information on the websites of the UNFCCC http://cdm.unfccc.int/Projects/Validation) and UNEP Risoe Centre CDM pipeline (http://unep-risoe-cdmji-pipeline-analysis-and-database) was used to select registered LFG CDM projects for the validation exercise with a cut-off date of April, 2014. Out of the six hundred and eight (608) projects submitted to the UNFCCC by the cut-off date, 287 (47 %) were registered with the CDM Executive Board. However, despite the requirement for project developers to include sustainable development benefits information in section A.2 of the PDDs (UNFCCC, 2006a), most downloaded PDDs had this information located in different sections. This, coupled with the voluminous nature of PDDs (on average 100 pages), made it difficult to consider all 287 registered projects in the study because the documents had to be carefully scrutinized to avoid missing any useful sustainable development benefit information. The country grouping used in the study was adopted from the UNEP Risoe Centre CDM pipeline, which groups countries into five regions of Africa, Asia and the Pacific, Latin America, the Middle East, and Europe and Central Asia (UNEP Risoe Centre, 2014b). Therefore, only projects from countries with the highest number of registered LFG CDM projects at landfill sites from each of the five regions were selected for the study. This was done to ensure that each region was represented. In Europe and Central Asia region, there was no country with more than two registered projects. As such, registered projects from the five countries of Armenia, Azerbaijan, Georgia, Serbia and Uzbekistan which, by the cut-off date had one project each were all selected in the study. This brought the total number of selected LFG CDM projects used in the study to 124 (Table 7.1).

Almost half of the 124 selected projects (49 %) were located in the Asia and Pacific region while Europe and Central Asia region had the lowest number of projects (4 %). The high distribution of projects in the Asia and Pacific region is not surprising. As a market mechanism, the distribution of CDM projects and CERs has generally matched the distribution of mitigation potential across countries as represented by national emissions and economic development (UNFCCC, 2012a). Although the number of CDM host countries has continued to grow, many countries with small economies and low GHG emissions have few, if any, CDM projects. The high number of CDM projects in China is due to the high mitigation potential that exists due to high GHG emissions from fossil fuels (coal) (Shen, 2011). The existing favourable political and economic environment for foreign investment and the relatively efficient institutions and well developed regulations have been cited as some of the reasons for China's dominance in the CDM market (Jung, 2006).

In terms of crediting periods (i.e., duration of a CDM project), more than half (57 %) of the total projects selected had a 7 year crediting period, which can be renewable twice while 43 % had a 10 year non-renewable crediting period (Table 7.2). However, at the regional level, the Asia and Pacific region, which had the majority of the projects had 64 % of its projects with a 10 year non-renewable crediting period while only 36 % had a 7 year crediting period. In most cases, project participants prefer a 7 year crediting period that can be renewed twice to the 10 year non- renewable crediting period (UNEP, 2004c). However, there is a risk with the 7 year twice renewable crediting period that the original baseline may no longer be valid after the 7 year period. In that case, the project must be revalidated by a DOE. This may explain why most projects in the Asia and Pacific region (China) have opted for the non-renewable 10 year crediting period. With regards to project types, 73 % were bilateral (have some foreign partner involvement) while just under a third (27 %) were unilateral (Table 7.3).

Table 7.1: Region/country location and number of LFG CDM projects used in the study

Region/Country		**Number of Projects**	
1.	**Africa**		
1.1	South Africa	7 (6 %)	
2.	**Asia and Pacific**		
2.1	China	61 (49 %)	
3.	**Europe and Central Asia**		
3.1	Armenia	1	5 (4 %)
3.2	Azerbaijan	1	
3.3	Georgia	1	
3.4	Serbia	1	
3.5	Uzbekistan	1	
4.	**Latin America**		
4.1	Brazil	43 (35 %)	
5.	**The Middle East**		
5.1	Israel	8 (6 %)	
TOTAL		**124 (100 %)**	

Table 7.2: Crediting periods for the projects

Region	Number of projects and crediting periods	
	7 year crediting period	**10 year crediting period**
Asia and Pacific	22	39
Latin America	38	5
The Middle East	4	4
Africa	5	2
Europe and Central Asia	2	3
TOTAL	**71 (57 %)**	**53 (43 %)**

Table 7.3: Project Types

Region	Number and type of projects	
	Bilateral	**Unilateral**
Asia and Pacific	59	2
Latin America	19	24
The Middle East	2	6
Africa	5	2
Europe and Central Asia	5	0
TOTAL	**90 (73 %)**	**34 (27 %)**

As with the three case studies used in section 3.7.3.7, ethical approval conditions for this study required confidentiality of the data collected from the 124 landfill sites implementing CDM projects. For ease of reference, each LFG CDM project selected for the validation exercise was assigned an identification code, which consisted of two parts: (i) a country letter indicating project location (e.g., SA-South Africa, I-Israel, C-China, B- Brazil etc.); and (ii) registration date (e.g., 12/01/09, 30/12/10, etc.). Table 7.4 is an example of how codes were assigned to all the 124 projects. The list of the 124 projects (coded names) is shown in Appendix 3.

Table 7.4: Coding Example for CDM projects Used in the Validation

No.	Country of Project	Date of Project Registration	Assigned Codes
1	South Africa	12/01/2012	SA -12/01/12
2	South Africa	18/08/2011	SA-18/08/11
-	-	-	-
-	-	-	-
-	-	-	-
61	China	30/05/2013	C-30/05/13

7.1.2 Qualitative and Quantitative Analysis

Using the computer software program Nvivo 10 (QSR International, 2009), text analyses and coding of downloaded PDDs from the UNFCCC website, in pdf format, and questionnaire survey responses in MS word was done using the 12 criteria in the developed framework (see section 6.3.1). Occurrences of any of the 12 sustainability benefit patterns and aspects in the textural data were coded and stored in containers called nodes. As shown in Figure 7.1, sustainable development benefits comprised the 12 criteria in the developed framework while the nodes comprised the three sustainable development dimensions. The quantitative analysis of results from the coding consisted of counting and comparing the number of sustainability benefits at aggregated levels. One caveat deserving mention is that the developed framework aims to assess sustainability benefits in a simple manner. In this case, the proxy measure of 'potential' benefits assumes that all sustainable development benefits are equally important and have an equal weight. For instance, no judgement is passed as to whether employment creation by a project is more important than air quality improvements. The framework's findings are therefore, the sustainable development profiles of CDM projects showing how the benefits are distributed among the three dimensions and the 12 criteria. The Nvivo approach was useful in this stage of the research because coding findings describe *how* CDM projects at an aggregated level (from five regions) contribute to sustainable development. Since the nature of Nvivo software is qualitative, there is no basis to conclude how much the CDM project is contributing to sustainable development, which is in contrast to quantitative methodologies for assessing GHG emission reductions. However, since the developed framework will be applied at an individual project level, this problem will not arise because each benefit will have been weighted (scored) accordingly and the average score will determine whether a project can be approved or not. This was not possible in the validation exercise because of the large number of projects involved (124) and hence the use of Nvivo software program.

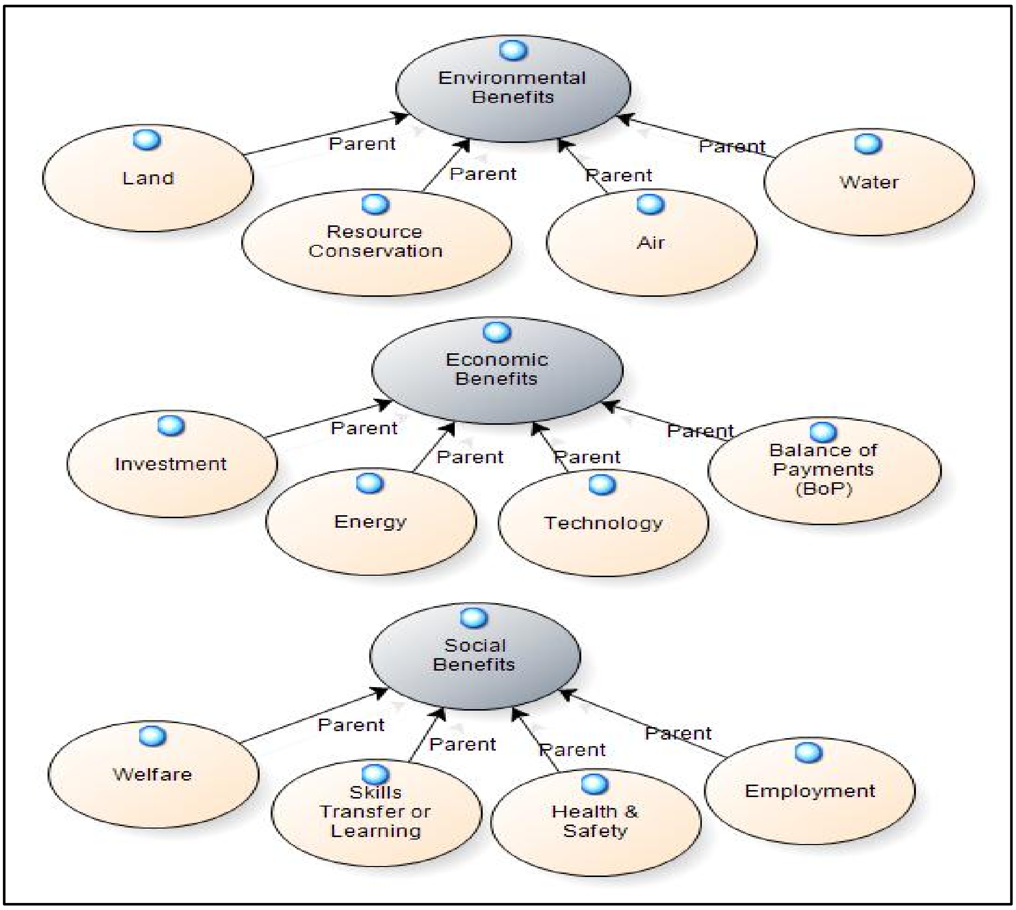


Figure 7.1: Sustainable Development Dimensions (3 Nodes-shaded) and 12 Criteria

7.2 VALIDATION OF THE FRAMEWORK USING PDDS AS SOURCES OF INFORMATION

Validation in this context means a process of confirming the suitability of the developed framework for use by DNAs as a template or basis for assessing projects before granting a letter of approval. Acknowledging the existing weaknesses in DNA criteria (section 5.3), a successful validation should show the sustainability benefits that have been stated in PDDs for registered projects being implemented at landfill sites. The metrics used to validate the framework are the 12 sustainable development benefit criteria as described in section 6.3.1 and the three sustainable development dimensions (Figure 7.1). Coding results must show the patterns and aspects of sustainability benefits as claimed in the PDDs.

7.2.1 Results

7.2.1.1 Characteristics of Projects

Table 7.1 shows the characteristics of the projects whose PDDs were used as sources of information in the study. Most of the projects (73 %) are bilateral while just under a third (27 %) are unilateral. A project is considered unilateral if the PDD (in Annex 1) does not mention any existence of a foreign entity participant. This however, does not preclude the possibility of a foreign project participant joining the project at a later stage at which point the project will lose its unilateral status. Economic constraints and the non-requirement by most developing country host nations' legislation to capture and treat landfill gas could be possible reasons for the lower number of unilateral CDM projects. Due to various constraints (that may include financial), landfill gas CDM projects are more likely to be bilateral CDM projects than unilateral (Jahn et al., 2003). The high costs associated with landfill gas technologies can be alleviated with the participation of one or two carbon credit buyers. Before a project developer is allowed to sell the credits (CERs) that have been achieved, the UNFCCC through a DOE must first certify, issue and register the GHG emission reductions – a costly and time consuming administrative process. Selling credits through a forward contract to a credit buyer usually helps reduce the risks surrounding the investment by adding a guaranteed revenue stream (Das, 2011). Furthermore, credit buyers may provide advice and assist in bringing in expertise that may ease technology transfer (Dechezlepretre et al., 2008). This view is supported by the findings of an empirical study on the performance of CDM projects by Michaelowa and Castro (2008), which found that bilateral projects were more successful than unilateral ones. They attributed the success of bilateral projects to improved access to technology, technical support, quality control and upfront financing provided by the foreign entities participating in the CDM projects. Despite restrictions that have been put on foreign entities' involvement in Chinese CDM projects (see section 5.3), 97 % of Chinese projects are bilateral. The explanation for this could be that, unlike other CDM projects, LFG CDM projects are mainly associated with the transfer of landfill technologies from developed countries, which are likely to be facilitated by the participation of one or two foreign entities.

In terms of crediting periods, more than half (57 %) of the projects have chosen a 7 year crediting period, which can be renewed twice (effectively 21 years) while 43 % have chosen a 10 year non-renewable crediting period (Table 7.5). It has been suggested that more benefits can be accrued from projects with a longer crediting period than a shorter one. A report commissioned by the High Level Panel on the CDM (2012) showed that most CDM project developers, particularly those that involve renewable technologies, prefer operating projects well beyond the 10 or 21 year crediting period. This is because most renewable technologies have payback or operational periods of between 15-25 years (Michaelowa, 2012).

