Approaches to improving data quality in municipal solid waste management in New Zealand

Michael-Agwuoke, Macbeda Uche

A thesis submitted to
Auckland University of Technology
In Fulfilment of the Requirements for the Degree of
Doctor of Philosophy (PhD)

2017

Geoinformatics Research Centre
School of Engineering, Computer and Mathematical
Sciences

ABSTRACT

Developments in Municipal Solid Waste Management (MSWM) systems are dependent on socio-cultural, political, economic and environmental issues. The ability to assess and evaluate the level and nature of these relationships plays a critical role in measuring the performance level vis-à-vis sustainability of waste management systems. The current criteria adopted for assessing waste management performance are not able to capture a true and comprehensive representation of MSWM scenarios from collection to disposal. In emissions measurement, the current methodology considers only landfills as emission sources, from within the MSWM cycle, omitting other activity areas and processes. Hence the models do not accurately measure the emissions related to waste management systems or, indirectly, the environmental, economic, social and cultural costs of MSWM. The aim of this thesis was to develop an improved framework or models for measuring the impact of MSWM practices and processes.

To establish the nature and requirements of such a framework, a critical evaluation was undertaken of existing models, such as emissions quantification models, and of the data available for implementing these models. It was also necessary that the framework considers the requirements and guidelines in MSWM policy at local, national and international levels. Therefore, an analysis of these documents was also undertaken.

As a result of the systematic review and analysis of existing models and policies, a framework, the *Comprehensive Emission Quantification Model (CEQ-Model)*, in which MSWM scenarios are holistically captured to provide a means of assessing sustainable MSWM, was proposed. This framework incorporates aspects of the Emission Trading Scheme Model (ETS-Model) and Life Cycle Thinking (LCT) and was framed using carefully selected MSWM scenarios in New Zealand. The utility of the *CEQ-Model* as a sustainability measurement tool was demonstrated using data from four territorial authorities-Auckland, Rotorua, Waikato DC and Opotiki. A comparison of emission quantification from the *CEQ-Model* and five other existing emission quantification models (EASEWASTE, LandGEM, IWM, IPCC, and Afvalzorg) was undertaken to determine the reliability of the *CEQ-Model* output.

One of the primary barriers to the implementation of the any MSWM model is the availability of reliable, comprehensive data. It was discovered that this challenge is in part due the commercial sensitivity of waste data due to the privatisation of the sector in New Zealand. Other challenges to furthering the development of MSWM evaluation and its environmental impact assessment were found to include variability in the quality, variables collected, and availability of data. These variables in part are due to non-standardized approaches to data collection nationally and internationally and in part due to a lack of appropriate legislative control as regards data and data standards in MSWM.

A solution to the data issues inherent in MSWM, ontology, was conceived and evaluated. The intended result of the ontology is a definition of data which should be collected at various points in the waste management life cycle. The ontology incorporates the holistic approach of the *CEQ-Model* and a new concept of waste as defined in this research and therefore should more accurately capture the economic, political, social-cultural and environmental costs of MSWM. The implementation of the proposed ontological framework would improve data and in turn, the models developed for MSWM. Ultimately it is hoped that it will improve the tools available to decision and policy makers and lead to true integration and sustainability within the waste management system.

TABLE OF CONTENT

TABLE OF FIGURE

LIST OF TABLE

ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

20 January, 2017

Candidates Signature | Date

ACKNOWLEDGEMENTS

My sincere thanks to All Mighty and Merciful God who kept me to see this today. He is ever worthy and deserves all the praise and adoration.

To my supervisory team – Professor Philip Sallis, Associate Professor Jacqueline Whalley, and Associate Professor Love Chile – I am highly indebted for your commitment, dedication, patience and supports in guiding me through this work. Your academic mentorships and suggestions are the magic wands that had made it possible to manoeuvre all the challenges which, at a point was looking insurmountable. Those encouraging words "take some leave and refresh, all is well". Now it is well.

My wonderful parents, Chief and Mrs Michael Okechukwu Agwu gave me the great parental supports that are the rock on which today's achievements are built upon. I can't finish paying back.

To the management of Federal Polytechnic Bauchi, Nigeria, I say a big thank you for the supports which made the long trip from Nigeria to New Zealand possible.

To my Lovely and caring wife, Courtesy, whose supports and encouragement was the syrup I needed at all time, to keep going at those disappointing points of the research. Your sacrifice and that of my kids who missed that fatherly caring will always be appreciated.

To Associate Professor Russel Pears, I say a big thank you. Even though I could not finish the research under your guide, your initial support got me somewhere before I was forced to make some changes due to disappointing non-available data.

Surveyor Bernard Orji Ekpete, your moral support, and encouragement were crucial in my determination to embark on a PhD research journey. You keep calling to know how it was going and giving that fatherly advice. Thanks so much.

My fellow Ph.D. students who I share challenging experiences with; Isaac Nti (Ph.D.), Enobong Bassey (Ph.D.), Sarah Zandi (Mrs) and many others whose names are numerous to mention, I thank you all for your good counsels which helped me in taking decisions that were useful in resolving some of those challenges.

My relations who contributed in one way or the other to make the completion of this research possible, I thank you all.

CHAPTER ONE

GENERAL INTRODUCTION

The challenges associated with Municipal Solid Waste Management (MSWM) vary from country to country, depending on the level of development of institutions, infrastructure, and facilities to manage their waste. These institutions, infrastructure, and facilities are more developed in the more industrial advanced economies than they are in the developing countries. In many countries, the most critical aspects of MSWM include the efficient disposal of hazardous biological and chemical waste, waste minimization, and recycling.

Waste is commonly disposed on land or into water bodies (legally or illegally), incinerated or stored in long term secured facilities. Disposal methods are subject to the existing legislation within the relevant territorial authority and depend on the condition of the waste being disposed of. The condition of the waste is defined in terms of its toxicity and other properties such as whether or not it consists primarily of organic or inorganic material. Various disposal methods have varying degrees of negative impact on the environment and the health of the population. Even "best practice" methods if not properly applied to waste disposal or storage will have a detrimental effect on the environment.

The growing public awareness of the environmental and health effects which can be linked to inappropriate waste management and disposal has led to increased expectation for an enhanced environmental standard. This awareness of issues related to waste management was triggered by a number of problems and scandals relating to the handling of waste. Notable among the scandals is the Khian Sea Waste Disposal incident (Burling, 2000) and the Koko toxic waste dump (Koko toxic waste dump, 2012). These scandals resulted in increased pressure from both local residents and the international community on Territorial Authorities, waste management companies, and other stakeholders to act in response to waste problems. As a response, the Waste Framework Directive (WFD), the Hazardous Waste Directive (HWD), and later the Waste Shipment Regulation (WSR) were adopted by the EU Member States. These policies put in place the foundation of the regulatory structure of waste and its management as seen today (European Commission, n.d). In the United States (US), The Resource Conservation and Recovery Act (RCRA) was enacted on October 21, 1976. The RCRA is an amendment to the Solid Waste Disposal Act (SWDA) of 1965. This amendment was introduced to address the increasing problems the nation faced from a growing volume of MSW and industrial waste. RCRA set the national goals for; protecting human health and the environment from the potential hazards of waste management and disposal, conserving energy and natural resources, reducing the amount of waste generated, and ensuring that waste is managed in an environmentally-sound manner (US EPA, 2013, 2 November). These two legislative moves (WFD and RCRA) had a great influence on MSWM globally.

In response to this legislation, visionaries through research and development, have developed new tools and methods which have been adopted in municipal solid waste (MSW) management to reduce its negative impact on the environment and health of citizens. Even where good legislation is absent, the “visible and political sensitivity of waste management on the credibility of a public administration” (van de Klundert & Anschütz, 2001, p. 9), is another impetus to strive to put things right in waste management sector. Therefore, cities and nations are responding to the demand of MSWM within their domain according to their needs and circumstances. These needs and circumstances are the drivers of waste management in those cities and countries (Contreras et al., 2010; Wilson, 2007; Zaman, 2013), and dictate their management policy direction.

The success of any waste management policy depends on the information used to inform the policy making, and the quality of the methods used to collect, interpret and analyse that data. One of the problems confronting present waste management methodologies is the lack of reliable data, which limits the effectiveness of performance measurement. This research, therefore, seeks to develop an ontology of data collection and performance measurement to enable effective assessment of the outcome of waste management by municipalities and countries.

1.1 Definition of the Problem

By the 1930s, New Zealand’s rubbish was largely carried in trucks rather than by horse and cart. From the 1950s, due to the reduction in the fertility of the farms and the increased use of chemical fertilizer and herbicides, some of the waste entering dumps in New Zealand was hazardous, such as agricultural chemicals and other highly toxic substances. Non-biodegradable materials were increasingly disposed of. The air was polluted by the open-air burning of waste, and waterways were polluted by leachate generated by decaying waste (Dann, 2012b).

The environmental effects of rubbish dumps were not officially acknowledged as a problem until 1970. The outcome of a National Physical Environment Conference (NPEC) that year, was a confirmation that ‘controlled tipping’ was the main form of solid waste disposal in New Zealand. This means that most residents disposed their rubbish on suitable sites in accordance with existing legislation. This was also known as a sanitary landfill, but New Zealand’s waste dumps were far from being sanitary, even though it was what the law permitted at the time. Controlled tipping was seen as the cheapest way to dispose of rubbish. When tips were full, they were covered in earth to create a land that could be committed to a range of uses including housing and other multiple uses. The main problem being the variation in the standards of practices at various controlled tipping sites (Dann, 2012a).

The situation continued to deteriorate until 1971 when the first national survey on waste disposal sites documented 563 landfills. In 1973, a committee set up to look at the pollution of the environment issued New Zealand’s first manual on solid waste disposal, which was to be used by local authorities. This first manual was an attempt to enforce standards. The committee observed that many landfills were “not better than open dumps which are aesthetically objectionable and dangerous to human and animal health” (Committee on Pollution of the Environment, 1973, p. 1). Overall, little or no progress was made over the 1970s, even though some small sized (low capacity) illegal waste dumps were closed.

In the 1980s, New Zealand’s landfills were still far from meeting the standards of overseas best practice. True sanitary landfills should have liners of impermeable synthetic or natural material in their base, such as clay to prevent underground water pollution. They also require collection systems for leachate and methane (CH_4) generated by the decomposing rubbish. New Zealand landfills did not adopt such practices in the 1980’s.

In 1995, the National Landfill Census (NLC), recorded that over 95 percent of New Zealand's waste was going to landfills. Some of this waste was identified as causing significant environmental and public health problems. The introduction of Waste Management Hierarchy through the Local Government Amendment Act (No 4) of 1996 to guide territorial authorities in their waste management efforts by introducing the concept of 'waste management plan' with clear guidelines for territorial authorities to prioritise management methods beginning in the order reduction, reuse, recycling, recovery, treatment, and disposal. Although the 1998/1999 NLC (Ministry for the Environment, 2000) showed some significant improvements, unsustainable practices like open burning were still carried out.

In the 1990s and 2000s, however, major improvements occurred. Green-waste dumping sites and recycling practices were introduced. Dumping of waste at disposal sites was increasingly being controlled. Instead of dumping rubbish at a disposal site, some transfer stations were built. At the transfer stations, workers monitor the waste and salvage items like plastics, paper, metals and other inorganic materials that can be recycled or reused. The rest is then moved by trucks to the landfill where they are buried (Dann, 2012a). Depending on human monitoring of waste for recovery of reusable and recyclable materials is not efficient enough to salvage a good percentage of waste from landfill.

Ministry for the Environment (2003) observed that the outcome of the 2002 landfill review and audit resulted in a general agreement between national and local governments on a national waste strategy. The national waste strategy set the targets for improving waste management, waste minimization, and the efficient use of resources. The result showed a reduction in the number of landfills to 115 from 563 recorded in 1971 and projected that there would be about 45 landfills in 2010. The literature search conducted as part of this research established the existence of 60 active landfills all over New Zealand as at 2016.

The 2006 to 2007 landfill census (the most current data available for New Zealand at the time of this research) recorded a definite shift towards fewer but larger rubbish dumps and good progress in leachate collection and prevention. But there was little progress in measuring the amount of gases generated by decaying rubbish at landfills as this vital data was not collected in 2007 (Ministry for the Environment, 2007) and has not been collected at regional or national level.

Some regional Councils in New Zealand such as in Rosedale and Greenmount landfills, and Redvale landfill in Auckland, and Omarunui Landfill in Hastings District Council are leading the way in developing landfill gas for energy generation as a means of reducing the negative environmental impact of landfilling. The effective coordination of these efforts could result in the substantial conversion of landfills to energy sources by 2020. But this is not happening today.

The coordination and planning need strategies and tools. What are these strategies and tools? Strategies are built into policies while tools include technology (software and hardware), human expertise, and enabling legislation. The combination of these instrument produces results which are analysed as a step toward meeting the expected targets. Results can be adequately be analysed if there is enough data.

Preliminary investigation motivating the direction of this research points to a lack of data in New Zealand waste management system. Therefore, how can this data inadequacy be solved? How can the sourced data be put to use in the anticipated waste management system, leading to integration and sustainability? The present waste management system may be looking good on the outside, but the ‘out of sight scenario’ is not an indication of a sustainable system.

1.2 Aim of the Research

The aim of this thesis was to develop an improved strategy for waste data collection and a framework or models for measuring the impact of MSWM practices and processes. The implementation of the framework will help in achieving New Zealand dream of ‘clean and green’.

The achievement of New Zealand dream of ‘clean and green’ needs efforts to reduce the impacts of waste management, which is one of the many polluting agents of the environment. Waste Minimisation Act 2008 and New Zealand Waste Strategy 2010 provides the environmental, social, economic, and cultural benefits of waste minimisation, reduction in the quantity of waste to landfill, and sustainable management of residual waste. This research provides the strategy to manage and measure progress in waste management and be able to refine the strategies in the form of policy modification to effect better performance.

To establish the nature and requirements of such a framework, a critical evaluation of existing models was undertaken, such as emissions quantification models, and of the data available for implementing these models. It was also necessary that the framework considers the requirements and guidelines in MSWM policy at local, national and international levels. Therefore, an analysis of these documents was also undertaken. The results of the analysis produced the required information pointing to the inadequacies in the existing models.

1.3 MSWM and Changing Legislation

The changing scenarios of waste management in New Zealand has resulted in changes in legislation. The climax was the emergence of Resource Management Act (RMA) of 1991 which is an all-inclusive legislation. The RMA (Parliamentary Counsel Office, 1991) is considered to be all inclusive legislation because it is a principal environmental legislation designed to deliver superior environmental protection with greater economic efficiency in resource use and public accountability. According to Frieder (1997, p. 4), the RMA advanced New Zealand's reputation of "clean and green" when it was enacted in 1991. MSWM is affected by the legislation due to the environmental impact of waste management and the understanding of the relationship between waste generation and efficiency of resource utilization.

In 2008, the Waste Minimization Act (WMA) (New Zealand Legislation, 2008) was enacted. WMA is targeted to encourage waste minimization and decrease the amount of waste to landfill. Hence the environment is protected from harm. In this way, environmental, social, economic and cultural benefits are provided. Therefore, RMA and WMA marked the climax of waste management legislation in New Zealand.

To help in the implementation and achieve the desired goals of the RMA and WMA, the New Zealand Waste Strategy (NZWS) was released in 2010 to replace the initial 2002 waste strategy. The NZWS filled a gap in the legislative framework for managing and minimising waste by setting targets at moving New Zealand towards 'zero waste' (Ministry for the Environment, 2010). These targets are set as part of the Waste Management and Minimisation Plans (WMMP) which are drafted by territorial authorities as specified in WMA.

Since 2010, a range of activities and regulatory changes have been introduced which have resulted in some progress towards the achievement of these targets (Ministry for the Environment, 2010).

The NZWS as government's core policy document, summarized the goals of the policy in two headings – (i) Reducing harm (ii) improving efficiency - as the government's long-term priorities for waste management and minimisation. The two goals in NZWS provide the direction to territorial authorities, businesses (including the waste industry), and communities on where to focus their efforts regarding the management of their waste to deliver environmental, social and economic benefits to all New Zealanders (Auckland Council, 2011).

Looking at all the legislative provisions, it is clear that the primary focus of the formulators is to reduce the amount of MSW that is disposed to landfill, which, to them is the best strategy to reduce direct environmental degradation expected from these waste. But what is the level of achievement and are there other strategies that can achieve emission reduction in MSWM?

1.4 MSWM and Emission Signature

According to World Bank (2012, p. 8), "about 1.3 billion tonnes of MSW is generated annually by urban settlers globally" and this MSW is estimated to be contributing 20 to 40 million tonnes of CH_4. This is approximately five to twenty percent of global anthropogenic CH_4 and equal to about one to four percent of the total anthropogenic greenhouse gas (GHG) (Jensen & Pipatti, 2000). This is a major concern as waste contributes significantly to reduce air quality. van de Klundert and Anschütz (2001), UNEP (2009b) and UNEP (2009a) agree that waste management cannot be effectively managed without due consideration of issues such as air quality.

The United States (U.S.) 2009 report targeting possible opportunities to reduce GHG emissions (US EPA, 2009b), showed that approximately 42 percent of U.S. GHG emissions were associated with the disposal of food waste through the energy that is used to produce, process, transport, and disposes of the food waste. This includes the extraction or harvest of materials used in producing the food, production and transport of the food, provision of services, reuse of materials, recycling, composting, and disposal. The report also indicated that traditional waste management practices result in one to five percent of U.S GHG emissions.

Since the enactment of the RMA in 1991, waste management in New Zealand has focused on reducing and managing the negative effects of waste on human health and the environment. The initiatives and solutions are driven by the introduction of standards for waste disposal to achieve the aim of the RMA. This may be the contributory factor to the trend in reduction of waste disposal volume in New Zealand. The amount of solid waste disposed of in New Zealand landfills reduced slightly from an estimated 3.180 million tonnes in 1995 to 3.156 million tonnes in 2006 (Ministry for the Environment, 2007). In 2011, 2.461 million tonnes of solid waste was disposed to municipal landfills in New Zealand, similar to the amount disposed of in 2010 (Ministry for the Environment, 2013b). But the volume increased again to 2.797 million tonnes in 2014 (Ministry for the Environment, 2015a). Some reasons may be advanced to explain this increase including population growth, increasing use of disposable packaging, and lack of public education about waste management.

The emission resulting from waste disposal has shown a steady trend at less than 1500 Gg CO_2-equivalent up to 2011 disposal year. Since 2011, there has been a steady increase of emission resulting from waste disposal, increasing from 1331.1 Gg CO_2-equivalent in 2011 (Ministry for the Environment, 2013a) to 4600.3 Gg CO_2-equivalent in 2013 (Ministry for the Environment, 2015b). This is representing 5.65 percent increase in the volume of waste disposed to a 245.60 percent increase in emission from waste disposal.

The trend represented in the above analysis is not including process generated emission (like transportation). It is also not representing the policy direction presented in NZWS. This is not a surprise as the only place there is a mention of MSWM and associated emissions is in the Emission Trading Scheme (ETS), which the Ministry for the Environment (2011) recommended that the waste management sector should join by 2012. There is no public record of whether this recommendation has been implemented. Therefore, what are the relationships between the present MSWM practices in New Zealand, the various local legislation and the achievement of government commitments in various international pacts with special reference to IPCC Kyoto Protocol?

This research aims to incorporate emissions from processes associated with MSWM such as transportation and energy consumption, into a model for MSWM using the principle of Life Cycle Thinking (LCT).

In applying the LCT principles, LCA principles are observed, but without all the analytical/scientific complexities involved in the implementation of a full LCA. LCT, as developed in this thesis, is a strategy that attempts to capture holistically waste generated at all stages of the waste management system. The basic idea is to multiply emission factor with the value of the activity data (waste volume, energy consumption, electricity consumption, refrigeration gas release) in the waste management system, repeated at all stages of the waste flow chain from collection through to disposal. We expect that this proposed model would provide a more accurate and comprehensive approach to waste management, as well as the emissions that result from them. The intention is that this model will help in MSW planning and management by providing a more integrated and sustainable approach than current practice provides.

1.5 MSWM and Climate Change

The claim by the Intergovernmental Panel on Climate Change (IPCC) is that warming of the climate system is indisputable and is now discernible from the various observations of increases in global average air and ocean temperatures, widespread melting of ice sheets and glaciers are leading to rising global average sea level (IPCC, 2007). The U.S. Environmental Protection Agency (EPA) (US EPA, 2009b, April 24) has suggested that climate change is primarily the result of GHG emissions, and its effects will worsen over time in the absence of regulatory action including the overall rate and magnitude of human-induced climate change. Therefore, the risks to public health and danger to the ecosystem will likewise grow over time. Hence, the impact on future generations will be especially vulnerable leading to catastrophic harms.

Some of these increases in emissions have been traced directly to MSW. The manufacture, distribution, and use of products, including the management of the resultant waste, results in the production of greenhouse gases (GHGs) that affect the earth's climate and the general ecosystem. Because of the level at which waste generation is increasing, waste prevention, recycling, and the adoption of other sustainable strategies in the management of residual waste are real ways to address climate change.

The impact of solid waste management on climate change comes mostly from CH_4 released by decaying biodegradable waste under anaerobic conditions in a landfill. Even though Nitrous Oxide (N_2O) and Carbon Dioxide (CO_2) also result from waste management, their quantity and percentage in anthropogenic emissions are negligible (about 1% and 0.5% respectively) (Williams, 2002).

Therefore, it is often assumed that reducing the amount of CH_4 from the landfill would significantly reduce the overall climate change impacts of solid waste management. Also, because the atmospheric life of CH_4 is relatively short, the percentage reduction in CH_4 emissions required to stabilise CH_4 concentrations is much smaller than those needed to stabilise the concentrations of the other major GHGs, CO_2, and N_2O (European Communities, 2001).

But the researcher is of the opinion that the modalities adopted in managing the residual waste after a significant reduction in landfill waste volume can result in the increase in other GHGs, hence, increase the contribution of waste management in environmental degradation. For example, transportation is a major source of N_2O, hence, if waste transportation is not properly planned, it can reduce the positive impacts of reducing landfill gas release to the environment.

New Zealand annually reports its GHG emissions in the Inventory of New Zealand GHG Emissions and Sinks. These reports quantify the country's primary human-induced sources and sinks of GHG emissions. This GHG quantification is based on detailed methodologies contained in international guidelines that enable parties to the United Nations Framework Convention on Climate Change (UNFCCC) to compare the relative contribution of different sources of emission and GHGs to climate change in a published emissions inventory (US EPA, 2016; Auckland Council (2014). The information in this emissions inventory is often summarized by separating the emissions according to economic sectors. This sector-based view of data in the inventory is important for the purpose of framing strategies for the mitigation of a range of GHG emissions, including any disposal method that may be adopted as a strategy for reducing emissions and technology substitutions within a sector (US EPA, 2009a). This is not, however, a good strategy because the sectoral contribution of GHG is not understood. Hence, appropriate strategies are not adopted in reducing their levels.

1.6 Scope and Limitations of the study

This research is to identify and evaluate methods for the estimation of a portion of New Zealand's emissions associated with MSWM practices based on the volume of MSW disposal. This is a demonstration of the use of *Comprehensive Emission Quantification (CEQ)* as a measure of sustainability. Second, it presents a set of MSWM scenarios as a first step to identifying areas of opportunity to reduce emissions through integrated MSWM and sustainable MSWM based on Life Cycle Thinking (LCT). Hence, the waste management scenarios as captured in Auckland Council, Waikato District Council, Rotorua District Council and Opotiki District Council were compared through a *CEQ*, producing the profiles of the various scenarios. This is a demonstration of the utility of the *CEQ-Model* in sustainability assessment, as developed.

To achieve a higher level sustainability, the thesis is routing for an integrated MSWM system. The integrated MSW initiative will enhance cooperation between Local Authorities (LAs). Therefore, there will be a shift from the present system of 'do your own thing' among the LAs. Additionally, unlike many GHG mitigation options, MSWM are heavily influenced by Councils and Communities through legislation, incentives, and behaviour. Working with all stakeholders, the authorities can leverage its MSWM programs to achieve measurable emission reductions while yielding multiple environmental, human health, and economic benefits for communities, the industries, and the nation. This thesis promotes the recognition that MSWM programs while complementing other government program goals, can also achieve significant benefit in climate change mitigation.

To better understand and describe the connections between MSWM and climate change, this thesis presents a systems-based view of New Zealand emissions, where each system represents and also comprises all the parts working together in harmony to fulfil the need of the MSW sector. Therefore, the generated waste are collected, transported, stored (where necessary) treated and disposed of.

The systems view is helpful for framing opportunities to reduce emissions through prevention-oriented mitigation strategies that act across an entire waste management system. This is achieved if the processes are assessed in a Life Cycle Thinking scenario which produces a *Comprehensive Emission Quantification* of the MSWM system.

To demonstrate the scenarios, some logical assumptions which affect the output of waste management models, but are the current situation as they exist in real life, was made. These assumptions are in data sources and collection methodology which help in quantifying the potential impacts of these hypothetical changes in MSWM practices.

The *Comprehensive Emission Quantification* refers to the estimated emissions that result if the scenarios presented are achieved, not considering economic, institutional, or technological limitations. Such scenarios, which are common first step adopted in climate policy analysis, allow for the examination of the emission reduction potential of various mitigation strategies contained in those scenarios. These *Comprehensive Emission*

Quantification scenarios are useful for scoping the order-of-magnitude impact of the activities and identifying areas of promise for more detailed analysis and potential activity. They also illustrate how changes in behaviour or management plan which will change the scenarios, can lead directly to significant reductions of emissions on a national scale.

The thesis focuses on the following:

1. Review of New Zealand MSWM
2. Legislative reforms and their impacts on MSWM. What are the barriers and drivers
3. The relationship between the MSWM scenarios in New Zealand and the commitment of New Zealand to international treaties and conventions like IPCC Kyoto Protocol
4. Suggestions for improvement in MSWM and the methodological approach towards the achievement of positive result
5. The expected impacts of the improved MSWM on the present MSWM practices and policies.

In general terms, the discussion touches the legislative systems in EU and the US vis-à-vis the New Zealand RMA, the Waste Minimisation Act and other legislation or strategies in New Zealand and other MSWM practices which may be necessary for explaining the ideas.

In summary, the aim of this research seeks to promote environmentally sound MSWM in response to increasing concern on the contribution of MSWM to environmental degradation through the emission of GHGs, underground water pollution, air quality reduction, noise and other health hazards. To do this, the thesis first and foremost reviews the MSWM scenario in New Zealand. The expository is to see where progress is being made in line with the current philosophy of sustainability in resource use and the inclusion of integration as a way of achieving a sustainable system. This is due to the recognition of the amount of waste from the economic and social activities of businesses and consumers as an indication of the level of efficient resource use (DEFRA, 2012; Department of Environment Food and Rural Affairs (DEFRA), 2011; Despaisse, Ball, & Evans, 2012; EEA, 2015; Science Communication Unit University of the West of England Bristol, 2013). Hence the priority for a metropolitan area, city or country is not just how to efficiently manage the waste generated from the system (downstream=end-of-pipe solution), but on how to reduce or prevent the waste from the point of generation (prevention=up-stream solution). The review of the scenario also points to the unsustainable practices that are currently resulting from the MSWM in New Zealand.

The review of MSWM of New Zealand can't be done without looking at the legislative framework which drives the policy direction of the waste management sector. The legislative framework is also influenced by some international agreements and protocols which New Zealand is a party to. The local legislation is tailored towards the protocols hence domesticating the conventions.

But what is a sustainable system? One may ask, sustainable for accomplishing what? Or sustainable in which circumstances? Or sustainable for whom? The entire scenario under discussion, from waste generation, minimization to final disposal, is connected in many ways, to many other environmental, economic, and social issues; most of the answers in MSWM have a broader implication. But these are answers provided in the course of this research.

With these in mind, the thesis is conceiving a sound practice or policy that embodies a reasonable balance of implementable, cost-effective, sustainable, environmentally beneficial, and socially sensitive solutions to some of the MSWM problems being encountered today. Stated in a different way, sustainable practices, in an integrated system, function together, as individual parts and collectively as a whole, to achieve defined MSW policy goals, while trying to respond appropriately to the entire set of conditions that constrain the choices available in specific MSWM decisions. In the end, a novel, numerical and theoretical algorithm inspired by the belief in a simplified model based on LCT as an adaptable technique for measuring sustainability in MSW, is developed. The algorithm hence captures the true representation of the MSWM scenario from collection to disposal.

Hence, the following research questions are answered:

1.0 Is it possible to develop a framework to improve data quality and availability?

- 1.1 What are the historical drivers influencing municipal waste management in New Zealand?
- 1.2 What Factors influence the viability to model a municipal solid waste management system?
- 1.3 What factors constrain the efficacy of current models?

1.4 Can an improved model integrating new factors be developed?

1.5 What ontological framework could be developed to improve the quality of municipal solid waste management?

LCT principle is based on Life Cycle Assessment (LCA) which involves the compilation and evaluation of the inputs, outputs and the evaluation of all potential environmental impacts of the product throughout its life cycle (ISO, 2006). In waste management, LCA is a holistic approach that quantifies all environmental burdens and hence, all environmental impacts throughout the life cycle of the waste management system. The life of waste starts from the point the consumer decides to discard any part of a product, or a producer decides that the production process has ended, and some residual materials which are not useful to the system are generated. Therefore, Winkler & Bilitewski (2007) assert that LCA is not an exact scientific tool, but a science-based assessment method for impacts of a product or system on the environment. Increasingly, Life Cycle Assessment has been utilized for waste management systems, especially in the process of decision-making and strategic planning. This is the encouragement to incorporate Life Cycle Thinking in the formulation of the *Comprehensive Emission Quantification -Model*.

In the face of the current waste management challenges, which has made it difficult for practitioners to achieve expected results, suggestions are made on how to overcome some of the challenges. Prominent among the challenges facing today's waste management include lack of reliable data, the increasing complexities of the MSWM system resulting from the increasing demand on the system to deliver acceptable results to stakeholders, the increasing complexities of the generated waste itself and the increasing cost.

The thesis proposes an ontological framework of the MSWM system to simplify the whole system and in that way enhances data collection and standardization which will improve service delivery through which sustainability is achieved.

The thesis is limited in scope by data availability. The conceived *Comprehensive Emission Quantification-Model* includes the emissions resulting from power consumption and gas discharged from cooling/refrigeration systems. But in the implementation of the model, these emissions are not included because they are not available. Therefore, the *Comprehensive Emission Quantification-Model* was implemented computing emissions from waste disposal sites and transportation of the waste. Four study sites, Auckland Council, Opotiki District Council, Waikato District

Council, and Rotorua District Council were selected to represent the mixed scenario depicted in New Zealand MSWM.

Secondly, the waste composition data are as reported at the localities, hence local conditions and method of data collection may affect the results as it is difficult to compare the used data. Therefore, this will have serious impact on the interpretation of the result from the thesis. But the aim of the research is achieved since it can be replicated in the mist of reliable data.

1.7 Contributions of the Thesis

The thesis made a number of contributions to waste management in particular and knowledge in general. Notable among the contributions include:

1.7.1 New Definition of waste

Comparing waste management with natural resource exploitation, resources extracted are only measured in terms of the final value of the extracted resource (having removed un-wanted materials). Therefore, this research recognises only waste that are disposed as the value of the waste generated. This new concept of waste is a reflection of integration and sustainability. Hence waste is defined as:

"Residual materials resulting from human activities which cannot be reused or recovered as a resource, recycled into material production processes or thermally/biologically utilized for energy production"

1.7.2 Modification in the boundary of waste and resources in Waste Management Hierarchy

The new concept of waste is reflected in Waste Management Hierarchy, putting the boundary between resource and waste between disposal and recovery in Figure 2.1. Traditionally, this boundary is between Prevention and reuse. This is because, this research argues that recovered and reusable materials are still resource as they are not going to landfill.

This is also represented in the material flow diagram in Figure 2.2

1.7.3 Development of CEQ-Model

The *CEQ-Model* was developed in Chapter Six. The conception of the CEQ-Model as a tool for sustainability measurement captures the waste management scenario in holistic manner and simplifies the representation of impact assessment. The model can be used as a monitoring tool for one municipality to understand the performance of the waste management plan. The model can also be used to compare the performance of different waste management plans as implemented in different cities.

1.7.4 Ontology for data collection and Standards

A major barrier encountered in the course of this research was data availability and the accompanying resistance to monitoring as displayed by waste management practitioners. Waste management contractors proved unwilling to release relevant data on the grounds of commercial sensitivity. This illustrated the lack of transparency and openness which is commonly encountered in the waste management sector. Transparency and openness encourage partnership and cooperation which in turn helps guide the move towards sustainable practices.

The approach to addressing the issue of data adequacy as conceived in the course of this research, is to design and specify data standards. Such a system should define:

- Data collection methods
- Data dictionary
- Data storage system
- Data reporting guidelines

In this research, a data collection system is proposed and developed through an ontological framework designed to cover MSWM scenarios. The ontology is conceptualized to capture the complex MSWM scenarios in a simplified form to allow easy collection of the relevant data. This is achieved through the principle of dividing the city into waste management zones. Each zone has four layers of data System - Generation, Management / Recovery, Treatment and Disposal. Each level contains several nodes of activity which can be represented using a pair of geographic coordinates or sets or series of geographic coordinates, depending on whether the node is a point or polygon.