Table 7.5: Characteristics of the Projects

Region/Country(ies)	Type of projects		Project crediting period	
	Uni-lateral	Bi-lateral	7 years twice renewable	10 years
Asia & Pacific				
China	2	59	22	39
Latin America				
Brazil	24	19	38	5
The Middle East				
Israel	6	2	4	4
Africa				
South Africa	2	5	5	2
Europe & Central Asia				
Armenia	0	5	2	3
Azerbaijan				
Georgia				
Serbia				
Uzbekistan				
TOTAL NO OF PROJECTS	**34**	**90**	**71**	**53**
%	**27 %**	**73 %**	**57 %**	**43 %**

7.2.1.2 Number of Projects with Sustainability Benefits

Table 7.6 shows the number of projects whose PDDs have reported aspects and patterns of sustainable development. On average, more projects reported sustainability benefits in the social (74 %) followed by the economic dimension (61 %) while fewer projects (51 %) reported benefits in the environmental dimension (Figure 7.2).

In terms of individual sustainability benefits (criterion), employment generation for local communities in project areas is the highest reported benefit in the social dimension present in 91 % of the projects. Skills transfer and learning is the lowest reported benefit in the social dimension with only 49 % of projects reporting it. In the economic dimension, technology transfer is the highest reported benefit with almost all (99 %) projects reporting that they would contribute towards technology transfer to landfill sites in project host nations (column 5). Except for one project in the Asia and Pacific region, all the projects (123) reported in their PDDs that they will transfer technology to landfill sites in host nations during project implementation. It is interesting to note that there is technology transfer in almost all the projects and yet only 49 % of projects have reported skills transfer and learning. The lack of agreement may be due to differences in judgement or interpretation of the way the two criteria were stated in the PDDs by the researcher. Improvement in the area's air quality is the highest reported benefit in the environmental dimension with 71 % of the projects reporting this benefit. However, few projects (only 32 %) have indicated that they will put in place measures and operational practices aimed at protecting surface and groundwater during project implementation. Equally, a limited number of projects (34 %) indicated that they will contribute towards minimising land disturbance at landfill sites. Although the economic dimension has the highest reported sustainability benefit (criterion) in technology transfer, it also has the lowest reported benefit (criterion) in relation to balance of payments. Out of the 124 projects, only two projects (1.6 %) have reported that they will contribute towards balance of payments in host nations (column 4).

Table 7.6: Number of Projects Reporting Sustainability Benefits

Regions	Total No. of Projects	Sustainable Development Dimensions											
		Economic Benefits				Environmental Benefits				Social Benefits			
		Investment	Balance of Payments	Technology transfer	Energy	Air	Water	Land	Resource Conservation	Skills transfer & learning	Health & Safety	Employment	Welfare
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Asia & Pacific	61	59	0	60	60	48	12	13	49	24	50	57	45
Latin America	43	16	0	43	16	23	20	20	18	26	35	37	32
The Middle East	8	3	2	8	7	6	3	6	6	3	6	7	6
Africa	7	5	0	7	4	6	2	0	5	5	4	7	6
Europe & Central Asia	5	4	0	5	4	5	3	3	3	3	4	5	4
TOTAL NO. OF PROJECTS	**124**	**87**	**2**	**123**	**91**	**88**	**40**	**42**	**81**	**61**	**99**	**113**	**92**
% (Totals of column(2-14)/ total of column 2) x100	**100**	**70**	**1.6**	**99**	**73**	**71**	**32**	**34**	**65**	**49**	**80**	**91**	**74**
Average % benefits		**61 %**				**51 %**				**74 %**			

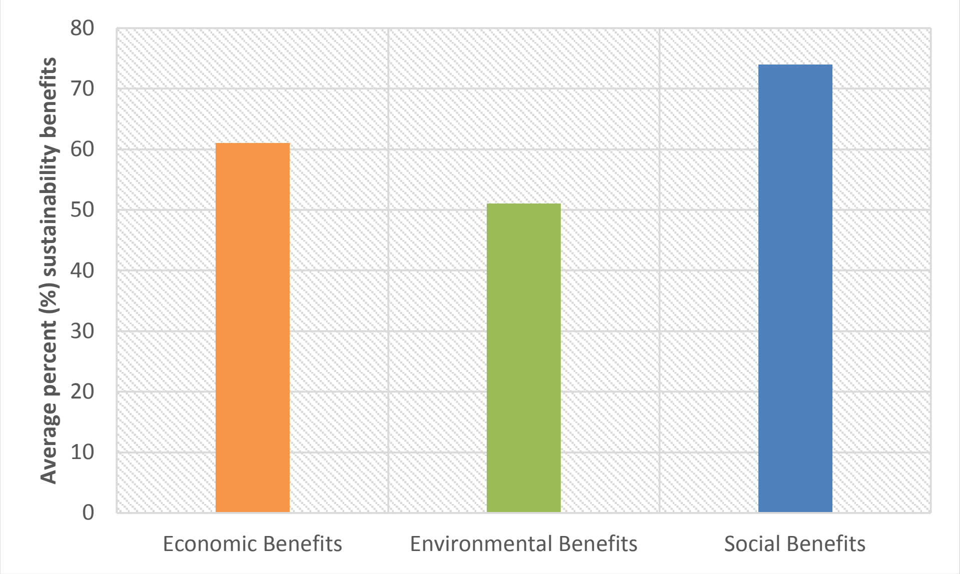


Figure 7.2: Average Percentage (%) Sustainability Benefits per Dimension Reported by Projects

7.2.1.3 Profile of Sustainability Benefits

Table 7.7 shows the aggregated occurrences of patterns and aspects of sustainability benefits reported in PDD texts across the three dimensions. The economic flexibility given to developed countries under the Kyoto Protocol to meet part of their GHG emission reduction targets by investing in projects in developing countries is the main driver for investing in CDM projects at landfill sites. Almost half (48 %) of the identified sustainability benefits are in the economic dimension followed by the social dimension (30 %). The environmental dimension has the lowest occurrence of benefits with 22 % (Figure 7.3). The same trend is seen at the regional level with all regions having high occurrences of benefits in the economic dimension (Figure 7.4). From this, it can be inferred that project developers' main interests in implementing CDM projects in developing countries are more economically driven than bringing social and environmental improvements to landfill sites - which in most cases are poorly managed and operated. To visualise the pattern of benefits in each sustainable development dimension (node), a tree map (Shneiderman and Plaisant, 2009) was generated where each benefit (criteria) appears as a rectangle (Figure 7.5). The tree map shows that technology transfer to a landfill site is the most likely benefit not only in the economic dimension but across all three dimensions. Although, it is not the core objective of the CDM, technology transfer is seen as the likely benefit of a landfill-based CDM project - at least based on the PDD information. According to Das (2011), the transfer of technology under the CDM is likely to be influenced by the involvement of foreign entities (bilateral CDM projects). Krey (2004) asserted that, the nature and extent of involvement of various actors in CDM projects largely depends on the design option for carrying out the project i.e., whether the project is bilateral or unilateral. Unlike technology transfer, balance of payments is seen as the least likely benefit of any LFG CDM project. In the environmental dimension, improvements to landfill air quality is the likely benefit while reduction in land and water disturbances are the least likely benefits, respectively. In the social dimension, health and safety benefits outweigh employment, welfare, and skills transfer benefits. The profile of benefits based on the information from PDDs suggest that there are few benefits in the environmental dimension compared to the economic and social dimensions for a LFG CDM project.

Table 7.7: Number of Occurrences of Sustainability Benefits as Reported in PDDs Texts

Region	**Occurrences of sustainability benefits per dimension**												
	Economic Benefits				**Environmental Benefits**				**Social Benefits**				**Total sustainability benefits per region**
	Investment	Balance of Payments	Technology transfer	Energy	Water	Air	Land	Resource Conservation	Skills transfer & learning	Health & Safety	Employment	Welfare	
Asia & Pacific	60	0	266	80	18	52	15	53	30	60	59	49	742
Latin America	19	0	180	20	30	41	30	19	49	49	39	44	520
The Middle East	3	2	28	16	4	10	7	9	5	11	7	6	108
Africa	8	0	28	5	5	13	0	5	6	12	8	6	96
Europe & Central Asia	4	0	21	7	3	5	3	3	7	4	5	4	66
Total No of frequencies (references) mentioned in PDDs	**94**	**2**	**523**	**128**	**60**	**121**	**55**	**97**	**97**	**136**	**118**	**109**	**1,540**
Percentage (%) of the total	**6**	**0**	**34**	**8**	**4**	**8**	**4**	**6**	**6**	**9**	**8**	**7**	**100**
Percentage(%) total per dimension	**48**				**22**				**30**				**100**

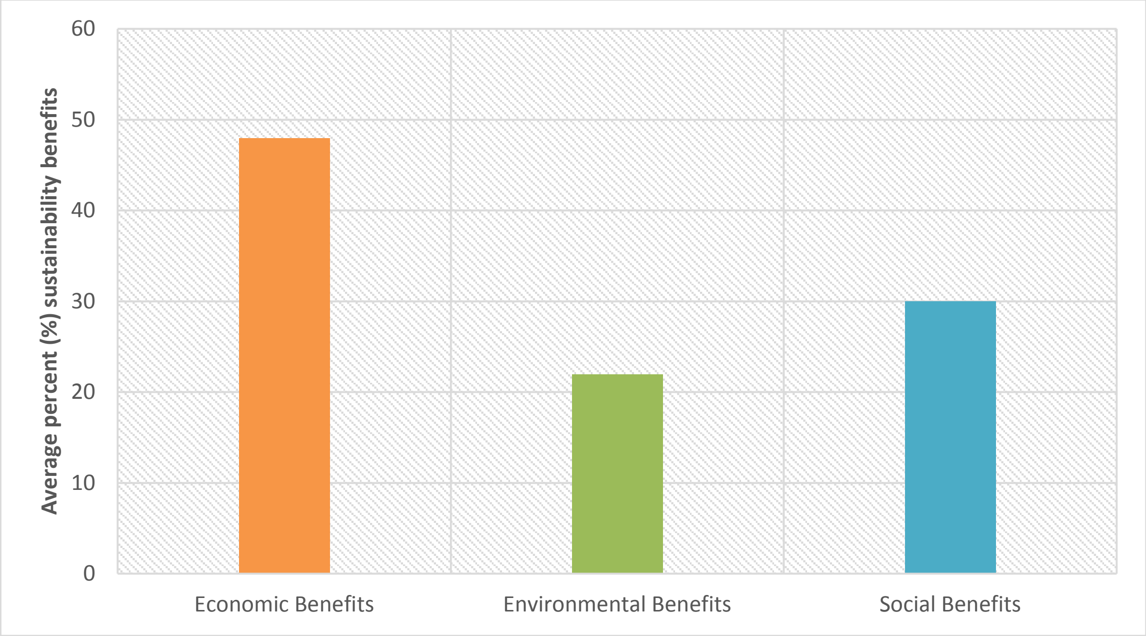


Figure 7.3: Sustainable Development Dimension Benefits of CDM Projects at Landfill Sites

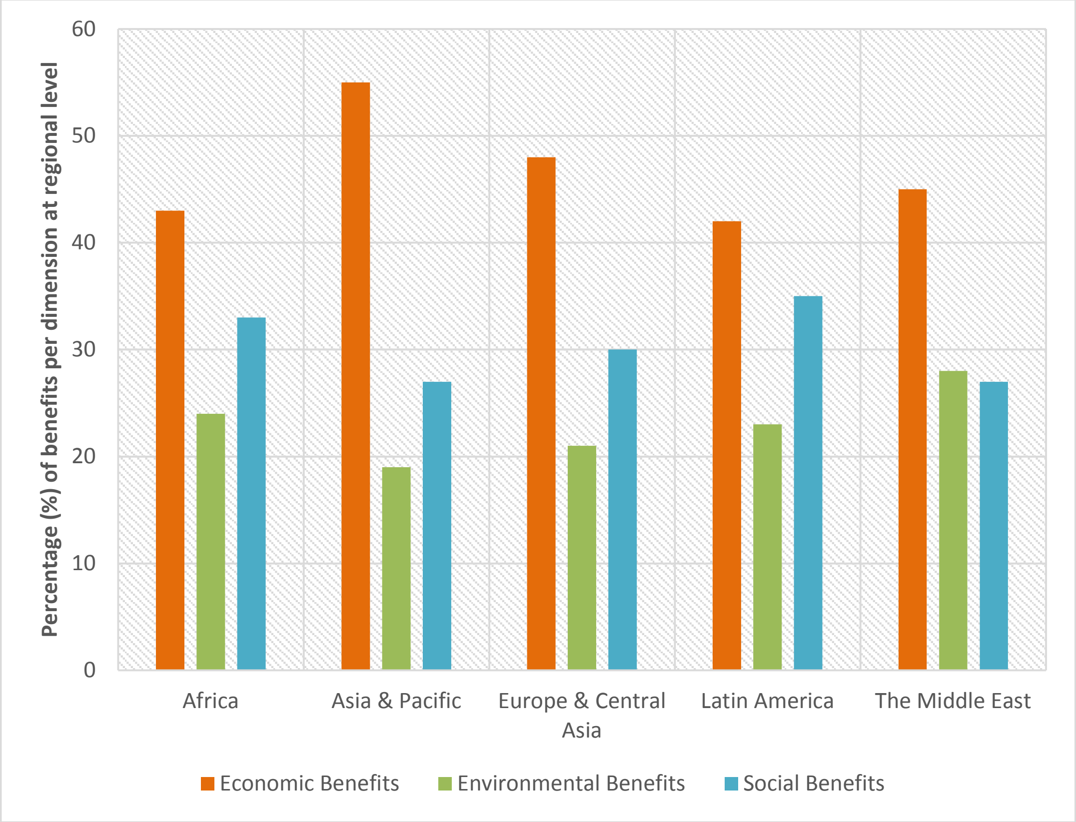


Figure 7.4: Sustainable Development Benefits per Dimension at Regional Level

Figure 7.5: Tree Map Showing Sustainable Development Dimensions (Nodes) and their Benefits (Criteria)