The ontology creates a better understanding of MSWM system and the points in the cycle where data collection is necessary as well as what data should be collect at each point.

1.8 Publications

The following papers were published during this research and are related to the research presented in this thesis. In all cases the research and publications were as a result of the candidate's work:

Michael-Agwuoke, M. U., Sallis, P., Whalley J, and Chile, L. (2016). **Expanding the Horizon of Waste Data Mapping and Collection.** International Waste Management Symposia. 06-10 Mar 2016. Phoenix Convention Centre, Phoenix USA

Michael-Agwuoke, M. U., Whalley, J., and Chile, L. (2014). **Assessing New Zealand Municipal Solid Waste for Integrated Sustainable Waste Management.** WasteMINZ Annual Conference and Expo-Resourceful Thinking-20-23 October 2014, TSB Bank Arena, Wellington New Zealand

Michael-Agwuoke, M U., Whalley, J., and Chile, L. (2014). **Achieving Environmental Sustainability through Effective Municipal Solid Waste Transportation.** Fifth International Conference on the Constructed Environment, 16–17 October 2014, University of Pennsylvania, Philadelphia, USA

Michael-Agwuoke, M. U. (2014). **Consideration of Emission Ratios in Integrated Sustainable Municipal Solid Waste Management Planning.** Proceedings of the XXV FIG International Congress, 16 - 21 June 2014 - "Engaging the Challenges, Enhancing the Relevance", Kuala Lumpur, Malaysia

Michael-Agwuoke, M. U (2013). **Justifying the Redefinition of Waste Generation.** 2nd International Conference on Final Sinks. 16 – 18 May 2013. Espoo, Finland

Michael-Agwuoke, M. U. and Ekpete, B. O. (2013). **Adding Value to Municipal Solid Waste in Nigeria through Mapping.** Proceedings of the FIG Working Week 2013 Abuja, Nigeria, 6 -10 May 2013

1.9 Structure of the thesis

Following this introductory chapter, this thesis consists of eight other chapters.

Chapter 2 presents an in-depth discussion of what sustainability and integration are, as captured in various literature, vis-à-vis their position in New Zealand waste management policy in general but with special reference to Auckland Council. The focus on Auckland Council is due to its position as the biggest city in New Zealand, contributing to nearly half of the total waste disposal in New Zealand. This chapter explores the implementation of sustainable waste management in Auckland Council as specified by various waste minimization and management plans (WMMP) and examines the forces behind the dynamics of MSWM over time.

Chapter 3 presents a review of international waste management frameworks. This review of the global agreements and protocols was undertaken because although ultimately waste management is a local challenge its impacts are global. As a result of this systematic literature review, an acceptable definition of waste and a chronological evolution of local legislation following international protocols and local events relating to waste generation and management were established.

Chapter 4 examines the relationship between emerging local legislation and the international protocols which New Zealand is a party to. It explores the conformity of local legislation to the protocols that have been signed. The international obligations of New Zealand play a central role in moulding emerging local and national waste management policies which are founded on principles of integration and sustainability.

Chapter 5 provides an account of the research methods adopted in executing this research. The chapter justifies the adoption a mixed method research approach, consisting of four phases, due to the complexity of the issues being addressed, the issues inherent in the current status of MSWM monitoring data, and different proposed solutions requiring different methods for development and evaluation.

Chapter 6 focuses on the formulation of a *Comprehensive Emission Quantification Model (CEQ-Model)* as a tool for sustainable measurement in the waste management system. The model is founded on two aspects, a carbon trading (CT) calculation model and life cycle thinking (LCT). The *CEQ-Model* is compared with five other existing models. The results from the *CEQ-Model* is compared with emission calculation from selected models as a means of showing the level of reliability of the emission quantifications from the *CEQ-Model*.

Chapter 7, uses the *CEQ-Model* to compare three MSWM scenarios at Waikato, Rotorua and Opotiki with that of Auckland to determine which of the region is more sustainable and to demonstrate the potential of the *CEQ-Model*.

Chapter 8 presents the ontology, designed as part of this research, which represents current MSWM processes. A common theme throughout this work has been that the data and models used to measure the impact of MSWM are insufficient. The ontology described in this chapter provides guidance for and a focus for future dialogue related to appropriate and adequate MSWM data provisioning and standardisation, not just in New Zealand but globally.

Chapter 9, the concluding chapter, reflects on the outcomes of this thesis and the contributions made. Finally, suggestions for future research are made.

CHAPTER TWO

SUSTAINABLE MUNICIPAL SOLID WASTE MANAGEMENT: A REVIEW OF ACADEMIC LITERATURE

2.0 Introduction

This literature review attempts a critical review of published academic literature relevant to the key themes of this thesis namely, integration, sustainability, and municipal solid waste management.

The chapter identified that the definition of waste is complex, and statistics on waste vary considerably between and even within countries. Invariably, planning and management of waste have become more and more complex (Eriksson & Bisaillon, 2011). Furthermore, the exponential growth in global waste volume and the socio-economic, cultural and environmental impact of waste on society puts tremendous pressure on governments, business, and civil society to develop policy frameworks for effective management of waste. Since the late 1990s, pressure from the United Nations and citizens to address the challenge of global climate change has become a significant factor for waste management and minimisation to achieve more sustainable development (Zaman, 2013).

The greater proportion of municipal solid waste goes to landfills, therefore effective waste management demands much more comprehensive management approach, which includes at the very minimum waste reduction, reducing the volume of waste going to landfills (Barton et al., 2008), and development of decision-making tools that combine a systemic approach to waste minimization (Contreras, Ishii, Aramaki, Hanaki, & Connors, 2010; Woolridge, Morrissey, & Philips, 2005) to optimise economic gains, and environmental sustainability (Ghinea et al., 2012; Morrissey and Browne, 2004; Pires et al., 2011).

Global waste management development trends were examined based on the studies of Contreras, 2010; Guerrero, 2013; Krausz, 2012; Lee, 2013; Louis, 2004; Ministry for the Environment, 2013b; Rojo, 2013; Scheinberg, 2011; Wilson, 2007; Wilson et al., 2012; Zaman, 2013; and Zotos, 2009. Key findings from these studies include:

- Municipal Solid Waste is a major contributor to the global environmental crisis because poor waste management is a major source of greenhouse gases (GHG)
- International agreements and protocols, including local legislation, have been developed to regulate how waste is managed and reduce its negative impacts
- Development of waste management systems is dependent on socio-cultural, economic, political, and environmental issues resulting from the entire system;
- Development of waste management systems is also dependent on the geographical location of cities, socio-cultural practices and behaviour changes;
- Waste treatment technologies are developed and applied to manage existing waste problems resulting from the existing local waste management systems and the awareness/expert knowledge of practitioners;
- The level of economic development is an important factor in determining waste generation, the definition of waste and management system to be adopted;
- Cost and economic consideration were a major driver that affected the trends in waste management before other drivers;
- Drivers of waste management development, are interconnected and dynamic in nature; therefore, the actual influence of an individual driver may not be seen in changing waste management development trends, without considering other drivers. For example, regulations influenced the development of different waste treatment technologies;
- Despite some of the progress achieved through innovations in MSWM, MSW still poses pressure on cities globally and remains one of the biggest challenges in environmental management.

Therefore, no one action or method may suit the generality of the people, the environment or scenario to deliver in MSWM. However, a strategic system in an MSW resource management planning approach will help in coordinating and defining a robust solution. A strategic system incorporates integration, considering the local circumstances. Therefore, even though international agreements and protocols are signed by parties, the implementation strategies of these protocols and agreements vary from country to country. The variation in implementation strategy is mostly reflected in local legislation promulgated to domesticate the protocols. The general goal is to achieve environmental friendly waste management system resulting in integration and sustainability.

Integrated waste resource management plan enables the creation of a comprehensive strategy that can remain flexible in the light of changing economic, social, material (products and packaging) and environmental conditions (Davidson, 2011). This is necessary for the sake of the environmental, economic, and social conflict resulting from the scenarios that are being created. The integrated Waste Resource Management is also necessary, due to increasing waste generation, increasing complexities in the composition of the generated waste and the resultant threat to the environment and health of citizens as a result of the attempt to effectively manage the waste. The neglect of these complexities in policy formulation and implementation by policy makers and other stakeholders is the general cause of the negative impacts resulting from waste management.

2.1 The Changing Scenarios of Municipal Solid Waste Management

Human activities are the primary source of waste generation. From food and agricultural refuse to discarded consumer products and their packaging, solid waste is materials that are no longer desirable to their owners (the waste generator) in its existing form. Waste management mainly consists of removing waste material from the point of production and transporting it for points of reuse, recovery or disposal.

In general terms, MSWM can be said to be all activities associated with the control of MSW generation, its storage, the collection, transfer, processing, and disposal. Effective waste management would usually be governed by principles of the protection of public health, consideration of the economic implications of the management system, applying available effective engineering methodologies to achieve optimum aesthetics and other environmental outcomes. Because waste is usually associated with things that are no longer wanted by the original owners, waste is viewed in negative terms, as a problem, a cost, and a pollutant. However, the development of the five-stage approach to waste management, and the possible economic benefits obtained through effective MSWM, waste is now seen not simply as a problem, but as a resource to be exploited to the benefit of humanity (European Commission, 2005; New Zealand Legal Information Institute, 2013a).

Urbanisation, the congregation of large numbers of people living close to each other, together with human activities such as industry, commerce, and agriculture, transport and their by-products (Scheinberg, 2011), have a significant impact on the generation of MSW. In large urban areas, there are few places where waste materials associated with these activities can be ignored (De Swaan, 1988). While in pre-industrial Europe, management of waste was considered to be individual or commercial responsibility, or, in the case of the resource value, an individual or commercial opportunity (Poulussen, 1987; Velis, Wilson and Cheeseman, 2009). The impacts of waste on public health and well-being makes waste management a more collective responsibility (De Swaan, 1988). Hence the significance of MSWM.

The development of cities and towns, with their concentrations of population and land-use density, stimulated the need for organized solid waste management. The cultural and religious belief, aesthetics and concerns for public health had a significant influence on the foundation of solid waste management systems in ancient cities as early as 2000 BC (Melosi, 1981). By 500 BC, the Greeks had organized what was believed to be the first 'municipal dumps' in the Western world and issued the first known edict (legislation) against throwing garbage in the streets (Louis, 2004).

A good percentage of MSW at the early stage of the urban settlement consisted of organic waste. The littering of organic waste created favourable conditions for rodents, and other disease carrying agents, and hence public health issues. The practice of littering of organic waste in the streets, roadways and vacant lands in cities of that time, contributed to the spread of plague, such as Black Death around Europe in the fourteenth century (Tchobanoglous et. al, 1978). Similar practices prevailed in colonial America, although cities in the colony were less populous than in Europe, and there was more vacant land available nearby for use as dumping sites. The application of human and animal waste as fertilizer was a common practice. In some cases, waste was used as fuel to light up burners indoors or outdoors. Food waste was used as animal feed, particularly swine. Waste was also deposited in open bodies of water, such as ponds, bogs, lakes, rivers, and the ocean. Sights of drainages turned into rubbish dumps were common. Thus, cities in colonial America (like other cities in the western world) suffered from poor sanitation and an absence of waste management services (Louis, 2004). Louis (2004, p. 307), quoting historian of garbage, Martin Melosi, describes the situation as follows:

……in eastern cities, where crowding became a chronic problem as early as the 1770s, the streets reeked with waste, wells were polluted, and deaths from epidemic disease

mounted rapidly. Indeed, the quality of sanitation in pre-industrial America was determined primarily by local circumstances. While rudimentary public-works systems emerged in several of the larger or more progressive communities, individuals or private scavengers handled the waste problems in many towns and villages.

In Dunedin, as New Zealand's largest city in the mid-1860s, the waste situation was no different to cities in Europe and America. The sanitary situation was so bad that a Sanitary Commission was constituted to investigate and recommend solutions. Auckland, Wellington, and Christchurch were also known to be "terribly dirty" (Dann, 2012).

From these and other socio-historical analyses, the picture that emerges is that until the middle of the 19th century, the maintenance of public hygiene was dependent on individual initiatives of households or businesses. Where these actions didn't occur frequently or consistently, laws were passed to require the desired individual or industrial behaviour (Poulussen, 1987; De Swaan, 1988; Gille, 2007). Despite such measures, there was little or no change recorded.

2.1.1 The Emerging Reuse Culture

The first idea of recycling emerged as a means of providing an income for the lower socioeconomic groups in society. Often newcomers to a city found (self)-employment in waste picking, collecting and using or selling the leftovers from those with a higher material standard of living (Chaturvedi, 2007; Melosi, 1981). Over time, scores of people came to rely on these secondary raw materials for their livelihoods, collecting them from households or dustbins and selling them into the developing value chains.

Waste as we know it – meaning materials that the owner intends to discard into a standard management and provisioning system that removes them from populated areas – increased considerably with industrialisation and the division of labour (Strasser, 1999). People in cities increasingly lost their relationship with a resource base that allowed them to produce their goods and fulfil their needs. Over time, they lost both skills and opportunities to re-make products from discarded household items. The making of things became more centralised and more distant from the user. So the leftovers could not find a place within the community in the city. Therefore, the amounts of waste grew, and neither the industrialised production processes nor the increasingly centralised distribution systems were able to serve as the channel to return these materials to industry (Strasser, 1999). Furthermore, as the cost of items became lower with mass production, the cost of repair and reuse became so close to the cost of a new item that it was not "worth" recycling or repairing. This has become known as the age of disposable consumerism.

2.1.2 The Emerging Hazards

At this period of urbanisation in the 19th century, the emphasis was on removing the waste from the cities in Northern Europe and North America as a result of public health concern. Migration to the cities increased both the absolute population and its density. Newcomers to urban life understood neither how to live in the city, nor how to manage their waste and excreta. Moreover, they seldom had access to enough space to do so in the ways they had been used to in the countryside. (De Swaan, 1988).

The density, amount, and unruliness of waste naturally began to overwhelm the private channels to reuse it, which formed the backbone of the removal system. Much of the "dust," street sweepings and manure still entered the agricultural value chain or was utilised in road construction. But products which did not decompose were increasing, and as industrialisation proceeded, waste products also became more complicated and harder to manage at the level of household or business (Velis, Wilson, and Cheeseman, 2009; Strasser, 1999). The response was to remove them, to a steep-sided ravine or swamp at the edge of town that was far enough away to reduce nuisance; it was better still if there was a need for that area to be filled. "The dump" was available for private individuals, businesses, and others to bring their refuse. The actual work of removal from households remained a private-to-private affair, with rag pickers going from house to house to collect whatever was not needed. Burning waste was an acceptable management strategy; even the dump was frequently burned to reduce volumes and keep rats and other vectors under control.

Epidemics and the fear they engendered in the public played a significant role in raising awareness about public health and the need for organized municipal sanitation services (Louis, 2004). Illustrative among these epidemics were the yellow fever outbreak in Philadelphia (USA) in 1793, which claimed more than 5600 lives (Pernick, 1978), and the cholera epidemics in New York in 1832, and 1849, which claimed an estimated 150 000 lives nationwide (Neira, 1997).

Although it is common knowledge today that yellow fever is borne by the Aedes Aegypti mosquito, and that the agent of epidemic cholera is the waterborne bacterium, Vibrio cholera, such knowledge was not available to physicians, public health officials, or the public in the mid-nineteenth century. Thus, there were no effective public health interventions available during these epidemics, and many citizens just fled the city when outbreaks occurred. Sometimes those fleeing affected cities carried the disease with them to their destinations, resulting in further spread of the disease.

In general, epidemics caused massive public hysteria and created an impetus to understand the aetiology of disease and develop organized systems for administering public health and municipal sanitation. The link between epidemic diseases and sanitation arose from the prevailing belief at the time that filth, pollution, and the squalid living conditions of the urban poor were primary causes of disease (Louis, 2004).

de Swaan (1988) and others identify the UK cholera epidemic of 1834, and the rise of cholera as the urban scourge of the 19th century, as the turning point in the institutional development of the solid waste sector. The threat posed to the middle, and upper classes of poor hygiene and risk of infection emanating from the densely populated urban centres and slums influenced the creation of municipal collection system and the willingness of the middle and upper classes to finance them. These new institutions took unto themselves the responsibility to organise and provide both waste management (which centred on collection) and sanitation services. At the middle of the 19th century, cities made themselves responsible for a general level of sanitation and welfare (de Swaan 1988; Velis, Wilson and Cheeseman 2009).

In the 19th century New Zealand, infectious diseases transmitted by contact with excrement were rampant. These include diseases like polio, typhoid fever, typhus, cholera, dysentery, and diarrhoea. So were diseases transmitted by breathing – scarlet fever, pneumonia, tuberculosis and others (Dann, 2012).

Scientific development was increasingly able to demonstrate that the spread of dreaded cholera – as well as other infectious diseases like polio – were related to poor sanitation and uncollected solid waste (Scheinberg, Wilson and Rodic 2010). The increasing concern about germs and the growing understanding of the relation between hygiene and disease at the beginning of the 1900s fuelled the growing development of an urban solid waste and sanitation infrastructure (Strasser, 1999). Mainly larger cities understood that keeping waste from the streets was both their mission and their obligation. During this time, the primary emphasis was to remove waste from urban areas, by collecting waste from households and sweeping streets, through a branching network of infrastructure and services, which persists as the dominant mode for waste management. (De Swaan, 1988; Melosi, 1981).

But the improved collection, combined with increasing waste volumes, needed bigger and better places for disposal. Cities needed a place outside the city to isolate these materials from urban populations. They found and used ravines, cliffs, low-lying areas, swamps, and waterways; these were available and convenient, but not always sufficient. As the cities get bigger in the middle of the 20th century, they required that the many high-rise apartment houses had their waste incinerators, fed by garbage chutes from the upper floors, which filled the urban air with the smell and emissions from burning garbage but indeed reduced its volume and septicity. In coastal, river, and lake cities, dumping waste in the water continued to be a preferred strategy, largely uncriticised, until the 1960s when the so-called environmental protection driver was born (Wilson 2007; Scheinberg, Wilson and Rodic 2010).

Beginning from the mid-1970s, industrialised countries started formulating MSW disposal policies that are focusing on reducing environmental impact (Daskalopoulos, Badr, & Probert, 1997). Hence, attempts were made to identify and categorise, in a systematic way, the material composition of the waste stream involved. This categorisation provides the policymakers with the best information, necessary for the determination of the best management option for dealing with the waste in a more economical and environmentally-sustainable way.

2.1.3 Opening the Lid

In line with the concern on the negative implication of unsustainable waste management, the EU pioneered waste legislation since 1975 (European Commission, 1975b) and had been consistent in updating their waste management legislation since then, in response to changing technological tools and general conditions in waste management scenarios. The legislative move opened waste management to research and development at industrial level leading to innovations in instrumentation and new ideas in managing specific waste fractions. These changes are reflected in the new Waste Framework Directive (WFD) (Directive 2008/98/EC) (European Commission, 2008) which repealed some of the previous Directives and amended others in such a way as to create an integrated approach to pollution control and management.

According to the new WFD, the first objective of any waste policy should be to minimize the adverse effects of the waste and its management on human health and the environment. The waste management policy should also aim at reducing the use of resources, and favours the practical application of the Waste Management Hierarchy. Hence, there is a shift from thinking about waste as an unwanted burden to seeing it as a valued resource.

The Directive also permits the Member States not to be rigid in applying the Waste Management Hierarchy but should take steps to encourage the options that deliver the best overall environmental outcome using life-cycle thinking.

Since no one single method of waste management can deal with all materials in waste in an environmentally sustainable way, Staniskis (2005) advised that instead of focusing on and comparing individual options, for instance, incineration versus landfilling, an attempt should be made at integrating waste management systems. In this way, the whole waste stream is dealt with, and the overall performance is compared in environmental and economic terms.

Traditionally, it is standard practice for municipalities to concentrate on waste collection and disposal. But with increasing environmental awareness, waste management has been identified as an important source of GHG leading to global warming (Herzog, 2005; Michiel & Morton, 1995; US EPA, 2006a) which is a global concern. Emphasis is shifting to recovery and reuse, hence the emergence of Waste Management Hierarchy, which started from 3R (reduce, reuse and recycle) (European Commission, 1975a) before expanding to include recovery and then disposal (European Commission, 2008a; UK DEFRA, 2011). The Waste Management Hierarchy is a representation of an order of preference for action to reduce and manage waste in a way as to protect the environment and conserve material resources through a priority approach system established in waste policy and legislation. The Waste Management Hierarchy creates a preferred program of priorities based on sustainability (Hansen et al., 2002). Therefore, to be sustainable, waste management cannot be solved only through technical end-of-pipe solutions but should include an integrated approach which considers all available possibilities, involving all stakeholders (US EPA, 2013c).

The 3R policy was formulated and applied in the context of waste management due to the general need for proper waste management. The sound waste management eliminates the social conflict on the location of landfills, the impact of waste on the aesthetic of the city environment, and the need to increase resource efficiency (Michikazu & Enri, 2009) and reduce environmental pollutions as a result of waste disposal.

The 3R approach in waste management is not only aimed at increasing recycling through source separation of waste but also include the development of understanding and cooperation among stakeholders to minimize the rate of exploitation and consumption of natural resources. The 3R approach should not merely be regarded as a way for waste handling. Successful implementation of 3R policies also has a beneficial effect in other areas, such as in generating employment and improving resource efficiency and productivity. It can help prevent emissions of GHG, reduces pollutants, saves energy, and stimulate the development of green technologies (Waste-to-Energy Research and Technology Council, 2009).

To promote this philosophy of 3R, countries around the world have promulgated special legislation targeting waste management. But with increasing population, changing lifestyle – leading to change in consumption pattern, increased exploitation and use of natural resources; waste generation has continued to grow. Changing technology which is impacting on innovations in the design of products has continued to increase the complexities of waste composition which has increased the difficulty in managing waste. These facts are presenting a complicated policy challenge for the government on how to handle the waste generation, particularly when funding is scarce, and infrastructure is limited. A closer evaluation of the scenarios, reveals a mix of general and specific elements of policy dynamics in the evolution and adoption of waste management systems (UNCRD, UNEP-RRCAP & IGES, 2009).

In New Zealand, Waste Management Hierarchy was first legally established through the Local Government Amendment Act 1996 (New Zealand Legal Information Institute, 2013e). The Waste Management Hierarchy created an expanded waste management ladder of preference – Reduce, reuse, recycle, recovery, treatment, and disposal- in that order of preference.

Due to the dynamism of cities, World Bank (2011a) advise that a comprehensive policy framework is needed at the national and provincial level to link public health, environmental, privatization, decentralization and policies on the economic instrument, to the needs of the solid waste sector so that they are mutually supportive. This framework includes incentives to municipal authorities to deliver better services, recover more costs from users, and cooperate with neighbouring municipalities. For smaller or weaker cities, a focus on technical and financial assistance is critical. Regional landfill and waste treatment approaches should be strongly considered since the economies-of-scale resulting from grouping smaller cities and sharing facilities significantly affect the affordability of services.

The emerging complexities in waste management are such that if not handled well, solving one emerging problem often introduces a new one, and if not well executed, the new issue is often of greater cost and complexity (World Bank, 2012).

Therefore, today waste management is an important part of the urban infrastructure as it ensures the protection of the environment and the health of the people. It is much a technical, environmental issue, just as it is highly political too. "Waste management is closely related to some matters such as urban lifestyles, resource consumption patterns, jobs and income levels, and other socio-economic and cultural factors" (ISWA & UNEP, 2002, p. 13).

Out of further protests and knowledge on the environmental consequences of these waste, the modern landfill developed. The essential characteristics of a controlled sanitary landfill were, and remain, a system of volume and surface management, consisting of a weigh-bridge, perimeter fencing, and daily and final cover. Which is combined with precise technical protection and control mechanisms: clay or geotextile liners, leachate and gas collection systems. Since the 1990s forced underground decomposition through fast recirculation was introduced. This is the paradigm of safe disposal in solid waste management, which focuses on placing waste in safe sinks, precisely as Bruner and others explained (Brunner, 2010; Scheinberg, Wilson, & Rodic, 2010). In some cases, and particularly in Europe and Japan landfills are supplemented by a waste to energy incinerators, which use incineration technology to reduce both biochemical activity and waste volumes and generate electricity with the heat it produced.

2.1.4 Impact Without Border

The level of certainty (more than 90 percent) that human activity is the dominant cause of observed global warming (IPCC, 2013), is increasing the need for an integrated approach to stop the rippling effect that may result in global economy and social structures (WCED, 1987). The World Commission on Environment and Development (WCED) opined that it was in the common interest of all nations that we establish policies for sustainable development. The reason being that there are a limited amount of resources available to the world's growing population, there is a need for global management of these resources to ensure the continued high quality of living for future generations of humanity (WCED, 1987). This can be said to be the where the concept of sustainable development started.

Also, as waste generation is seen as an indication of poor resource utilization, MSW became part of the global concern for sustainable development to be achieved. Waste overflows national boundaries regarding problems and solution (Fagan, O'Hearn, McCann, & Murray, 2001). And has become one of the pollution sources that had caused a diverse environmental impact that is detrimental to human health and safety (Shazwin, 2010), so cannot be treated in isolation or as a technical problem (Fagan et al., 2001). The recognition of these international linkages led to the signing of International treaties which have affected the decisions and policies of countries and territories in MSWM.

New Zealand as a country, signed some of these treaties. The treaty like London Dumping Convention on the prevention of marine pollution by dumping of waste and other matter (United Nations, 1977). Others include Montreal Protocol on substances that deplete the ozone layer (UNEP Ozone Secretariat, 2013), The Earth Summit (Agenda 21, the Rio Declaration on Environment and Development) (Ministry for the Environment, 2012a).

Since the early 1980s, OECD has been leading in the formulating and developing international policies at the regional level. The policies are aimed at preventing and reducing waste generation and managing the residues in an environmentally sound manner. It has, however, become evident that waste minimization policies which address only end-of-life products and materials are no longer effective in reducing increasing amounts of waste associated with economic activity and material consumption. This underscores the need for creative and far-reaching and integrated solutions, using life-cycle thinking to reduce the negative environmental impacts of the utilization of materials in a cost-effective manner (OECD, n.d). The OECD Environmental Strategy, adopted by OECD countries in May 2001, clearly stated the need for governments to look for integrated solutions such as Sustainable Materials Management (SMM), to address current environmental concerns (OECD, 2014).

The EU in European Commission (n.d) recognised that environmental problem goes beyond national and regional boundaries and can only be resolved through concerted action at EU and international level, have adopted an environmental policy that has evolved since the 1970s. From an initial focus on single pollutant and impact, it has moved into an integration phase, with the emphasis on the collective understanding and addressing the total pressures on the environment and examining the efforts of different policies and behaviour pattern.

For example, actions to prevent waste, can create or lead to losing of control on the consumer behaviour, can create or reduce costs for business, can create or result in losing of jobs. These impacts are not always easily predictable because of difficulties in tracking them as a result of lack data. Moreover, waste can genuinely be seen as a local issue or global problem, depending on the scale of the assessment. A recycling scheme organised at a remote settlement can have impacts over thousands of kilometres away, where the products of the project are traded on the international market. Therefore, waste is complex – difficult to grasp, difficult to gather useful statistics on, in the manner it is managed today, and difficult to regulate and control.

Hence, the impacts vary along the part and at different points as the status of the waste is changing.

Sweden is a good model for sustainable waste management whose effective MSWM is impacting across the border. The country now imports about 800,000 tonnes of waste each year from other European countries like Norway, who in turn pays Sweden to take the waste (GreenConduct, n.d). Hence, the waste management effort in Sweden is impacting on the other EU countries in a positive way as less waste is disposed of in landfills as a result of Sweden Waste-to-energy initiatives.

2.2 Emerging from the Doldrums

As the scenario of MSWM changes, new drivers are emerging to help better understanding of MSW planning and management. Wilson (2007) suggests that understanding what drove developments in waste management in the past, (that is the mechanisms or factors that significantly impact development in solid waste management) and what these are now, is critical to understanding how best to move forward in developing sustainable waste management systems.

The cost of managing waste, characteristics of waste fractions, legislation, the value of recycled materials, the value of land, technology, public perception of waste and understanding of the negative impact of certain practices are some of the drivers identified. But the understanding of some practices and the real content of waste composition and emissions have not been possible until recently through the emergence of Life Cycle Assessment (LCA) models. LCA emergence has further developed to become one of the key approaches to understanding solid waste management processes (Ekvall et al., 2007; Khoo, 2009; Kirkeby et al., 2006; Kirkeby et al., 2006; Liamsanguan & Gheewala, 2008; McDougall et al., 2002; Slagstad, 2012; Thomeloe, Weitz, & Jambeck, 2007; Winkler & Bilitewski, 2007).

LCA is a systematic process for identifying, quantifying, and assessing environmental impacts throughout the lifecycle of a product, process, or activity (Elcock, 2007). The International Organisation for Standardisation (1997) defines LCA as: "a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product throughout its life cycle". LCA considers energy and material use including what is released to the environment from creation to disposal, (i.e., from raw material extraction through manufacturing, transportation, use, to disposal of the residue). LCA can be used to help ensure that cross-media (where reducing one pollutant increases another pollutant from the same source) and multimedia (the impact of the same pollutant on various environmental media (land, air, and water)) environmental impacts are considered when designing solutions and implementing decisions. LCA can also be used to identify potential environmental impact "hot spots," compare one or more aspects of specific products or processes, and establish the baselines for further research (McDougall et al., 2002; Slagstad, 2012). To enhance the decision-making power of LCA, it is often used in conjunction with other environmental management tools such as risk assessment and environmental impact assessment.

A lifecycle approach does not necessarily embody every methodological aspect called for in a traditional LCA, but it does apply a cradle-to-grave systems perspective to assess and evaluate the full lifecycle impacts of a product or process (Elcock, 2007). Van der Werf and Basset-Mens (2012) reviewed some of the current applications of LCA to include:

- Comparison of the environmental impact of different products that have the same function: e.g., what is the most eco-efficient way to produce 1 kg of protein? Is it the same for fish, beef, chicken or Soya bean?

- In a global economy, comparison of the environmental performance of the same products produced by different countries taking into account the country-specific constraints and resources, e.g., where is it most eco-efficient to produce milk for the European market? Is it in New Zealand where pastures can reach a very high yield but markets are very distant, or locally in Europe?
- Comparison of agricultural practices in order to determine for example what the best technology is for applying liquid manure to a field?
- To provide information in the form of eco-labelling, to consumers to help them in choosing goods whose consumption and residual materials will have less harm on the environment, e.g., Food products that have been air-freighted have a high energy consumption and impact on climate change.

LCA has been applied to various aspect of waste management. For example; LCA has been used as a decision support tool for waste management planning (Clift, Doig, & Finnveden, 2000; Harri, Jan-Olov, & Asa, 2007; Muñoz et al., 2004; Sound Resource Management Group, 2009). They have also been applied in environmental impact analysis (Kong et al., 2012; Ponder, 2010) and as a means of comparing treatment technologies (Arena, Mastellone, & Perugini, 2003; Bovea et al., 2010; Cherubinia, 2009; Clift et al., 2000; European Communities, 2007; Liamsanguan & Gheewala, 2008; Munoz et al., 2004; Ozeler, 2006; Tulokhonova, 2013; Zaman, 2010).

In recognition of the truth or trust in results of LCA in waste management, the European Union Parliament recently accepted that the Waste Management Hierarchy defined by the European Union is superseded if a decision is based on an LCA (European Commission, 2008). Hence even though using the Waste Management Hierarchy should lead to the waste being dealt with in the most resource-efficient way LCA may be used to complement the Waste Management Hierarchy to ensure that the best overall environmental option is identified (European Union, 2011). So in particular circumstances and for specific waste streams, deviating from the Waste Management Hierarchy may be what is needed to select the best solution for the environment. Also, in many cases, alternatives exist at a given level of the Waste Management Hierarchy (e.g., different recycling options for a given waste stream). However, these alternatives are frequently not equivalent from an environmental perspective.

The next section examines the key driving forces that help our understanding of life cycle assessment.

2.3 The Driving Forces of MSWM?

The factors influencing the centrality or otherwise of a city's recycling scheme in the waste management system range from physical constraints, the knowledge about recycling and availability of facilities (Tonglet, Philips, & Bates, 2004), to household income associated and social stratification (Binder & Mosler, 2007). Other factors include market demand for solid waste as a resource, for example, the import of organic waste for district heating purposes in Sweden, which has influenced solid waste flows and composition in other countries (Ericsson & Nilsson, 2004).

The EEA (2004) defines drivers as the forces that lead to pressures on the environment or as anthropogenic activities that may have an environmental effect. According to Desmond (2010), drivers can be described as factors. These factors are not only limited to particular type of pressures but also to social and economic changes. For example, population growth and changes in solid waste composition are key drivers influencing or characterizing a city's waste management system.

Other authors have characterized the development of solid waste systems drivers from a historical context to current practices (Contreras et al., 2010). Wilson (2007) identified public health, environmental protection, resource value of waste, and public awareness as separate groups of drivers behind the development of solid waste management. Neilsen (2003) concluded that shortage of treatment capacity and the existence of a waste incineration tax were additional driving forces affecting the gate-fee differences and thus import/export. On the other hand, Rudden (2007) described the use of policies such as 'pay as you throw' and regulatory instruments as the drivers behind a better environmental practice and the implementation of an integrated waste management system in Ireland.