7.2.1.4 Profile of Sustainability Benefits by Region

The variability between the number of projects per region and the number of sustainability benefits was determined using Pearson's coefficient of determination (R^2). Results showed that there is a strong correlation (r^2 =71 %) between the number of projects per region and the aggregated number of benefits. The Asia and Pacific region with 49 % of the sampled projects has the highest number of benefits while Europe and Central Asia has the lowest number of projects (4 %) and the lowest number of benefits (Figure 7.6). The high number of benefits recorded in the Asian and Pacific region is attributed to the high number of projects in China. In 2011, China hosted 47 % of the total CDM projects registered with the CDM Executive Board (Shen, 2011). This however, is not always the case with individual benefits. For example, the Middle East region with only 6 % of the projects has higher balance of payment benefits than the Asia and Pacific region. Looking more closely at the profiles of benefits in all five regions, technology transfer is the most likely benefit in all the five regions while BoP is the least likely benefit (Figure 7.7).

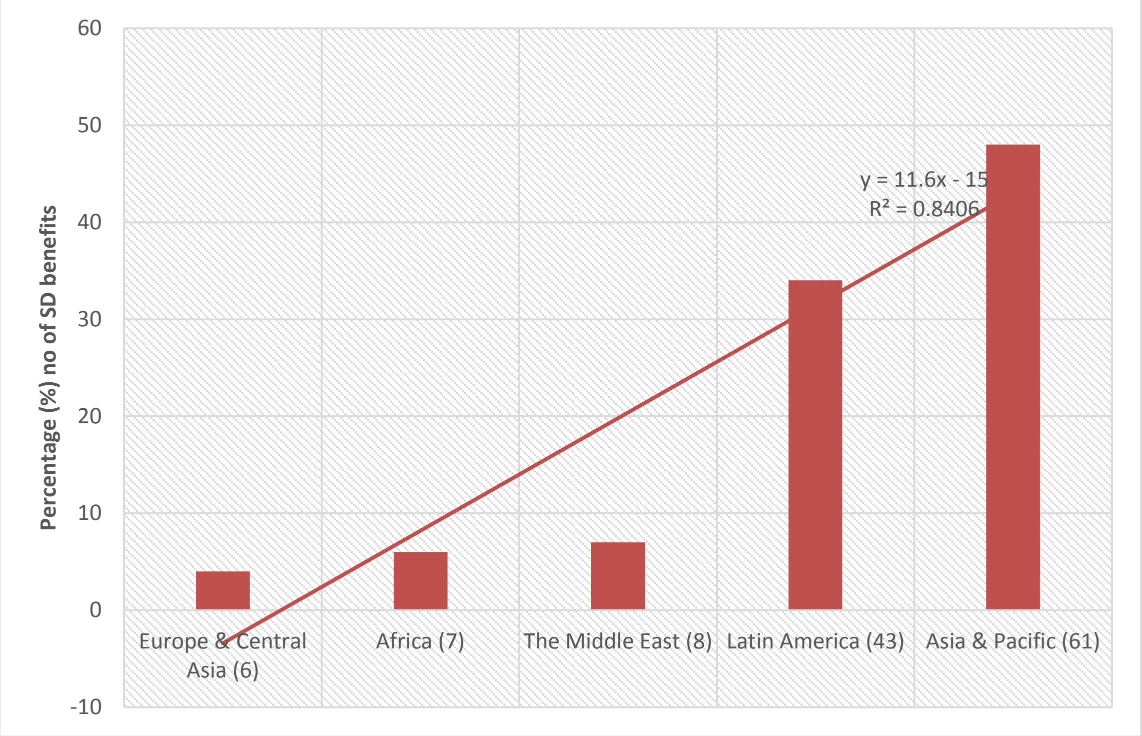


Figure 7.6: Correlation between Number of Sustainability Benefits and Number of Projects

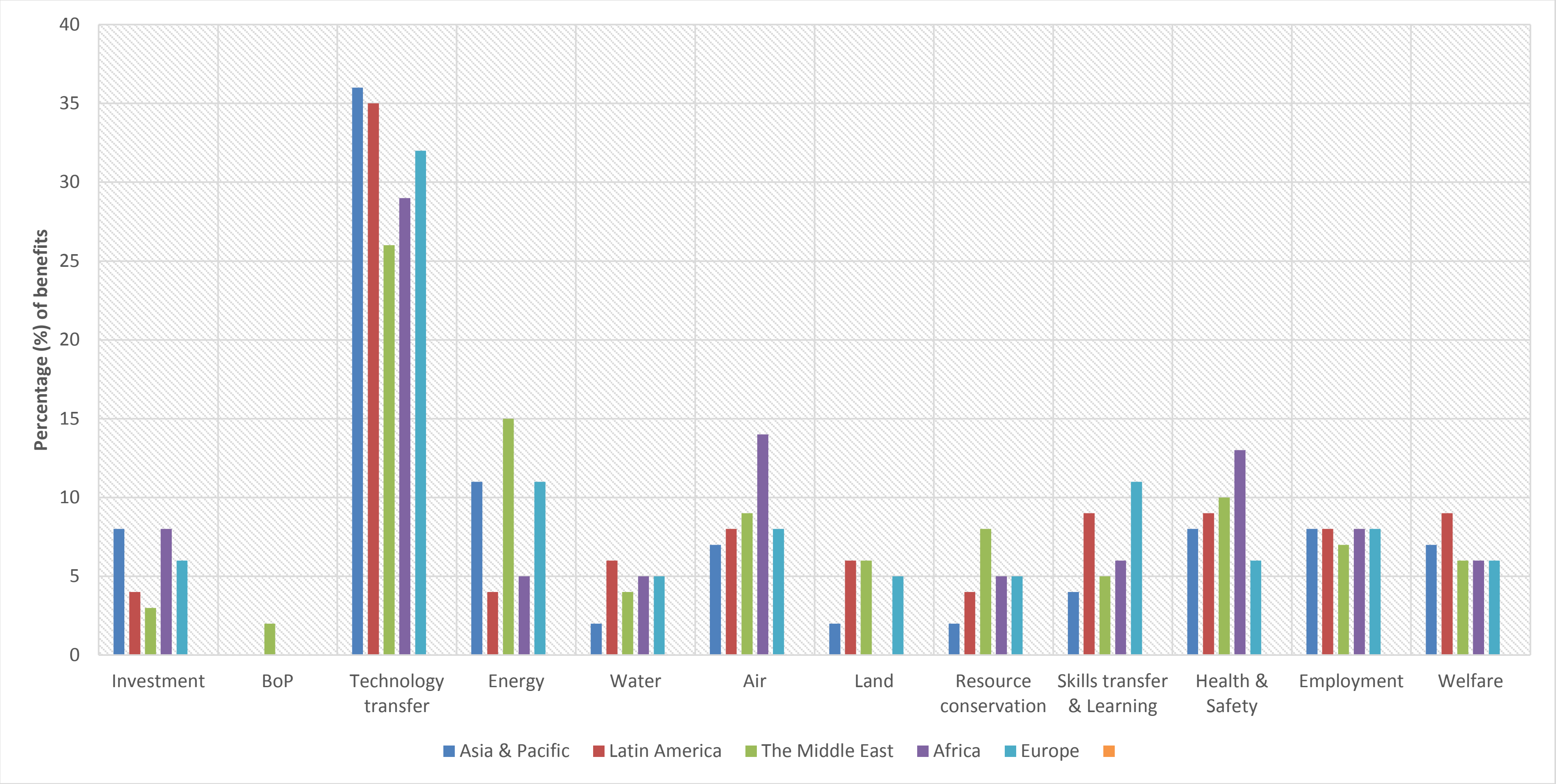


Figure 7.7: Profile of Benefits across the Five Regions

Out of the 12 potential sustainability benefits (criteria) in the developed framework, a ranking of benefits has emerged. Information from PDDs shows that CDM projects at landfill sites will on average have more benefits in the economic dimension followed by the social dimension with the environmental dimension recording the lowest benefits. Furthermore, Table 7.8 shows that technology transfer to landfill sites in developing country host nations is the most likely benefit of any CDM project proposed by a developer while BoP is the least likely benefit. The high ranking of technology transfer could be explained by the maturity of technologies used to manage methane contained in landfill gas in most developed countries (EPRI, 2011). Therefore, transferring such technologies to developing countries that are eligible to host CDM projects is not seen as a problem by most project developers – at least at the project preparation phase. Although, most regions show that they will generate renewable energy from landfill gas, BoP contribution by CDM projects to host nations is very low. The reason for this could be that most of the countries hosting CDM projects at landfill sites used in this study have their own reserves of fossil fuel and do not depend on imported reserves, which impact on foreign exchange. As such, the generation of energy from landfill gas only helps them reduce the use of fossil fuel with no impact on balance of payments. For example, China and South Africa have high reserves of fossil fuels (coal), which they use for energy generation (World Energy Council, 2013). The replacement of these sources of energy with renewable energy generated from landfill gas may be regarded as an environmental benefit, which does not contribute to balance of payments in contrast to Israel, which does not have fossil fuel reserves of its own for energy generation (DRAT, 2011).

Table 7.8: Ranking of Benefits Based on PDD Information

Ranking	Sustainable development benefits	Occurrences	%
1.	Technology transfer	523	34
2.	Health and safety	136	9
3.	Energy	128	8
4.	Air	121	8
5.	Employment	118	7
6.	Welfare	109	7
7.	Resource conservation	97	6
8.	Skills transfer and learning	97	6
9.	Investment	94	6
10.	Water	60	4
11.	Land	55	4
12.	Balance of Payments	2	0.1
Cumulative Total		**1,540**	**100**

7.3 VALIDATION OF THE FRAMEWORK USING QUESTIONNAIRE SURVEYS

Section 7.2 of this chapter utilised the information contained in PDDs for registered CDM projects at landfill sites to validate the developed framework. Since PDDs only reflect ‘potential’ and not ‘real’ benefits (see section 3.10.1), a questionnaire survey based on the developed framework was used to assess the actual project impacts or benefits. The questions in the survey sought to assess whether sustainable development benefits have been achieved at a landfill site as a result of the implemented CDM project. Since the questions asked were specific to the developed framework and sought specific responses, closed questions were used in the questionnaire survey. The survey was administered to developers of projects whose PDDs were used as sources of information in section 7.2. The questionnaire survey was administered using the Bristol Online Survey (BoS) tool (see Appendix 4). The questionnaire survey responses were imported into the Nvivo 10 software program. As with the occurrences of patterns and sustainability aspects in PDDs, aspects and patterns of sustainability benefits in questionnaire survey responses were coded and stored in the software program.

7.3.1 Challenges with Questionnaire Response Rates

Unlike PDDs whose information is publicly accessible from the UNFCCC website (see section 7.1.1), obtaining information on sustainable development benefits of CDM projects from project developers was challenging. The contact information provided in Annex 1 of the PDDs for project developers was in most cases not helpful. A number of questionnaires, which were sent as email attachments were rejected or undelivered (Table 7.9) because the email addresses were either incorrect or did not exist. For those that were delivered, the response rate was poor. Efforts were made to improve the response rate by contacting project developers by telephone using contact details indicated in the PDDs and by searching for project developers’ websites to check for alternative email addresses. Although these efforts resulted in a few additional responses, the overall response rate was poor. A common answer given, particularly by project developers from the Asia & Pacific region (China), was that “they were busy and not obliged to accept the request or would respond after discussing with relevant managers.” The language barrier could have contributed to the poor response rate from this region. Other developers contacted by telephone indicated repeatedly that they would respond until the survey closed. Another possible reason for the poor response rate could be that most of the contact information indicated in PDDs is often for executives of the companies who may have restricted technical knowledge (Santo, 2014 Pers. Comm., 28th

July). As such, they may ignore or feel uncomfortable responding to technical information such as that sought in the questionnaire.

As shown in Table 7.9, from the 124 survey questionnaires administered to project developers, only 19 responses (15 %) were received. The African region (South Africa) provided the highest response rate (70 %) while the Asian and Pacific region (China) provided the lowest (3 %). In Latin America (Brazil), of the eight responses received, two were for projects that had not yet been installed/implemented despite being registered with the CDM Board. Similarly, in the Middle East (Israel), of the three responses, one was for a project that had been terminated due to financial reasons.

Table 7.9: Questionnaire Survey Responses

Region/Country	**Number of projects**		**No. of responses**	**Type of projects**		**Emails /undelivered**	**Non-responsive**	**Response rate (%)**
				Bi-lateral	Uni-lateral			
Africa								
South Africa	7		5	1	4	0	2	71
Asia and Pacific								
China	61		2	1	1	20	41	3
Europe and Central Asia								
Armenia	1	**5**	1	0	1	2	20	20
Azerbaijan	1							
Georgia	1							
Serbia	1							
Uzbekistan	1							
Latin America								
Brazil	43		8	5	3	19	16	19
The Middle East								
Israel	8		3	1	2	3	2	38
TOTAL	**124**		**19**	**8**	**11**	**44**	**63**	**15**

The limitation of a poor response rate is however, not unique to this study. Other related CDM studies have faced similar challenges (see Table 7.10). For example, Lloyd and Subbarao (2011) compared sustainable development benefits assumed in PDDs against actual delivered benefits in the development of rural communities associated with small-scale renewable energy CDM projects. In this study, only 5 out of 500 (1 %) registered CDM projects were able to be assessed for the actual development benefits delivered to local communities. Similarly, in a study by Sutter and Parreno (2007) assessing CDM projects in terms of their contribution to employment generation, equal distribution of returns, and improvement of local air quality, only 4 out of 16 (25 %) surveys were completed by project developers. Furthermore, Tewari (2012) only received 10 responses from a sample size of 50 (20 %) in the study “Mapping of criteria set by DNAs to assess sustainable development benefits of CDM projects.”

Table 7.10: Response Rate from Similar CDM Studies

Reference	CDM study	Total Sample	Received	Response rate (%)
Lloyd & Subbarao (2011)	Can the CDM deliver? - Investigating the uptake of small-scale renewable energy projects	500	5	1
Sutter & Parreno (2007)	Does the current Clean Development Mechanism (CDM) deliver its sustainable development claim? – Assessment of CDM projects’ contribution to employment generation, equal distribution of CDM returns, and improvement of local air quality	16	4	25
Tewari (2012)	Mapping of criteria set by DNAs to assess sustainable development benefits of CDM projects	50	10	20

7.3.2 Results

7.3.2.1 Characteristics of the Projects

Out of the 19 responses from project developers, three projects had either not yet been installed or had been terminated. Therefore, only 16 projects (13 % of the total questionnaires sent out) were used to validate the framework. Of the 16 projects, only one project (6 %) is implemented fully on a closed landfill cell (Table 7.11). This suggests that investing in a CDM project at a closed landfill site or cell may not be profitable in the long term because landfill gas emissions (GHG emissions) occur during the early stages of decomposition when decomposable organic content is more readily available (see section 4.2.3.2). Once a cell is closed and no more degradable organic carbon is added, the amount of landfill gas generated declines. With regards to treatment of landfill gas, a combination of energy generation (e.g., electricity and heat) and flaring of LFG are the common methods for treating the landfill gas collected from the cells. Fourteen of the 16 projects (88 %) use this treatment method while only a project each (6 %) flare and use the collected LFG for energy generation, respectively.

In terms of crediting periods, 12 projects (75 %) adopted a 7 year twice renewable crediting period (21 years) while only four (25 %) adopted a 10 year non-renewable crediting period. These findings are in line with the findings in PDDs where most of the project developers see greater benefits in choosing a longer crediting period than a shorter one (section 7.2.1.1).

Table 7.11: Characteristics of Projects

Region/Country	No. of Projects	Location of CDM Projects on Landfill Sites			Landfill gas Treatment Method			CDM Project Crediting Periods		Status of CERs Issuance	
		Closed cells	Active cells	Active & closed cells	Landfill gas flaring	Energy generation(e.g., electricity and heat)	Both flaring & energy generations	10 years	7 years	Issued/Partially issued	Pending/Not issued yet
Africa											
South Africa	5	1		4	1		4	1	4	3	2
Asia & Pacific											
China	2			2			2	2		1	1
Europe & Central Asia											
Armenia	1			1		1			1	1	
Latin America											
Brazil	6		6				6	1	5	5	1
The Middle East											
Israel	2			2			2		2	1	1
Total	**16**	**1**	**6**	**10**	**1**	**1**	**14**	**4**	**12**	**11**	**5**
% Total	**100**	**6**	**38**	**62**	**6**	**6**	**88**	**25**	**75**	**58**	**26**

7.3.2.2 Challenges Faced by Project Developers

Project developers were asked to identify the challenges they were facing when implementing CDM projects at landfill sites. Table 7.8 shows that the low prices of CERs is the main challenge followed by high registration fees charged by the UNFCCC. The high costs charged by designated operating entities (DOEs) for validating projects before CERs are issued is the other main challenge followed by UNFCCC bureaucracy or “red tape.” The results suggest that gas yields from landfill sites is not a major issue as only 2 % of project developers reported it as a challenge.

Table 7.12: Challenges Faced by Developers

Ranking	Challenges	Responses (%)
1	Low CER prices	32 %
2	High costs for project registration	30 %
3	High fees charged by DOEs	25 %
4	UNFCCC red tape	11 %
5	Low gas yield	2 %

7.3.2.3 Sustainability Benefits – Results

7.3.2.3.1 Number of Projects Reporting Sustainability Benefits

Table 7.13 shows the sustainability benefits of the 16 projects as reported by project developers. Similar to the findings in the PDDs, more projects reported higher social benefits (on average 92 %). However, unlike in PDDs where economic benefits were the second highest reported benefits by projects, environmental benefits are on average the second highest reported by projects (75 %) with economic benefits being the lowest reported (70 %) (Figure 7.8). In terms of individual benefits (criterion), all projects reported that they were or had contributed towards technology transfer as well as health and safety improvements at landfill sites in host nations (columns 5 and 12). In contrast, only 6 % of the projects reported that they had contributed towards host nation’s balance of payments (column 4).

Table 7.13: Projects Reporting Sustainability Benefits from Survey Responses

Regions	**Total No. of Projects**	**Projects per region contributing to sustainability benefits**											
		Economic Benefits				**Environmental Benefits**				**Social Benefits**			
		Investment	Balance of Payments	Technology transfer	Energy	Air	Water	Land	Resource Conservation	Skills transfer and learning	Health and Safety	Employment	Welfare
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Asia and Pacific	2	2	0	2	2	2	2	2	0	2	2	2	2
Latin America	8	5	0	6	4	5	5	5	1	5	6	5	5
The Middle East	3	2	1	2	2	2	2	2	0	1	2	2	2
Africa	5	5	0	5	4	5	5	5	1	5	5	5	4
Europe and Central Asia	1	1	0	1	1	1	1	1	1	1	1	1	1
TOTAL	**16**	**15**	**1**	**16**	**13**	**15**	**15**	**15**	**3**	**14**	**16**	**15**	**14**
% (Totals of column(2-14)/ total of column 2) x100	**100**	**94**	**6**	**100**	**81**	**94**	**94**	**94**	**19**	**88**	**100**	**94**	**88**
Percentage average (%)		**70**				**75**				**92**			

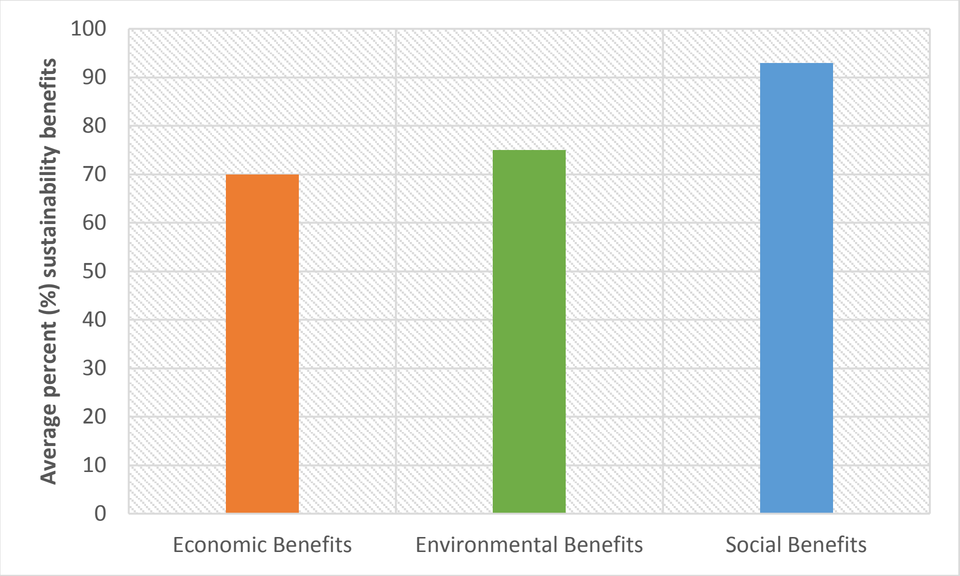


Figure 7.8: Average Percentage (%) Sustainability Benefits Reported by Survey Responses

7.3.2.3.2 Sustainability Benefits per Dimension

Table 7.14 shows the occurrence of sustainability patterns and aspects in the survey responses from project developers across the three dimensions. In contrast to PDD findings (where economic benefits were seen to be the main driver for investing in landfill gas CDM projects), the survey results suggest highest benefits at a project level are in the environmental dimension (air, land, water, and resource conservation) followed by the social dimension with lowest benefits in the economic dimension (Figure 7.9). This pattern is the same at the regional level where environmental related benefits are seen to be higher than social and economic related benefits in all the regions except for the Middle East region where economic benefits are higher (Figure 7.10).

Table 7.14: Sustainability Benefits Occurrences in Survey Responses per Region

Region	Number of sustainability benefits occurrences (coded) in survey responses per region												
	Economic Benefits				Environmental Benefits				Social Benefits				Total sustainability benefits per region
	Investment	Balance of Payments	Technology transfer	Energy	Water	Air	Land	Resource Conservation	Skills transfer and learning	Health and Safety	Employment	Welfare	
Asia and Pacific	11	0	8	2	17	6	6	0	4	4	4	5	67
Latin America	25	0	19	4	47	35	23	1	13	11	16	23	217
The Middle East	9	1	9	3	6	3	4	0	1	5	6	5	52
Africa	20	0	21	4	31	25	10	1	7	10	18	18	165
Europe and Central Asia	5	0	5	1	7	6	4	2	1	4	2	3	40
Total No of occurrences (references)	70	1	62	14	108	75	47	4	26	34	46	54	541
% of the total	**13**	**0**	**11**	**3**	**20**	**14**	**9**	**1**	**5**	**6**	**8**	**10**	**100**

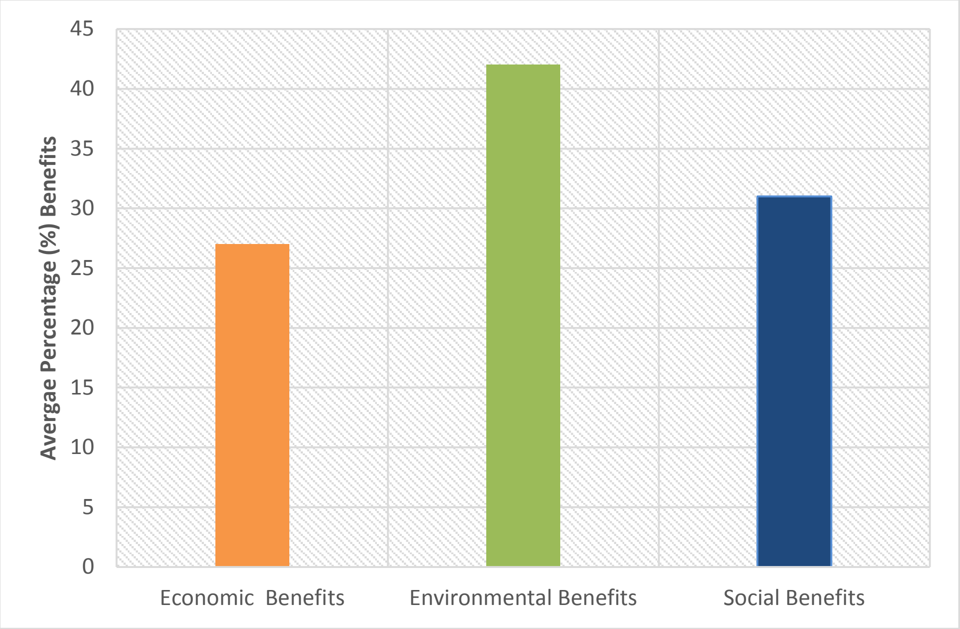


Figure 7.9: Sustainability Dimension Benefits of CDM Projects at Landfill Sites (Actual)