Although there have been several studies in this regard, the formulation of driver categories will be according to the characteristics of the solid waste system. In some situations, public health may be chosen as a representative driver type behind the development of solid waste. From another perspective, a type describing laws and regulations could also represent the influence of public health, environmental protection and other relevant drivers in the development of waste management. The OECD (2004) suggested that increased disposal costs, including 'tipping fees' charged by landfill per tonne of garbage including the market price of recycled materials, policies on increase number of kerbside recycling programs including public's perception of a shortage of landfill space as some of the major drivers in MSWM in the United States.

Another school of thought has it that waste management systems are dependent on socio-economic issues such as growth in population and Gross Domestic Product (GDP) (EEA, 2003; Mazzanti, 2008; Yu-Min et al., 2008). Both GDP and population size have a relationship with the consumption and generation of waste.

The collection of waste or management of waste is actually more complex than that and may be influenced by additional drivers such as recycling. Miliute and Plepys (2009), identified two types of drivers (market driven and policy driven) for household waste recycling systems.

The societal perception of waste determines how it is handled and affects the general management outcome. Waste was seen as valueless with 'no economic value' (Ludwig, Hellweg, & Stucki, 2003) before oil crisis. But in the 1970s, this view began to change as a result and waste started to be view as a precursor to energy. In 2016, waste is beginning to be treated as resource and source of energy.

All these drivers are interrelated and considered in the integrated sustainable environment formulated by the Collaborative Working Group for waste management in middle and low-income countries (CWG, 2006; Schübeler, van de Klundert and Anschütz, 2001; Wehrle, & Christen, 1996). The integrated sustainable environment recognizes three dimensions of a waste management system (Figure 2.1):

- All components of a waste management system, from waste generation through collection and transportation, treatment to final disposal.
- All the aspects, including the environmental, social, health, legal, political, institutional and economic, as well as the technical and financial.
- All the Stakeholders involved in a waste management system, including service users, NGOs, national and local government, the private and informal sectors and external support agencies.

The summary of the interrelationship of the development drivers and their connection to the three pillars of integrated sustainability (Social, Economic, and Environmental) is captured in Figure 4.1 and summarized in Section 4.1.3.1 to 4.1.3.3.

2.3.1 Economic Drivers

Financial and other economic considerations have played a significant role in directing the way waste is treated, what Melosi (1981), referred to as a philosophy of 'out of sight is out of mind.' The key economic drivers included scarcity of land for disposal facilities and high transport costs of moving waste to disposal sites. Incineration of waste without energy recovery was adopted as a way to reduce the volume of waste to be transported and landfilled, as well as open burning in landfills/refuse dumps, to increase the availability of disposal space. In some cases, food waste was fed to animals, and food and animal waste used as manure, with serious human and environmental consequences.

Initially, dumping of municipal refuse in waterways was much more heavily favoured as a disposal method, since the flow of water takes the waste out of sight than burning which produces visible air pollution. Today, due to advanced technology, incineration plays a much more significant role as a waste management technology (Louis, 2004), while dumping in waterways has been seen as a problem in water pollution and other environmental challenges like flooding.

But, as human population increased, leading to further pressure on the demand for land, less space became available for waste disposal. Hence, disease, inconvenience, smell, and ideas of cleanliness drove the early change in activities in waste management. The separation, collection or extraction, and valorisation of ashes, rags, broken items, and manures drove the beginnings of materials recovery, providing means of livelihood for others in the society than the discarders of the materials. The historical capture and valorisation of materials from waste streams and their re-direction to the beneficial utilisation in the agricultural and industrial value chains are based on the economic value of materials and their potential to re-enter production chains. In most developing countries, this is primarily a private sector activity located within the industrial or agricultural value chains (Scheinberg, Simpson, & Gupt, 2010; Scheinberg et al., 2010).

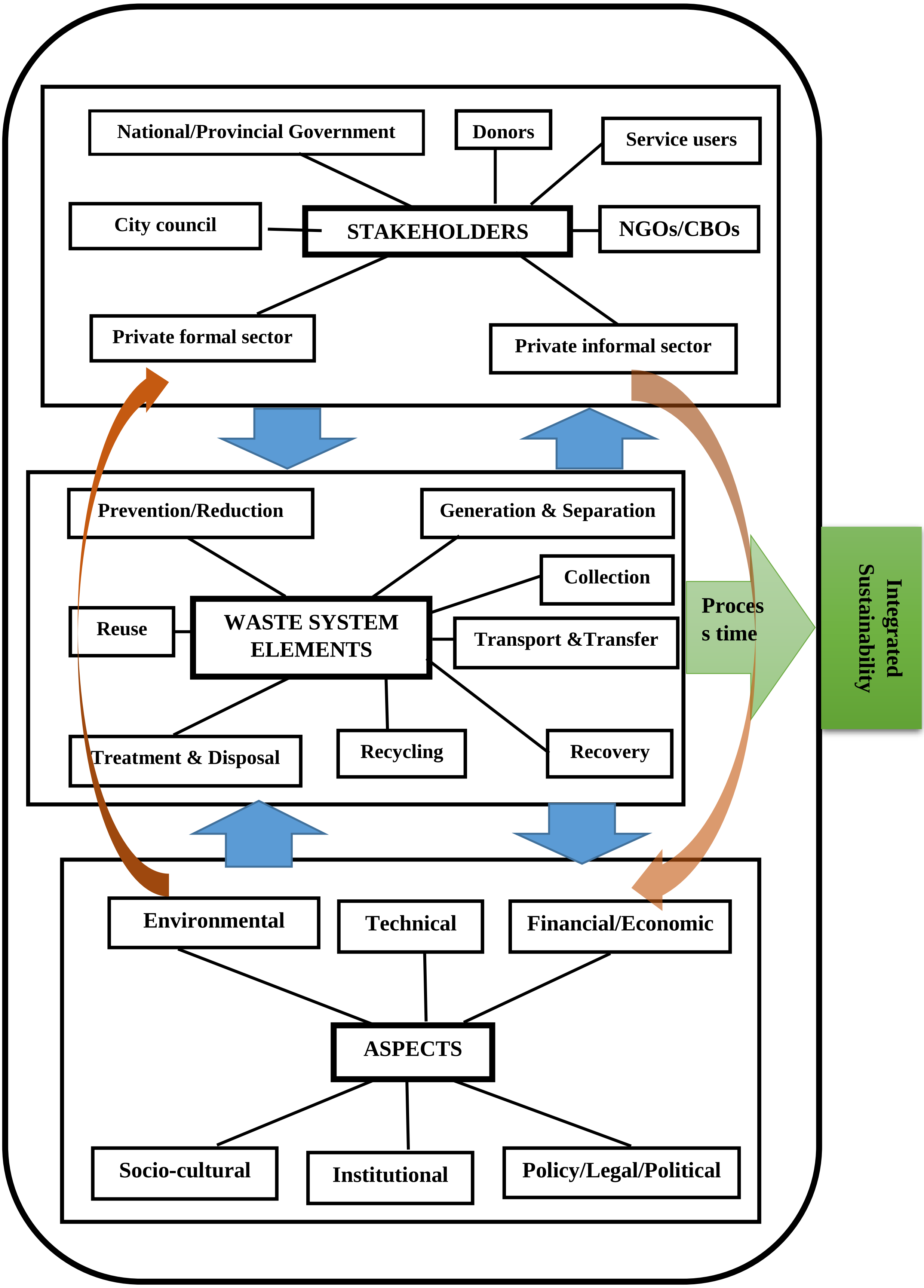


Figure 2.1: Integrated sustainable MSWM model. Modified from: van de Klundert & Anschutz (2001)

The development of waste-to-energy technologies emerged in response to the consideration of the economic implication of disposing of the waste, as well as shifting perceptions of waste from ‘no economic value’ to a resource. Environmental concerns pushed for further refinement in waste-to-energy technologies, resulting in further economic benefits and less negative impact on the environment and health of residents. Furthermore, the increase in landfill taxes pushed waste management and treatment costs higher, forcing individuals and organisations to finds ways of diverting waste from landfill (Zaman, 2013).

Some other authors have demonstrated that the financial burden of disposal on citizens is a primary driver in determining their behaviour (Bilitewski, 2008a, 2008b; Bozec, 2008; Dunne, Convery, & Gallagher, 2008; Puig-Ventosa, 2008; Reichenbach, 2008; Šauer, Pařízková, & Hadrabová, 2008; Skumatz, 2008). Today, in an attempt to avoid payment of disposal fee imposed by WMA in New Zealand, illegal dumping is adopted by some waste generators. Illegal dumping is a persistent problem which threatens human health and the ecosystem, imposing significant management costs on the communities, and hurts the quality of life (US EPA, 2013).

2.3.2 Social Drivers

Social indicators identified as potential drivers in the waste sector are population movement, the volume or rate of waste generation, people’s behaviour, local waste management practices and the processes of urbanization. Population change and the amount or rate of waste generation are a vital factor in the planning and design of waste management systems (Zuma, 2013). In recent studies (Lehman & Geller, 2004; Steg & Vlek, 2009), human behaviour and human behavioural change have been identified as primary drivers in waste management systems and environmental pollution. Socio-political drivers such as local and international rules and regulations are also important in moulding societal behaviour and the development of waste treatment technologies. Legislation has been acting as a supporting tool for some of the drivers through the promotion, development or restriction of the system. The landfill is the conventional waste management system in New Zealand today. However, new regulations are being initiated, focusing on new targets which will impose new restrictions on the disposal of certain waste such as food waste and combustible waste into landfill (Auckland Council, 2012). This is expected to impact on the behaviour of generators and practitioners and subsequently the volume of waste to landfill.

2.3.3 Environmental Drivers

Environmental drivers such as climate change and environmental awareness appeared after the 1990s when sustainability became an important factor for global sustainable development (Zaman, 2013). Increasingly, municipalities in deciding factors to consider in their waste management planning and implementation, additionally address urban environmental issues (World Bank, 2011) alongside with their routine solid waste management services. Public concern and sensitivity to environmental issues are driving this expanded agenda. This include:

- Public health and environmental impacts of accumulated uncollected waste and surreptitious disposal sites,
- Negative impacts of solid waste management facilities, including transportation, composting and landfill on health and the environment,
- Impact on air quality resulting from waste collection and transportation vehicles,
- Special handling and disposal of hazardous waste, including healthcare and industrial hazardous waste.

Now in most of the development and urbanization processes, socio-economic and environmental sustainability are the key criteria. Due to local awareness on the health impact of emissions from incineration, the pollution from incineration of waste has been controlled and systematically improved through improved technology due to the influences of environmental drivers.

As an ‘end of pipe’ solution, landfilling and incineration without energy recovery were predominantly applied in the early 1960s at the global level. Later in the global oil crisis of the 1970s and environmental awareness in the 1990s commercialization of the waste treatment technology became popular. Recent development and implementation of anaerobic digestion of organic food waste have reduced environmental pollution and became a source of bio-fertilizer compared to landfilling. The need to reduce the release of GHG causing Climate change and restrictions on environmental pollution resulting from landfill led the EU Parliament to promulgate the Landfill Directive (European Communities, 1999a).

Some of the drivers are mutually inclusive hence, cannot be aligned to only one category. For instance, waste characteristics (organic, combustible or recyclable) is one important factor for selecting waste treatment technology applicable to the system. This, in turn, can be considered as the socio-economic driver. Economic and technological efficiency and rules and regulations are also mutually inclusive with more than one driver. However, a simplified diagram of key waste treatment development drivers is presented in Figure 2.2 showing their relationship with one another in waste management systems. However, little is known if the role of these drivers in the dynamics of the waste management system has always been the same. Thus, being able to identify these drivers distinctively and how they have influenced solid waste systems (individually and collectively) is a major step in understanding the future direction of a sustainable solid waste management plan for particular local circumstances.

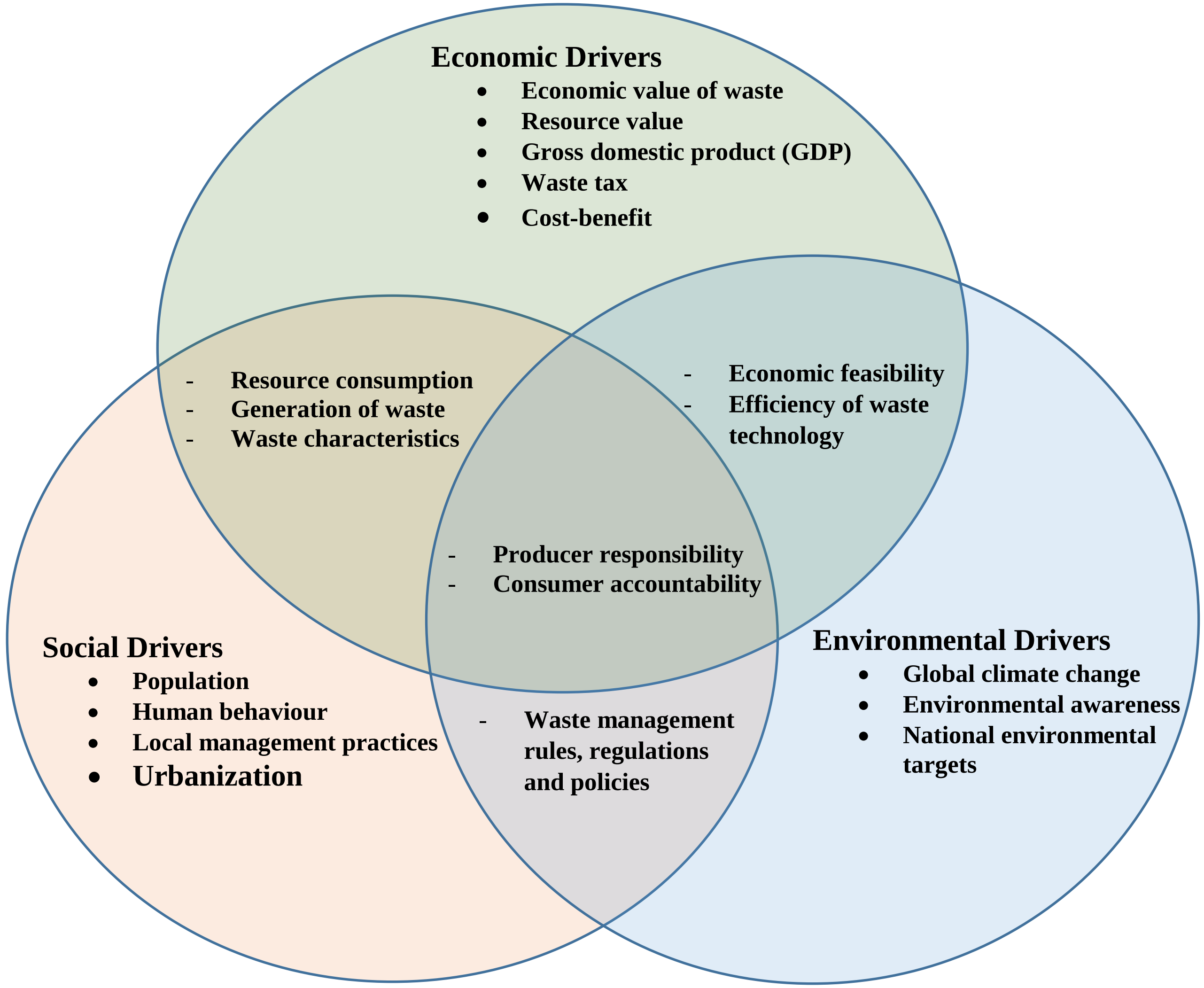


Figure 2.2: Drivers of integrated sustainable waste management. Source: Zaman (2013)

This is equally supported by Wilson (2007) who agreed that each driver might be related to the familiar pillars of sustainable development, i.e. environment and resource, economy and social acceptance.

Thus, finding a common strategy to analyse these drivers and the way they are affecting our waste management systems can be itself difficult. Mostly, this is due to the differences in local realities/circumstances and waste management (Contreras et al., 2010) and between stakeholders perspective of the drivers and waste (Wilson, 2007). Because of this, the development of a common ground and strategy to attain sustainable management has been increasingly difficult (Contreras et al., 2010).

2.4 Waste Management and the Environment

Everything that is consumed ultimately becomes waste in some form. Waste is generated by human activities in all sectors of the economy and often is an indicator of the inefficient use of natural resources (Philips, Pratt, & Pike, 2001). Waste, especially when disposed of, leads to losses of materials and energy within a production process and unsustainable consumption patterns (European Environment Agency, 2002). The way and manner waste are treated and disposed of may cause an environmental problem (Jibril et al., 2012) and expose humans to harmful substances and bacteria that affect people's health. The effort to avoid these adverse environmental drivers, which are clearly closely related to social drivers, results in changes in human attitudes to waste.

The rate of waste generation is generally considered to be an indicator of the level of socio-economic development and economic prosperity of a region or country. Increasing industrialization and rising incomes lead to greater use of resources (The International Bank for Reconstruction and Development/THE WORLD BANK, 2004). Waste composition is also influenced by factors such as the extent of urbanization, the standard of living, age and sex of population, industrial development and climate (Adhikari, Dahal, & Khana, 2014; Niloufer & Swamy, 2015). Therefore, waste quantities, as well as composition, are indistinguishably linked to the dynamism of economic activities and the rate of resource consumption of the society which generates the waste (Sastry, n.d).

Although we sometimes perceive waste as just ‘something we throw away,' most of which is simply collected and moved out of sight – into a landfill or poured down the drain (Statistics New Zealand, 2008). But research has shown that it is beyond this, hence questions regarding waste management practices and how they affect population health and the environment. These concerns, have possibly grown within the general population due to popular science reporting of research regarding sources of toxic emissions and level of their impacts on the environment and human health (European Environment Agency, 2013; Ministry for the Environment, 2009; Rushton, 2003). The World Bank (2012) highlighted the connections between global MSW growth, global pollution trend in volume, and the economic development of countries. This means that growth in a country's economic activities directly impacts on the volume of pollution and waste generated.

The general understanding of the impact of waste management on the environment has contributed to a better perception of the role of the waste sector in ecological, economic, and social frameworks of the society. This understanding has also contributed to the formulation of the notion of sustainable development (Haider et al., 2015; ISWA & UNEP, 2002). One of the greatest steps in progress has been in the increased level of awareness among the public and politicians. As a result, MSW generation and its management including the associated externalities have been addressed as the key targets in environmental policies (Ayalon, Avnimelech, & Shechter, 1999; Commonwealth of Australia Productivity Commission, 2006). Regarding costs, it increases annually across regions and territories. To show the level of growing attention, Beloff, Beaver, and Massin (2000) estimated that the total annual cost of operations for pollution abatement across all sectors in the US was more than US$ 150 billion.

Modernization and progress in human standards of living have had its share of disadvantages in impacting on the continuous increase in the volume of MSW and associated adverse effects of the waste and its by-products or waste of waste. Science and technology have also increased the complexities of the associated waste. Science and technology have increased the level of innovation in design and material application in a production system. Therefore, management of MSW will continuously, be a major issue to be considered in looking for solutions to environmental challenges facing humanity. It is one thing that is common in every city government, though service levels, environmental impacts, and costs may vary. The problem is compounded where landfilling is the most popular management option.

With increased volume of waste to landfill, the conditions in landfill design and management have been improved upon through the incorporation of safety system in engineering designs. Engineered landfills are meant to reduce the level of emissions to the environment. But no matter how modern these landfills may be, concern on the actual impacts of burying these waste (Health Protection Agency, 2011; Jin-Won & Ho-Chul, 2001; Ministry for the Environment, 2012c; Peter & Erling, 1995; Themelis & Ulloa, 2007) have and will continue to dominate discussions in meetings, conferences and workshops. Hence awakening several decisions at the various level of human associations – globally through the various organs of the United Nations (UN), regionally through groups like European Union (EU) and Organisation for Economic Co-operation and Development (OECD). At the national level in New Zealand, Ministry for the Environment is pioneering the efforts in regulating the whole process of waste management while at the local level the various City Councils are putting their resources and efforts together in making sure that the processes are done in the most environmentally friendly manner. These have resulted in different legislation at these various levels, focusing on waste management – generation, collections, transportation, and treatments.

Globally, solid waste disposal sites (including landfills) contribute approximately five to twenty percent of the global anthropogenic methane which is equal to about one to four percent of the total anthropogenic GHG emissions (EPA, 2013). In New Zealand, it was estimated at 2.7 percent in 2011 (Ministry for the Environment, 2013a). Climate change being a serious issue, New Zealand is embarking on some voluntary actions to reduce the emissions of GHGs and hence climate change. This includes waste management strategy to reduce the overall impact of waste management. Waste diversion from the landfills can, therefore, have significant upstream GHG minimization benefits (World Bank, 2012). Hence, waste minimization is a serious government programme leading to the enactment of Waste Minimization Act 2008 (Ministry for the Environment, 2013b).

Methane from solid waste disposal sites around the world represents about 12 percent of total global methane emissions (US EPA, 2006). Landfills are responsible for almost half of the CH_4 emissions attributed to the municipal waste sector in 2010 (IPCC, 2007).

Through innovations in MSWM, GHG emissions from waste management systems can readily be reduced. Within the European Union, the rate of GHG emissions from waste has declined from 69 mtCO_{2}-e per year to 32 million tCO_{2}-e per year from 1990 to 2007 (ISWA, 2009).

Apart from gaseous emission contributing to global warming, MSWM has other negative impacts which include; odours, underground and surface water pollution, aesthetics, dust particles, etc.

Waste management is beyond the collection and disposal of waste and includes any plan to use natural resources more efficiently, including managing the waste that may arise through the processes of managing the waste. Recycling, reuse, recovery process and even disposal systems, generates their waste which may be referred to as 'waste of waste'. Therefore, any sustainable MSWM must also consider how to manage the 'waste of waste' as part of the waste to be managed. This is one area of awareness that is created this research.

The continued increase in the volume of waste to landfill in New Zealand is an indication of a continued problem, because of emission and other environmental impacts as a result of MSWM are still on the increase. For example, illegal dumping is an increasing problem in Auckland (Morgan, 2011).

2.5 Integrated Solid Waste Management System

The rising energy prices and increasing commitment to the reduction in the amount of global number of landfills and GHG emissions are driving the development of new approaches to the management of MSW. World Bank (2011b) pointed out the increasing needs for municipalities to address urban environmental issues relating to MSWM. Public concern and sensitivity to issues concerning the environment are driving this expanded agenda.

The World Bank report reiterated that urban environmental management considering MSW should respond to the local regulatory framework that is typically enunciated within the municipal ordinances and the national public health code. Municipalities need to address national environmental policies and regulations equally in a holistic manner. In doing these, there is an opportunity for cities to motivate citizens and practitioners to pursue environmental improvements in MSWM through economic instruments. Such instruments should provide incentives and disincentives for waste generators and polluters to reduce emissions and recycle waste beyond regulatory requirements.

Solid waste accumulations at official solid waste disposal facilities or illegal dumpsites raise public concerns because of potential air pollution through smoke from open burning, odours from decomposing waste, insects, and rodents growing within the body of waste, gaseous emissions and water pollution that might result. Therefore, to avoid future complaint, public consultation and consensus building involving all stakeholders in an integrated system, becomes vital to a successful development of new and improved solid waste disposal facilities.

Therefore, according to the World Bank (2012), Integrated Solid Waste Management (ISWM) reflects the need to approach MSWM in a comprehensive manner with careful selection of acceptable methods that are sustainable. The selected methods must be supported by the sustained application of appropriate technology, good working conditions, and the establishment of a 'social license' between the local community and nominated waste management authorities (most commonly local government or territorial authority), including licensed waste management companies. This is as a result of increasing environmental awareness (Broitman, Ayalon, & Kan, 2012).

ISWM is based on a combination of high level of professionalism on the part of solid waste managers and professionals including the appreciation of the critical position of the community, employees, and local (and increasingly global) ecosystems in an effective solid waste management (World Bank, 2012). Staniskis (2005) agrees that the approach should holistically look at the environmental burdens and economic costs of waste management, OECD (2004) points out that it may be challenging since waste management system is in most cases split up into many different departments – collection, treatment, and disposal – handled by different companies. Whatever is the situation, however, the World Bank (2012) insist that ISWM should be driven by clear objectives which are based on Waste Management Hierarchy: reduce, reuse, recycle — which is now expanded to include a fourth 'R' for recovery. The four 'R' which are waste diversion options are then followed by waste-to-energy (which is a waste recovery process) and landfill, or other disposal options.

The perception of what is waste has a significant effect on the way it is managed (Staniskis, 2005; Van Craen & Van Velthoven, 2007). In an ISWM, the concept of 'waste' is replaced by a concept of 'resource', included in a well-coordinated and controlled waste flow system. A modern ISWM policy is based on a combination of the various levels of the Waste Management Hierarchy in the order of priority as laid out in Figure 2.2 - waste prevention and avoidance being on top of the priority, followed by maximized recycling of used goods, waste re-use, sorting and separate waste collection. Such an integrated system concept, where the waste stream is passed through the whole length of Waste Management Hierarchy automatically results in the reduction of the volume of waste to landfill.

The application of LCA can equally be applied to compare the chosen systems on the Waste Management Hierarchy (Arena et al., 2003; Assamoi & Lawryshyn, 2012; De Feo & Malvano, 2012; European Commission, 2011; Staniskis, 2005; UNEP, 2004a) where there is conflict. Within the overall system, the inputs (solid waste, water, and energy) and outputs (emissions to air, water, and underground pollution) are calculated for each operation within the stage.

Experience shows that LCA offers a good prospect of mapping the overall material and energy flows within a waste management system as well as the resource utilization, solid waste outflow, and the total emissions resulting from the total system. Comparing this system maps for a different product and the alternative options available for the management of residual materials allows the identification of areas where environmental improvements can be made (Staniskis & Stasiskiene, 2005).

Therefore, in an integrated system, the industry contributes to waste reduction through product design (eco-design) considering the need for the people and consumer behaviour (Staniskis, 2005).

In an integrated system, every stakeholder is important. Therefore, there should be flexibility in the definition of waste, which means the same thing may be waste or non-waste for different persons in different places or at different times (Staniskis, 2005). Hence, materials will have to pass through the whole Waste Management Hierarchy to be defined as waste, where it is disposed (Figure 2.2).

Although the Waste Management Hierarchy is easier to use in an integrated system, it has some drawbacks:

- it has poor scientific or technical basis (e.g. material recycling is always preferred to energy recovery;
- it does not address costs, hence, cannot help in assessing the economic affordability of different waste management options;

- the Waste Management Hierarchy is of little use when a combination of options are used;
- the Waste Management Hierarchy alone cannot account for the wide variety of specific local situations for waste management systems to operate effectively, for example, a sudden increase in population in a season which may call for a change in operational strategy.

Therefore, there is a need to support the Waste Management Hierarchy with LCA, especially where there is conflict on the best choice (European Commission, 2011).

According to McDougall et al., (2001, p. 21), the most significant definition of ISWM took place in 1991, when a task force from the United Nation Economic Commission for Europe (UNECE) published a Draft Regional Strategy for ISWM that defined ISWM as: "a process of change in which the concept of waste management is gradually broadened to include eventually the necessary control of gaseous, liquid, and solid material flows in human environment".

To achieve an integrated waste management will require significant system changes from the present MSWM scenario in New Zealand. The objective of an ISWM system is to be both environmentally and economically sustainable, which is difficult in a single move. But, it is possible to reduce environmental burden in the system continually through the continuous monitoring of the system performance. The adoption of *CEQ-Model* in the monitoring of the system will assist in system change that will help in achieving sustainability.

2.5.1 What is Sustainability in Waste Management?

According to Staniskis (2005), integrated waste management system can itself become a part of a resource management system, where all resources, such as water, power, CO_2 balance and solid waste are managed within a single optimized system. This management will eventually enable the development of a sustainable waste management. He continued by reiterating that sustainability requires that resource conservation measures should be adopted, which in turn requires that attention is given to more than just existing waste. Therefore, serious attention is given to waste minimization through eco-design.

Within the range of instruments that can lead to sustainability, waste reduction appears to be much greater than that which the traditional Waste Management Hierarchy would suggest. Agreeing on what constitutes a waste in a system is crucial. So more efforts are required to evolve and further develop the theory on which to base our waste management which will help in attaining a more in-depth description of the waste management domain (Staniskis, 2005). In turn, this will assist in strategizing to reduce waste generation at all stages.

Over the last few years, cities around the world, have risen against waste, fighting landfilling and incineration and in many cases stopping them. This behaviour is in the spirit of sustainability in waste management. To show the seriousness in this fight against disposal and the desire to eliminate disposal in Waste Management Hierarchy, the zero waste thinking has been articulated in such cities. The concept of zero waste which is a desire to create sustainable communities and present vast opportunities for employment and local economic development have emerged. Zero Waste is a new brand in MSWM being adopted for change and diverse, flexible range of management policies. The Zero Waste concept utilizes available technologies and any actions aimed at efficient resource use starting with and include; eco-design of products, industrial ecological thinking, cleaner production, extended producer responsibility (in managing the residues of their products). It also includes sustainable consumption (products that are contributing to the quality of life of the people but consume less of natural resources and less toxic release to the environment), educating the local populace and help them in domestic economic development, up to waste minimization and resource recovery at the end of the pipe.

Therefore, Zero Waste International (2009) adopted a working definition which defined Zero Waste as "a goal that is ethical, economical, efficient and visionary, to guide the people on how to change their consumption pattern and general practices to emulate sustainable natural cycles in resource use, where all discarded materials are designed to become resources for others to use" (http://zwia.org/standards/zw-definition/). It went further to refer to Zero Waste as developing and managing products and processes in such a way as to systematically avoid and eliminate the toxicity of waste streams and materials, conserve and recover all possible resources, and not burn or bury any residual material. So that implementing Zero Waste is aimed at eradicating all discharges to land, water or air that are a threat to planetary, human, animal or plant health.

The concept of Zero Waste has a direct relation to industrial ecological approach as applied in manufacturing. It involves the design of industrial processes and products from the dual perspectives of product competitiveness (also considering profitability) and environmental interactions. One of the most important concepts that are embedded in industrial ecology is that, like biological systems, it should reject the concepts of waste. Instead, materials and products that are obsolete should be termed residual materials rather than waste and it should be recognised that these materials are merely residues that our economic system has not yet been able to utilize efficiently (Snow, 2003). Therefore, to be certain on the usability of the materials, they have to pass through the whole length of the Waste Management Hierarchy.

The experience in the field of sustainability and waste minimization has shown that sustainable development cannot be achieved without deliberate and fundamental changes in the ways societies produce and consume (OECD, 2001, 2002a; UNEP, 2012; United Nations, 2012). Such progress should be pursued by all countries and regions, with developed countries taking the lead. China is a good example as reported by West et al., 2013). Moving the global economy into a more socially / environmentally responsible and resource productive path will be highly beneficial to the society, the environment and the economy in every country (Staniškis, 2005).

To achieve sustainability in MSWM, UNEP (2005) agrees that the role of national government should be three-fold;

- to articulate and enact legislation and policies focused on promoting and ensuring the protection of the environment
- to establish agencies or departments that are tasked with the implementation of these programs, and
- to perform pertinent research and development aimed at further improving the strategies.

Ideally, these programs should be formulated locally so that they are consistent with the objectives of programs that have been articulated and adopted at the international level, such as those outlined in Agenda 21 of UN and UNFCCC.

In New Zealand, Zero Waste has been mentioned in the Waste Management and Minimisation Plan of some Territorial Authorities as a long-term aspirational goal (Auckland Council, 2011; Waikato District Council, 2012). But the general waste management practices displayed nationwide is that of ‘from-kerbside-to-landfill’. Little efforts are put into recovering materials from rubbish bins.

Waste Management Hierarchy has also been appearing in Waste Management and Minimisation Plans, but no single plan (as far as the record can show) anywhere to implement the Waste Management Hierarchy and include a system like waste-to-energy.

2.5.1.1 Historical and Conceptual Review of Sustainability

The birth and developments of what is today referred to as sustainable concept in human and environmental development around the world started at the United Nations Conference on Human Environment in Stockholm Sweden on 16 June 1972. This marked the emergence of international environmental law. This Declaration on the Human Environment is also known as the Stockholm Declaration laid down the principles for various global environmental issues, including human rights (in relation to the environment), natural resource management, prevention of pollution and the relationship between the environment and development (Hongyuan, 2008). The conference resulted in the creation of the United Nations Environmental Programme.

Following the Stockholm Declaration, the World Commission on Environment and Development (WCED) (The Brundtland Commission) (World Commission on Environment and Development, 1987), published its report in which it presented a new concept – sustainable development. The report recognized the global nature of all environmental problems and that there will be unprecedented depletion of our natural resources which would have rippling effects throughout the world economy and social structures if steps are not taken to address the global consumption rate. Therefore, the report suggested that it was in the common interest of the international community to establish policies for sustainable development.

The report informed that there is a finite amount of resources available to the world’s growing population. Hence, there is an immediate need for global management of these resources so that the continued high quality of life of future generations are not imperilled as a result of the present level of consumption. The Brundtland Commission’s report (World Commission on Environment and Development, 1987, p. 16) then, defined sustainable development as “development which meets the needs of current generations without compromising the ability of future generations to meet their needs”. This concept and definition became one of the most successful and accepted the idea to be introduced in many years. In fact, it assisted in the shaping of the local and international agenda (till date), the general thinking and attitude towards economic, social and environmental development.

The 1992 Earth Summit in Rio de Janeiro, where 182 countries adopted Agenda 21 which has sustainable development as the way forward in global resource management further popularized this concept.

For this purpose, resource efficiency is the key. As waste generation is an indication of poor resource management, Adams et al. (2000) point out that sustainable development (Figure 4.3) is about striking the right balance between economic development, social equity, and environmental protection. For MSWM sector, meeting this objective translates into the challenge of satisfying market demands at the lowest economic, social and ecological cost possible. Therefore, sustainable waste management is a top priority by encouraging the prudent use of natural resources which is essential for future prosperity and the protection of the environment.

Subsequently, IRU (2014) recognised that in economics as in ecology, the rules of interdependence apply and that separate actions are impossible. Thus, a policy which is not carefully articulated, considering the interdependency of human needs, will have various perverse or even adverse effects, not only on the economy but equally for the environment.

Therefore, integrated sustainable waste management will involve seeing the whole region or country as one in waste management sector without a border.

Performance indicators are an integral part of the strategy as they help to identify and prioritise areas for future action (Mitchell, 1996).

The reflection on the economic cost of waste has to start from reducing the rate of waste disposal. Waste generation is a reflection of an inefficient use of resources, as materials which could be reused or recycled such as plastics, metals, paper, organic waste, and glasses are disposed to landfills (Ministry for the Environment, 2009). The social and cultural cost relate to the acceptability and fairness in the general externalities to the people. While the environmental cost is a reflection of the volume and composition of emissions (example GHG) produced through the various MSWM strategies which can have significant health impacts on humans and animals. Waste and the different processes of its management can also pollute our waterways, air, and land if not adequately managed.

Figure 2.3 above illustrates that the people will resist any waste management program, and especially a waste treatment technique which ignores the social/cultural context of the society. The resistance of the people will lead to the failure of such a system. The issue of public acceptance, public participation in the planning and implementation of the system, consumer behaviour, and changing value systems are all important including the technical or economic aspects of waste management and the planning of the system.

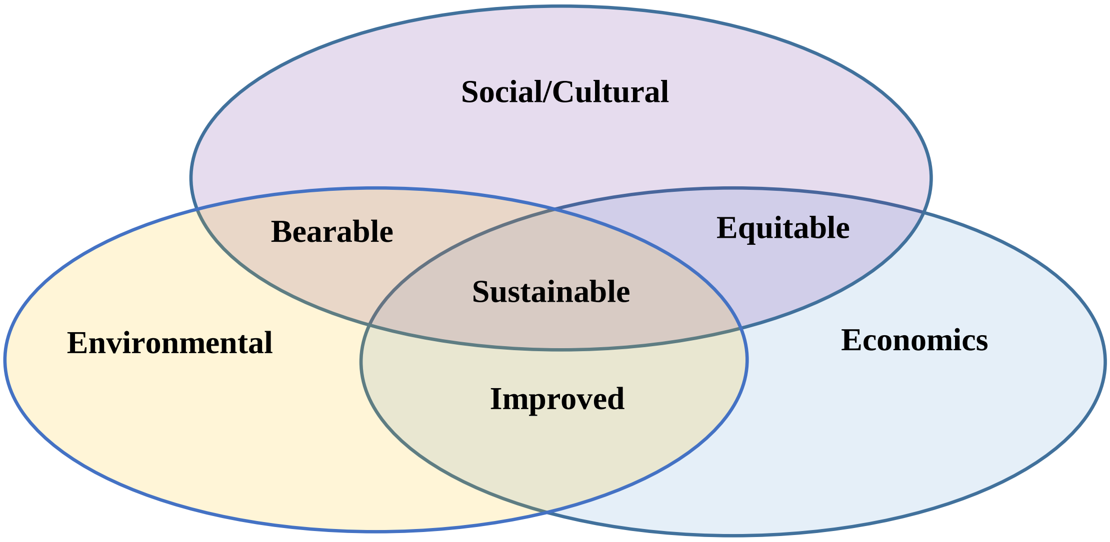


Figure 2.3: Sustainability relationship. Source: World Bank (2012)

2.5.2 Integrated Sustainable Municipal Solid Waste Management

From the analysis of the drivers of waste management, it is pertinent that MSWM systems try to address a particular issue or problem at each time during the periods of its evolution. But the understanding of the need for a comprehensive approach resulted in Integrated Sustainable Waste Management. According to Barton, Issaias, and Stentiford (2008), Ghinea et al. (2012), Morrissey and Browne (2004), and Pires, Martinho, and Ni-Bin, (2011), waste management should not aim solely to reduce the volume of waste heading to incineration or landfills, but must also optimize social acceptability, economic gain, and environmental compatibility, while promoting a sustainable and fair society.

Moreover, one of the main issues associated with sustainable waste management lies in the ability of decision-making tools to combine the notions of systemic approach and minimization of the impacts in a global and dynamic fashion (Contreras et al., 2010; Woolridge et al., 2005).

Relating to sustainability and MSWM, Woolridge et al. (2005) defined sustainable management as an environmentally efficient, economically affordable and socially acceptable system. White, Franke and Hindle (1999) highlighted the need for a sustainable system to be an integrated management process, where the system processes are considered holistically starting from waste collection and considering an efficient sorting system. In this way, the emphases will be on the recycling of material, adopting biological treatment of organic materials, thermal treatment before disposal. McDougall et al. (2002) represented sustainable solid waste management through the level of impact on public health and how the system can prevent the spread of disease and ensure the safety of workers and recognizing the following system aspects:

- The effectiveness of the system in relation to the environmental safety by taking into account the reduction of environmental burdens of waste management, either by the reduction of air, water or land emissions.
- Economic affordability (efficiency) to operate at a cost acceptable to the community, including all private citizens, business, and government.
- Social acceptability (equity) – a management system that is operating in an acceptable manner for the majority of people in the community, including stakeholder groups. Therefore, all citizens are entitled to an appropriate waste management system for environmental health reasons.

Hence, Van de Klundert & Anschütz (2000) identified three dimensions that are central to a sustainable waste management system: Stakeholders, System elements, and Aspects. For the system to be integrated, there has to be some level of interaction among the elements of the dimensions and the dimensions as a whole. This is represented in Figure 4.1. These interactions produce the highest level of resource utilisation and reduce the number of wasted materials in waste generation. The arrows in Figure 4.1 are representing these interactions which are absent in van de Klundert, and Anschutz (2000).

A stakeholder can be said to be a person or organisation that has a stake or interest which varies according to the stakeholder, but they can cooperate to achieve a common goal.

The waste system element is like the movement of or flow of materials from generation stage, through treatment to disposal. In that case, a waste management system is a combination of several stages which can be adopted in managing the flow of materials within the city, region or nation. Therefore, a waste management plan is built into an integrated materials management strategy so that deliberate and normative decisions are taken about how the material should flow.

The third dimension – aspects distinguish six parts through which the existing system can be assessed and with which a new or expanded system can be planned to take. In this way, a municipal manager is given a set of tools which will help them to perceive, study and balance priorities and create measures to give the desired results.

Dutch NGO, WASTE, cited by van de Klundert and Anschütz (2001) concluded that ISWM should be based on four basic principles:

- **Equity**: within which all citizens should have access to waste management systems for the sake of public health reasons,
- **Effectiveness**: so that the waste management system safely removes the waste,
- **Efficiency**: so that the benefits are maximized, costs are minimized, and the use of resources are optimized, and
- **Sustainability**: of the system by considering aspects such as technical, environmental, social/cultural, economic, financial, institutional, and political perspective.

UN HABITAT (2010) provided an alternative framework identifying three key system elements within an ISWM which include; resource management, public health, and environmental protection.

In most jurisdictions, the concern on public health is the foremost concern on which solid waste management programs are based. Inefficient MSW collection and poor disposal systems can be a breeding ground for insects, vermin, and scavenging animals (European Union, 2013a), and can thus be a source of air and water borne diseases. Surveys conducted by UN-Habitat (UN Habitat, 2010) show that in areas where waste is not collected frequently, the incidence of diarrhoea is twice as high and acute respiratory infections is up to six times greater than in areas where the collection is frequent.

Poorly collected or improperly disposed of MSW can have a detrimental impact on the environment. In low - and middle-income countries, MSW is often dumped in low-lying areas (which are sometimes liable to flood) and land adjacent to slums. Lack of enforceable regulations encourages the mix disposal of potentially infectious medical and hazardous waste with MSW, which exposes waste pickers to infections and leads to the contamination of the ecosystem. The environmental threats of such unsustainable practices include contamination of underground water and surface water by leachate resulting from decomposing materials, as well as air pollution from burning of waste that is not properly collected and disposed of (UN Habitat, 2010).

A well-coordinated integrated sustainable MSW system can represent a considerable potential for the resource. Although the global recyclable market regime is not stable, in recent years, it has increased significantly. The world market volume for post-consumer scrap metal is estimated to the tune of 400 million tonnes annually and around 175 million tonnes annually for recovered paper and cardboard. This represents a global value of not less than $30 billion per year. (UN Habitat, 2010).

Although recycling occurs (in most cases) usually at informal sector, it represents a significant level of energy saving in the production chain. For example, producing aluminium from recycled aluminium requires 95% less energy than producing it from virgin materials. As the costs of accessing virgin materials and their environmental impacts increases, the relative value of secondary materials is expected to increase (UNEP, 2004b).

2.6 Global Patterns of MSWM

Globally, MSWM is being transformed into business with the private sector, either directly or through public-private partnerships, getting involved at various stages. The level of which the private sector is involved varies depending on the local MSWM policies, the size of private sector organization and type of business within the waste management chain.

Also, the philosophy of MSWM has further evolved from focusing on public health by focusing only on collecting waste and environmental aspects by properly disposing of waste, to an additional aspect which is that waste is a resource. Therefore, MSW could be converted into a material and energy source.

There are two identifiable benefits from this approach. First, the final waste volumes heading to landfill reduces substantially as a result of management/recovery processes adopted in managing the waste. Hence, the costs of disposal and waste management are reduced significantly. On the other hand, recovered materials and energy generates revenue to support the cost of MSWM. This is the philosophy on which 3R (reduce, reuse and recycle) and integrated approach to waste management are based.

Increasing concern and challenges of climate change have brought focus on the linkages between MSW and climate change. GHG emissions from open dumps, landfills and open burning and other anthropogenic activities are considered to be substantial in amount. Furthermore, if CH_4 is captured and some percentage of the waste is converted into an energy source, then this could replace the dependence on fossil fuels and may result in substantial reduction in GHG that is usually produced by the use of fossil fuels. This is part of the clean development mechanism (CDM) (Gillenwater & Seres, 2011). Therefore, the projects under CDM are trying to bring waste management and converting waste into energy into its fold; thus, creating new investment opportunities.

But the general lack of data on waste generation globally (World Bank, 2012) is a major indicator of non-sustainability of waste management. Secondly, the management strategy is still very low on the Waste Management Hierarchy scale. Table 2.1 and Figure 2.4 are a graphic representation of the amount of waste disposed of using various waste management strategy worldwide. Landfill which is at the bottom of Waste Management Hierarchy is leading the pack, followed by recycling with less than half the value of waste to landfill. This is notwithstanding the propagation of 3R, which is a response to financial, environmental, social and management considerations.

Table 2.1: Global patterns of MSW disposal

	Landfill	**Recycled**	**Waste-to-Energy**	**Dumps**	**Compost**	**Other**
	(million tonnes)					
High Income	250	129	122	0.05	66	21
Upper Middle Income	80	1.9	0.18	44	1.3	8.4
Low Income	2.2	0.02	0.05	0.47	0.05	0.97
Lower Middle Income	6.1	2.9	0.12	27	1.2	18
Total Disposal	338.3	133.82	122.35	71.52	68.55	48.37

Source: (World Bank, 2012)

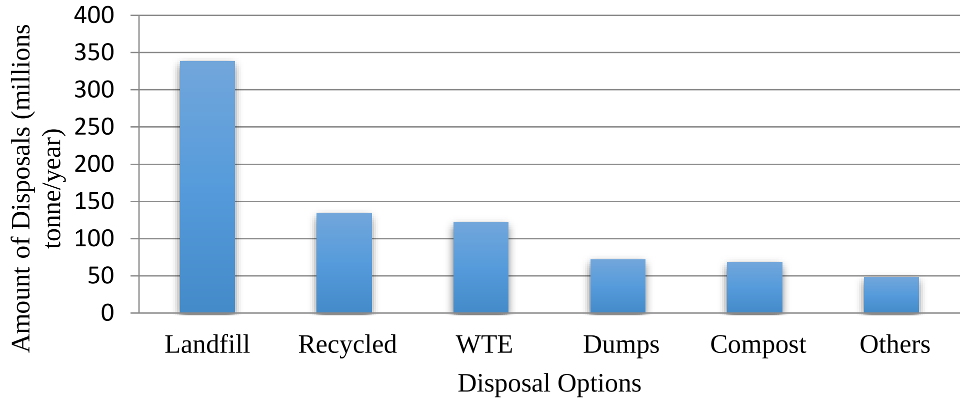


Figure 2.4: Global trend in MSW disposal options. Source: World Bank (2012)

Some countries and regions are making some noticeable progress in some ways. But UNEP (2004) observed that the continuous rise in the rate of raw material consumption and waste generation shows that in many countries, as well as globally, the demand for natural resources, is exceeding the amount available. Countries that are not able to support their national consumption with their natural resources are running at an ecological deficit. Therefore, these countries have to either import the shortfall of their ecological capacity needs from other places or take it from future generations. The step into the ecological need for next generation may result directly from over-exploitation of the natural resource or indirectly as a consequence of the adverse environmental impact caused by the present consumption pattern. Hence, Crawford (2011) agrees that there is still tremendous potential to do more to reduce the climate impact of this sector.

Figure 2.5 shows MSW generation trend globally clearly reflecting the link between the affluence of regions and the volume of MSW that is generated there. The OECD countries which are the collection of most developed nations in the world contribute almost half of global MSW (44 percent).

Waste generation rates have been positively linked to per capita energy consumption, GDP and private final consumption (Bogner, 2008; European Union, 2013b; OECD, 2002b). Climate can also influence the waste generation in a city, country, or region (UNEP/GRID-Arendal, 2004).

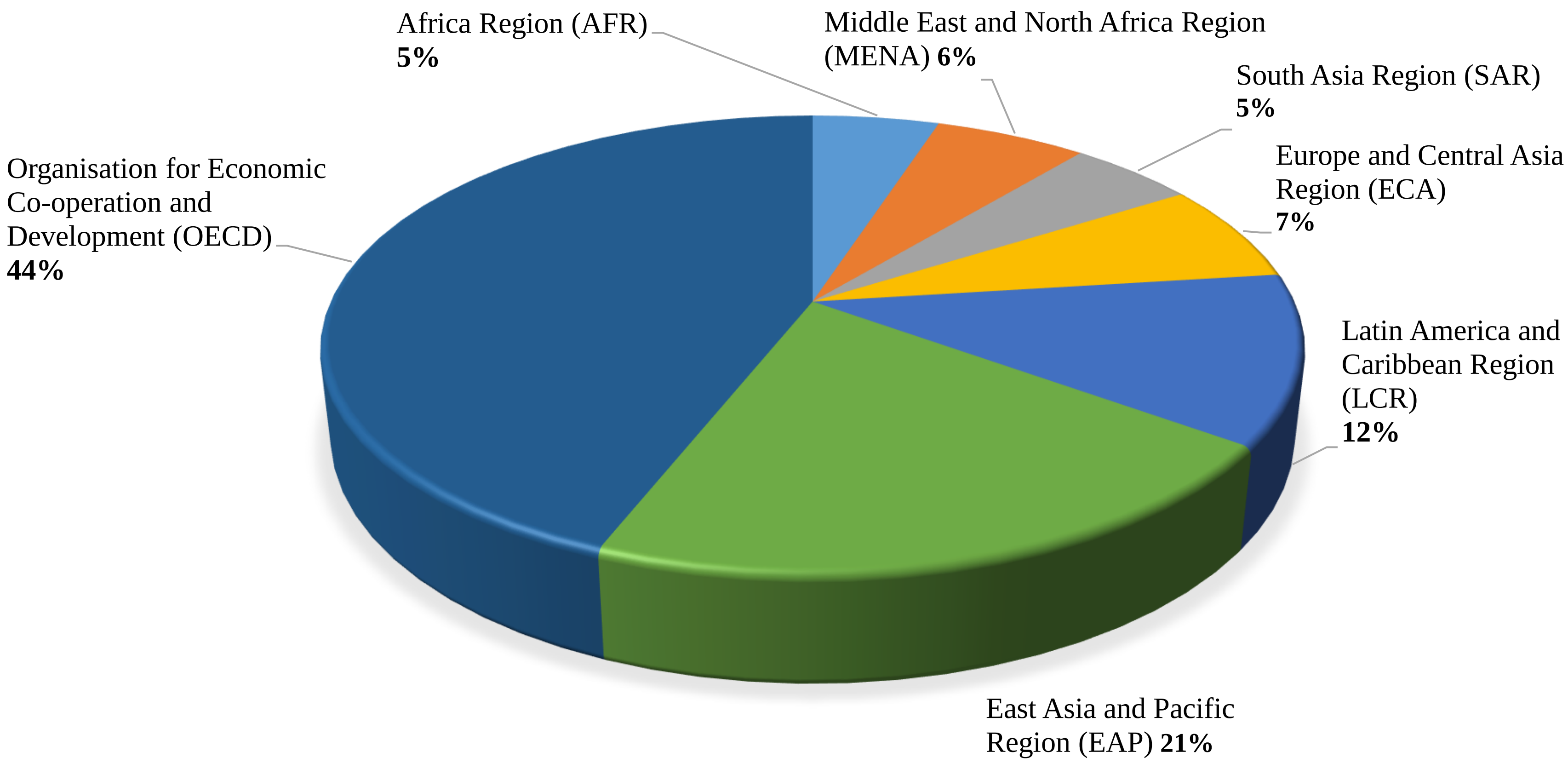


Figure 2.5: Global MSW generation trend. Source: World Bank (2012)

Although developed countries are striving to decouple waste generation from economic growth. The overall reduction in waste generation remains a challenge, especially when populations are increasing.

In countries where the same production/consumption pattern persists, and progress is made towards achieving a higher standard of living, waste generation per capita and overall national waste production are set to increase accordingly. This development is common in OECD countries. Although the annual per capita waste generation average in developing nations is estimated at 10-20 percent that of developed countries, this figure is continually rising in response to economic growth. Globally, waste generation is increasing.

2.6.1 Global Waste Composition and Management

The composition of waste is influenced by factors such as climate, culture, economic development, and energy sources. Waste composition is an important factor in determining how waste is managed.

Low-income countries have the highest proportion of organic waste while paper, plastics, and other inorganic materials make up the highest percentage of MSW in high-income countries (World Bank, 2012).

By region, East Asia & Pacific (EAP) region has the highest percentage of organic waste at 62 percent while OECD countries have the least at 27 percent, although the total amount of organic waste generation is still highest in OECD countries (World Bank, 2012). Figure 4.5 represents the composition according to the regions of the world grouped according to the level of economic development of the countries.

Although the waste composition is usually provided by weight, following the trend in the affluence of countries, waste volumes tend to be more important, particularly in regard to collection. Organics and an inert waste decrease in relative terms to development, while paper and plastic increases in overall waste volumes.

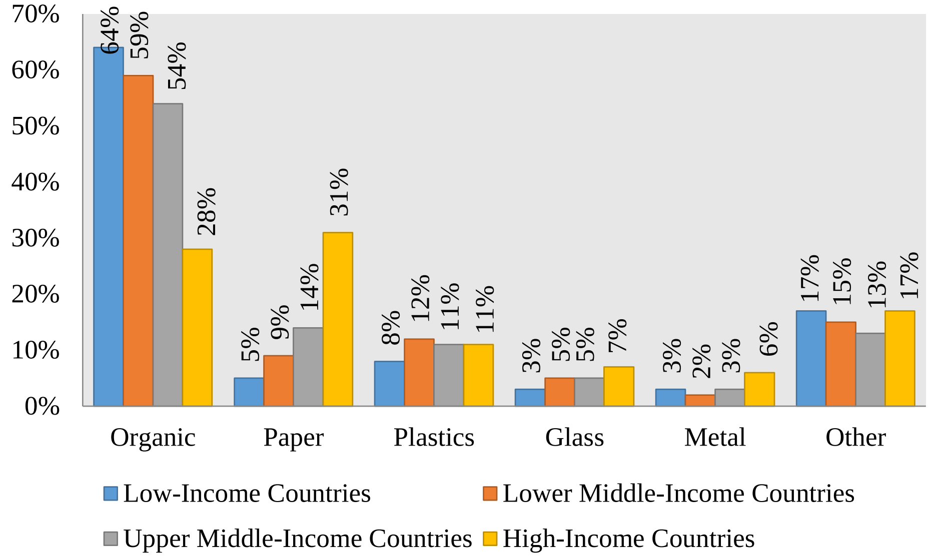


Figure 2.6: Global waste composition by regional income profile. Source: World Bank (2012)

From the composition of MSW in Figure 4.6, there are indications of opportunities for recovering more resources from the disposed waste. Also, the scenario painted is far from sustainable consumption and production as prescribed by UNEP (2012).

2.7 Global View on Integrated Sustainable MSWM (ISWM)

The Rio+20 summit was nothing short of an epic failure. In the face of accelerating climate change and an ever-increasing use of resources, governments failed to deliver the transformational change needed to safeguard our planet's future. There was no commitment to an energy revolution based on renewables and energy efficiency, or to urgently end deforestation. Overall, the world got just words and greenwash, not the urgent action required to provide prosperity for all without exceeding our planet's limits (Naidodo & Mittler, 2013, p. 16).

The above statement was a representation of the general view of many, 21 years after the first Earth Summit was held in 1992 and sustainable development was adopted as the way out of the expected catastrophe humanity may face because of depletion of human and material resources. The whole system was centred on sustainable consumption and production (SCP) which UNEP (2012) summarized as:

- Improving quality of life without increasing environmental degradation, and without compromising the resource needs of future generations;

- Decoupling economic growth from environmental degradation by -
    a. reducing material/energy intensity of current economic activities, and reducing emissions and waste from the extraction, production, consumption, and disposal, and
    b. promoting a shift of consumption patterns from one group of goods towards another group of goods and services with lower energy and material intensity without compromising the quality of life of the people;
- Applying life cycle thinking, which considers the impacts from all life cycle stages of production and consumption process;
- Guarding against the rebound effect, where efficiency gains are cancelled out by resulting increases in consumption.

Therefore, there is a link between the pattern of consumption and production and the prosperity of the people, hence sustainability.

From the various reports of the United Nations and its agencies, it is very clear that the general situation of waste generation and management at the global level is not positive. Waste generation is linked to consumption and production pattern, urbanization and economic development. Waste generation is also increasing in the same pattern as economic development as waste generation is less in low income (or rural) areas due to low purchasing power and higher levels of reuse and recycling (UNEP, 2004; World Bank, 2012). As reported by the World Bank (2012), world cities generate about 1.3 billion tonnes of MSW per year, translating to about 1.2 kg/capita/day. This volume of generation is expected to increase to 2.2 billion tonnes by 2025. There is a further projection by World Bank that waste generation rates will double over the next twenty years in lower income countries. The World Bank projected that globally, solid waste management costs would increase from the present annual $205.4 billion to about $375.5 billion in 2025. The cost increases will affect the low-income countries more than developed countries (more than 5-fold increases) and lower-middle income countries (more than 4-fold increases). The report went further to describe the situation as sobering hence urgent attention is needed.

Therefore, the World Bank (2012) agrees that ISWM reflects the need to approach solid waste management in a comprehensive manner with carefully selected and sustained application of appropriate technology and working conditions. The establishment of a ‘social license’ between the community and designated waste management authorities (most commonly local government) is also needed. ISWM requires both a high degree of professionalism on behalf of solid waste managers, and on the appreciation of the critical role that the community, employees, and local (and increasingly global) ecosystems have ineffective SWM. Clear objectives should drive the implementation of ISWM and based on the Waste Management Hierarchy.

Table 2.2: Waste generation per capita (kg/capita/day) by world region

Region	**Waste Generation Per Capita (kg/capita/day)**		
	Lower Boundary	Upper Boundary	Average
AFR (Sub-Saharan Africa)	0.09	3.0	0.65
EAP (East Asia and Pacific)	0.44	4.3	0.95
ECA (Europe and Central Asia)	0.29	2.1	1.1
LAC (Latin America and Caribbean)	0.11	14.0	1.1
MENA (Middle East and North African)	0.16	5.7	1.1
OECD (Organisation for Economic Co-operation and Development)	1.10	3.7	2.2
SAR (South Asia Region)	0.12	5.1	0.45

Source: World Bank (2012)

Table 2.3: Waste generation per capita by country income level. Source: World Bank (2012)

Income Level	**Waste Generation Per Capita (kg/capita/day)**		
	Lower Boundary	Upper Boundary	Average
High	0.70	14	2.1
Upper Middle	0.11	5.5	1.2
Lower Middle	0.16	5.3	0.79
Lower	0.09	4.3	0.60

Note: Countries are classified into four income levels according to World Bank estimates of 2005 GNI per capita. High: $10,726 or above; Upper middle: $3,466-10,725; Lower middle: $876-3,465; and Lower: $875 or less

Tables 2.2 and 2.3 shows the link between income level of countries (affluence) and waste generation. This is an indication of non-sustainability in resource utilization and waste generation and management.

Though the global picture of waste management and sustainability is not a good story, some countries have made significant progress. The review of such good achievements is necessary as a showcase of some steps which can help in good policy making and implementation, to achieve success. In this line, Sweden is chosen.

2.8 Sweden as a Model

Sweden can be said to be the global leader when it comes to dealing with waste and recycling waste. The waste management system is being developed continuously following evolving technology. The developments in Swedish waste management system is also the result of patient long-term work. Not only on the part of municipalities and their companies but in cooperation with private players. This involved risk-taking in developing new technology and the courage to invest heavily in necessary infrastructure. This has resulted to inhabitants enjoying a good level of service and increased recycling. To achieve all these successes, a well-functioning cooperation between and within municipalities has been necessary (Avfall Sverige, 2013).

In 2008, a total of 4,731,660 tonnes of household waste was treated, a small increase of 0.3 percent compared to 2007. If divided by the population, this means that each Swedish resident produces 511.2 kg of waste per year (Avfall Sverige, 2009).

Although Swedish legislation places the responsibility for dealing with household solid waste on municipalities, it leaves the decision on how to execute this responsibility to the municipalities to decide. Three out of every four Swedish cities contract the collection of household waste to external actors; however, most municipalities process waste internally, either through municipal waste management departments or municipal waste management companies that are fully-owned by a single city or a collection of districts (Avfall Sverige, 2010).

From history, Sweden has shown a strong commitment to protecting their environment through sound initiatives and general policies, particularly in the area of MSWM. By 1969, The Swedish Environment Protection Act imposed far-reaching environmental obligations on new waste treatment facilities. Several new regulations came into force during the 1990s, including the need to increase producer responsibility and a concentrated effort on measures to reduce the landfilling of waste.

By 1999, a new environmental code came into effect, replacing the previous Environmental Protection Act. The new environmental code integrated 15 previously existing environmental laws and formed an umbrella legislation governing all environmental impacts within the framework of a sound sustainable development for Sweden. In 2005, the Swedish Waste Plan ‘A Strategy for Sustainable Waste Management’ laid down the future direction of the waste management and set distinctive targets to be met by 2010. The Waste Plan was drawn based on the Swedish Environmental Objectives which were enacted by the Swedish government in the same year (Swedish Environmental Protection Agency, 2005).

All stakeholders and actors in Swedish MSWM have particular responsibilities and tasks. Municipalities are required to develop a waste management plan and bear the responsibility of collecting and disposing of household waste. This is not however including waste resulting from product categories covered by producer responsibility. Therefore, municipalities may issue local regulations regarding the management of household waste, including fees (ETC/SCP, 2009).

It is the responsibility of households to separate and deposit their waste at the various available collection points maintained by municipalities. Households are also responsible for complying with municipal waste management regulations. Lastly, producers are obliged to take care of waste arising from their products (Avfall Sverige, 2011). Producer responsibility in Sweden for end-of-life packaging, cars, tyres, recycled paper, batteries and electrical and electronic products are in place (Swedish Environmental Protection Agency, 2005).

Swedish MSWM is governed by the principle of waste minimization as a top priority. Hence, the principles as contained in Waste Management Hierarchy found in the Waste Framework Directive (2008/98/EC) (European Union, 2008), are strictly applied.

The generation of MSW in Sweden peaked in 2008, reaching 4.73 million tonnes. In the next two years following 2008, the generation of MSW fell to 4.36 million tonnes, which was around the same amount as in 2005 with 4.35 million tonnes. One possible explanation for this reduction in quantities of waste has been argued to be the economic recession, as reduced consumption inevitably leads to reduced waste quantities (Avfall Sverige, 2009).

EU decisions set the frameworks for Swedish waste management. The environmental objectives of the Swedish Parliament govern the waste management and its environmental aspects.

Sweden is widely considered a waste-to-energy success story. International comparisons show that Sweden is the global leader in recovering energy from waste. In 2009, 49 percent of all household waste, or 232.6 kg per person was converted into energy (letsrecycle.com, 2010). Sweden continues to add waste-to-energy capacity as it continues to wean itself off of fossil fuels (Williams, 2011).

From landfilling more than twenty per cent of its MSW in 2001, Sweden as at 2014, recycles and incinerates equal shares of MSW (49 percent for each), with less than one percent of total MSW going to landfills. The major key to this successful development has been attributed to the imposition of taxation on landfills. Other reasons include the introduction of household waste charges and clear goals set by the government. For example, a 50 percent recycling target by 2010 was set in 2008. At the same time, there has been a concerted effort to explain the many benefits of reducing MSW to landfill in favour of waste as a source of energy (Ohrling & Odebjer, 2014). These efforts assisted the Swedish system to achieve the target.

The happy story is resulting to Sweden running out of MSW to feed its waste-to-energy incineration programme. In recent years, it has resorted to importing more than 800,000 tonnes of MSW from its neighbours, mainly Norway (Burgess, 2013; Ringstrom, 2012).

At the same time, evolving technology means emissions from incineration are less of an issue. Sweden is not the only EU country importing trash – Germany, Belgium, and the Netherlands are importing waste too. Germany is the biggest in actual amounts, but as a share of rubbish burnt, Sweden is the leading importer (Ringstrom, 2012). It is working for Sweden as she is paid for the waste while the residual ash is transported back to Norway for disposal (Poudyal, 2013). This is unlike the US and many other places in the EU and around the world where the waste burden is still high.

As a way of demonstrating one of the strategies towards this success story, which is cooperation between districts to achieve national goal, Hume (2006) described the situation in Malmo Sweden. With a population of over 500,000 people, Malmo, Sweden's third-largest city, combined with thirteen other districts and municipalities to operate Sysav Corporation, an incineration plant that incinerates waste through which district heating and electricity are provided. Indeed, 40 percent of Malmo homes is heated by Sysav, which also supplies 40 percent of local power. The plant, built in 1974, has been updated and expanded several times to meet growing demand and the stringent European Union emission standards. Thanks to advanced flue gas cleaning technology which make it possible for the incineration plant to produce exhaust of 98 percent water. The exhaust is now so clean the locals didn't make a peep when the most recent expansion was launched in 2007. After completion of the expansion in 2008, the facility is currently generating 60 percent of the region's electricity.

Hume (2006) quoting Sysav Corporation President Haken Rylander, stressed that Swedish cities were forced into dealing with their waste back in the late 1960s when the national government passed stiff environmental protection laws. Communities that realized that they couldn't meet these new demands alone because of their size and other conditions came together to form 31 incineration plants spread across Sweden. Unlike Canada, Sweden rejected landfill because it is inefficient, dangerous and disgusting. It is a smaller country, of course, with fewer resources to squander and perhaps that means greater pressure to deal with the issue of efficient resource utilization, rather than try to bury it. Public involvement is critical, Rylander concluded.

Like some other parts of the world, Swedes initially feared incineration because it conjured up visions of black toxic exhaust spewing from huge smokestacks. But that was three decades ago. It wasn't very true then, and it is less so now. But Hume (2006, p. 2) quoting Christian Kallerdahl, communication chief of Renova Corporation, West Sweden’s equivalent of Sysav, "More incineration means cleaner air; we are extremely environmental. Two-thirds of our plant is devoted to cleaning and recovery”. By way of illustrating how clean the exhaust level is, Rylander pointed out that in 1985, when Sweden had 18 incineration plants, they emitted 35 grams of dioxin. But in 2006, with 30 plants, dioxin emissions in all of Sweden are one gram. Sweden in 2016 is running a total of 31 incineration plants.