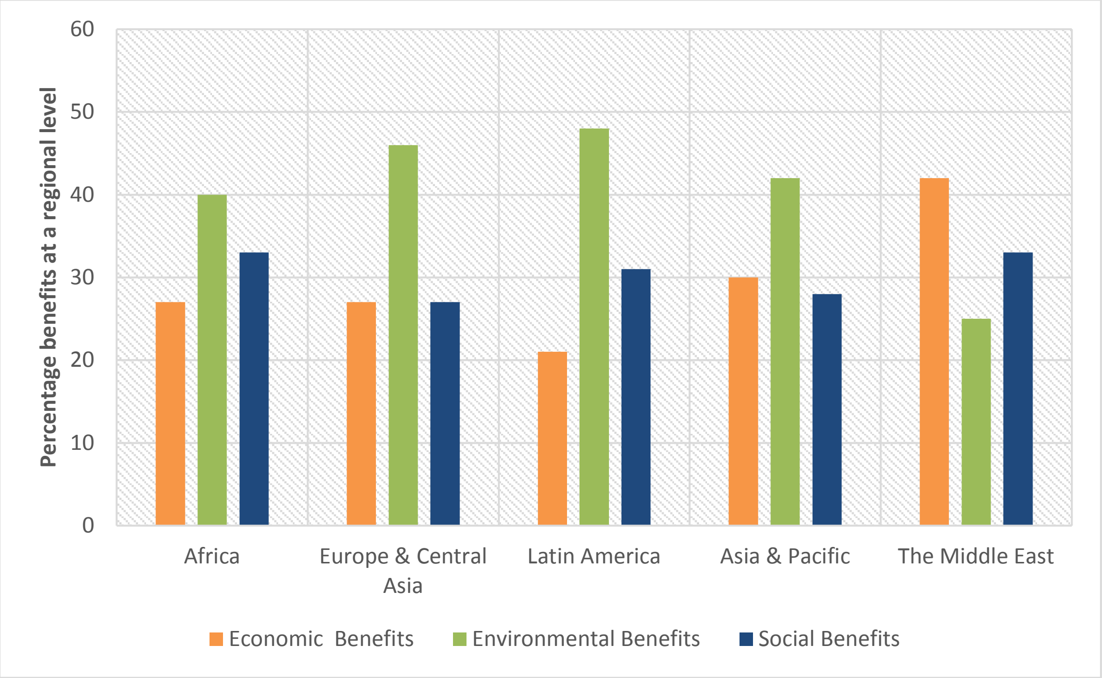


Figure 7.10: Sustainability Benefits per Dimension at Regional Level

Table 7.15 ranks occurrences of sustainability benefits in each dimension. Investment, welfare improvements, and protection of surface and groundwater are the highest ranked benefits while balance of payments, skills transfer & learning, and resource conservation are the lowest ranked benefits in the economic, social, and environmental dimensions, respectively.

Table 7.15: Ranking of Sustainability Benefits from Survey Responses in each Dimension

SD Dimensions	Ranking	Criteria (sustainability benefits)	Occurrences	% Occurrences in the dimension
Economic Dimension	1	Investment	70	48
	2	Technology transfer	62	42
	3	Energy	14	9
	4	Balance of Payments	1	1
	Total		147	100
Social Dimension	1	Welfare improvement of communities around project area & Air quality improvements area	54	34
	2	Generation of employment for the local people	46	29
	3	Health & Safety improvements in the area	34	21
	4	Skills transfer & learning	26	16
	Total		160	100
Environmental Dimension	1	Protection of surface and groundwater	108	46
	2	Air improvement in the area	75	32
	3	Reduction in Land degradation	47	20
	4	Resource conservation	4	2
	Total		**234**	**100**

7.3.2.3.3 Profiles of Sustainability Benefits by Region

Protection of surface and groundwater (environmental dimension) is the main benefit realised from implementing landfill gas CDM projects in four of the five regions. Figure 7.11 shows that, apart from the Middle East region, which ranked investment and technology transfer as the highest benefits, results from the questionnaire survey suggest that the other four regions ranked the protection of surface and groundwater highly. This is in stark contrast to the information reported in PDDs, which ranked technology transfer (economic dimension) as the highest benefit in all the regions. The PDD information (section 7.2.1.3) and questionnaire survey responses (7.3.2.3.2), however, agree on balance of payments as being the least achieved benefit from a landfill gas CDM project.

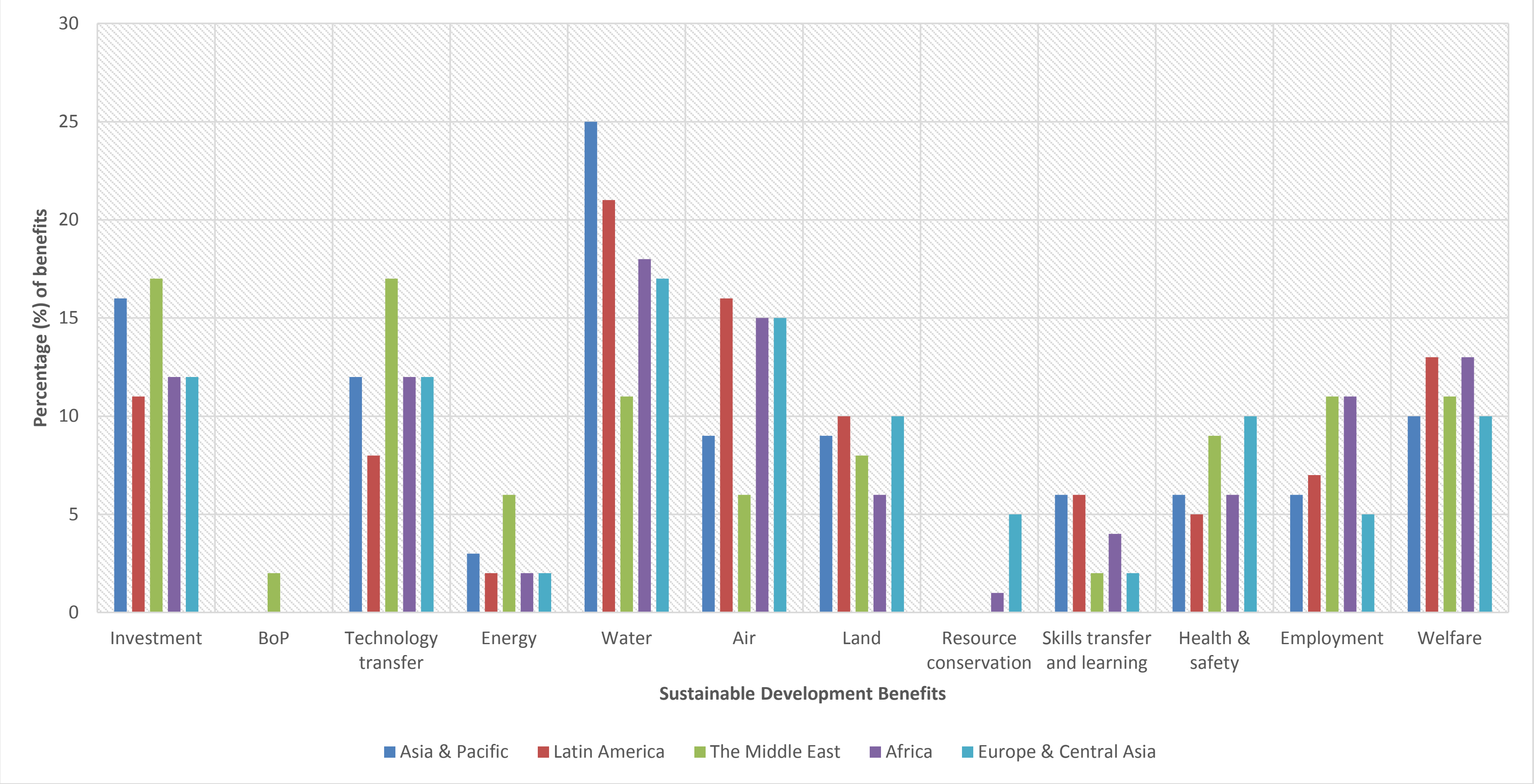


Figure 7.11: Profile of Actual Benefits per Region

To ascertain whether the observed sustainability benefits at the project level are attributed to the CDM project, the responses (information) given by project developers in the questionnaire surveys was used. As part of the survey, project developers were asked to rate the CDM project's contribution towards specific benefits at their landfill sites. Table 7.16 shows that out of the 16 projects that have been implemented, the higher sustainability benefits observed (ranked 1st) with respect to protection of surface and groundwater water criterion (environmental dimension) may, after all, not be attributed to the presence of CDM projects at landfill sites. Only 12 % of project developers agreed that improvements in leachate management - the main source of surface and groundwater pollution at landfill sites (Randerson et al., 2010) were attributed to the CDM project. However, 44 % were not sure (neutral) while 44 % disagreed. From these findings, it can be inferred that most project developers hosting these CDM projects may have had adequate resources to enable them to put in place good management and operational practices for protecting surface and groundwater even before CDM projects were implemented at their landfill sites. These management and operational practices could have included installation of leachate collection and treatment systems, and bottom and top containment systems. However, it is suggested that the high improvements in the area's air quality – another environmental benefit – is attributed to the presence of CDM projects. It was found that 75 % of the project developers agreed that CDM projects had contributed to improvement in the area's air quality, 19 % were not sure (neutral), and only six per cent disagreed. Similarly, benefits such as investment (new equipment and infrastructure) and employment creation (new jobs) could be said to be attributed to the implementation of CDM projects. Sixty nine per cent of the project developers agreed that implementing CDM projects at their sites had brought new equipment and/or infrastructure, 25 % were not sure (neutral), and only six per cent disagreed. With respect to job creation, 67 % of the project developers agreed that implementing CDM projects at their landfill sites had generated new jobs for the people.

7.3.2.3.4 Site Management during Operational and Aftercare Period

The challenge of low CER prices identified earlier (Table 7.12) is more visible from the responses given by developers on whether the revenue from CER sales would assist them in managing landfill sites both during the operational and aftercare period. It was found that 63 % of the project developers disagreed or were not sure (neutral) that the revenue would be adequate to assist them in site management. Only 37 % felt that there would be sufficient income from CERs to assist them in site management. This may explain why two projects had not yet been implemented and why one had been terminated.

Table 7.16: Rating of Benefits Attributed to CDM Projects

Benefits attributed to CDM Project	Agree	Neutral	Disagree	Total Number Responses
Bringing of new equipment /infrastructure	11 69 %	4 25 %	1 6 %	16
Creation of new jobs	10 67 %	4 27 %	1 7 %	15
Local economy has benefited from CDM project	10 63 %	3 19 %	3 19 %	16
Improvement in landfill gas management and odour	12 75 %	3 19 %	1 6 %	16
Improvement in leachate management	2 12 %	7 44 %	7 44 %	16
Improvements in dust management	6 37 %	7 44 %	3 19 %	16
CERs has/will assist operator in management of site both during operational and aftercare period	6 37 %	3 19 %	7 44 %	16

7.4 SUMMARY

This chapter addressed the fifth objective and last part of the research aim presented in section 1.2. Validation results have shown that the developed framework can be used by both host nations DNAs and DOEs to assess LFG CDM projects' contribution to sustainable development at national approval, validation and verification stages. Using PDDs and survey responses as sources of information, the developed framework has shown that registered CDM projects at landfill sites contributed to 11 of the 12 sustainable development benefits in the developed framework. Results from both the PDDs and survey responses have shown that balance of payment benefits would not be achieved at a landfill site CDM project. Of the 11 sustainability benefits, there were discrepancies between those indicated in PDDs, which reflects potential benefits, and the benefits obtained at the project level. The explanation for this discrepancy could that PDD statements about contribution to sustainable development are based on expectations at the time the project is being planned and seeking approval from a host nation. The actual sustainable development contributions of a project may be different at the project level due to external factors that could include fluctuations in CER prices and changes in investment climate in host nations. Furthermore, PDDs are designed and written by project developers, which implies that their project's contribution to sustainable development is usually presented in a favourable way to avoid being rejected by the host nation.

The validation exercise has shown that the aggregated occurrence of sustainability benefits in PDDs are higher in the economic dimension followed by the social dimension, with the environmental dimension having the lowest benefits. However, the actual benefits achieved at the project level were different. The results from survey responses showed that more benefits were being achieved in the environmental dimension followed by the social dimension with the economic dimension having the least benefits. Similarly, there were discrepancies on the individual sustainability benefits. The PDDs showed that technology transfer would be the highest benefit of any CDM project at a landfill sites. Survey results however, showed that improvement in air quality within and around the landfill sites were the highest benefits achieved by implementing a CDM project at a landfill site.

CHAPTER 8 : DISCUSSION

8.1 INTRODUCTION

This chapter discusses the main findings of the research. The main focus of the research study was to develop a framework for assessing sustainable development benefits of landfill gas CDM projects in developing countries. This chapter also discusses the findings related to the aims and objectives stated in section 1.2

8.2 MAIN FINDINGS

The findings from the literature review (Chapter 2) showed that waste disposal by landfill remained the dominant waste management option in developing countries. However, most developing countries do not have in place policies, regulations or technologies required to mitigate the negative impacts associated with landfilling. Consequently, many sites remain poorly managed and operated, which leads to serious negative impacts on both human health and the environment.