Equally important in the Swedish approach to MSWM is the need to cut back on waste, especially packaging. The legislation forced companies such as McDonald's and Burger King, who are heavy users of packaging materials, to organize and pay for their recycling.

At the time of the Swedish incineration debate in the 1960s and '70s, not everyone agreed with the concept. But the political will lead to the decision to implement it and since then much has improved. In 2010, it produced heating which corresponds to the need of 820,000 average households, approximately 25 percent of all the district heating produced in the country. It also generated electricity which corresponds to the need of more than 275,000 houses (Avfall Sverige, 2010).

Swedish waste management is an environmental, financial, safe and stable contribution to the country's energy supply, economic sustainability, green environmental policy and resource savings through;

- The generation of as much as 1.1 million cubic metres of oil, which reduces carbon dioxide emissions by 2.2 million tonnes per year. This is as much CO_2 as 680,000 petrol-powered cars emit in a year (Avfall Sverige, 2013).
- The waste sector reduction of emissions of GHGs, which was calculated to the level of 34 per cent during the years 1990-2006. A forecast from Klimatberedningen (the Climate Committee), appointed by the Swedish Parliament and Government, calculated that emissions will fall by 76 per cent during the years 1990-2020 (Avfall Sverige, 2013).
- Increasing the energy from incineration by 300 per cent since the mid-1980s and energy-from-waste (including biofuel) to 500 percent while reducing emissions by almost 99 percent (Avfall Sverige, 2013).
- Earning of carbon credit through the carbon savings from waste-to-energy.
- Financial benefits from imported waste from neighbours who see paying for the disposal a cheaper alternative.
- Financial sustainability through the inflow of capital from various sources – generated energy, waste tax, revenue from imported waste, carbon credit, savings from expenditure as a result of healthy environment, etc.
- Socially acceptable as all citizens are fairly treated in the process.
- Huge financial savings on landfill maintenance and environmental treatment as a result of discharges (gases and leachate) to the environment.

The following contributed to the success (EEA, 2013; Eurostat, 2012):

- The EU Waste Framework Directive of 1975.
- The introduction of Environmental Code, which came into force on 1 January 1999.
- The landfill tax which came into effect on 1 January 2000 made disposal more expensive, hence, played a major role in the decision of citizens to divert MSW from landfill to recycling and incineration. Consecutive increases in landfill taxation level in 2002, 2003 and finally in 2006 instigated a continuous increase in material recycling of MSW.
- 2001 Landfill Ordinance.

- The landfill ban on sorted combustible waste in 2002.
- Landfill ban on organic waste in 2005.
- 2005 environmental objectives setting a target of 50% recycling of household waste by 2010.
- By 2010, at the latest, a minimum of 35 percent of food waste from homes, restaurants, large-scale kitchens, and stores shall be recycled through biological treatment. The objective refers to source separated food waste for both home composting and central treatment.
- By 2015, at the latest, at least 60 percent of phosphorus pollution in effluent shall be treated and used on productive lands, of which at least half should be used on arable land.
- 2006 sharp increase in landfill tax.
- 2006 incineration tax which was introduced to boost further material and organic recycling but was repealed in 2010.
- 2008 landfill compliance according to 2001 landfill ordinance
- The EU 2008 Landfill Directive
- The environmental objectives set by the Swedish Government in 2005 include, among others, the target of 50 percent recycling of household waste by 2010.
- In 2006, in an attempt to encourage recycling, incineration tax was introduced
- Implementation of 2006 EU Directive 1013/2006 regarding transportation of waste
- EU Waste Incineration Directive 2000/76/EC.
- EU Directive on the use of Best Available Techniques (BAT) under both the IPPC Directive (2008/1/EC) and the IED (Industrial Emissions Directive (IED, 2010/75/EU).
- Cooperation between Districts, Cities, and companies in setting up projects that will achieve the environmental targets of the government and also achieve economic viability and sustainability.
- Recognizing the citizens as strong stakeholders in the MSWM and carry them along in all decision making.
- The introduction of secured recycling centres for accurate statistics.
- Implementation of various EU Directives as a member state.
- 2006 Best Available Techniques Reference Document (BREF).

Also, there are over one hundred laws and ordinances that apply to issues related to waste management (Avfall Sverige, 2013).

2.9 Integrated Sustainable Waste Management in New Zealand

The concept of 'integrated waste management is now emerging as a mature strategy to cope with the ever-growing complexities of handling large volumes of solid waste. Within the private sector, many companies that have been particularly associated with one particular technological approach such as recycling or waste-to-energy, are now developing a more integrated concept, responding to the demands of evolving legislation and the needs of local communities. In an integrated waste management, the idea of 'waste' is replaced by a concept of 'resource', combined with a well-organized and controlled waste stream (Van Craen & Van Velthoven, 2007).

This idea of integration is yet to happen in New Zealand as the waste stream is not yet controlled, there is no data on generation. Waste generation is the base data for measuring other performance indicators and planning for better targets.

An integrated waste management policy is based on a combination of waste prevention and avoidance, maximized recycling of used goods, waste re-use, sorting and separate waste collection. Such a concept automatically results in minimized landfilling leaving only a final amount of MSW for further treatment. This is displayed in Swedish scenario, leading to 49 percent incineration and 49 percent recycling.

Van Craen and Van Velthoven (2007) represented the actions in an integrated waste management system in the following way:

- Integrated waste management separates the municipal solid waste into very specific remainder fractions, allowing optimal recycling and energy recovery of each specific waste stream.
- The organic fraction of the waste management is sent through an aerobic or anaerobic process for recycling through composting and energy capture via digestion to biogas
- The non-organic fraction that cannot be recycled or composted is considered for waste-to-energy system through thermal production processes

- Other waste fractions or materials such as inert steel, aluminium, and ash residues are recycled and utilized for other purposes. This may include using the ash as sand or granulate for a multitude of construction purposes, the non-ferrous metals, as industrial salt, gypsum and much more
- Dedicated technologies ensure that every last fraction of the waste can be re-used.

More and more countries and cities around the world (particularly in Europe) are limiting or even banning landfill, driving alternative waste solutions towards combinations of maximum recycling and alternative energy generation.

In New Zealand, there is no comprehensive or statutory integrated framework covering the management of waste and hazardous waste. Though the WMA is the primary legislation, the current management of waste in New Zealand is subject to a combination of other statutes, bylaws and regulations, policy documents and waste management plans. This includes the Resource Management Act 1991 (RMA), Local Government Acts 1974 and 2002 (LGA), and the Hazardous Substances and New Organisms Act 1996 (HSNO) (Environment Canterbury Regional Council, 2014). These legislative combination is contributing to making the management of waste a complex issue.

New Zealand has made some progress in its waste management sector, but a lot still need to be done if integrated sustainable waste management is to be achieved. According to (Ministry for the Environment, 2010, p. 3) “although there have been considerable improvements in access to recycling services and environmental controls around disposal facilities, waste management, and minimization practices still vary around the country, and further improvements can be made”. The volume of MSW to landfill has continued to increase (Figure 4.7). From 2009 when waste disposal levy was implemented, nearly 2.5 million tonnes of waste was disposed. The volume rose slightly to 2.553 million tonnes in 2010, reducing to 2.447 million tonnes in 2012. Since 2012, the disposal volume has continued to increase, reaching 3.09 million tonnes in 2015.

The issues affecting the general progress in New Zealand MSWM are discussed in section 2.9.1 to 2.9.4.

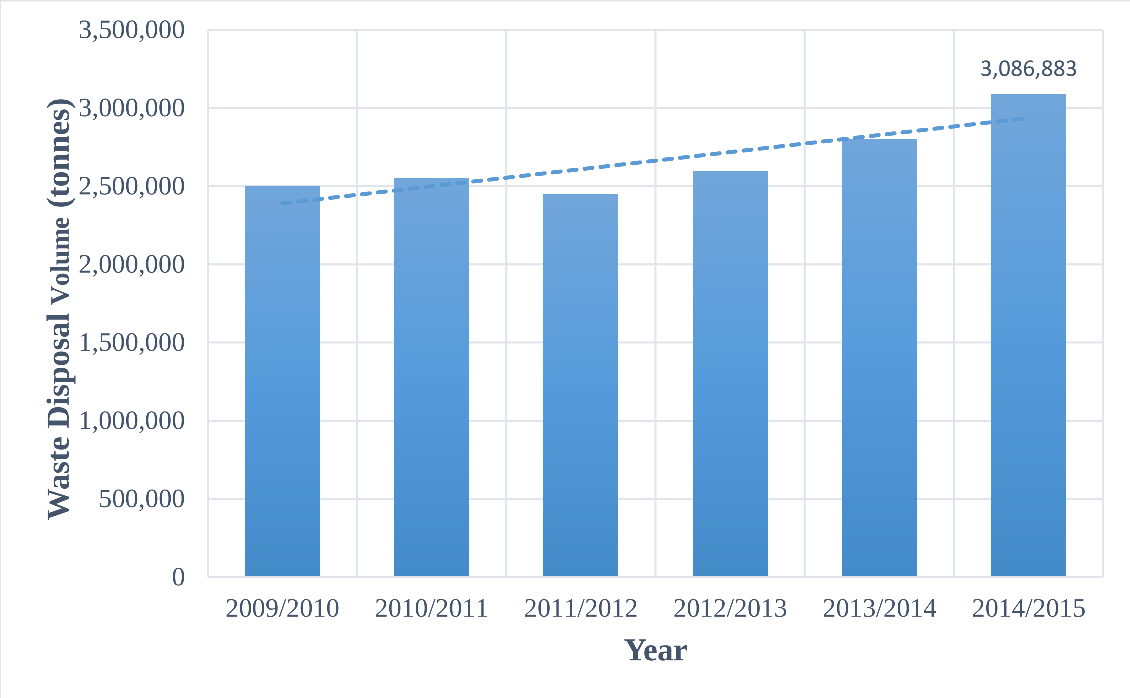


Figure 2.7: New Zealand waste to landfill between 2009 and 2015. Data Source: Ministry for the Environment (2016)

2.9.1 New Zealand Perception of Integration and Sustainability

The Resource Management Act 1991 has one of its objectives, "to promote the sustainable management of New Zealand's natural and physical resources" (Parliamentary Counsel Office, 1991, p. 68). The Act provided for the establishment of national policy direction and standardised planning permitting and enforcement but extends to Local and Regional Authorities the flexibility and autonomy to identify the most suitable and least-cost implementation methods. This is however in line with the Local Government Acts where the Local Authorities have all the authorities to manage their affairs. But the autonomy given to them in Part 4 of the WMA in the sense of sustainability created a fragmented system of RMA implementation, particularly when there is no national policy direction. Each of the local authorities has its local interest to pursue.

Although, this level of powers may be seen as a way of "giving credence to the concept of intergenerational equity referring to the 1987 Brundtland Commission's definition of sustainable development and imploring current generations to consider the impact of their actions on future generations" (Frieder, 1997, p. 7). But the fragmentation of the implementation of RMA, waste management strategy, and WMA is working against integrated environmental management which provides a suitable framework for identifying and resolving complex resource problem which may escape undetected in non-integrated management approach. According to Frieder (1997, p. 8), “just as the concept of sustainable management provided a basis for rationalising resource policy development; the idea of integrated management can and should form the basis for streamlining resource policy implementation”. The rationalisation of resource policy implementation is achieved in integrated management through the coordination of the actions of multiple management agencies, removing redundancies, consolidating information, improving communication, and promoting a holistic understanding of the environment. Therefore, the situation where every territorial authority draws its waste management plan without considering some of the national environmental policies does not augur well and should be addressed.

Integration also allows the waste stream to pass through all management processes before the residual waste is disposed to landfill. To allow this to happen, all stakeholders work together to accept different fractions of the waste stream into their system. The disposed waste must have passed through the whole system to emerge as a disposable fraction.

Section 543 of the Local Government Amendment Act 1979 states that a territorial authority may permit any other territorial authority or regional council or united council to use any refuse disposal service or refuse disposal works operated and maintained by the council (New Zealand Legal Information Institute, 2013a). This is equally the case in section 56(1)(e) of WMA (New Zealand Legislation, 2008, p. 31). This is against the principles of integrated sustainable waste management and has a negative implication on New Zealand waste management strategy.

If it is understood that MSW is a local challenge with global impact (US EPA, n.d), New Zealand will need to harmonise its waste management plan, following the EU strategy. Therefore, the Ministry for the Environment should as a matter of urgency, implement sections 48 and 49 of the WMA (New Zealand Legislation, 2008, p. 27) by setting a National standard which should be applied by all territorial authority within a time frame. There may be a need for a staggered implementation of such policy since the prevailing circumstances may vary from Council to Council. Take the Landfill Directive of the EU (Council Directive 1999/31/EC) (European Communities, 1999a) as an example. The advantage of this is that there will be a harmonised integrated system taking the entire country as an entity. That is what we mean by an integrated sustainable system.

There is the need to implement section 51 of WMA which is on waste assessment. Subsection (b) is talking about the forecast of future demand for the MSWM systems. Therefore, characterization is a critical issue if a useful forecast can be made. The characterization should be based on source generated data, not disposal data as is practiced now, not on samples collected from landfills as practiced currently.

The present practice of some of the Territorial Authority s is shifting the local environmental burden of their waste management practices to other parts of the country. But, only a few burden like soil contamination can be localised. The burden of air pollution has no boundary. The understanding of this theory will change their perception of integration and sustainability.

2.9.2 Implementation of the Waste Management Hierarchy

Part XXXI of the Local Government Act was enacted through a 1996 amendment Number 84, (New Zealand Legal Information Institute, 2013b). The Act was able to establish a Waste Management Hierarchy with five management levels in the order of priority starting with Reduction as the most preferred, followed by Reuse, Recycling, Recovery, Treatment and Disposal as the least preferred. This is better than WMA which gives a general directive to Territorial Authorities to "promote effective and efficient waste management and minimisation within their district" (New Zealand Legislation, 2008, p. 25). The 'effective and efficient waste management' should be embedded within the Territorial Authority's waste management and minimisation plan. In so doing; (a) have regard to environmental and economic costs and benefits for the district and (b) ensure that the management of waste does not cause a nuisance or be injurious to health. It directed that the waste management plan shall be made following the Waste Management Hierarchy as established and amended from time to time as deemed right by the territorial authority. But the entire waste management plans that are currently being run by all the Territorial Authorities have not been able to implement the Waste Management Hierarchy. Hence, recovery has been ignored for disposal. The implementation of Waste Management Hierarchy will see waste-to-energy projects in New Zealand in the form of combined power and heat projects or bio-fuel.

Public awareness is needed to educate the populace to understand that waste recovery systems are more environmentally friendly than prescribed by law. The available waste-to-energy technologies are different from incineration (UK Institute of Mechanical Engineering, n.d). Therefore, a waste-to-energy technology is no longer a threat to the environment and human health as incineration (Avfall Sverige, 2013; German Federal Ministry for the Environment Natural Conservation and Nuclear Safety, 2005).

For example, Table 2.4 shows the statistics of emission from various sources in Germany in the year 2000, compare to 1990 and 1994. The illustration shows that between 1990 and year 2000, the reduction in dioxin resulting from waste-to-energy reduced by 99.9 percentage. This is a result of emerging technologies which is taking care of general emission cleaning in waste-to-energy systems.

Table 2.4: Dioxin emission sources in Germany, annual dioxin loads, in grams per toxicity unit (g TU)

Emission per year in g TU (toxicity units)				
`	1990	1994	2000	Percentage change between 1990 and year 2000
Metal Extraction and Processing	740	220	40	-94.6
Waste Incineration	400	32	0.5	-99.9
Power Stations	5	3	3	-40
Industrial Incineration Plants	20	15	<10	-55
Domestic Firing Installations	20	15	<10	-55
Traffic	10	4	<1	-91
Crematoria	4	2	<2	-52.5
Total Emissions, Air	1,200	330	<70	-94.3

Source: German Federal Ministry for the Environment Natural Conservation and Nuclear Safety (2005)

Table 2.5: Emissions from large and small MWC unit (impact of technology on waste-to-energy emissions)

Pollutant	**1990 Emission (tpy)**	**2006 Emission (tpy)**	**Percentage Reduction**
Dioxins/Furans, TEQ basis (*)	4,400	15	99+%
Mercury	57	2.3	96%
Cadmium	9.6	0.4	96%
Lead	170	5.5	97%
Particulate Matter	18,600	780	96%
HCl	57,400	3,200	94%
SO2	38,300	4,600	88%
NOx	64,900	49,500	24%

(*) dioxin/furan emissions are in units of grams per year toxic equivalent quantity (TEQ), using 1989 NATO toxicity factors; all other pollutants emissions are in units of tonnes per year. Source: US EPA (2007)

Table 4.5 illustrates the impact of waste-to-energy technology on emission from large and small municipal waste combustion, as released by US EPA (2007) (US EPA, 2007). The result showed that all major fractions of the gases have gone down drastically between 1990 and 2006. The position is the reason for the environmental friendliness of waste-to-energy technologies.

2.9.3 Legislative Impediments

In line with the expected implementation of certain sections of RMA and WMA, there may be a need for a review or outright enactment of new laws or by-laws which will set national targets in MSWM. These targets will indicate the direction of New Zealand waste management strategy. The expectations are that the new legislation will look at environmental, economic and social pressures and impacts, which often cut across MSWM system and strategy. They will equally consider the links between environmental impacts and regional/sectoral policies, look at a broad range of options and a varied policy mix, including the use of market-based instruments, technology, and innovations to deal with the problems that are being confronted in the present scenario.

The current waste legislation in New Zealand is more centred on individual TAs than on New Zealand as a country. There should be a shift to national objectives and standard. This will impact on the prosperity of the country, impacting on the national environmental standards and create an integrated approach to pollution control.

2.9.4 Lack of Data

The absence of data on waste generation, composition, and recovery rate has been emphasized (Ministry for the Environment, 2007a, 2007d) and the situation has not changed. Therefore, waste inventory development should be given the attention it deserves. This will include source identification, quantification, and characterization of the waste. This can be achieved through collating the available data where they already exist and field monitoring and analysis to develop good baseline data on waste generation and recovery.

Recognising the importance of waste data, the EU Regulation (EC) No 2150/2002 of the European Parliament and the Council of 25 November 2002 on waste statistics (European Union, 2002) was enacted. This Regulation empowered the municipalities and created a framework for the production of community waste management statistics. This framework provides the European Union (EU) with regular and comparable data to monitor the implementation of the city policy on the generation, recovery and disposal of waste.

Ministry for the Environment (2007c) recognised the need for enhanced data collection and improvements in waste monitoring and reporting. The report agreed that to achieve an accurate picture of waste collection, disposal, and recycling across New Zealand; it may be necessary to introduce mandatory waste data collection and reporting. The 2007 OECD review of New Zealand's environmental policies has similar conclusions about New Zealand's approach to waste management (OECD, 2007).

The OECD review though noted some progress in landfill standard, recognised the need to address the following:

- The increasing rate of MSW generation with no sign of decoupling from GDP.
- The fragmented legislative and institutional framework for waste management.
- Current legislation that mostly deals with the disposal end of the Waste Management Hierarchy. The issue of recycling, recovery and minimization are handled solely on a voluntary basis. This idea is making it difficult to take a cradle-to-grave approach to materials management.
- The limited economic viability of recycling of a range of materials because of the distance from larger markets is making recycling activities vulnerable to collapse

- Lack of aggregated waste management information at all level is hampering New Zealand MSW strategic planning.

The OECD review specifically recommended the following:

- The expansion and upgrading of waste management infrastructure and applying waste disposal tax through the polluter pays principle.
- An increase in regulatory support for recovery and recycling, which may include deposit-refund systems of priority waste which may also involve producers. In New Zealand, this is known as product stewardship and involves producers or manufacturers taking part in managing waste resulting from their products.
- Creating standard through the strengthening of the strategic monitoring mechanism for waste generation and treatment, to ensure baseline consistency of the entire methods used at a local level to facilitate data aggregation and periodic reporting of the main environmental indicators at all levels.

These reviews clearly demonstrate the need for further work on waste reduction if New Zealand is to achieve the social, ecological and economic gains to be made from the efficient use of resources, reducing waste and improving its beneficial reuse. In devising a new strategy for waste monitoring, and reporting, data is needed at all point of the waste management processes to facilitate strategic planning and management (Ministry for the Environment, 2007b). Addressing the data need of New Zealand waste management system will help in this direction.

2.10 Measuring Performance Indicators

To be able to assess the success of any waste management plan, it is standard practice for decision makers to set goals and targets as a means of measuring success and failures and as a guide in reviewing the policies. Examples of this are captured by the New Zealand waste strategy which was first published in 2002 as a long-term strategy to help reduce and better manage waste in New Zealand (Ministry for the Environment, 2004b). But unfortunately, Ministry for the Environment (2004a) observed that information available for setting and measuring these targets was poor. It also noted that while some of these objectives should be readily achieved, others may be difficult and perhaps even impossible to achieve.

The targets covered some priority waste management areas like;

- waste minimization
- organic waste
- special waste
- construction and demolition waste
- hazardous waste
- contaminated sites
- organochlorines
- trade waste
- waste disposal.

But the level of success or failures could not be measured because of a general lack of data on which the targets were based. Hence, the objectives were speculative (Ministry for the Environment, 2004b) and there is no specific, measurable goal. Compare the scenario with the Swedish situation where specific targets are set, like recycling 50 percent of household waste and recycling 35 percent of food waste (Section 4.6).

"You can't manage what you did not measure" (Peccoud, 2014; Potter, 2013; Sustainability Roadmap, n.d.; The Chartered Institute of Purchasing & Supply, 2007) is an old management adage which is still accurate today. So unless something is measured, it is difficult to accurately determine if it is getting better or worse. System improvement may not be achieved if we are unable to develop measures to determine its progress (Reh, 2014). Measurement is the most effective way of managing and preventing negative side effects of a system (WRAP UK, 2012). This applies to waste management systems. The need for waste data collection includes:

- To facilitate a consistent and coordinated approach to data collection, which will allow for better waste characterization and classification of the waste streams, the quantity of waste that is generated, volume of waste diverted from landfill, a number of resources recovered and materials recycled.
- To facilitate waste management strategic planning, help in sound financial budgeting and cost control for all levels of government.
- To facilitate the identification of priority areas and opportunities to increase resource recovery.

- To measure progress, that is made in all sectors of the waste management system, including resource recovery (Environment Protection Agency (TAS), 2013).

This will enable the development of better waste prevention strategies, and enhance the recovery opportunities presented in waste composition. Improved data collection and data management systems will also provide a robust framework, reliable, on which to measure the progress of initiatives and actions designed to meet the objectives of the system at both local and national level (Environment Protection Agency (TAS), 2013). This will enable meaningful, achievable and realistic targets to be set.

Presently, some of the goals as embedded in New Zealand waste management strategy are national goals, but their achievement is significantly dependent on the actions of Territorial Authorities and other stakeholders. The Ministry for the Environment as the umpire assumes that Territorial Authorities would take action through setting their targets in ways that contribute to the national targets. The National Council of Local Government in New Zealand advised local authorities to adopt the strategy as the basis for their programmes, policies, and plans (Ministry for the Environment, 2004b). But the lack of legislative obligations is seen as one of the major hindrances in achieving the set targets.

At the regional level, the Ministry for the Environment (2004b), identified one initiative, encouraged through the New Zealand Waste Strategy, which is the development of regional approaches to waste management planning. Waikato, Auckland, Taranaki and Bay of Plenty regional councils have facilitated regional approaches to waste management planning directly involving the Territorial Authorities within their regions. The Ministry for the Environment is also working with West Coast Regional Council to develop a regional approach similar to those of Auckland, Waikato and Taranaki regions, in their waste management planning. These initiatives will enable coordinated projects on waste data collection and public information. The ability to measure progress towards targets at a regional level will make it easier to measure progress at national level.

In other parts of the country, such as Canterbury and Southland, groups of territorial authorities have also been cooperating and collaborating in the development of joint policies.

The difficulties in achieving these specific targets, lead to the decision to take a flexible approach with two broad goals in 2010 (Ministry for the Environment, 2010);

- reducing the harmful effects of waste
- improving the efficiency of resource use.

The flexibility approach is to ensure waste management and minimization activities are appropriate for the local situation.

Meanwhile, the review of the targets in 2006 (Ministry for the Environment, 2007c) recognised that despite some successes, waste minimization, and management practices are still widely variable, and the challenge now is to ensure a consistently high level of service throughout New Zealand. The report also pointed the urgent need for enhanced data collection and improvements in waste monitoring and reporting.

Even in areas where Council measurement of waste disposal and recycling has improved, it is still difficult to compare data from different areas due to the lack of standardised monitoring and reporting criteria by Territorial Authorities and waste and recycling operators. To achieve an accurate picture of waste collection, disposal and recycling across New Zealand it may be necessary to introduce mandatory waste data collection and reporting. Hence seeking the need for;

- sound legislation
- high environmental standards
- efficient pricing
- adequate and accessible information
- the efficient use of materials

But it can be argued that specific targets are easily assessed and measured based on local needs and situation. That is reflected in EU Landfill Directive (1999/31/EC) (European Commission, 2012) which set targets for bio-waste and another biodegradable waste disposal in EU countries. The Landfill Directive, however, obliges the Member States to reduce the amount of biodegradable municipal waste that they landfill to 35 percent of 1995 levels by 2016 but extending the deadline to 2020 for some countries because of varying local situation. Countries like Sweden implemented the targets using a mix of local legislation, choosing performance indications and local incentives (Avfall Sverige, 2009, 2010, 2013).

In the midst of a lack of data which is still plaguing waste management sector in New Zealand, measuring the successes or failures of waste management targets is difficult. But one thing common with all waste stream is movement (transportation) to point to treatment or disposal. This can be the basis for measurement.

Therefore, this research recognises transportation as a critical component of any waste management system as all waste must be transported to the treatment or disposal point from the point of generation. Transport and energy consumption can be used as means of measuring progress on set targets and assessing the level of integration and sustainability of the waste management network over time. This is true as the load is directly influenced by the impacts associated with transport (Bovea et al., 2007; Eisted, Larsen, & Christensen, 2009; Salhofer, Schneider, & Obersteiner, 2007) measured regarding emissions. Therefore, the quantity of waste that is transported can be measured as a performance indicator. Accurate quantification and detailed documentation of emissions data from MSWM enable a city or region to demonstrate transparency in its waste management system and enhance the credibility of its corporate environmental and climate change strategy.

Establishing a comprehensive emissions inventory is an important step to take in planning/developing an environmental and climate change monitoring strategy. This is justified if adequate resource utilization and environmental implications are considered as important factors in planning the collection, transportation and treatment/disposal of MSW, hence developing a city-wide, regional or national Integrated Sustainable MSWM system.0

The research presents the best practices in establishing the organizational and operational boundaries of an MSWM scenario emissions inventory in a sustainable city, region or national environment, using selected landfills in New Zealand. Site dependent data for the landfills together with the Territorial Authority's waste composition are used with associated collection, transportation, and treatment/disposal data, to determine the emission levels associated with the waste flow system up to the landfills. Hence, the environmental profile of the landfills and other waste management processes are evaluated and compared in relation to each other.

2.10.1 Emission Reporting

Presently, as a result of New Zealand commitment to the UNFCCC, it is the duty of the country to report the emission scenarios from various activities to UNFCCC as a means of responding to global climate change (NZ Parliamentary Library, 2001). This resulted in the establishment of the emission trading scheme (NZ ETS) which the waste management sector joined in 2012 (Ministry for the Environment, 2011). To be able to comply with the reporting requirements in the midst of a lack of requisite data, a default methodology has been established and adopted based on ‘mass balance’ approach of 1996 IPCC Guideline on GHG reporting (Ministry for the Environment, 2011). This methodology considers one emission factor for all waste disposed of and does not consider emissions from other activities or processes within the waste management system. Therefore, in considering the possibility of measuring the sustainability level, this system of reporting does not capture the exact emission level of the waste management system.

This thesis, therefore, provides guidance (suggestions) on continuous reporting, improvement, and maintenance of the emissions inventory in the MSWM sector to guide stakeholders in reducing the impact of MSW through an integrated sustainable manner. The need for zoning MSW collection/transportation and treatment system using available disposal/treatment/recovery sites as focal points is therefore advocated. This will simplify the present complex nature of WM collection and transportation system. A modified generalized emissions inventory model for the MSW sector is suggested.

2.11 The Expectations of Integration and Sustainability

Integration provides a platform for the waste stream to pass through all management processes before the residual is disposed of. Integration also encourages corporation among practitioners and Territorial Authorities. This partnership may lead to agreements that will result in better service delivery for consumers of waste management services. Therefore, the application of new technology in the midst this partnership will reduce environmental impact and increase resource utilization, contribute positively to both local and national economy and become more socially acceptable.

The case of Sweden as described in Section 4.6 is a case in point of how the unity of purpose and transparency helps in achieving sustainability.

One problem working against the introduction of waste-to-energy in New Zealand is the sparse nature of some of the cities and smaller settlements. Cooperation among the regions and TAs in New Zealand will increase the viability of a waste-to-energy technology through a sustained supply of required quantity of waste. The expected scenario where waste-to-energy is implemented will lead to greater adherence of New Zealand to Kyoto Protocol targets as carbon credits will be earned to offset the deficit that may be derived from other sectors of the economy producing emissions. To achieve these set goals, the country will be seen as a unit factor in the planning, and management of MSW, streamlining all stages of waste management sector (collection, transportation, storage, recovery, and disposal) so that they become economically viable and sustainable, socially acceptable, and environmentally friendly.

Timeline database will be built to enhance the future planning and management of New Zealand MSW system leading to sustainability. This can be achieved through a radical change in waste data collection. The adoption of the ontological framework developed in this thesis will contribute to better data collection and definition of standards.

2.12 Conclusion

Unlike some other countries and regions of the world like the US and the EU, New Zealand has no environmental protection standards at national level. The introduction of national environmental standards will provide an equal bottom line health protection for all New Zealanders. National environmental standards have been advocated by the industrial players to give both a level playing field across regions and certainty in decision-making under RMA (Ministry for the Environment, 2004a).

The introduction of Resource Management (Energy and Climate Change) Amendment 2004 confirms Government’s recognition that emissions of GHG are better controlled at the national level. The Act “aims at national co-ordination by removing the power of local government to consider the effect of GHG emissions on climate change when making rules in regional plans, or when determining air discharge consents (except where it is required to implement a national environmental standard)” (Ministry for the Environment, 2014, p. 5). Hence, it is necessary to prescribe minimum standard in waste data collection and general practices in waste management, which is contributing to the GHG portfolio of New Zealand.

Lack of funding was identified as a significant barrier to progress in waste diversion and recovery. The implementation of Waste Management Hierarchy and use of waste-to-energy will increase the financial profile of New Zealand waste management sector since resources will be saved which should have been used in fossil fuel. The generated power will bring in income, and the emissions savings can be traded in the global emission market to generate revenue.

The EU Council Directive 96/61/EC of 24 September 1996 (European Union, 1996) concerning integrated pollution prevention and control, discourages the shifting of pollution between the various environmental media rather than protecting the environment as a whole. Therefore, establishing a general framework for integrated pollution prevention and control to achieve a greater level of protection for the environment as a whole through the application of the principle of sustainable development is the way out. New Zealand can make lots of success by considering the entire country as an entity and enact legislation similar to EU proximity principle (European Communities, 1999b) and implement the Waste Management Hierarchy fully and at the national level.

The problem of the small and dispersed populations in New Zealand towns (Ministry for the Environment, 2010) can be reduced through the economy of scale when accurate waste data is available resulting in an integrated sustainable system. The National strategy will be developed to carry all towns and cities along, and the integrated sustainable system is drawn up to serve everybody.

Therefore, a well thought ISWM will create up to date MSW inventory, which will enable adequate planning and sound management of the residual MSW in a manner that is economically viable, environmentally friendly, and socially acceptable with minimal health impact, without any shift of burden.

A healthy environment, demands an integrated approach that involves the complementary use of a variety of practices to handle the MSW stream safely and efficiently with the least adverse impact on human health and the environment. An integrated approach would be adopted to dispose of the MSW generated in the cities as the approach amalgamates three stages of MSWM. The adoption of this method would streamline the collection of MSW from diverse generating points in the country and transport them to the treatment facilities. The residual waste resulting from composting and other management methods would then be disposed of in a scientific landfill.

The integrated approach is vital for the MSWM to work efficiently. A well-integrated approach captures the primary collection, secondary collection and treatment and disposal; add value by vertically integrating the MSW process (iDeck, 2009). An integrated approach would reduce the illegal dumping, the littering on the streets, roads, and parks. The integrated sustainable system will also enhance the cleanliness of the cities, and increase the viability, profitability and sustainability of MSW systems through their impact on rising incomes, employment while reducing pollution levels.

CHAPTER THREE

REVIEW OF INTERNATIONAL FRAMEWORKS AND MSWM

3.0 Introduction

Chapter two was able to identify the true definition of integration and sustainability. But to achieve this two basic concepts, municipalities and countries require guidelines to point to the direction of the intended waste management policy. These guidelines are built in the form of rules to help stakeholders understand their roles. At the international arena, rules are made in form of protocols and agreement which are referred to as frameworks. This chapter reviews some of the frameworks that impacted the implementation of waste management policies around the world, both nationally and at the municipal level.