Almost 20 years ago, Ogawa (1996) reported that solid waste management projects, which included landfill projects were carried out in some developing countries in collaboration with external support agencies. This was after some developing countries through their local authorities recognized the importance of improving solid waste management in their cities. Some of these projects were successful in producing lasting positive impacts such as the construction of engineered landfill sites for the disposal of the collected waste, and training of staff to manage them. However, many projects struggled financially or were unable to continue with their development once support from external agencies ceased. Ogawa (1996) attributed the failure during this time to a number of factors, which included both technical and financial. In general, solid waste management, which included landfill, was given low priority in most developing countries. As a result, limited funds were provided to the sector resulting in levels of services required for protecting human health and the environment not being met. The findings from one of the landfill case study site used in this research agree with Ogawa's observations. Landfill C located in Zambia was built with financial support from the Danish Government through the Danish International Development Agency (DANIDA). The site was constructed as a sanitary landfill and was equipped with a composite lining system comprising a clay liner and a High Density Poly-Ethylene (HDPE) membrane. It was also equipped with a leachate collection system. The site operated as a sanitary landfill until the end of the two-year service agreement period (2007-2009) with DANIDA. Since this period, the operation of the site has been below sanitary landfill requirements with no leachate collection and treatment or gas mitigation. Landfill fires have become a common feature while groundwater monitoring to detect potential contamination is no longer carried out despite monitoring boreholes having been installed by DANIDA during construction. Sustaining sanitary landfill operations have been hampered by budgetary constraints faced by the operator. The gate fees charged are not sufficient to enable the operator manage the site in a sanitary manner (interview with landfill operator in July, 2013). Consequently, the landfill is operated as a semi-managed open dumpsite. Landfill C is a typical example where long-term sustainability of sanitary landfill sites built with external support has not been achieved especially where operational and maintenance costs are left to be met by local operators' budgets that mainly come from gate fees. Apart from financial and technical factors, there is also insufficient legislation requirement for managing landfill sites in most developing countries. Where legislations exist, there is little or no enforcement by regulatory agencies.

Processes are, however, slowly developing, particularly in urban areas where there is a paradigm shift away from open dumping towards more managed practices. Managed practices now include confining the disposal of the collected waste to engineered disposal sites and covering it with layers of soils to prevent emission of odours and discourage scavenging by both animals and humans. This coupled with the collection of waste, which is predominantly organic creates a situation that leads to more anaerobic conditions for the organic waste within the landfill site and a corresponding increase in the production of methane gas. The installation of some form of emission mitigation of the generated methane at these new types of landfill sites presents an opportunity for operators to earn additional revenue and access landfill gas technology through the CDM. This income can assist in site management. There are many socio, economic, and environmental benefits of adopting landfill gas CDM projects in developing countries. The findings from the second landfill case study B showed these benefits. By implementing a CDM project at Landfill B in South Africa, the operator gained access to landfill gas technology from a developed country. The accessed technologies include landfill gas collection and pumping equipment, and control devices (engines for energy generation and gas flaring units). This has contributed to improvements in the overall management of both landfill gas and leachate (Parkin, 2013) – the two main pathways for landfill pollutants. Leachate management has improved because gas collection wells that were installed by the CDM project were also equipped with leachate collection systems. Additional revenue is also being generated by the operator through the sale of carbon credits (CERs) and the sale of electricity generated from landfill gas. This additional revenue has helped the operator in managing both closed and active cells at the landfill site (interview with landfill operator in July, 2013). Furthermore, the CDM project has brought local benefits such as creating new employment opportunities for the local people and improvements in the local environment by reducing the emission of noxious gases.

However, despite the many benefits associated with CDM projects, the research has identified a weakness in the way the mechanism is operating. The CDM was designed with two objectives: (i) to contribute to local sustainable development in the host country; and (ii) to assist Annex 1 countries in meeting their GHG emission targets cost-efficiently (UNFCCC, 1997). While project specific methodologies exist at the international level for monitoring, verifying and certifying emission reductions of GHGs, there is no internationally accepted standard for assessing sustainable development benefits of CDM projects. Rather than setting international standards for sustainability assessment, which developing countries argued would impinge on their sovereignty (Olsen and Fenhann, 2008), the Marrakech Accords (2001) affirmed that "it is the project host country's prerogative to confirm whether a project contributes to sustainable development." Designated National Authorities in developing countries are mandated to issue a letter of approval or reject projects according to their own sovereign sustainable development criteria. However, as host nations set their own sustainability criteria, fears have been raised about a 'race to the bottom' as countries use less demanding sustainability criteria in order to attract CDM investment (Rindefjall et al., 2010). Most host nations are more concerned with attracting projects and the revenues that they bring than applying stringent sustainable development criteria (Monceau and Brohe, 2011). The findings from the evaluation of DNA sustainability criteria used for assessing projects (Chapter 5) confirmed these fears. Although DNAs have published guidelines that, a priori, excludes projects that are not likely to deliver sustainable development, the study showed that once a letter of approval has been granted, there is no follow up over time by DNAs to ensure that sustainability benefit claims in PDDs are achieved at the project level. Thus, a project that fails to deliver sustainability benefits claimed in PDDs cannot be sanctioned at the validation (prior to registration) or verification (prior to issuance of CERs) stages. The lack of common sustainability criteria and monitoring requirements makes it difficult to do an ex-post evaluation of the performance of CDM projects. For example, a study by Gupta et al. (2008) of 44 projects of the Dutch CDM portfolio concluded that benefits directly related to GHG emission reduction (e.g., technology transfer) are usually achieved. At the same time, indirect benefits such as retrofitting a nearby park under a landfill gas project, were generally not monitored and non-fulfilment of such contributions did not affect the project as long as emission reductions were achieved according to the plan. In the absence of an international standard, developing countries may continue to provide easy and rapid approval of CDM projects thereby creating a disincentive towards high sustainability standards. For example, a study by Rindefjall et al. (2010) showed that Chile has chosen to use the CDM as a tool to attract foreign investments, a choice reflecting emphasis on economic development of the country's development strategy at the expense of setting stringent sustainability criteria. Therefore, it is considered that having an efficient and robust project specific framework for assessing sustainable development benefits of CDM projects is essential. This research has developed a framework that could be used at an international level for assessing sustainable development benefits of CDM projects at landfill sites.

A conceptual framework has been developed to describe sustainable development benefits of CDM projects at landfill sites (Figure 6.1 of section 6.3). The choice of dimensions for the developed framework is based on the widely agreed definition of sustainable development, which includes the three mutually reinforcing dimensions namely: (i) economic development; (ii) social development; and (iii) environmental protection. The developed framework's criteria are specified and supplemented with clearly defined and assessable indicators (Table 6.1 of section 6.3). The indicators measure the extent to which a CDM project meets sustainable development criteria. Although, the choice of criteria in the developed framework is informed by existing methodologies used by host nations, it focuses on LFG CDM projects. To avoid violating host countries' prerogative to define their sustainable development priorities (Marrakech, 2001), it is recommended that the developed framework be a requirement at the international level in addition to any guidelines that have been established by a host nation. The scoring of benefits (criteria) in the developed framework has been left to individual host nations DNAs and DOEs to determine. The developed framework, however, contains the necessary details (indicators and specifications) required to make such decisions.

The developed framework was validated by using it to assess the achievement of sustainable development benefits by LFG CDM projects that have been registered with the CDM Executive Board using PDDs and survey responses as data sources (section 7.2.1.3). Table 8.1 shows the results of the assessment carried out as per the developed framework.

Table 8.1: Validation Results Using PDDs and Survey Responses AS Sources of Information

Source of Information	**Ranking of Benefits**		
	1st	2nd	3rd
PDDs	Economic benefits (46 %)	Social benefits (33 %)	Environmental benefits (21 %)
Survey Responses	Environmental benefits (42 %)	Social benefits (31 %)	Economic benefits (27 %)

As shown in Table 8.1, PDD results, which reflect ‘potential’ sustainability benefits showed higher economic benefits followed by social and environmental benefits. Some studies that have used PDDs as sources of information for assessing sustainable development contribution of CDM projects obtained similar findings. These studies have shown that economic benefits, which are associated with GHG emission reductions, dominate other benefits (social and environmental) (Table 8.2). From these findings, it can be inferred that the economic flexibility given to Annex 1 countries (developed countries) to meet part of their GHG abatement costs by investing in environmentally benign projects is the main driver for investing in CDM projects. Furthermore, some Annex 1 countries may have taken advantage of the absence of an international sustainability standard by being negligent on their own sustainability development criteria. For example, a study by Teravainen (2009) showed various weaknesses in the Finnish DNA sustainability criteria that included:

(i) The disregard of environmental and social aspects of sustainability;

(ii) A strongly nationally oriented approach to promote national technology, using the CDM as an opportunity to boost exports; and

(iii) A lack of attention to the development needs at the local level.

Table 8.2: Sustainability Findings by Studies that Utilised PDDs as Sources of Information

Study	Findings/Conclusions
Olsen (2007) - Review of 19 studies that focused on PDDs for non-registered CDM projects on sustainable development	The main finding of the review were that, left to market forces, the CDM does not significantly contribute to sustainable development
Olsen and Fenhann (2008) – Text analysis of 744 PDDs submitted for validation by 3rd May 2006	The sustainability analysis showed that the five most common benefits are employment generation, economic growth, a better quality of air, access to energy and welfare improvements
Boyd et al. (2009) – Review of 10 PDDs cases that capture (a) diversity of CDM project types that include biomass, waste heat recovery, hydroelectricity, fuel switch, land fill, construction and biogas and (b) regions	All of the cases appeared to make significant GHG emission reductions while falling short in delivering direct local benefits
Sirohi (2007) - Examined 65 project design documents (PDDs) for CDM in India	Concluded that PDDs ‘‘offer just lip service regarding expected contribution to socioeconomic development of the masses, particularly in rural areas.’’ Nearly all the projects were business oriented and were not directed to the development of the rural poor.
Sutter and Parreno (2007) - Used PDDs to review integrity of emissions reductions and sustainable development contribution of the first 16 registered CDM projects.	They found a stark contrast: 72% of purported GHG reductions are reliable in scientific terms, while less than 1% of projects contribute significantly to sustainable development.
Lee and Lazarus (2011) - Analysis of 77 PDDs for biomass CDM projects	Claims of economic benefits exceeded those of environmental and social benefits
UNFCCC (2011a) – Assessment of project’s contribution to sustainable development	Findings were that only three percent (3%) of sustainability benefits claimed in PDDs were achieved at the project level

The validation results from survey responses, which reflect sustainability benefits at the project level are different from PDD results. As shown in Table 8.1, environmental benefits exceeded social and economic benefits. A survey conducted by the UNFCCC (2011) to assess each CDM project’s contribution to sustainable development obtained similar discrepancies. The survey responses were compared with indicators compiled from the PDDs. The results showed that the survey responses and the indicators from PDDs were identical (100% match) for only nine of the 332 projects (3 %) (Table 8.3). The discrepancies are not surprising because sustainable development statements in PDDs are expectations at the time a project is seeking approval from the host nation and being validated by a DOE. Therefore, the sustainable development benefits of projects achieved at the project level may be different. Boyd et al. (2009) warned that it can be misleading to assess CDM project’s sustainable development outcomes and draw conclusions based on project proposals such as PDDs. This is because PDDs reflect only ‘potential’ and not ‘real’ benefits as conditions may change due to external factors such as fluctuations in prices of CERs and investment climate in host nations. Statements in PDDs are expectations at the time the project is being validated.

Table 8.3: Comparison of Sustainable Development Indicators from PDDs and Survey Responses (UNFCCC, 2011)

Percentage match between survey and PDD indicators	Number of projects	Percentage of projects
0%	27	8%
25%	33	10%
33%	64	19%
50%	100	30%
67%	82	25%
75%	17	5%
100%	9	3%
	332	100%

In the case of this study, the discrepancy shown in sustainability benefits between the two sources of information (PDDs and survey responses) could be attributed to two reasons. Firstly, the prices of CERs have fallen from over €20 per tonne in 2008 to around €0.30 per tonne by late 2012 (Ward, 2013). Consequently, many economic benefits that may have been envisaged such as employment generation for the local people, investment in energy generation and transmission infrastructure stated in PDDs were not realised. This was confirmed in the survey responses from landfill CDM project developers (section 7.3.2.2). They ranked the existing low prices of CERs as a major challenge. Secondly, the high environmental benefits seen at the project level (landfill sites) as shown in the survey responses could be attributed to the access of landfill gas technologies that came with CDM projects. Although landfill gas technologies that are associated with many environmental benefits are mature, available, and well-developed world-wide (EPRI, 2011), they are expensive for most landfill operators in developing countries. The CDM therefore, provides an opportunity for operators to access such technologies leading to improvements in the overall management and operation of their sites. At Landfill B in South Africa where a CDM project is being implemented, the improvements in site management are mainly attributed to the landfill gas technologies that came with the CDM project since regulations (DWAF, 1998) do not prescribe landfill gas management (Parkin, 2013). In addition to reducing GHG emissions, the treatment of landfill gas using the landfill gas technology has improved the local environment by reducing noxious air pollutants. As an added benefit, all the gas collection wells that were installed by the CDM project were equipped with leachate collection pipes that has contributed to the protection of surface and groundwater from possible contamination.