Municipal waste is a major contributor to the global environmental crisis because poor waste management is a major source of greenhouse gases (GHG). To help address the environmental challenges associated with waste management, some international agreements and protocols have been developed to help regulate how waste is managed to reduce its negative impacts. In this chapter, we review some of the key international frameworks which have been developed since the 1970s to help mitigate the negative impacts of municipal waste globally. The chapter provides a critique of the contesting and also changing definitions of waste and waste management, critically examines the evolution of waste management in New Zealand from the late 19th –to– the early 20th century. The greater part of the chapter identifies some of the key New Zealand legislation and policies and examines how major international protocols and frameworks have shaped the development of New Zealand policy frameworks on waste management.

3.1 Changing Definitions of Waste and Waste Management

A number of factors affect the dynamic nature of waste management, namely population, human behaviour, technology, legislation, to mention a few. The concept of ‘waste’ itself has changed over time. Historically waste was generally conceived of as ‘rubbish.' It may be argued that the use of the word ‘rubbish’ is a reflection of society’s perception of waste as having no value. The perception of waste as rubbish also informed the lack of organised waste management systems. The perception of waste as rubbish began to change as society's understanding of waste shifted and new forms of managing waste emerged. For example, waste was recognised as a health hazard in New Zealand in the late 1860s, which led to waste being defined as 'nuisance' (New Zealand Legal Information Institute, 2013d, p. 182) because it constituted a public health nuisance. The term nuisance may be considered to be a reflection of society's behaviour and attitude towards waste. The reference to waste as rubbish was re-defined in 1968, as 'Litter' (New Zealand Legal Information Institute, 2013f, p. 1106), because of the prevailing indiscriminate dumping of MSW in urban and rural communities across New Zealanders. In 1979, the Litter Act broadened the definition of 'litter' from mere rubbish to include waste components and materials like animal remains, debris, glass, garbage, dirt, filth, rubble, stones, refuse, rubbish and metals, constituted litter.

This dynamism in the meaning of waste was reflected in the definition of 'disposal' in a 1979 amendment to the New Zealand Local Government Act of 1974. The amendment expanded disposal to include treatment and recycling (New Zealand Legal Information Institute, 2013i, p. 888).

The Waste Management Act (WMA) is New Zealand's major national waste management legislation: (New Zealand Legislation, 2008, p. 8), defines waste as;

- "anything disposed of or discarded; and
- includes any waste that is defined by its composition or source (for example, organic waste, electronic waste, or construction and demolition waste); and
- to avoid doubt, includes any component or element of diverted material, if the component or element is disposed of or discarded" (Waste Management Act, 2008, Section 5(a)).

The definition of waste under the WMA appears to align with the Waste Framework Directive (WFD) (Directive 2006/12/EC) (European Union, 2006), as amended by the new Waste Directive (Directive 2008/98/EC) (European Union, 2008, p. 9), which places emphasis on the word 'discard' to define waste. Thus was is defined as: "Any substance or object which the holder discards or intends or is required to discard" (European Union, 2008, p. 9). The word 'discard' has been controversial since the directive did not clearly explain ‘discard’ means. Thus some schools of thought argue that ‘discard’ should not include materials with economic value while others argue otherwise (Gaia, 2004).

The complexities in reaching a comprehensive definition for waste are reflected in the recorded opinions of nations and organisations globally. For example, the United Nations Statistics Division (UNSD), The Organisation for Economic Cooperation and Development (OECD) (OECD, 2003: March 17), define waste as:

> *Materials that are not prime products (that is, products produced for the market) for which the generator has no further use regarding his/her own purposes of production, transformation or consumption, and of which he/she wants to dispose of.*

This OECD definition is uni-centric in nature, considering only the point of origin of the material. Even if the generator of waste can pass this ‘waste’ on for reuse, the items are considered to be a waste. Similarly, the Basel Convention (UNEP, 2004b, p. 38), defined waste as:

> *Substances or objects which are disposed or are intended to be disposed of or are required to be disposed of by the provisions of national laws.*

On the other hand, Zero Waste America (n.d), defines waste as:

> *A resource that is not safely recycled back into the environment or the marketplace.*

The Zero Waste America definition considers waste, not as ‘rubbish’ but as a resource of value, although is poor management constitutes a threat to the environment and public health, particularly with unsafe disposal and recycling practices. This definition of waste as a resource suggests a need for strong emphasis on a comprehensive approach to waste management practices which incorporate the five management priorities identified in the New Zealand waste management legislation (1996) reduction, reuse, recycling, recovery, treatment, and disposal discussed in Chapter One above. These different conceptualisations of waste have led to the development of hierarchies or categories of waste. These are examined in the following section.

3.1.1 The Conflicts

Notwithstanding the disagreement on the meaning of “discard” and “dispose of”, the WFD accepts that some categories of waste cease to be a waste - Article 6 (End-of-waste status) - after going through a recovery operation (Article 10). Hence, categorizing waste management operations as being either a “recovery operation” or “disposal”. The Guideline on the interpretation of the R1 Formula notes marks a shift away from thinking about waste as an unwanted burden (rubbish or litter) to seeing it as a valuable resource (European Commission, 2011). The R1-formula can be deduced from the energy calculation formulas presented in BREF WI (Annex 10.4.4) (European Commission 2012, p.21).

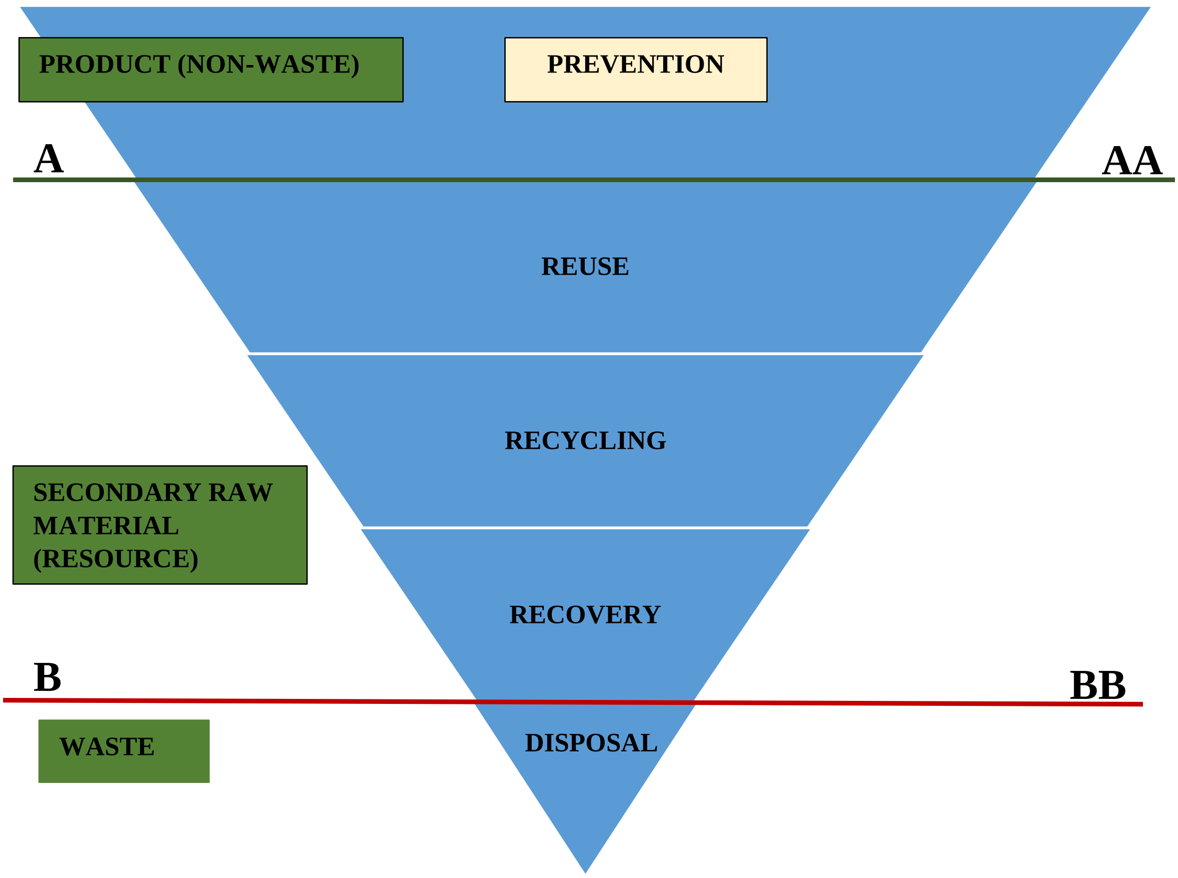


Figure 3.1: Five-step Waste Management Hierarchy that underpins definition of waste

This thesis adopts the EU Directive in defining municipal waste management. The Directive establishes a five-step waste management hierarchy according to their level of environmental friendliness, from (i) prevention as the most preferred, through (ii) reuse,

(iii) recycling, (iv) recovery and (v) disposal as the least preferred, (Figure 3.1). The deviation, however, is the conceiving of a definition of waste.

The general concept of waste categorizes all material from ‘A – AA’ on the Waste Management Hierarchy (Figure 2.1) covering Reuse down to Disposal. But this research categorizes waste as all residual materials that are disposed of in landfills as demarcated by ‘B – BB’ in Figure 2.1. Hence waste is defined in this thesis as:

> *Residual materials resulting from human activities which cannot be reused or recovered as a resource, recycled into material production processes or thermally/biologically utilized for energy production.*

The principle behind this definition is represented in Figure 3.2. Based on this definition, the activities in Waste Management Hierarchy is divided into the three groups defined in Figure 3.1. At the level of ‘prevention’ waste is yet to be created. The second group is called ‘secondary raw material’ because it is still possible to put the materials to a useful purpose. The third group is one where the materials are confirmed to be not useful and are therefore only suitable for discarding or disposal as waste.

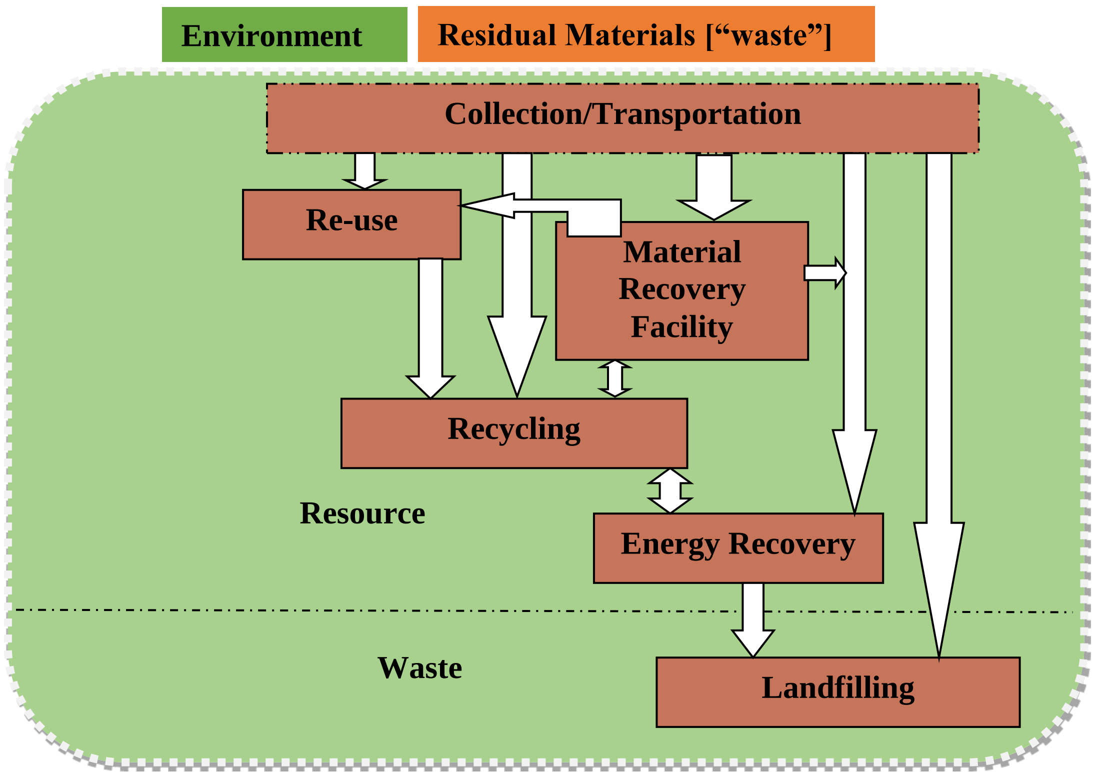


Figure 3.2: Material flow diagram based on this researcher's novel conception of waste

Figure 3.2 shows the possible flow/movement of materials within the system, from the original owner. At the point of the owner discarding the material, it is tagged as 'waste'. But it is possible in this system for waste to be relabelled as a resource depending on the path that the waste takes through the waste management process. The point at which the material is definitively waste occurs after any potential energy recovery occurs (at this point the material has been deemed as waste by the authority responsible for waste management (collection and disposal) or at the point of collection (usually in this case the waste has been deemed as non-recoverable by the owner of the waste). At the landfill point, materials have been determined to be unsuitable to be reused, recycled or used as feedstock in a waste-to-energy system for energy recovery.

As this thesis focuses on municipal solid waste management, it is important to provide a brief definition of what we define as municipal solid waste. Although the definition of MSW varies and conflicts from country to country, the diagram in Figure 2.3 provides an overview of what constitutes MSW. In the United States of America, MSW is more commonly known as trash or garbage, and consists of everyday items used and then throw away. Such items include product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries. MSW includes all solid waste from homes, schools, hospitals, and businesses (US EPA, 2014). In both New Zealand and the EU, construction and demolition waste are included in MSW (European Environment Agency, 2000; Ministry for the Environment, 2009b, 2011c).

In section 3.1.2 we provide a more detailed examination of the different types of waste.

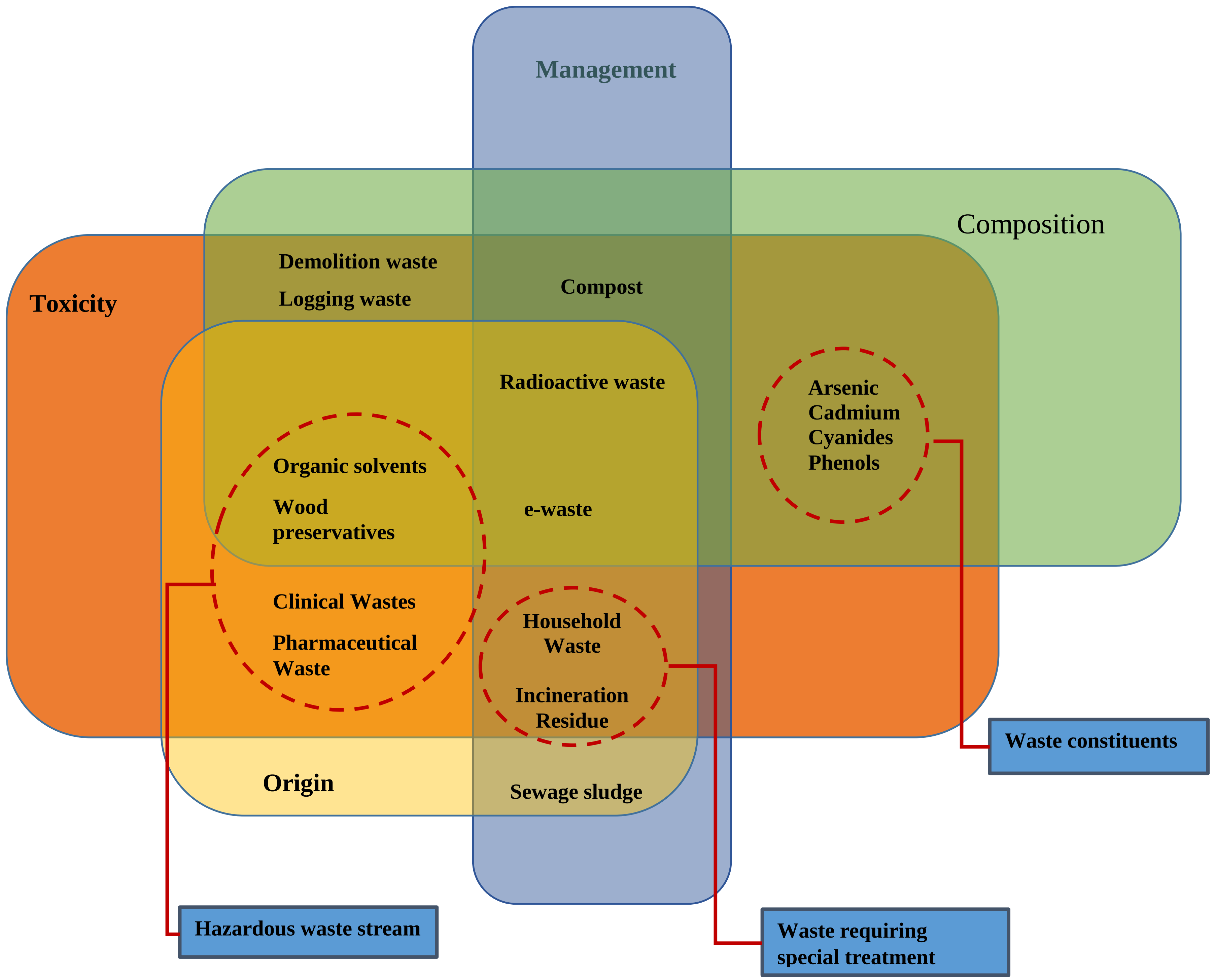


Figure 3.3: Overlapping definition of municipal solid waste. Source: UNEP (2004b)

3.1.2 Types of Waste

Waste is normally classified as liquid, solid, or gaseous waste and in any of these states could be hazardous or harmful (Figure 3.4). For example, liquids may be highly flammable, reactive (can easily explode when exposed to heat), corrosive and/or toxic. Figure 2.3 illustrates the overlap between these three types of waste and the transitions which can occur between types. These transitions often lead to hazardous forms. For example, solid waste can burn, emit particulate matter and gases and leave ash residue. The solid ash will become sludge when exposed to rainfall and other liquids in the waste system before completely turning to liquid waste. This liquid waste can turn into spray-drift during the process of becoming gaseous waste. At any stage in the changing state of waste, it can become hazardous.

Figure 3.4: Overlapping types of waste. Source: Ministry for the Environment (n.d-a)

According to UNEP (2004a), the industry at each stage of the production process generates a specific type of waste as a result of:

- Extraction and transportation of raw material
- Manufacturing and production of goods (including building construction)
- Distribution and consumption of manufactured products.

The UNEP document goes further and describes municipal waste as any waste materials, including those resulting from production, which is collected and treated by municipalities. Such waste is typically generated by households, small businesses, commercial enterprises and other municipal activities.

In summary, the state of the waste material can be distinguished by taking into account the management process, composition, origin, and toxicity (Figure 3.4). Overlapping conditions may also exist between categories so for example, radioactive waste can be a factor in the management, composition and toxicity of waste.

3.2 Waste Management

Waste management should encompass the collection, transportation, processing or disposal, managing, and monitoring of waste materials to minimize the consequences on human health and the environment. There are several methods for managing the various types of waste. Five basic means of dealing with waste have been used over and over in history; dumping, burning, reuse, recycling and waste minimization. Some of these waste management methods can cause additional harm to the environment. But not doing anything as a result of the negative impact of management methods is not a solution.

Waste management did not emerge as a system until about early eighteenth century, which was the peak of poor waste management in Europe, North America and around the world. Without any argument, poor waste management contributed to some of the epidemics of the past, like Bubonic Plague, cholera, and typhoid fever, to mention but a few. At that time, the only solution was to get the waste out of sight by setting them on fire in the open after taking anything that is saleable and reusable. The pressure to enforce changes in the system which can increase environmental standards has resulted in the emergence of legislation.

In response to this legislation, visionaries, through research and development, have developed various tools and methods which are adopted in managing MSW aimed at reducing the negative impact of waste on the environment and health of citizens. Even where this legislation is absent, the “visible and political sensitivity of waste management on the credibility of a public administration” (van de Klundert & Anschütz, 2001, p. 9), is another impetus to strive to put things right in waste management sector. Therefore, the social, economic, cultural and environmental needs of cities and nations about MSWM determines how to respond to waste management.

The concept of waste as rubbish explained in Section 3.1 led to other legislation targeting specific waste categories and conditions (European Commission, 2012). However, increasing concerns about resource depletion and the socio-economic, cultural and environmental impacts of growing waste encouraged global, national and local community movements towards a more holistic approach to effective waste management. It was in this context that the idea of the 3R's (reduction, reuse, and recycling) became central to waste management (Figure 3.5). The 3R's are in fact only part of the five-stage Waste Management Hierarchy discussed in Section 3.1.1, and seek to extract the maximum practical benefits from products and to generate the minimum amount of waste.

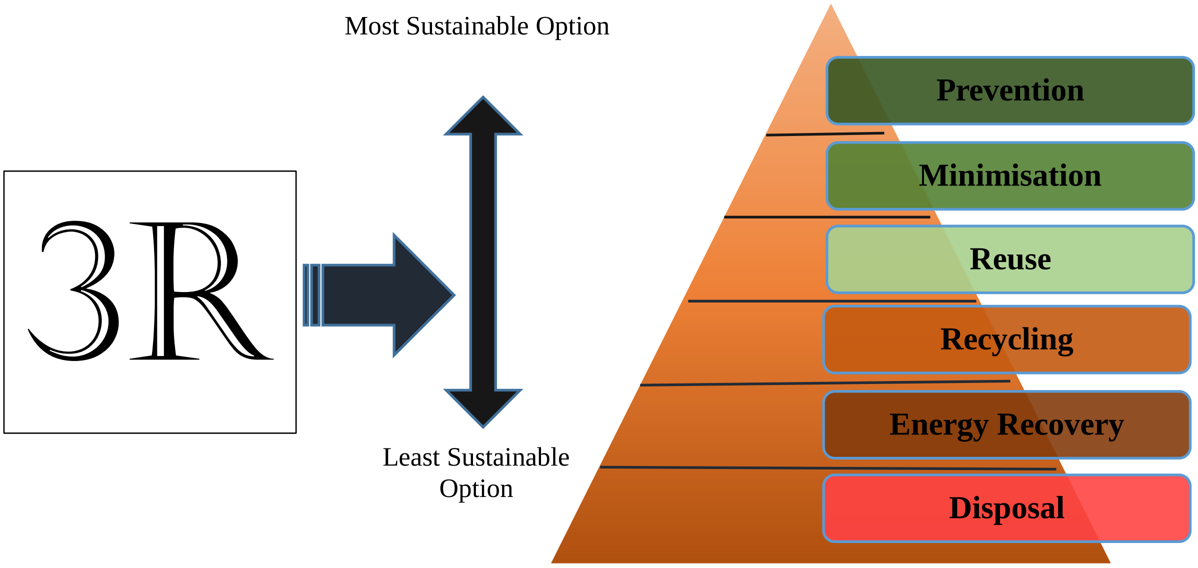


Figure 3.5: From 3R to a deeper Waste Management Hierarchy.

Source: Drawn by the author

Concerns related to the contribution to overall GHG emissions by landfilling and the resistance of people against landfills being located in their neighbourhoods encouraged greater efforts toward the reduction of the volume of waste being introduced to landfill. These drivers have resulted in innovations in the utilization of landfill gases. For example, treating methane gas emitted from decomposing garbage to produce electricity, heat, and fuels. Such methods are known as waste-to-energy processes (World Energy Council 2013; Pike Research, 2012; Plastics New Zealand Incorporated 2012; Rotter, 2011). Waste-to-energy technologies are not just focused on waste reduction and reuse, but also on how to reduce/manage the 'waste of waste' (waste generated by waste management practices), including GHG and other contaminants.

Technologies that were not available in 1975 when European Union Parliament issued the Waste Framework Directives are now available largely due to the impact of the issuance of Waste Framework Directives. Today, (2016), incineration technology not only produces energy from waste but also treats the gases that are produced as a result of energy recovery from waste. Materials that were useless in the past are now reusable as direct raw materials or recoverable as a substitute for virgin materials. Today's MSWM system include composting, incineration, landfilling, recycling, anaerobic digestion, gasification, plasma arc, pyrolysis, and waste autoclaves.

3.2.1 Evolution of Waste Management in New Zealand

The problem of poor waste management in New Zealand was first recognized as an issue that required attention in Dunedin (then the biggest settlement in New Zealand) in the 1860s. The first sanitary commission was appointed to investigate and recommend a solution to bad waste management. At that time, water quality was low as a result of pollution from poor sanitation. Sewage management was non-existence. Table 2.1 gives a timeline of some of the major events in the waste management sector in New Zealand. As all efforts to solve the problem yielded no result, the Health Act 1920 was enacted as a step towards using legislation to address the impact on health (New Zealand Legal Information Institute, 2013d). The Act defined waste as a nuisance and authorized local authorities to manage waste within their localities. A new Health Act in 1956 further recognized the danger of open burning of waste materials (Ministry for the Environment, 2013b). A National Physical Environment Conference that year noted that 'controlled tipping' was the main form of solid waste disposal. And New Zealand's tips were far from being sanitary. It was the cheapest way to dispose of rubbish, and when tips were full they were covered in earth, creating useful land – but standards varied (Dann, 2012a).

The various events in Table 2.1 show the situation which prompted the emergence of various legislation (Table 2.2) which had little or no impact till 1991 when Resource Management Act (RMA) (Parliamentary Counsel Office, 1991) was enacted. RMA had a major impact on MSWM. It was a major influence on the release of New Zealand Waste Strategy in 2002 (Office of the Parliamentary Commissioner for the Environment, 2002:p17) and subsequently Waste Minimization Act (WMA) (New Zealand Legislation, 2008) in 2008.

The RMA has one of its objectives, “to promote the sustainable management of New Zealand’s natural and physical resources” (New Zealand Legislation, 2008, p. 58). It provided for the establishment of national policy direction and standardised planning permitting and enforcement but extends to Local and Regional Authorities the flexibility and autonomy to identify the most suitable and most cost effective implementation methods. This is however in line with the Local Government Acts where the Local Authorities (LAs) have all the powers to manage their affairs. But the autonomy and power given to Local Authorities in Part 4 of the WMA in the sense of sustainability created a fragmented system of RMA implementation, especially where there is no national policy direction. Each of the Local Authorities has its local interest to pursue.

The New Zealand Waste Strategy of 2010 filled a gap in the legislative framework for managing and minimising waste by setting targets to move New Zealand towards ‘zero waste’. But in this strategy, landfilling is still the most common method of solid waste disposal in New Zealand. Although landfill space is not quite the same problem as in more densely populated countries, landfills in some of the larger urban areas are reaching capacity and the availability of new space is limited by local opposition (the 'not in my backyard' syndrome) and higher environmental standards (such as the need to avoid sites that could contaminate groundwater or streams) (Ministry for the Environment, 1997b). The conditions of New Zealand landfills were noted to have consistently improved since 1995 in the first landfill audit for New Zealand (Ministry for the Environment, 2003). Table 2.4 gives a summary of the changing scenarios of the landfill situation between 1995 and 2013.

Table 3.1: Timeline of some waste management events in New Zealand

Date	Event	Source
1860	Sanitary Commission was appointed in Dunedin to investigate and recommend solution to bad waste management	(Dann, 2012b)
1867	The mayor of Dunedin, John Hyde Harris failed to clean up his unsanitary cottages on the edge of the badly polluted swamp on the north edge of the town despite several warnings and being fined.	(Dann, 2013)
1870	Study showed poor water quality caused by pollution from poor sanitation in Wellington	(Dann, 2012b)
1875	Typhoid killed 49 people in Christchurch as a result of poor sanitation	(Dann, 2012b)
1882	Christchurch sewerage system was completed	(Dann, 2013)

1889	The first incinerator was constructed in Wellington by the City Council	(Dann, 2012d)
1899	First sewerage system was completed in Wellington	(Dann, 2013)
1900	Five outlets were discharging raw sewage into Auckland Harbour	(Dann, 2012b)
1905	Auckland City Council constructed a destructor as a solution to its solid waste problem	(Dann, 2012d)
1908	Dunedin sewerage system was completed	(Dann, 2013)
1914	Auckland sewerage system was completed	(Dann, 2013)
1927	First municipal restroom was built in Dunedin	(Dann, 2013)
1969	End of night-soil collection which was in Auckland	(Dann, 2013)
1970	First National Physical Environmental Conference was convened which acknowledged the problem of 'controlled tipping' in sanitary landfills to the environment. Committee on Pollution of the Environment was created.	(Dann, 2012a)
1971	The first national survey documented 563 landfills in New Zealand.	(Dann, 2012a)
1973	Committee on Pollution of the Environment issued New Zealand's first manual on solid waste disposal.	(Dann, 2012a)
1976	Devonport Borough Council Begin New Zealand's first municipal recycling scheme	(Dann, 2012c)
1986	The very last night cart in New Zealand	(Dann, 2013)
1996	1996 Packaging Accord (1996 – 2001) was signed: A five-year strategy to minimise packaging waste	(PAC NZ, 2014)
1998	Dumping of raw sewage was stopped in Wellington	(Dann, 2012e)
2000	Landfill Guideline was published by Centre for Advanced Engineering, University of Canterbury, Christchurch	(Centre for Advanced Engineering, 2000)
2001	Dumping of raw sewage was stopped in Hutt Valley	(Dann, 2012e)
2002	New Zealand Waste Strategy 2002: With Zero waste as the target. Many of its targets were unable to be measured or achieved.	(Office of the Parliamentary Commissioner for the Environment, 2002:p17)
2004	Packaging Accord (2004 – 2009) was signed: The Packaging Accord is a joint initiative between the packaging industry, local and central Government, and the recycling industry, to reduce packaging waste.	(PAC NZ, 2014)
2004 (8 October)	The National Environmental Standards for Air Quality (NES): NES are regulations made under the Resource Management Act 1991 which aim to set a guaranteed minimum level of health protection for all New Zealanders.	(Ministry for the Environment, 2013a)
2009 (1 July)	Implementation of 'thrower pay policy' of WMA: \$10 per tonne disposal levy	(Ministry for the Environment, 2009a)
2010	Revised New Zealand Waste Strategy: Changing from zero waste targets to a more flexible target of reducing harm and improving efficiency.	(Ministry for the Environment, 2010)
2011 (1 January)	Landfill operators registered as participants in ETS and could report their emissions voluntarily:	(Ministry for the Environment, 2012e)

2012 (1 January)	All landfill operators were required to register and to collect necessary data to calculate and report their emissions over the calendar year by 31 March 2013 unless exempt.	(Ministry for the Environment, 2012e)
2013 (1 January)	All landfill operators who are not exempt will have obligations to collect necessary data to calculate and report their GHG emissions return by 31 March 2014 and surrender sufficient emission units by 31 May 2014.	(Ministry for the Environment, 2012c)

Note: The sources for each of these events are contained in column three of the table

Table 3.2: Milestone legislation affecting waste management in New Zealand

Date	Legislation	Source
1920	Health Act 1920: - Definition of waste as nuisance Appointed Sanitary inspectors. - Empowered Local Authorities to manage waste within their territorial authority. - Local authorities to make by-laws for the purpose managing waste.	(New Zealand Legal Information Institute, 2013d)
1956	Health Act 1956: Recognised the danger of burning waste materials	(New Zealand Legal Information Institute, 2013e)
1968	Litter Act 1968: - Defined litter and made it illegal to litter. - Litter prevention officers were appointed: Police, forest officers, rangers, traffic officers, harbourmasters. - Provision of receptacles by public authorities	(New Zealand Legal Information Institute, 2013f)
1979	Litter Act 1979: Expanded definition of litter to includes any refuse, rubbish, animal remains, glass, metal, garbage, debris, dirt, filth, rubble, ballast, stones, earth, or waste matter, or any other thing of a like nature. Littering as an offence includes and not limited to: "Depositing", about litter, includes- (a) Casting, placing, throwing, or dropping litter; and (b) Allowing litter to be cast, thrown, dropped or, without reasonable excuse, to escape, from any a motor vehicle or trailer:	(New Zealand Legal Information Institute, 2013g)
1979	Local Government Amendment Act 1979: Part XXXI was an amendment to 1974 Act. The amendment defined 'Disposal' to include 'treatment', 'recycling', and 'the deposit of refuse. Refuse' to mean any rubbish of any kind, even if it is of monetary or reusable value. The Act gave the territorial authorities the powers to make provision for the collection and disposal of refuse so as not to be a nuisance or injurious to health. The Act empowered the Authorities to dispose of refuse by all or any of the following means: deposit on land set apart for the purpose; by composting,	(New Zealand Legal Information Institute, 2013i)

	incineration, pulverisation, shredding, compacting, or other means of destroying or treating refuse; by separation or extraction or converting it into a useful marketable product (including energy), and selling or otherwise deposing of the same.	
1986	The Environment Act 1986 established the Ministry for the Environment and the Office of the Parliamentary Commissioner for the Environment.	(New Zealand Legal Information Institute, 2013b)
1991	Resource Management Act 1991: - National environmental standards. - District and regional plans and resource consents	(Parliamentary Counsel Office, 1991)
1992	Local Government Amendment Act 1992: Section 7 (37SB) amended Local Government Act 1974 to include the power of the Regional Council to fund, establish and manage sites for the regional disposal of hazardous waste	(New Zealand Legal Information Institute, 2013j)
1994	Maritime Transport Act 1994 (1994 No 104): Prohibiting the dumping of waste in the sea	(Parliamentary Counsel Office, 2013)
1996	Hazardous Substances and New Organisms Act 1996: - The purpose of this Act is to protect the environment, and the health and safety of people and communities, by preventing or managing the adverse effects of hazardous substances and new organisms. - The Act established the Environmental Risk Management Authority (ERMA New Zealand) to assess and decide on applications to introduce hazardous substances or new organisms into New Zealand.	(New Zealand Legal Information Institute, 2013c)
1996	Local Government Amendment Act (No 4) 1996 (1996 No 84): Part XXXI of LGA was enacted through a 1996 amendment. The Act was able to define 'Disposal', 'Recovery', 'Recycling', 'Reduction', 'Reuse', 'Treatment' and 'Waste management plan.' The Act also established a Waste Management Hierarchy in the order of priority starting with Reduction as the most preferred, followed by Reuse, Recycling, Recovery, Treatment and Disposal as the least preferred. The Act empowered territorial authorities to promote effective and efficient waste management within their district through a waste management plan and in so doing; (a) have regard to environmental and economic costs and benefits for the district and (b) ensure that the management of waste does not cause a nuisance or be injurious to health. The waste management plan shall be made following the 5R hierarchy as established and amended from time to time as deemed right by the territorial authority.	(New Zealand Legal Information Institute, 2013k)