The aspect of landfill gas technologies (section 2.2.5.2.1) being responsible for the environmental benefits at landfill sites is supported by the findings from both PDDs and survey responses in this study. Ninety nine percent of the PDDs showed that there is technology transfer to landfill sites during project implementation. Similarly, 70 % of the survey responses agreed that landfill gas technology brought by CDM projects has contributed to environmental benefits at their landfill sites. A UNFCCC study on claims of technology transfer by the 25 UNEP CDM project types also showed that landfill gas projects were one of the highest project types claiming technology transfer with 86 % of project PDDs with technology transfer to landfill sites during implementation (UNFCCC, 2011a). This is supported by a study by Das (2011) who carried out an empirical study of 1000 CDM projects from 49 countries. Das concluded that projects that involved technology transfer were on average substantially larger than those not involving any technology transfer.

8.3 POLICY IMPLICATIONS OF THE DEVELOPED FRAMEWORK FOR SUSTAINABILITY ASSESSMENT

The current design of the CDM has inherent weaknesses within it regarding supporting sustainable development in developing country host nations. The two main weaknesses are the absence of an international standard for assessing sustainability benefits, and a mechanism to ensure that potential sustainability benefits stated by developers in PDDs are realised at the project level. Although the CDM has had a positive impact, particularly with respect to technology transfer to developing countries as shown in this study, this weakness may undermine its credibility. The findings from the developed framework's validation exercise challenge the general assumptions that the sustainable development benefits as stated in PDDs will be achieved at the local or project level.

However, more important than the findings from the validation exercise is the potential role that the developed framework can play in addressing some of the existing weaknesses in the governance of the CDM. The DNAs can play a significant role in enhancing the achievement of sustainable development benefits of CDM projects. This is because, as per CDM rules, it is the prerogative of the host country to define sustainable development criteria. Clearly, a host country does have some scope to influence the extent and nature or type of benefits by including project specific benefits under its sustainable development criteria. The DNA can also define the criteria or indicators as well as their implementation. The other problem that may arise is that, where a host country DNA has included all the necessary project specific criteria and indicators in their criteria, the project proponents may try to exaggerate these benefits in PDDs to increase the chance of getting the project cleared by the DNA. This fear is supported by Monceau and Brohe (2011) who showed that no project has ever been rejected as a result of not meeting sustainable development criteria set by a host nation. The CDM project assessment criteria adopted by a DNA will therefore, play a significant role in addressing such issues. However, as revealed by Newell (2009), most DNAs often lack the capacity and resources to enable them verify the sustainable development claims made by project developers. The developed framework addresses both these two issues. The framework can serve as a template to guide DNAs on how to review PDDs for proposed CDM projects at landfill sites. The framework can also be used by DOEs to validate and verify the achievement of sustainable development benefits that were stated in PDDs before making recommendation for the issuance of CERs. This will ensure that only projects that meet the CDM’s objectives as stated in Article 12 of the Kyoto Protocol are rewarded with certified emission reductions (CERs).

CHAPTER 9 : CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS OF THE STUDY

This research has developed an international level framework for assessing sustainable development benefits of CDM projects with a specific focus on landfill gas projects. This has resulted in several significant and original outputs contributing to the existing body of knowledge:

(i) Firstly, the research has developed a framework for assessing sustainable development benefits of LFG CDM projects. The developed framework comprises three sustainable development dimensions (economic, environmental, and social) with 12 matching criteria with specific indicators. This novel approach has enabled a better understanding of the benefits of LFG CDM projects as compared with existing methodologies;

(ii) Secondly, the research has increased awareness of the potential sustainability benefits that landfill operators in developing countries can accrue by implementing CDM projects at their landfill sites. This is in relation to the economic and technological constraints they face, as well as the inadequate regulatory requirements for managing landfill emissions in their countries;

(iii) Thirdly, from a practical point of view, the research has developed a framework that can assist developing country host nations DNAs in approving LFG CDM projects. The framework can also be used by DOEs to both validate and verify that planned sustainability benefits stated in PDDs are realized at the project level; and

(iv) Fourthly, the majority of previous research studies that assessed the CDM's contribution to sustainable development have only used PDDs as sources of information. For example, of the 19 studies reviewed by Olsen (2007) that focused on sustainability aspects of the CDM, none were for registered projects (i.e., all were based on PDDs). However, PDDs reflect only 'potential' and not 'real' benefits. There is therefore, a tendency by project developers to put forward statements that are likely to meet eligibility criteria set by host nations for the purpose of obtaining letters of approval (section 3.10.1). To address this issue, the study used information from PDDs and survey responses from project developers to validate the developed framework. The findings from the validation exercise contribute new knowledge on how LFG CDM projects contribute to sustainable development including the nature and type of these benefits (i.e., list of indicators against which a project is assessed). The outputs of this research will add value to ongoing debate on the reform of the CDM and its role in a future climate regime that is being discussed by national governments (Kilani, 2015).

9.2 RECOMMENDATIONS AND FUTURE RESEARCH

In view of the findings of this research, the following recommendations are made to the UNFCCC, DNAs, DOEs, CDM consultants, academia and others involved in the CDM and future market mechanisms.

9.2.1 Recommendations for the UNFCCC, DNAs, DOEs, CDM Project Developers, Landfill Operators, and Regulatory Agencies

- In order for the CDM to achieve sustainable development benefits on an equal basis as GHG emission reductions, there is a need to address the existing methodologies used by DNAs for approving CDM projects and the assessment criteria used by DOEs to validate and verify projects;

- Sustainable development benefit methodologies that are efficient, robust and project specific must be developed at an international level; and

- In line with methodologies used for assessing GHG reductions, the proposed sustainability methodologies must be a requirement at the international level.

9.2.2 Recommendations for Future Research

- During the development of a framework for assessing sustainability benefits of landfill gas CDM projects, a list of environmental, social and economic benefits (criteria) and indicators were identified (section 6.3). The challenge of finding and selecting appropriate criteria for each of the three sustainable development dimensions in the developed framework was highlighted because of the correlation or cross linkages of benefits among the dimensions. This presents an important area for further research in developing a comprehensive list of sustainable development benefits for the developed framework;

- Only three case studies were used in this research for assessing management practices at existing landfill sites in both developed and developing countries (Chapter 4). Including case studies from other regions could assist in generalising the contents within Chapter 4 and Chapter 6, which contains the developed framework. Case studies were geographically limited and a broader approach would add to the development of criteria and refinement;

- Similarly, the selection of landfill CDM projects used in the validation of the developed framework was based on projects located in countries with the highest number of CDM projects registered with the CDM Executive Board. Validating the framework by selecting projects located in countries with the highest number of unilateral (no foreign partner involvement) and bilateral (foreign partner involved) CDM projects presents another interesting area for further research. This would highlight the nature and type of benefits realised from the two project categories in host nations; and

- The validation of the developed framework had some limitations with respect to survey responses. A small sample size was used to assess sustainability benefits realised at the project or local level against those stated in PDDs. This presents another interesting area for further research. This could be achieved by visiting landfill sites implementing LFG CDM projects to assess and observe the actual sustainability benefits being realised at landfill sites.

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APPENDICES

APPENDIX 1: Ethics approval letter

uclan
University of Central Lancashire

11 November 2013

Karl Williams / Alick Bulala Muvundika
School of Built & Natural Environment
University of Central Lancashire

Dear Karl / Alick

Re: STEM Ethics Committee Application
Unique Reference Number: STEM 102

The STEM ethics committee has granted approval of your proposal application '**Management of Municipal Solid Waste (MSW) Landfills – Development of Best Practice Guides (BPG) for Zambia and South Africa**'.

Please note that approval is granted up to the end of project date or for 5 years, whichever is the longer. This is on the assumption that the project does not significantly change, in which case, you should check whether further ethical clearance is required.

We shall e-mail you a copy of the end-of-project report form to complete within a month of the anticipated date of project completion you specified on your application form. This should be completed, within 3 months, to complete the ethics governance procedures or, alternatively, an amended end-of-project date forwarded to roffice@uclan.ac.uk quoting your unique reference number.

Yours sincerely

Paola Dey
Deputy Vice Chair
STEM Ethics Committee

NB - Ethical approval is contingent on any health and safety checklists having been completed, and necessary approvals as a result of gained.

APPENDIX 2: Landfill Case study Questionnaire guide

Research Topic: **Management of landfills in developed and developing countries**

Researcher: **Alick B. Muvundika**

The aim of this research is to identify the factors affecting landfill management including aftercare in developed and developing countries. The lessons that will be learned will be utilised to develop a framework for assessing sustainable development benefits of landfill gas CDM projects in developing countries host nations. Give a true picture of the situation at your site(s) and feel free to express your views and please do not write your name on the questionnaire.

Basic information:

Name of landfill owner/operator:……………………………………………………………………….

Name of landfill Site:…………………………………………………………………………………..

Title of person responsible for landfill:………………………………………………………………….

Date: ……………………………………………………………………………………………………

1. What type of landfill is your site? (i.e., municipal, hazardous, inert, and/or combination of the three)?..
2. When was the site opened?...
3. What is the size of the landfill site (ha)?...
4. Is waste separated or processed into different categories prior to disposal at your site?:…...
5. Characteristics of waste disposed of at your landfill. Please indicate the estimated percentages in the table

Component	%by weight
Paper and cardboard	
Plastics and rubber	
Metals	
Putrescibles (i.e., organics and/or vegetables)	
Glass and ceramics	
Textile	
Wood	
Soils, ashes & dust	
Construction & demolition (C&D) debris	
Others	

What are the main legislations that govern the management of your landfill site:……………...

6. What legislation(s) require you to manage closed landfill sites or cells and how long do you have to manage closed sites or cells? ....

7. Is there a requirement for you to provide financial resources for the management of your closed site(s) during the after-care period (Please briefly explain what happens or what will happen to the site during the aftercare period i.e. after the site or cell has ceased accepting waste)?...

8. How strongly do you agree/disagree with this statement?

	Strongly agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**
Existing legislations on management of landfill sites (including closed landfills) are adequate in the country					
Implementation of legislations on landfills by regulatory agency is adequate					

Comments:……

9. How much waste has been deposited so far at your site?...

10. What is the average daily/weekly/monthly waste received (in tons)?..

11. Is incoming waste weighed and is there a tracking system for the deposited waste (i.e., audit trail system)?...

12. What are the charges for waste disposal per tonne?..

13. How many hours is your site open per day (i.e. indicate the time it opens and it closes) and how many days is it open in a week?..

14. How much total income is generated per year from waste disposal gate fees?................................

15. How many employees are employed at the site?...

16. How is leachate managed at your landfill site?..

17. Are bottom liners installed at all the landfill cells and if they are, what type of lining or layers are in place?..

18. How is landfill gas (LFG) managed at your landfill site?..

19. Is daily, intermediate or final cover applied at the site and what is the composition of these covers? ....

21. Rate your landfill site’s performance using the following scoring in terms of managing the following parameters:

Parameter		Poor	Satisfactory	Good	Very Good	Excellent
Leachate Management	In relation to the capture of generated leachate to prevent surface & groundwater contamination					
	In relation to treatment of generated leachate on site					
	In relation to quality of leachate discharged into the environment after treatment					
Landfill gas (LFG)	In relation to the captured volume of the total amount of landfill gas generated on site					
	In relation to the treatment of methane content contained in landfill gas generated at the site (e.g. whether gas is flared or used to generate electricity)					
Dust Management						
Odour Mitigation						
Land remediation at site						
Security issues at site (e.g. is site guarded 24hrs to prevent scavenging?)						

Comments on the above scores:………………………………………………………………………

22. Issues encountered in landfill management. Please tick appropriate spaces

Issue	Poor	Satisfactory	Good	Very Good	Excellent
Financial resources for site management					
Trained personnel for site management					
Equipment for site management					
Spares for site equipment					
Capability to maintain site equipment					
Legislations for landfill management					

22. What are the main challenges faced by your company in the management of the landfill site (i.e., both operating as well as closed cells)?:……………………………………………………………

30. GENERAL COMMENTS:……………………………………………………….....................

THANK YOU!