1996	Ozone Layer Protection Act 1996: - New Zealand's commitments under the Montreal Protocol on Substances that deplete the Ozone Layer are contained in the Ozone Layer Protection Act 1996 and the Ozone Layer Protection Regulations 1996. - The Ozone, Layer Protection Act, lays down the broad controls for ozone-depleting substances.	(New Zealand Legal Information Institute, 2013l)
2002	Local Government Act 2002: Territorial authorities are empowered to make by-laws for the purpose of; a) protecting the public from nuisance: b) protecting, promoting, and maintaining public health and safety: c) minimising the potential for offensive behaviour in public places and of regulating one or more of the following: (i) on-site wastewater disposal systems: (ii) waste management: (iii) trade waste: (iv) solid waste: (v) keeping of animals, bees, and poultry: (vi) trading in public places:	(New Zealand Legal Information Institute, 2013h)
2002	Climate Change Response Act 2002: - The Act puts in place a legal framework to allow New Zealand to ratify the Kyoto Protocol and to meet its obligations under the United Nations Framework Convention on Climate Change. - The Act includes powers for the Minister of Finance to manage New Zealand's holdings of units that represent New Zealand's target allocation for GHG emissions under the Protocol. - It enables the Minister to trade those units on the international market. It establishes a registry to record holdings and transfers of units. - The Act also establishes a national inventory agency to record and report information relating to GHG emissions by international requirements.	(New Zealand Legal Information Institute, 2013a)
2004 (26 February)	Resource Management (Energy and Climate Change) Amendment Act 2004: - This Act (among other things) recognises the Government's preference for national co-ordination of controls on GHG emissions. - National policy will create a consistent and even application of climate change policy, and provide a clear indication to industry as to the Government's expectations.	(New Zealand Legal Information Institute, 2013m)
2004 (28 June)	Imports and Exports (Restrictions) Prohibition Order (No 2) 2004: To aid the implementation of the requirements of the Stockholm Convention, Rotterdam Convention and Basel Convention, which New Zealand is a party to.	(Parliamentary Counsel Office, 2004a)

2004 (6 September)	Resource Management (National Environmental Standards for Air Quality) Regulations 2004: - The 2004 regulations set threshold concentrations for certain air pollutants including particulate matter less than 10 microns in diameter (PM_{10}). - These regulations required restrictions to be in place before 2013, and a complete ban on granting consent for the industry after 2013, if the PM_{10} standard was not met. - The air quality standards help protect public health while providing equitable compliance costs.	(Parliamentary Counsel Office, 2004b)
2008 (28 September)	Waste Minimization Act 2008: - Encourages waste minimization and management plans. - Waste disposal levy. - Waste minimization fund. - Product stewardship. - Waste Advisory Board. - Other regulations	(New Zealand Legislation, 2008)
2010	Climate Change (Waste) Regulations 2010: - Information required calculating emissions from Operating disposal facilities. - The method of calculating emissions from operating disposal facilities.	(Parliamentary Counsel Office, 2010)
2010 (23 September)	Climate Change (Unique Emissions Factors) Amendment Regulations 2010: Permitting unique emission factor for disposal facilities that have reason not to use the default emissions factor	(Parliamentary Counsel Office, 2010)
2012	Climate Change Response (Emissions Trading and Other Amendment) Bill: This Amendment Act was passed by Parliament in November 2012. It makes two changes that will affect the waste sector: - Along with other mandatory participants, landfill operators will submit only one emission unit for each two tonnes of CO2-equivalent emissions; - The emission factors for methane will change to incorporate an updated Global Warming Potential for methane. This will be given effect by a further change to the regulations in 2013	(Parliamentary Counsel Office, 2012)

3.2.2 Waste Disposal Volume in New Zealand

Despite a large number of policies dealing with waste management, the amount of solid waste disposed of is difficult to estimate due to the difficulty of obtaining accurate data. The *State of the Nation Report: Landfilling Practices and Regulation in New Zealand* estimated that “average household waste generation per capita in New Zealand to be around 560 kg/inhabitant/year" in 2010 (International Solid Waste Association 2012, p.2). The WMA introduced a waste disposal levy, which provides some indication of waste disposal to landfills. However, this is only a fraction of the overall waste generated, as a substantial amount of waste does not necessarily go to landfill, and is consequently lost in the statistics of waste generation. Waste disposal volume before the Act estimated since 1990 shows a reduction in waste from 3.180 million tonnes per year in 1995 to 3.156 million tonnes per year in 2006. The per capita estimate also showed a drop from 898 kilogrammes per person to 784 kilogrammes per person in 1995 and 2006 respectively (Ministry for the Environment, 2007d). The figures for 2010 and 2011 were 2.461 million tonnes and 2.531 million tonnes respectively, are based on the amount of funds collected from levy, which is calculated by weight. But as explained above, with large quantities of waste not going to landfills, it may be difficult to accurately compare pre- and post-WMA figures (Ministry for the Environment, 2012c).

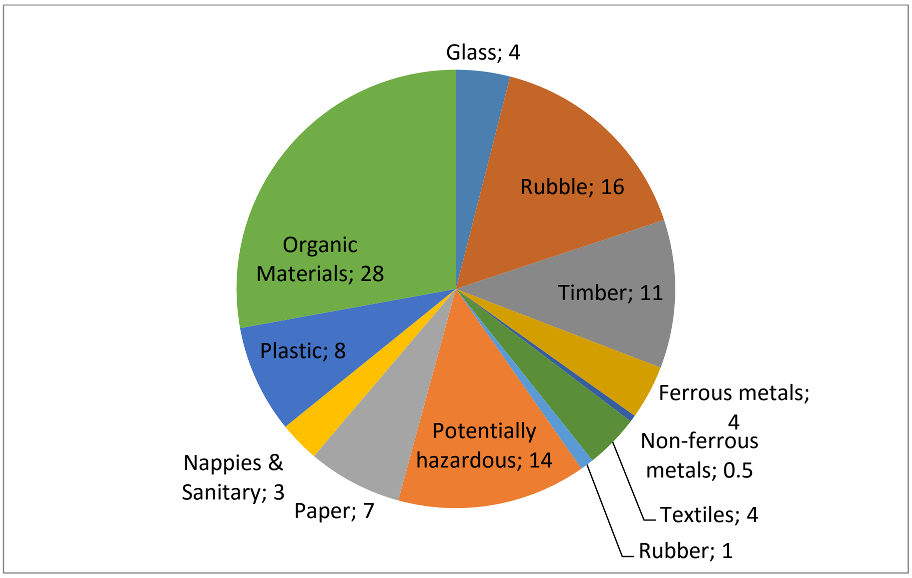


Figure 3.6: 2007-2008 New Zealand waste composition proportions.

Source: Ministry for the Environment (2009b)

The results of a 2008 survey of waste composition in municipal landfills are represented in Figure 3.6. This survey found that showed that approximately three-quarters of the waste disposed to municipal landfills could have been potentially diverted to being recovered, reused or recycled (Ministry for the Environment, 2009b). Other recent surveys (Christchurch City Council, n.d.; MWH, 2013; Waikato District Council, 2011; Waikato Regional Council, 2012; Wetherill, n.d) showed that similar proportions of domestic waste being disposed of in municipal landfills could have also potentially been diverted.

The volume of waste disposed of can be a pointer to how efficient we are in using some of our natural resources. Combining the information on waste volume with waste composition and diversion rate can help inform waste minimization policies and initiatives (Ministry for the Environment, 2012c).

For effective planning, waste characterization data, which includes generation and composition, is critical. However, it is difficult to ascertain the actual quantity of waste generation in New Zealand. Assessing trends over the past decade or so are also difficult because of both the ambiguous definition of waste and the general incomplete data before 1995 (Ministry for the Environment, 1997b).

The OECD's average output of municipal waste per person rose by 28 percent between 1975 and 1992, from 390 kg/person to 500 kg/person (OECD, 1993, 1995). However, New Zealand's waste estimates over this period vary too widely to chart any reliable trends. In 1975, for example, the total municipal waste was estimated at 390 kg/person and in 1980 it was put at 662 kg/person (OECD, 1993). An OECD report (OECD, 2002) estimates that in 2002, New Zealand produced approximately 1.6 million metric tonnes of MSW.

Individual, community, local and central government initiatives in recent years have successfully diverted large amounts of waste from landfills. For example, the recovery of packaging (which includes aluminium, glass, paper, plastics, and steel) increased by 26 percent to approximately 430,000 tonnes between 2004 and 2009 (Packaging Council of New Zealand, 2012).

Participation in recycling by households has also increased in recent years – from 85 percent in 2000 to 94 percent in 2010 (Hughey, 2010). A 2010 survey indicated that 78 percent of households recycled all or most of those items that they knew could be recycled (Statistics New Zealand, 2011). No are not recent reports indicating any change since 2011.

The growing volume of waste to landfill despite all efforts to change the situation suggests that a radical departure from the present framework of MSWM in New Zealand may be required. This research investigates an integrated sustainable approach to MSWM using a Decision Support System to streamline the entire process.

3.3 Waste - An Environmental Problem

Waste is clearly an environmental issue. Every time a rotten lettuce is thrown in the bin, a broken toy discarded, or industrial scrap carted away, resources are being used up. This all contributes to the environmental pressures on our planet. And once a product is thrown away and becomes waste, a whole new set of impacts are involved in treating it. But the environmental impacts are only part of the waste story. It is impossible to examine them in isolation without looking at economic and social factors (European Commission, n.d).

Actions to prevent waste, for example, can create - or lessen - constraints on the consumer, can create or reduce costs for business, can create or remove jobs. These divergences in impacts are not always easily predictable and do not always pull in the same direction.

Moreover, waste can genuinely be described as a local problem with global impact. A recycling scheme organised by a local authority can have an impact thousands of kilometres away, as the products of the scheme are traded on the international market. Waste is complex – difficult to grasp, difficult to gather good statistics on, and difficult to regulate and manage.

In general terms, the environmental problem resulting from waste and its management include emissions resulting from decomposing waste. This emission is a major contributor to global climate change. Other problems from waste management include emissions from the use of fossil fuel in transportation, including the generation of dust leading to climate change, air pollution and noise. Therefore, waste is an issue that has an impact on a very wide range of stakeholders. This pollution can also result to surface and underground water pollution.

During the first part of the communal settlement, individuals and families generated waste and discarded through any cheap means. The impacts on local streets and the pollution associated with poor management resulted in cities and territorial authorities looking for a solution. The solutions were a shift of the problems from the local level to global level which resulted in seeking a solution through cooperation and agreements which are referred to as ‘international framework’. Table 2.3 is a representation of some of the international frameworks that have had an impact on MSWM.

3.3.1 The International Frameworks

The main method available under international law for countries to work together on global issues is the Multilateral Agreement (MA). MAs are agreements between countries which may take the form of "soft law", setting out non-legally binding principles which parties will respect and subscribe to when considering actions which affect a particular issue or "hard-law" which specifies legally-binding actions to be taken to work toward an objective (UNEP, 2010).

The realization that some of the waste treatment practices and of course, some other issues of the environment have an impact beyond the boundary where they occur raises questions as to what constitutes a suitable solution or remedy. The factors which occur regardless of the boundary, such as GHG emissions or leaching into shared waterways, have resulted in treaties and pacts at regional level between local authorities. At the national level, a country adopts a national waste management plan/strategy. At the regional level, a group of countries come together to form a block and agree on common management plans, like the European Union, and OECD countries and globally through the United Nations. These agreements are here referred to as International Frameworks, and the following discussion will concentrate on those treaties that have a relationship with or impact on waste management in New Zealand.

A number of conferences, summits, and gatherings under the auspices of The United Nations beginning in 1972 form the basis for the development of international agreements relating to waste management. The first of these were the Stockholm Conference on the Human Environment held in Stockholm, Sweden, on 16 June 1972, and the London dumping convention on the prevention of marine pollution, on 13 November 1972. These two conferences and the subsequent agreements marked the emergence of international environmental law.

3.3.1.1 Stockholm Declaration on Environment and Development, 1972

The Stockholm Conference on Environment and Development was the first UN summit on the environment and in all respects succeeded in putting the issue of the environment on the global political agenda. It was agreed, based on what was achieved over the two weeks' period of the conference, to be the most successful international conference held in recent years (Sohn, 1973). These achievements included the adoption of a basic declaration, which provided a framework for what became known as "Institutional and

Financial Arrangements for International Environmental Co-operation" (UNEP, 2010) providing detailed institutional and financial arrangements for achieving set international targets. The conference attendees also agreed on 109 recommendations and 26 principles for future implementation at national and international levels (United Nations, 1973).

Among its concrete achievements were:

The endorsement of the creation of a Governing Council for Environmental Programs leading to the establishment of United Nations Environmental Program (UNEP)

The development of the Stockholm Declaration which recognized in principle the need for an environment with acceptable quality as a vehicle to advance other substantive goals of humanity within the environmental realm

Preparation of a solid grounding and structure for subsequent conferences of the United Nations like the Earth Summit in 1992.

The Declaration on the Human Environment, also known as the Stockholm Declaration, set out the principles for various international environmental issues including human rights, natural resource management, pollution prevention, and the relationship between the environment and development. The conference also led to the creation of the United Nations Environmental Programme.

3.3.1.2 1972 London Dumping Convention on the Prevention of Marine Pollution

The London Convention set out to address the issue of dumping of waste in international waters, which had been of international concern since the early 19th century. Before the convention, waste dumping at sea was one of the cheapest ways of waste disposal both by cities, moving vessels and aircraft. Since the impact of such practices knows no border, international cooperation was the only viable solution. Notice of the London Convention was given at the United Nations Conference on the Human Environment which was holding in Stockholm, and the conference held on 13 November 1972. The agreement convention was opened for ratification on 29 December 1972 and entered into force on 30 August 1975 being ratified by 15 nations.

The primary focus of the convention was to develop frameworks to protect international waterways and other marine environments from human activities, by introducing international guidelines to control marine pollution and to providing practical steps to help prevent pollution of oceans. Although the recommendations were not legally binding on the 87 member states who were parties to the agreement, and no compliance mechanisms were introduced under the remit of the London Convention, it provided a framework for the development of compliance procedures and mechanism in subsequent years (International Maritime Organisation, IMO (2016; Stokke, 2002).

The London Convention consists of 22 Articles and three Annexes grouping the various materials that can be granted a permit for dumping into the sea. It adopted a "black and grey" list approach. This is determined by the level of toxicity of the contents of the waste materials. Annex I materials (black list) are not permitted for dumping into the ocean (though for certain Annex I materials, dumping may be permissible if they designated materials are present only as "trace materials" in the waste stream or can be "rapidly be rendered harmless" through natural means. The Annex II materials (grey list) require "special care" before they can be dumped into the ocean. Annex III lays out general technical factors to be considered in establishing criteria for issuance of ocean dumping permits.

Since entering into force in 1975, the Convention has provided a framework for international control and prevention of marine pollution by which the Contracting Parties have achieved continuous progress in keeping the oceans clean. Among its milestones of achievements are the 1993 ban on ocean disposal of low-level radioactive waste and the resolutions to end the dumping and incineration of industrial waste. The efforts of the Parties are supported by a permanent Secretariat hosted by the International Maritime Organization (IMO) (UNEP, n.d).

A new Protocol was adopted on 17 November 1996, at a special meeting of the Contracting Parties, including New Zealand, which was a replacement to the 1972 Convention, subject to ratification. In line with United Nation Conference on Environment and Development (UNCED) Agenda 21, the 1996 Protocol reflected changes in thinking since 1975 and prohibited all dumping of waste. The signing Parties agreed to move from controlled dispersal at sea of a variety of land-generated waste towards integrated land-based solutions for most and controlled sea disposal of few, remaining categories of waste or other matter (Sapota, Wik, Lundberg, & Kleverlaan, 2011). Extended compliance procedures and technical assistance provisions were included in the protocol with a five-year transitional period to allow for parties to transition their waste management practices.

New Zealand ratified the treaty on 30 April 1975, and all requirements are being implemented through two legislative schemes:

the Resource Management Act 1991 (RMA) and the Resource Management (Marine Pollution) Regulations 1998

the Maritime Transport Act 1994 (MTA) and the marine protection rules in Part 80 - Dumping of Waste or Other Matter.

The RMA (1991) and Resource Management (Marine Pollution) Regulations 1998 applies to areas of the sea within the outer limits of the territorial sea of New Zealand (the coastal marine area or CMA); the MTA applies to dumping beyond 12 nautical miles.

Also, both sets of legislation prohibit the dumping and storage of radioactive waste or other radioactive matter in the waters and seabed under New Zealand jurisdiction. The MTA also gives effect to some other New Zealand obligations under the 1996 Protocol. It is a crime to export waste or other matter to countries outside New Zealand for dumping or incineration at sea. It is also a crime to load waste on ships in New Zealand ports for the purpose of dumping, except where the appropriate permit/consent is held (Maritime Safety Authority of New Zealand, 1999).

Applications for resource consents/dumping permits must be directed to the appropriate issuing authority, as summarised in Figure 3.7.

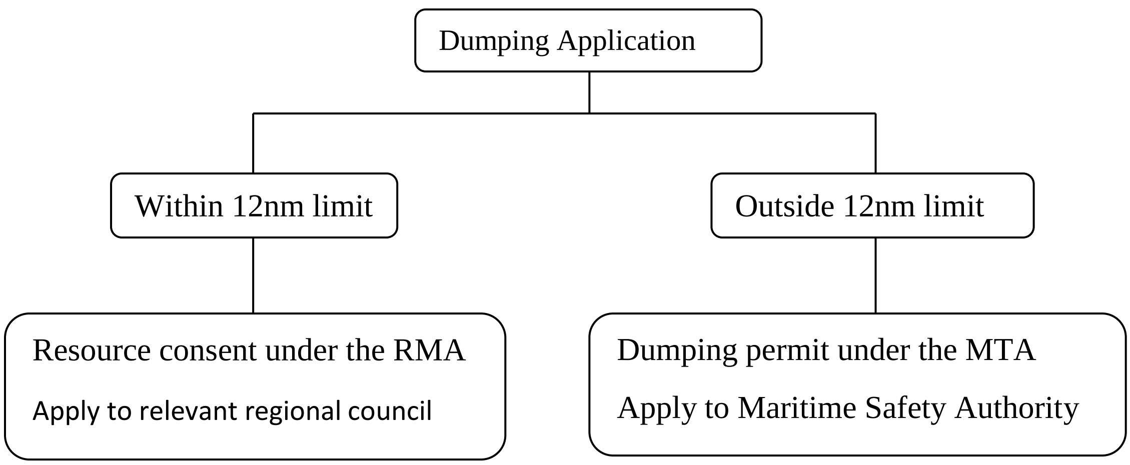


Figure 3.7: Jurisdiction of issuing authority in waste disposal and management

Source: Maritime Safety Authority of New Zealand (1999)

Table 3.3: Summary of landfill conditions between 1995 and 2010 in New Zealand

	1995	1998	2002	2010
Total number of operation sites	327	209	115	43
Sites with consent to operate	-	157	104	43
Low-permeability underlying materials	-	10%	15%	42%
Leachate management system:				
engineered liner	-	4%	20%	67%
leachate collection system	13%	35%	47%	88%
leachate recirculation	-	7%	10%	Not known
Storm water management system:				
storm water diversion	41%	67%	74%	100%
storm water monitoring	-	23%	50%	77%
storm water treatment	9%	27%	36%	67%
Landfill gas management system:				
landfill gas monitoring	3%	11%	27%	77%
landfill gas collection (flaring or beneficial use)	-	5% (10)	10% (12)	30% (13)
Working cover daily or more	-	25%	30%	93%
Landfill fire	52%	24%	17%	Not known
Hazardous waste management system:				
hazardous waste accepted	33%	20%	-	Not known
definition				
CAE guideline	-	9%	20%	Not known
HSNO definition	-	3%	6%	Not known
Standard list	-	5%	18%	Not known
USEPA	-	2%	6%	Not known
No definition	-	68%	18%	Not known
Documentation required	-	33%	53%	Not known
Measuring the quality of water	39%	63%	83%	100%
Charging for the disposal of waste	-	45%	82%	100%

Note: The figures for 2010 are projected values made by the Ministry for the Environment

Source: Ministry for the Environment (2003)

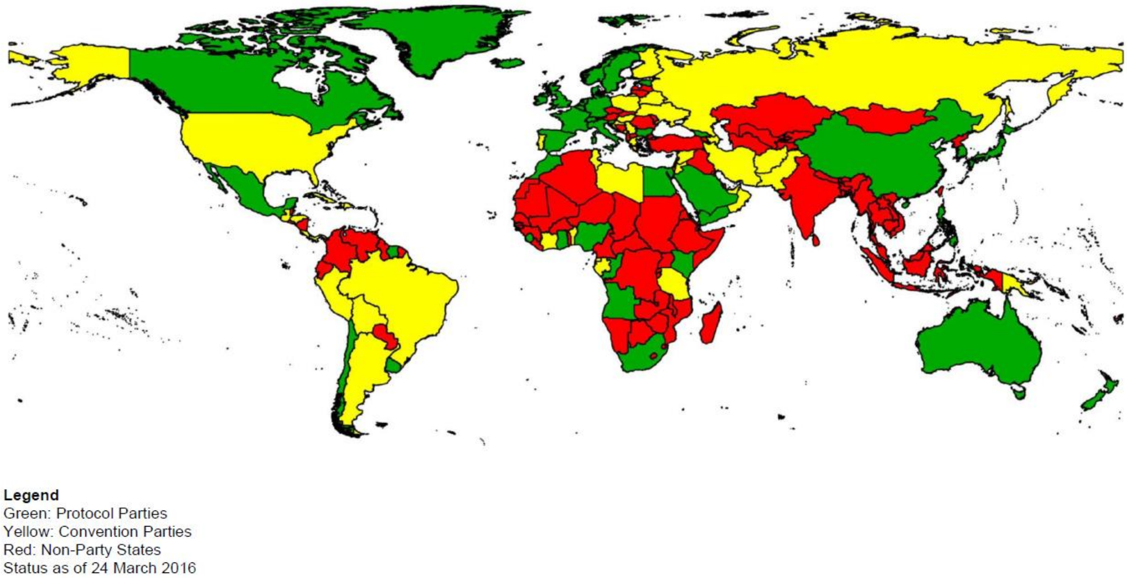


Figure 3.8: Parties to the London Convention and Protocol as at March 2016
Source: International Maritime Organisation (2016)

3.3.1.3 The 1985 Vienna Convention for the Protection of the Ozone Layer

The Vienna Convention is often called a framework convention because it served as a framework for efforts to protect the globe's ozone layer. The high altitude or stratospheric ozone layer of the air acts as a shield or barrier in the atmosphere that protects life on Earth from the sun's harmful ultraviolet (UV) radiation. During the 1980s, scientists observed that the earth's ozone layer was becoming depleted or in layman's terms 'getting thinner' (US EPA, 2012). New Zealand is one country which has a relatively thin ozone layer making international efforts to protect the ozone layer, such as the Vienna Convention, particularly relevant. New Zealand has readings of 280 Dobson units in the south to 240 units in the north as of May 11th, 2016 (NIWA, 2016). A Dobson reading of 220 units is the baseline value and has been chosen as the starting point for an ozone hole.

The Vienna convention was adopted in 1985 and entered into force on 22 Sep 1988. In 2009, the Vienna Convention became the first convention of any kind to achieve universal ratification. The objectives of the Convention were two-fold. Firstly, to promote international cooperation in order to monitor, research and exchange information on the effects of human activities on the ozone layer and secondly to develop legislative or administrative measures against activities likely to have adverse effects on the ozone layer.

Being aware of the potentially harmful impact on human health and the environment through the modification of the ozone layer and recalling the pertinent provisions of the Declaration of the United Nations Conference on the Human Environment (in particular Agenda 21, which provides that countries have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their resources pursuant to their environmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other states or of areas beyond the limits of national jurisdiction). Additionally, being aware that measures to protect the ozone layer from modifications due to human activities require international co-operation and action, and should be based on relevant scientific and technical considerations and determined to protect human health and the environment against adverse effects resulting from modifications of the ozone layer, the Vienna Convention parties agreed to (UNEP, 2009).

Cooperate through systematic observations, research, and information exchange in order to better understand and assess the effects of human activities on the ozone layer, and the effects on human health and the environment from modification of the ozone layer;

Adopt appropriate legislative or administrative measures and cooperate in harmonizing appropriate policies to control, limit, reduce or prevent human activities under their jurisdiction or control should it be found that these activities have or are likely to have adverse effects resulting from modification or likely modification of the ozone layer;

Cooperate in the formulation of agreed measures, procedures, and standards for the implementation of this Convention, (or “intending to”) the adoption of protocols and annexes;

Cooperate with competent international bodies to implement effectively this Convention and protocols to which they are a party (UNDP, 2009, retrieved from http://ozone.unep.org/en/handbook-vienna-convention-protection-ozone-layer/2208.

The Vienna Convention and the Montreal Protocol are both dedicated to the protection of the earth’s ozone layer. With 197 parties, they are the most widely ratified treaties in United Nations history, and have, to date, been reported to have enabled reductions of over 97 percent of all global consumption of controlled ozone-depleting substances (Global Environment Facility, 2014).

3.3.1.4 The 1987 Montreal Protocol

The Montreal Protocol on Substances that Deplete the Ozone Layer seeks to gradually phase out the production and consumption of ozone-depleting substances. This is a major international instrument designed to reduce the impact of hydrochlorofluorocarbons (HCFCs),

Used in cooling and refrigeration appliances. The Montreal Protocol was adopted on 16 September 1987 and became effective on 1 January 1989. The Protocol established legally binding controls for developed and developing nations on the production and consumption of halogen source gases.

The Montreal Protocol includes a unique adjustment provision that enables the Parties to the Protocol to respond quickly to the new scientific information and agrees to accelerate the reductions required on chemicals already covered by the Protocol. And since the signing of the first Protocol, it has repeatedly been strengthened by both controlling additional ozone-depleting substances (ODS) as well as by moving up the date by which already controlled substances must be phased out. These adjustments are then automatically applicable to all countries that ratified the Protocol.

According to US EPA (2010), in the original Protocol in 1987, developed countries were required to begin phasing out CFCs in 1993 and achieve a 50 percent reduction relative to 1986 consumption levels by 1998. Under this agreement, CFCs were the only ODSs addressed. Later amendments came in the years after as shown below:

The 1990 London Amendment changed the ODS emission schedule by requiring the complete phase-out of CFCs, halons, and carbon tetrachloride by 2000 in developed countries, and by 2010 in developing countries. Methyl chloroform was also added to the list of controlled ODSs, with phase-out in developed countries targeted in 2005, and in 2015 for developing countries.

The 1992 Copenhagen Amendment significantly accelerated the phase-out of ODSs and incorporated an HCFC phase out for developed countries, beginning in 2004. Under this agreement, CFCs, halons, carbon tetrachloride, and methyl chloroform were targeted for complete phase out in 1996 in developed countries. Also, methyl bromide consumption of methyl bromide was capped at 1991 levels.

The 1997 Montreal Amendment included the phase-out of HCFCs in developing countries, as well as the phase-out of methyl bromide in developed and developing countries in 2005 and 2015, respectively.

The 1999 Beijing Amendment included tightened controls on the production and trade of HCFCs. Bromochloromethane was also added to the list of controlled substances with the phase out targeted for 2004.

At the 19th Meeting of the Parties in Montreal on September 17-21, 2007, the Parties agreed to adopt more aggressive steps to phase out HCFCs in both developed and developing countries. To achieve this target, The United States, Canada, and Mexico together submitted a proposal to phase-down consumption and production of hydrofluorocarbons (HFCs) under the Montreal Protocol on Substances that Deplete the Ozone Layer in April 2013. Global benefits of the proposal can yield significant reductions of over 90 gigatons of carbon dioxide equivalent (CO2-eq) through 2050. Also, the United States reached separate agreements with the G-20 and with China to combat global climate change by addressing the rapid growth in the use and release of climate-damaging hydrofluorocarbons (HFCs) (US EPA, 2013).

New Zealand's obligations under the Montreal Protocol are implemented through the Ozone Layer Protection Act 1996 and the Ozone Layer Protection Regulations 1996. Ministry for the Environment (2015), reported that New Zealand has phased out the import of all ozone depleting substances by the Protocol. The import of halons was phased out by 1994, and chlorofluorocarbons (CFCs), other fully halogenated CFCs, carbon tetrachloride, methyl chloroform and hydro Bromo fluorocarbons by 1996. The import of methyl bromide for non-quarantine and pre-shipment purposes ended in 2007. The remaining controlled substances are bulk hydrochlorofluorocarbons (HCFCs). Although New Zealand accelerated the process to phase-out of HCFCs as required by the Protocol, at the target of 100 percent reduction of imports by 2015 (Ministry for the Environment, 2012a) was not achieved at the end of the year. The Minister announced in August 2015 that "The regulations will complete the phase-out of HCFCs in New Zealand by removing a residual category of wholesale import permits. This will enable us to meet our commitment to phase out ODSs by 2020 under the Montreal Protocol ahead of schedule – which is fitting given New Zealand's early championship of what is considered to be the most successful environmental protection agreement in the world" Smith, (2015; https://www.beehive.govt.nz/release/consultation-steps-ozone-recovery-and-asbestos-ban-1).

Figure 3.9 illustrates the impact of Montreal Protocol as shown by Fahey et al. (2006) as cited in US EPA (2010).

The left-hand side of Figure 3.9 is showing the progress made in the reduction of effective stratospheric chlorine in the atmosphere from the period before Montreal Convention (shown on the red line) and subsequent agreements (reducing systematically towards the right). Effective stratospheric chlorine is an acceptable parameter adopted in quantifying the effects of halogens on ozone depletion in the atmosphere. The right-hand part of the Figure is showing the reduction in reported cases of skin cancer. The high level on red is a period before Montreal Convention, down to the period after the Copenhagen Conference in 1992.

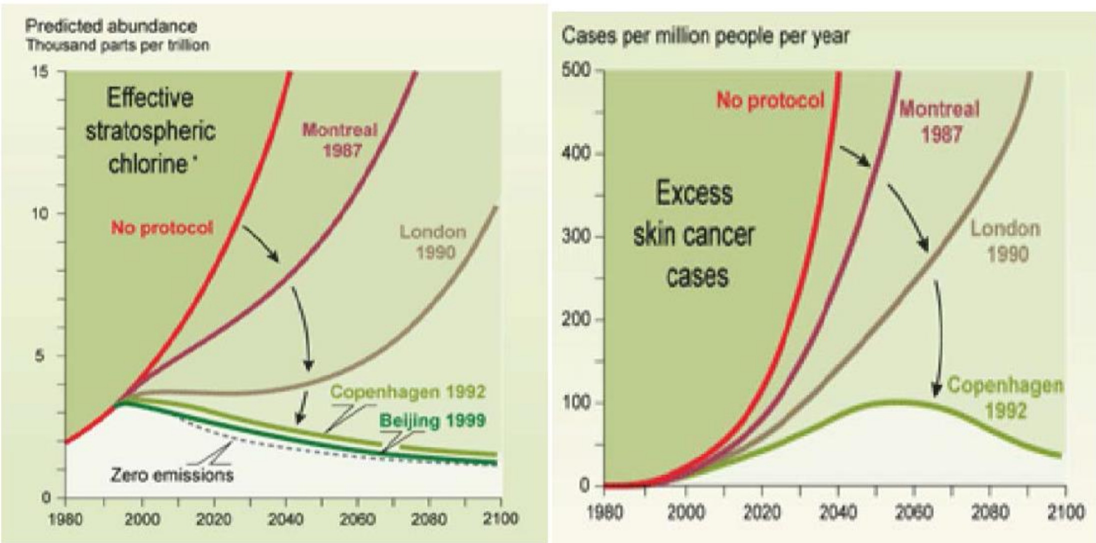


Figure 3.9: Decline of emissions and skin cancers which have been attributed to the effects of Montreal Protocol. Source: US EPA (2010)

3.3.1.5 The 1989 Basel Convention

The Basel Convention on the Control of Transboundary Movements of Hazardous Waste and their Disposal, usually known as the Basel Convention, is an international treaty that was designed to reduce the movements of hazardous waste between nations and specifically to prevent the transfer of hazardous waste from developed to less developed countries (LCDs). The Convention was also intended to minimize the amount and toxicity of waste generated, to ensure their environmentally sound management as closely as possible to the source of generation and to assist LCDs in environmentally sound management of the hazardous and other waste they generate.