APPENDIX 3: List of Registered Landfill Gas CDM Projects (coded) Used in the Study

Region/Country		
African Region (South Africa)		
No.	**Project Code Name**	**Date of Registration with CDM Board**
1.	SA-15/12/06	15/12/2006
2.	SA-27/04/07	27/04/2007
3.	SA-26/03/09	26/03/2009
4.	SA-24/08/09	24/08/2009
5.	SA-26/10/10	26/10/2010
6.	SA-24/05/12	24/05.2012
7.	SA-12/11/12	12/11/2012
Europe and Central Asia Region		
1.	EU-28/11/05	28/11/2005
2.	EU-06/04/07	6/04/2007
3.	EU-19/12/09	19/12/2009
4.	EU-12/11/12	12/11/2012
5.	EU-14/12/12	14/12/2012
The Middle East (Israel)		
1.	I-06/02/06	6/02/2006
2.	I-11/03/07	11/03/2007
3.	I-09/02/08	9/02/2008
4.	I-13/07/09	13/07/2009
5.	I-12/02/11	12/02/2011
6.	I-29/05/12	29/05/2012
7.	I-21/12/12	21/12/2012
8.	I-15/05/13	15/05/2013
Latin America (Brazil)		
1.	B-18/11/04	18/11/2004
2.	B-15/08/05	15/08/2005
3.	B-24/11/05	24/11/2005
4.	B-23/01/06	23/01/2006
5.	B-20/02/06	20/02/2006
6.	B-03/03/06	03/03/2006
7.	B-09/03/06	09/03/2006
8.	B-15/05/06	15/05/2006
9.	B-02/07/06	02/07/2006
10.	B-15/12/06	15/12/2006
11.	B-08/04/07	08/04/2007
12.	B-30/04/07	30/04/2007

13.	B-27/05/07	27/05/2007
14.	B-17/08/07	17/08/2007
15.	B-14/10/07	14/10/2007
16.	B-15/10/07	15/10/2007
17.	B-30/01/08	30/01/2008
18.	B-12/02/08	12/02/2008
19.	B-06/05/08	06/05/2008
20.	B-28/05/08	28/05/2008
21.	B-29/05/08	29/05/2008
22.	B-12/07/08	12/07/2008
23.	B-13/08/08	13/08/2008
24.	B-19/02/09	19/02/2009
25.	B-08/07/11	08/07/2011
26.	B-11/08/11	11/08/2011
27.	B-29/09/11	29/09/2011
28.	B-08/05/12	08/05/2012
29.	B-18/07/12	18/07/2012
30.	B-04/09/12	04/09/2012
31.	B-17/10/12	17/10/2012
32.	B-23/10/12	23/10/2012
33.	B-20/12/12	20/12/2012
34.	B-20/12/12	20/12/2012
35.	B-11/12/12	11/12/2012
36.	B-26/12/12	26/12/2012
37.	B-26/12/12	26/12/2012
38.	B-27/12/12	27/12/2012
39.	B-26/02/13	26/02/2013
40.	B-08/03/13	08/03/2013
41.	B-21/06/13	21/06/2013
42.	B-24/06/13	24/06/2013
43.	B-24/08/12	24/08/2013
Asia and Pacific Region (China)		
1.	C-18/12/05	18/12/2005
2.	C-03/03/06	03/032006
3.	C-09/04/07	09/04/ 2007
4.	C-04/05/07	04/05/2007
5.	C-13/05/07	13/05/2007
6.	C-19/09/07	19/09/2007
7.	C-30/11/07	30/11/2007

8.	C-14/04/08	14/04/2008
9.	C-26/05/08	26/05/2008
10.	C-06/07/08	06/07/2008
11.	C-27/08/08	27/08/2008
12.	C-17/11/08	17/11/2008
13.	C-21/11/08	21/11/2008
14.	C-25/12/08	25/12/2008
15.	C-27/03/09	27/03/2009
16.	C-17/06/09	17/06/2009
17.	C-25/06/09	25/06/2009
18.	C-25/06/09	25/06/2009
19.	C-28/07/09	28/07/2009
20.	C-10/11/09	10/11/2009
21.	C-30/11/09	30/11/2009
22.	C-28/12/09	28/12/2009
23.	C-11/01/10	11/01/2010
24.	C-16/01/10	16/01/2010
25.	C-11/03/10	11/03/2010
26.	C-02/12/10	02/12/2010
27.	C-04/12/10	04/12/2010
28.	C-22/12/10	22/12/2010
29.	C-20/01/11	20/01/2011
30.	C-07/04/11	07/04/2011
31.	C-07/04/11	07/04/2011
32.	C-26/04/11	26/04/2011
33.	C-25/07/11	25/07/2011
34.	C-05/08/11	05/08/2011
35.	C-21/08/11	21/08/2011
36.	C-22/08/11	22/08/2011
37.	C-22/08/11	22/08/2011
38.	C-04/10/11	04/10/2011
39.	C-07/10/11	07/10/2011
40.	C-08/02/12	08/02/2012
41.	C-08/02/12	08/02/2012
42.	C-24/02/12	24/02/2012
43.	C-19/03/12	19/03/2012
44.	C-23/03/12	23/03/2012
45.	C-26/03/12	26/03/2012
46.	C-12/04/12	12/04/2012

47.	C-12/06/12	12/06/2012
48.	C-13/06/12	13/06/2012
49.	C-27/06/12	27/06/2012
50.	C-05/07/12	05/07/2012
51.	C-23/12/12	23/12/2012
52.	C-25/07/12	25/07/2012
53.	C-30/07/12	30/07/2012
54.	C-30/07/12	30/07/2012
55.	C-24/08/12	24/08/2012
56.	C-26/09/12	26/09/2012
57.	C-16/11/12	16/11/2012
58.	C-28/12/12	28/12/2012
59.	C-08/03/13	08/03/2013
60.	C-03/09/13	03/09/2013
61.	C-22/10/13	22/10/2013

Appendix 4: Bristol Online Survey (BoS) Questionnaire guide for validating the developed framework

Submission Date:
1. What is the name of the landfill CDM project?
1. a. What is the CDM project host nation?
Azerbaijan
Brazil
China
Georgia
Israel
Serbia
South Africa
Uzbekistan
2. Which area of your landfill site is the CDM project located?
Closed area
Operating/active area
Closed & operating area
Entire site
3. What activities does your CDM project cover?
Landfill gas flaring
Energy generation (e.g., electricity generation)
Generation of compressed natural gas (CNG)
4. What is the total CDM project investment (US$/€)?
5. Is your project a Uni-lateral (no foreign partner involved) or a Bi-lateral (foreign partner is involved) CDM project?
Bi-lateral CDM project (Go to Question 6)
Uni-lateral (Go to Question 7)
6. Which developed country (ies) (Annex 1) is/are the partner(s) from?
7. What equipment/infrastructure has been brought by the CDM project at your landfill site?
Gas extraction infrastructure
Gas flaring unit(s)
Spark ignition gas engines
Other
8. How many jobs, in the following categories, have been created by the CDM project at your site?
8.a. Long-term (employed to operate & maintain the CDM project equipment/infrastructure) -- Number of jobs

8.b. Short-term (contractors engaged during the construction/installation of the CDM project) -- Number of jobs
8.c. Permanent (employed due to presence of the CDM project but will work beyond the duration of the CDM project) -- Number of jobs
9. Has the CDM project brought about any skills transfer/learning?
Yes (Go to Question 10)
No (Go to Question 11)
10. What type of skills/learning?
On the job training
Bursaries for students
Educational shows

Section 1

11. What is the CDM project's crediting period?
10 years
7 years (renewable twice)
12. How much greenhouse gas (GHG) emission reductions (tCO2eq) are expected during the crediting period?
13. Has your CDM project been issued with any certified emission reductions (CERs)?
Yes (Go to Question 14)
No (Go to Question 16)
14. How many CERs (tCO2eq) have been issued?
15. How much revenue (US$/€)has been generated from the sale of CERs?
16. Are the following design systems working at your landfill site?.
16.a. Top and bottom liners -- Design system
Working
Partially working
Not working
Not applicable (Not installed)
16.b. Leachate collection and treatment systems -- Design system
Working
Partially working
Not working
Not applicable (Not installed)
16.c. Storm water and sediment control systems -- Design system
Working
Partially working
Not working

Not applicable (Not installed)
16.d. soil/mudslide bundwalls -- Design system
Working
Partially working
Not working
Not applicable (Not installed)
16.e. weigh bridge -- Design system
Working
Partially working
Not working
Not applicable (Not installed)
17. How often do the following management practices occur at your landfill site?.
17.a. Cover application -- Management practice
daily
weekly
monthly
rarely(>month)
does not occur
17.b. Waste compaction -- Management practice
daily
weekly
monthly
rarely(>month)
does not occur
17.c. Leachate collection and treatment -- Management practice
daily
weekly
monthly
rarely(>month)
does not occur
17.d. Leachate and groundwater monitoring -- Management practice
daily
weekly
monthly
rarely(>month)
does not occur

18. What type of cover material are used at your landfill site?
Inert material (e.g., soils)
Waste derived material (e.g., shredded wood)
Artificial/synthetic material (e.g., geotextile matting)
19. What leachate treatment processes are used at your landfill site?
Re-circulation on landfill waste body
On-site treatment (e.g., sequencing batch reactor (SBR))
Off-site treatment (e.g., sent to a wastewater treatment facility)
Passive treatment system (e.g., constructed wetland)
20. Is waste disposal at your landfill site restricted to working faces (tipping areas)?
Yes (Go to Question 21)
No (Go to Question 23)
21. What is the width of the working faces (tipping areas)?
<4m
4-10m
>10m
22. What is the height of the working faces (tipping areas)?
0-2m
2-5m
5-10m
>10m
23. How are waste pickers (scavengers) predominantly managed at your landfill site?
Organised & managed by the landfill operator
They have a co-operative
Managed by a private entity
operate freely (not organised)
Not applicable (no waste pickers)
24. How is access to your landfill site restricted?
Fenced around and entrance is via a the gate
Fenced but porous (i.e., fence has holes/openings)
Not fenced but guarded 24hours
Accessed freely (i.e., no restrictions)
25. How are valuable resources such as plastics and ferrous metals in the waste stream prevented from disposal at your landfill site?
Relies on kerbside collection where separation is done at source of waste
Site has a separation and/or recycling facility

Waste pickers are allowed to remove them
No separation is done (i.e., waste disposed of co-mingled)
26. What are the long-term plans for managing landfill gas at your landfill site when the CDM project crediting period comes to an end?
Apply for renewal of the CDM crediting period
Seek overseas assistance (e.g., seek help from multi-lateral agencies like the World Bank)
Continue management using local budget
Abandon landfill gas management
27. What problems relating to the landfill CDM project have you encountered?
High costs for project registration
high fees charged by designated operating entities (DOEs) for validating projects
UNFCCC red tape
Low prices of CERs
28. How strongly do you agree/disagree with the following statements regarding the CDM project at your landfill site
28.a. The CDM project has brought new equipment/infrastructure
Strongly agree
Agree
Neutral
Disagree
Strongly disagree
28.b. New jobs have been created by the CDM project
Strongly agree
Agree
Neutral
Disagree
Strongly disagree
28.c. The local economy has benefitted from the CDM project
Strongly agree
Agree
Neutral
Disagree
Strongly disagree
28.d. Landfill gas management has improved due to the CDM project
Strongly agree
Agree

Neutral
Disagree
Strongly disagree
28.e. Leachate management has improved due to the CDM project
Strongly agree
Agree
Neutral
Disagree
Strongly disagree
28.f. Dust and odour management has improved at the site due to the CDM project
Strongly agree
Agree
Neutral
Disagree
Strongly disagree
28.g. Revenue realised from CER sales has/will assist the operator in managing the landfill site during both the operational and aftercare period
Strongly agree
Agree
Neutral
Disagree
Strongly disagree
29. Please feel free to add any comments that have not been covered by the questionnaire regarding the CDM project at your landfill site

APPENDIX 5: Publications during the PhD Study

Journal and Conference Papers:

2. Muvundika, A.B., Williams, K.S., Lowe, C.N. (2014). Potential Benefits of Implementing Landfill Gas (LFG) Clean Development Mechanism (CDM) Projects at Waste Disposal Sites: Case Study for Implementation at Chunga Landfill Site in Lusaka, Zambia. *In:* Girotto, F. (ed.). A Glance at the World. *Waste Management*, 35, I-V.

3. Muvundika, A.B., Williams, K.S., Lowe, C.N. (2014). The Clean Development Mechanism (CDM) as a Potential Source of Additional Financing for Managing Existing Landfill Sites: Case Study at Chunga Landfill Site, Zambia. *In*: Russo, M.A.T., Lopes, G.A., Ramisio, P.J., Vieira, J.M.P, Juca, J.F.T. (Eds.). Proceedings of the II Africa Sustainable Waste Management. ISWA/APESB 2014 International Congress, 22-24 April 2014, Luanda, Angola. ISBN 978-989-96421-8-8, Lisbon, 276-281.

4. Muvundika, A.B., Williams, K.S. and Lowe, C.N., 2014. Landfill Closure and Aftercare in Africa. Can EU Strategies be used? *In:* Russo, M.A.T., Lopes, G.A., Ramisio, P.J., Vieira, J.M.P, Juca, J.F.T. (Eds.). Proceedings of the II Africa Sustainable Waste Management. ISWA/APESB 2014 International Congress, 22-24 April 2014, Luanda, Angola. ISBN 978-989-96421-8-8, Lisbon, 176-181