The management of hazardous waste has been on the international environmental agenda since the early 1980s when it was identified as one of the three priority areas in the United Nations Environment Programme's (UNEP) first Montevideo Programme on Environmental Law in 1981. The Basel Convention on the Control of Transboundary Movements of Hazardous Waste and their Disposal (from now on referred to as "the Basel Convention") was adopted in 1989. This was in response to a public outcry following the discovery in the 1980s, in Africa and other parts of the developing world of deposits of toxic waste imported from abroad.

Awakening environmental awareness and corresponding tightening of environmental regulations in the industrialized world in the 1970s and 1980s had led to increasing public resistance to the disposal of hazardous waste – in accordance with what became known as the NIMBY (Not In My Back Yard) syndrome – and to an escalation of disposal costs. This, in turn, led some operators to seek cheap disposal options for hazardous waste in Eastern Europe and the developing world, where environmental awareness was much less developed, and regulations and enforcement mechanisms were lacking. It was against this background that the Basel Convention was negotiated in the late 1980s, and its thrust at the time of its adoption was to combat the "toxic trade", as it was termed. The Convention entered into force in 1992 (United Nations, 2013).

As a result of the tightening of environmental laws in developed nations in the 1970s, disposal costs for hazardous waste rose dramatically. At the same time, globalization of shipping made the trans-boundary movement of waste more accessible, and many LDCs were desperate for foreign currency. Consequently, the trade in hazardous waste, particularly to LDCs, grew rapidly.

One of the incidents which led to the creation of the Basel Convention was the Khian Sea Waste disposal incident (Burling, 2000). The incidence involved a ship is carrying incinerator ash from the city of Philadelphia in the United States dumped half of its load on a beach in Haiti before being forced away. It sailed for many months, changing its name several times. Unable to unload the cargo in any port, the crew was believed to have dumped much of it at sea.

Another scandal which attracted global attention was the 1988 Koko toxic waste dumping in which five ships transported 8,000 barrels of hazardous waste originating from Italy to the small town of Koko in Nigeria. In exchange, $100 monthly rent was paid to a Nigerian for the use of his farmland (Koko toxic waste dump, 2012). These practices of dumping waste unlawfully have been tagged "Toxic Colonialism" by many developing countries (Koné, 2010).

Therefore, during the mid-1980s, the political discussion of the issue of international transport of hazardous waste in general, and illegal transboundary traffic in such waste, had gathered momentum. The concerns and efforts reached its culmination in 1988 in widely publicized media reports on incidents involving the illegal dumping of toxic waste from industrialized nations to Third World countries. The problem was taken up and pressure mounted by governments and intergovernmental agencies. They were supported by non-governmental environmental groups, at the national and international levels. The growing interest in the issue is reflected in the number of States represented at the sessions of the Working Group, which increased from twenty-four at the organizational meeting to almost eighty at the last session, and in a similar increase in the number of organizations participating in the proceedings as observers.

The convention accepted that there is a risk of damage to human health and the environment caused by hazardous waste and other waste and the trans-boundary movement thereof. Hence, agreed on the following:

That the best way to handle the negative effect of hazardous waste is to encourage the reduction in the generation of hazardous waste,

Countries should take necessary steps to ensure that the management of hazardous waste and another waste including the transboundary movement of these waste, including their disposal, is consistent with the protection of human health and the environment. These efforts should cover all disposal methods.

Transportation and disposal in a manner that is consistent with the protection of the environment, whatever the place of disposal, is the responsibility of the generator,

Countries have the right to ban the movement of such waste in its territories,

Countries should take measures for the proper exchange of information on and control of the trans-boundary movement of hazardous waste.

New Zealand as a party to Basel Convention, and as required as a member of OECD, restricts the export of hazardous waste and other waste for final disposal. Locally the Import and Exports (Restrictions) Prohibition Order (No 2) of 2004 (Parliamentary Counsel Office, 2004a) (Table 2.2) was an attempt to give the Convention legislative backing.

3.3.1.6 The 1992 United Nations Framework Convention on Climate Change

This Convention is also known as the Rio Declaration on Environment and Development, or the United Nation Conference on Environment and Development (UNCED) was an international Convention where the environmental treaty was negotiated. Informally known as the Earth Summit, held in Rio de Janeiro, Brazil, from 3 to 14 June 1992.

This UNCED was a follow up on Stockholm conference. The objective of the treaty was to stabilize GHG concentrations in the atmosphere at an acceptable level that would not interfere with the climate system (UNFCCC, 2014a). The conference was aimed at establishing a new and equitable global partnership among nations through the creation of new levels of cooperation among countries, key sectors of societies and people. It was part of the evolving framework of international agreements which respect the interests of all humanity and protect the integrity of the global environmental and developmental system. The Rio agreement was based on 27 principles divided into 40 chapters which were tagged ‘Agenda 21’.

The treaty did not set binding limits on GHG emissions for individual countries, nor were there strict enforcement mechanisms, thus may not be considered legally binding. Rather, it provides a framework for negotiating specific "protocols" that may set binding limits on GHGs (Botanic Gardens Conservation International, 1999).

The whole concept which is based on sustainable development which came out of the United Nations Conference on Human Environment held in Stockholm, Sweden in 1972 (Habitat.igc.org, n.d) and the report of the Brundtland Commission (1982) called Our Common Future (United Nations World Commission on Environment and Development, 2013)

The UNFCCC was opened for signature on 9 May 1992 after an Intergovernmental Negotiating Committee produced the text of the Framework Convention as a report following its meeting in New York from 30 April to 9 May 1992. It entered into force on 21 March 1994.

The issues addressed in the Agenda include:

Systematic scrutiny of nations patterns of production – particularly the production of toxic components such as lead in gasoline, poisonous waste including radioactive chemicals.

Adopting alternative source of energy to replace the use of fossil fuels which is linked to global climate change.

Developing, adopting and relying more on public transportation systems to reduce vehicular emissions, congestion in the cities. This way, the health problems caused by polluted air and smoke will be reduced.

How to integrate environmentally sound management of waste and sewage into government business

Appropriate use of science and technology in supporting the prudent management of the environment and development for the daily survival and future development of humanity

Developing national policies and strategies to encourage changes in unsustainable consumption patterns.

The parties to the convention have met annually from 1995 in Conferences of the Parties (COP) to assess progress in dealing with climate change. In 1997, the Kyoto Protocol was concluded. The Protocol established legally binding obligations for developed countries to reduce their GHG emissions. A key element of the UNFCCC is that parties should act to protect the climate system by equality and by their common but differentiated responsibilities and respective capabilities.

The principle of common but differentiated responsibility includes two fundamental elements. The first is the common responsibility of parties to protect the environment, or parts of it, at the national, regional and global levels. The second is the need to take into account the different circumstances, particularly each party's level of contribution to the problem and its ability to prevent, reduce and control the threat. Another element underpinning the UNFCCC is the polluter pays principles. This means that the party responsible for producing pollution is responsible and should pay for the damage done to the natural environment (Lead International & Lead India, 2014).

In implementing the agreement, the first tasks set by the UNFCCC was for signatory nations to establish national GHG inventory of GHG emissions and removals, which were used to create the 1990 benchmark levels for the accession of Annex I (developed) countries to the Kyoto Protocol and for the commitment of those countries to GHG reductions. Updated inventories must be regularly submitted by Annex I countries.

The Rio Declaration describes countries' obligations in promoting the principle of sustainable development. This principle involves managing natural resources in a way that provides our needs in using those resources, and at the same time provide for the protection of the resources – both for the inherent value of the resources, and the ability to preserve humanity's future interests in the resources. The obligation to conserve, protect and restore the health and integrity of the Earth's ecosystem is framed in a way that recognises the variability of countries' abilities and methods in dealing with environmental problems.

Ten years after the Rio Summit, World Summit on Sustainable Development (WSSD) or Earth Summit 2002 took place in Johannesburg, South Africa to agree on the implementation action plans for Agenda 21. After twenty years in 2012, the United Nations Conference on Sustainable Development (UNCSD) or Rio+20 was held in Rio de Janeiro to review Agenda 21. The conference centred on Agenda 21, the outcome document from Earth Summit 1992. That document was considered revolutionary in that it essentially created the term sustainable development and created the global environmental agenda for the next 20 years. The representatives of participating governments gathered in Rio de Janeiro to discuss what the draft text of the outcome document was then.

Rio+20 sought to secure affirmations for the political commitments made at past Earth Summits and set the global environmental agenda for the next 20 years by assessing progress towards the goals outlined in Agenda 21 and implementation gaps therein and discussing new and emerging issues. The UN wanted Rio to endorse a UN "green economy roadmap," with environmental goals, targets, and deadlines, whereas developing countries preferred establishing new "sustainable development goals" to protect the environment better, guarantee food and power to the poorest, and alleviate poverty (www.guidian.co.uk, 2012, 21 June).

Recent amendments to facilitate the implementation of the Climate Change Protocol include the Doha Amendment to the Kyoto Protocol (8 December 2012) created a second commitment period in the recently completed climate change negotiations, which ran from 2013 to 2020 (UNFCCC, 2014b).

Some other agreements which resulted from the Earth Summit include Framework Convention on Climate Change, Convention on Biological Diversity, Forest Principles, and the NGO Alternative Treaties.

New Zealand ratified the UNFCCC in 1993 and signed the Kyoto Protocol (an agreement under the UNFCCC) in 1998 (NZ Parliamentary Library, 2001). These agreements target the reduction of GHGs. Under the Kyoto Protocol, countries including New Zealand agreed to reduce its GHG emissions back to 1990 levels by 2012 or pay for any excess. The outcome was the establishment of the global carbon market and countries and economic blocks establishing emission trading schemes as an incentive to reduce the emissions.

These resulted in the establishment of New Zealand Emission Trading Scheme (NZETS) through the Climate Change Response Act 2002 (CCRA) (New Zealand Emission Unit Register, n.d; NZ Parliamentary Library, 2001). Emission Trading Scheme (ETS) is a way of putting a price on emissions and creating an incentive for people and businesses to change their behaviour towards emission reduction (Ministry for the Environment, 2012d). Under ETS, those who operate waste disposal facilities including landfills will have obligations to report their emissions from 1 January 2012 using a default formula (Tonkin & Taylor Ltd, 2010). The targets and objectives of these initiatives can only be achieved if adequate information is available. As of 2007, only 13 of the 60 landfills in New Zealand collect their gases for treatment or useful purposes (Ministry for the Environment, 2007b). Landfilling, being the most common solid waste disposal method in New Zealand and its study is relatively a recent phenomenon globally (Ministry for the Environment, 1997a), are some of the motivations to carry out this research. Therefore, this research is making a contribution to the resource base for decision making and future studies.

Recent amendments to facilitate the implementation of the Climate Change Protocol include:

Doha Amendment to Kyoto Protocol (8 December 2012) was made to create a second commitment period of the present climate change negotiation, which runs from 2013 to 2020. This amendment comes into force when 144 countries have accepted it (UNFCCC, 2014b). New Zealand accepted the Doha amendment on 30 November 2015 (Ministry for the Environment, 2016).

The Paris Agreement (12 December 2015), was adopted by Parties to the UNFCCC (Ministry for the Environment, 2016). It will take effect from 2020 as soon as 55 countries have ratified the Agreement. This marks the unfolding of a UN climate change regime, creating a new beginning in the global effort to combat climate change. The Paris Agreement is aimed at accelerating and intensifying the actions and investment needed for a sustainable low carbon future. This is expected to keep the global temperature rise below two degrees Celsius this century. The reduction in relative temperature rise is expected to be pushed further down to 1.5 degree Celsius. New Zealand signed the Paris Agreement on 22 April 2016 (Ministry for the Environment, 2016).

3.3.1.7 The 1985 Waigani Convention

This Convention governs the trans-boundary movement of hazardous waste in the South Pacific region. It prohibits the export of hazardous waste from New Zealand and Australia into the Convention area in the South Pacific but does allow imports from the Pacific Island are developing parties into New Zealand and Australia. New Caledonia and French Polynesia are French territories and so come under the Basel Convention, rather than the Waigani Convention (Ministry for the Environment, 2011b).

The Waigani Convention provides a mechanism to stop waste traders from using the South Pacific as a highway for hazardous waste or as a waste dump. Once a party to the Waigani Convention, a country is eligible for technical and financial assistance to help in the management of hazardous or nuclear waste thereby creating an effective regional mechanism to facilitate the clean-up of hazardous and radioactive waste.

Promoting and strengthening the Environmentally Sound Management (ESM) of hazardous and radioactive waste, was one of the main targets identified by the international community as a priority for the follow-up to the Rio Earth Summit in 1992. The Waigani Convention seeks to address these issues in the South Pacific. New Zealand was involved in all stages of the negotiating process and was one of the original signatories when the Waigani Convention was opened for signature in September 1995 (New Zealand Ministry of Foreign Affairs & Trade, 2011).

The Waigani Convention largely mirrors the obligations set out in the Basel Convention on the Control of Trans-Boundary Movements of Hazardous Waste and Their Disposal, 1989 (the Basel Convention). New Zealand has been party to the Basel Convention since 1995. As a result, New Zealand has in place a robust import screening process for ensuring the protection of human health and the New Zealand environment from imported hazardous and radioactive waste, within which the requirements of the Waigani Convention could easily be met.

As at December 2002, ten parties had ratified the Waigani Convention. These were Australia, Cook Islands, the Federated States of Micronesia, Kiribati, New Zealand, Papua New Guinea, Samoa, Solomon Islands, Tuvalu and Vanuatu (Australian Government Department of the Environment, n.d-a).

3.3.1.8 The 1998 Rotterdam Convention

This convention may not directly relate to waste management. But it has an indirect impact on the trans-boundary movement of waste require that the waste conforms to the requirement of this Convention. This is most necessary where countries may require treating of certain hazardous waste outside their boundaries.

The Rotterdam Convention is a result of dramatic growth in chemical production and trade during the past three decades which raised concerns about the potential risk posed by hazardous chemicals and pesticides. Hence, countries lacking adequate infrastructure to monitor the import and use of these chemicals are particularly vulnerable (Rotterdam Convention, 2010).

In response to these concerns, UNEP and FAO (Food and Agricultural Organization) developed and promoted voluntary information exchange programmes in the mid-1980s. FOA launched the International Code of Conduct on the Distribution and Use of Pesticides in 1985 and UNEP established the London Guidelines for the Exchange of Information on Chemicals in International Trade in 1987. In 1989, the two organizations jointly introduced the voluntary Prior Informed Consent (PIC) procedure into these two instruments. Together, these instruments helped to ensure that governments had the necessary information to enable them to assess the risks of hazardous chemicals and take informed decisions on their future import.

Hence, officials attending the Rio Earth Summit in Brazil in 1992 adopted Chapter 19 of Agenda 21 which called for a legally binding instrument on the voluntary PIC procedure by the year 2000. On 10 September 1998, the text of the Rotterdam Convention was adopted and opened for signing at the Conference of Plenipotentiaries held in Rotterdam

The Rotterdam (PIC) Convention seeks to control the movement of certain hazardous chemicals and pesticides on the basis of PIC that is, the formal and advance agreement of the importing party to accept the substance. The provisions of the Convention facilitate such decision-making by providing parties with full information on the environmental and human health risks of each substance. The Convention does not ban trade but gives each party the option to ban or restrict imports based on its assessment of the risks involved and its national circumstances.

New Zealand signed the Convention in 1998 and ratified it on 23 September 2003. The Convention entered into force in February 2004. Discussion started in March 1996 and was concluded in 1998.

3.3.1.9 The 2001 Stockholm Convention on Persistent Organic Pollutants

This is an international environmental treaty signed in 2001 and effective from May 2004, that aims to eliminate or restrict the production and use of persistent organic pollutants (POPs), with New Zealand ratifying the convention on 24 September 2004.

The Convention is a global treaty that aims to protect human health and the environment from the effects of POPs The Convention has a range of control measures to reduce and, where feasible, eliminate the release of POPs, including emissions of unintentionally produced POPs such as dioxins. The Convention also aims to ensure the sound management of stockpiles and waste that contain POPs.

According to Ministry for the Environment (2011a), POPs are organic compounds that do not break down readily in the environment are capable of long-range transport. Such pollutants can bioaccumulate in human and animal tissue and biomagnify in food chains. In this way, they pose a risk of causing adverse effects to human health and the environment.

Therefore, POPs are a global issue for the environment and human health. In wildlife, exposure to POPs is known to cause birth defects, various cancers, immune system dysfunction, and reproductive problems.

The weight of evidence concerning human impacts indicates that high levels of exposure to POPs over a long time may be associated with birth defects, fertility problems, greater susceptibility to disease, diminished intelligence, and some types of cancers. Emerging evidence indicates that many POPs may act as endocrine disruptors.

In 2004, 12 POPs (the Dirty Dozen) were listed in annexes to the Convention. These were: Aldrin, Chlordane, Dieldrin, Endrin, Heptachlor, Hexachlorobenzene (HCB), Mirex, Toxaphene, Polychlorinated biphenyls (PCB), DDT, Dioxins, and Furans.

More recently, in 2010, nine additional POPs were added to the Convention. They are (Australian Government Department of the Environment, n.d-b):

- Chlordecone
- Lindane
- Hexabromobiphenyl
- Pentachlorobenzene
- Alpha hexachlorocyclohexane
- Beta hexachlorocyclohexane
- Perfluorooctane sulfonic acid, its salts and perfluorobutane sulfonyl fluoride (PFOS)
- Tetrabromodiphenyl ether and pentabromodiphenyl ether ('commercial pentabromodiphenyl ether')
- Hexabromodiphenyl ether and hexabromobiphenyl ether ('commercial octa Brom diphenyl ether).

The Convention recognises that there are other chemicals that could pose similar risks to human health and the environment. Therefore, other chemicals may be added to the annexes in the future.

To integrate some of the aspects of the Basel Convention, Article 6(2) of the Stockholm Convention outlines the requirements for cooperation between the two ruling bodies. By integrating and ratifying the various global instruments for dealing with hazardous waste and POPs, regional and national leaders can establish effective legal and institutional controls on such chemicals (United Nations Industrial Development Organisation, n.d).

3.3.1.9.1 Application of Persistent Organochlorine Pesticides (POPs)

Before the Stockholm Convention, POPs were widely used in New Zealand. From the mid-1940s until the 1970s some persistent organochlorine pesticides (including DDT, dieldrin) were used widely in agriculture, horticulture, timber treatment, and public health. Smaller amounts were also used f in households. The use of pesticides in New Zealand was not subject to compulsory regulatory control until the Agricultural Chemicals Act 1959 established the Agricultural Chemicals Board. The use of persistent organochlorine pesticides was then progressively restricted by a succession of legislative measures, so that, by the mid-1970s their use had effectively ceased in agriculture and horticulture. All Stockholm Convention on POPs were formally deregistered by the Pesticides Board in 1989 (Ministry for the Environment, 2011a).

Polychlorinated biphenyls (PCBs) were also used widely in industry as electrical transformer fluids, heat transfer fluids, hydraulic fluids, solvent extenders, flame retardants, plasticisers, dielectric fluids, some paints and printing inks, immersion oils, and sealants. The unusual industrial versatility of PCBs is directly related to their chemical and physical properties, which include resistance to acids and bases, compatibility with organic materials, resistance to oxidation and reduction, excellent electrical insulating properties, thermal stability, and non-flammability. Of course, these properties also mean that they are not readily degradable in landfills and leach toxic chemicals as they break down.

The widespread use of PCBs, coupled with industrial accidents and improper disposal has resulted in significant environmental contamination, particularly within the more industrialised northern hemisphere. Most New Zealand stocks of PCBs have already been shipped overseas and destroyed in a nationwide recall of PCBs used in the electrical supply industry. New Zealand is committed to complete the PCB replacement programme by 2016 (Ministry for the Environment, 2011a).

'Dioxin' which is a generic term used to describe a family of chlorine-containing chemicals. Dioxins and furans are 'by-product' chemicals formed in very small amounts when chlorine is present in some industrial processes and during the burning (combustion, incineration) of organic materials. They can be found throughout the world in air, soil, sediment and water. Once in the environment, dioxins accumulate in the fatty tissue of birds, fish, shellfish, marine mammals, and in people. Dioxins are known to cause serious health effects such as cancer, birth defects, and reproductive and developmental problems. Dioxins can travel great distances on air currents, affecting people and wildlife far from their point of release.

Through the Imports and Exports (Restrictions) Prohibition Order (No. 2) 2004, the New Zealand Customs Service (Customs) which is the border enforcement agency, monitors the cross-border movement of goods for compliance with the relevant legislative requirements. This includes a requirement for importers and exporters to lodge electronic entries with Customs for goods imported into and exported from New Zealand. In practice, shipments identified as being covered by an import or export prohibition are held by Customs until the importer/exporter produces the required approval from the government agency administering the legislation (Ministry for the Environment, n.d-b).

Table 3.4 provides a brief summary of how international protocols and conventions have influenced New Zealand waste management policies.

Table 3.4: Landmark treaties and international laws affecting waste management in New Zealand

Date Ratified by New Zealand	Treaty/International Law	Information Source
1975 (30 April)	London dumping convention on the prevention of marine pollution by dumping of waste and other matter, 1972	(United Nations, 1977)
1987 (2 June)	Vienna Convention for the protection of ozone layer, 1985	(Ministry for the Environment, 2015)
1988 (21 July)	Montreal Protocol on substances that deplete the ozone layer, 1987	(UNEP Ozone Secretariat, 2013)
1992 (3-14 June)	The Earth Summit (Agenda 21, the Rio Declaration on Environment and Development), 1992	(Ministry for the Environment, 2012)
1993 (8 September)	Framework Convention on Climate Change which was drafted in 1992	(Ministry for the Environment, 2012a
1994 (20 December)	Basel Convention on the control of trans-boundary movement of hazardous waste and their disposal, 1989	(UNEP (Basel Convention), 2011)
2000 (30 November)	Waigani Convention on trans-boundary movement of hazardous waste in South Pacific region, 1995	(Ministry for the Environment, 2011)
2002 (December)	Kyoto Protocol 1995; Under the Kyoto Protocol countries agreed to reduce GHG emissions back to 1990 levels by 2012 or pay for any excess. And agreed to: - Submitting an annual inventory of GHG emissions to UNFCCC (Article 7); - Formulating, implementing and publishing regular updates to national and regional programmes containing measures to mitigate climate change and measures to facilitate adequate adaptation to climate change (Article 10); and - Cooperating internationally in relation to policies and measures including scientific and technical research and development and facilitating public awareness and access to information on climate change	(Ministry for the Environment, 2010)
2003 (23 September)	Rotterdam Convention on prior Informed Consent (PIC) procedure for Certain hazardous chemicals and pesticides in International Trade, 1998	(Ministry for the Environment, 2014)
2004 (24 September)	Stockholm Convention on persistent organic pollutions 2001; Mindful of the precautionary approach as set forth in Principle 15 of the Rio Declaration on Environment and Development, the objective of this Convention is to protect human health and the environment from persistent organic pollutants.	(UNEP (Stockholm Convention), 2008)
2015 (30 November)	Doha Amendment to Kyoto Protocol which was adopted by Conference of the Parties at Doha, Qatar, in December 2012	(Ministry for the Environment, 2016)
2016 (22 April)	Paris Agreement on new commitment to low carbon future, 2015	(Ministry for the Environment, 2016)

Note: The sources for each of these events are contained in column three of the table

3.4 Conclusion

The aim of the international frameworks is to protect human health and promote a healthy environment. Agenda 21 brought a new dimension to this agenda namely the sustainable use of resources. The volume of waste generated in society is an indication of the pattern of resource use. Waste generation has been linked to population and economic prosperity. But an understanding of the meaning of sustainability is a challenge. The needs of a country or municipality determine how it defines sustainability. In order to have adequate sustainability practices in waste management, it is important to have a common sustainable and public health and environmentally focused index and understanding of waste, especially in relation to resource use. Hence, the need to decouple economic growth from waste generation hence environmental degradation (European Environment Agency, 2011).

All the international frameworks as discussed in the previous sections are aimed at affecting either waste generation (Stockholm Convention, Vienna Convention, Rio declaration), waste handling/transportation (Rotterdam Convention, London Convention, Basel Convention, Waigani Convention, Vienna Convention) and waste impact remediation (Rio Declaration, Vienna Convention, Montreal Protocol, Rotterdam Convention, Stockholm Convention, Kyoto Protocol). If examined critically, these frameworks combined should be affecting waste from generation to disposal. The impacts of implementation of these frameworks prioritise the environment over public health (although because health is linked to the environment, these frameworks could arguably also be favourable to increasing public health).

To achieve sustainability in waste management will involve all stakeholders without considering the source of the waste. If the objectives of the agreements are achieved, the mother Earth will become a better place for all of us.

For example, the Basel Convention is the sole global legal instrument addressing trans-boundary movements and environmentally sound management of hazardous and other waste. In the 20 years since its adoption, it has become the centrepiece of an international legal regime on the issue. Some of its fundamental principles include the principles of the proximity of disposal of waste, environmentally sound management and prior informed consent to the import of potentially hazardous substances. These principles have arguably contributed to the development of customary international law in the relevant field and have been incorporated into local legislation and waste management policies in some countries. Some regional treaties incorporating these principles have since been adopted by groups of countries in different parts of the world to complement the global regime of the Basel Convention and address specific regional needs.

The enforcement of these principles is still a major challenge. Recent years have seen efforts to cooperate with organizations like the World Customs Organization and Interpol in the area of enforcement and with the International Maritime Organization in the area of marine pollution by substances subject to trans-boundary movement, as well as of dismantling of obsolete ships (United Nations, 2013).

Although the Stockholm Convention of 1972 was the first global conference on human environment and marked the emergence of international law, the 1992 Rio UNCED, commonly referred to as the Rio Conference or Earth Summit, succeeded in raising public awareness of the need to integrate environment and development. The Earth Summit influenced subsequent UN conferences, including Rio+20 and set the global green agenda. "The World Conference on Human Rights, for example, focused on the right of people to a healthy environment and the right to development; controversial demands that had met with resistance from some Member States until the Earth Summit (United Nations, 1997b).

Major outcomes of the conference include the Climate Change Convention, which led to Kyoto Protocol, Agenda 21 and a Convention on Biological Diversity. It also created new international institutions, among them the Commission on Sustainable Development, tasked with the follow-up to the Rio Conference, the United Nations Framework Convention on Climate Change (UNFCCC) and led to the reform of the Global Environment Facility (United Nations, n.d). In 2002 at Johannesburg, the concept of three mutually reinforcing pillars of sustainable development was incorporated into the plan of implementation (Figure 3.10).

The report of the Rio+20 (United Nations, 2012) identified political commitment as one of the major hindrances towards achieving sustainability. The report also accepts the need to integrate economic, social, and environmental aspects and recognized their interlinkages. The achievement of the desired level of linkages will help to achieve sustainable development in all its dimensions. Even though local conditions may differ, countries working in isolation make it difficult to achieve the desired goals. Hence, the agreement between the United States and the G20 countries and China is a welcomed development

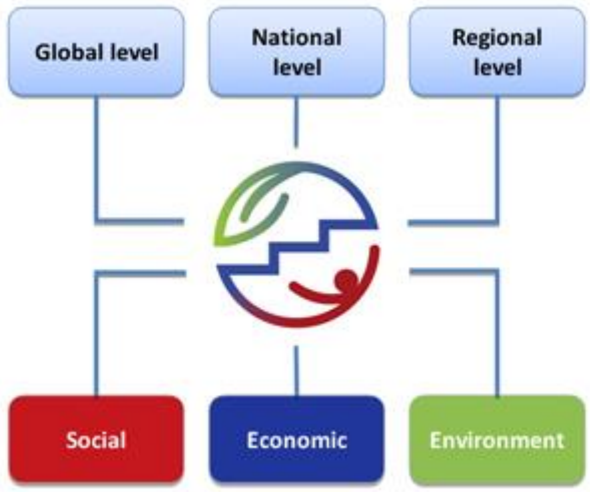


Figure 3.10: Three pillars of sustainable development. Source: United Nations (2011)

Central to the ability of Governments to formulate policies for sustainability and to regulate their impact is the development of a set of internationally accepted criteria and indicators for sustainable development. The Commission on Sustainable Development is spearheading this work, which will enable countries to gather and report the data needed to measure progress on Agenda 21. It is hoped that a “menu” of indicators — from which Governments can choose those appropriate to local conditions — will be used by countries in their national plans and strategies and, subsequently, when they report to the Commission (United Nations, 1997a).

Therefore, achieving sustainable development nationally and globally depends largely on changing patterns of production and consumption — what we produce, how it is produced and how much we consume, particularly in the developed countries. This can be measured through waste generation where the amount of waste from the system is an indication of the level of economic activity. What is the economic development trend and what is its relationship with waste generation? An efficient system, however, can generate less waste in the midst of increased economic activity. This is a proof of a sustainable system. But this can only be proven with sufficient data to facilitate the required measurement. Therefore, data availability and standard are very vital if such a proven calculation can be made successfully.

Developing a national waste management plan in line with Agenda 21 and all the signed treaties and pacts will improve waste management strategies and reduce the negative impact of MSWM on health and environment. New Zealand as a country should borrow a leaf from the EU and streamline her MSWM strategy which may need some new legislation or review of existing ones to reflect a shift from the present disintegrated system to an integrated sustainable system.

CHAPTER FOUR

NATIONAL AND REGIONAL LEGISLATIVE FRAMEWORKS IN MSWM IN NEW ZEALAND

4.0 Introduction

According to Dann (2012a), New Zealand urban settlement dates back to the 1840s and accumulation of waste around residential houses, businesses and in the streets became visible about the 1860s. In the mid-1860s conditions in Dunedin, which was then New Zealand’s largest city were so bad that a Sanitary Commission was set up to investigate and recommend solutions (Dann, 2012b). The situation was, without exception, the same all over the country.

All efforts to tackle the waste problem resulted only in shifting the burden from general environmental decay, resulting from indiscriminate dumping of waste to water pollution (as a result of the dumping of waste in waterways) and air pollution (through waste burning). As a result, it became necessary to invoke legislative solutions. This chapter focuses on the development of the legislative measures for managing MSWM in New Zealand. The legislative solution was also influenced by international frameworks which New Zealand signed as a party, as discussed in chapter three. This discussion is necessary to help in understanding the driving force of legislation in achieving integration and sustainability.

4.1 The Legislative Struggle

Conflict of interest was the first major obstacle to waste management. Politicians who owned properties used their powers to resist the imposition of property rates as a means of paying for proper sanitation. This lack of property rates was the situation between the 1860s and 1870s (Dann, 2013). Dann (2012c) records one attempt to enact the “Pollution of Water Bill” which was introduced to Parliament in 1912 but was eventually dropped. In 1937 another attempt to protect waterways was made; the “River Pollution Prevention Bill” was drafted in 1937 but again this bill failed to gain support, and the subsequent inter-departmental committee on pollution which was convened in the same year only made ad hoc recommendations. Before the emergence of Health Act 1920, which was the first major legislative event to impact on waste management, there were other largely unsuccessful attempts to adopt a legislative approach to solving waste management problems in New Zealand.

Some of these legislative attempts to tackle the waste problem, including non-statutory policy statements, included the Health Act 1956, the Radiation Protection Act 1965, the Litter Act 1979, the Ozone Layer Protection Act 1996, and the Agricultural Compounds and Veterinary Medicines Act 1997 (Table 3.2). Additionally, the Building Code (issued under the Building Act) and the requirements of the Health and Safety in Employment Act of 1992, made provisions for the storage and management of hazardous substances that intended to minimise adverse effects on population health and the environment. The Land Transport Act 1998, Maritime Transport Act 1994 and the Civil Aviation Act 1990, and their subsequent amendments in succeeding years, together control the way dangerous goods transportation are handled, including hazardous waste.

The minimal impact of the introduction of pre-2008 legislative measures led to the emergence of the Waste Minimization Act of 2008 (WMA) which was introduced to Parliament by the Green Party on the fourth of May 2006. According to Hinchey (2013), this Act was introduced at a time of relatively strong economic prosperity and high levels of global resource consumption when several other western countries were also reviewing their waste management legislation. In its original form, WMA sought to strengthen waste minimization efforts in New Zealand by replacing the existing, largely voluntary, industry-led approach with a national waste minimization framework. This framework included increased regulation and control by central and local government, along with price-based mechanisms.

The Act generated a lot of interest and was eventually passed by a Labour Party Government with significant amendments including (New Zealand Parliament, 2008)

- removing the proposal requiring all New Zealand businesses to implement waste minimization plans by 2016. The Review Committee in its report on the Bill stated that this would be too burdensome on businesses but encouraged businesses to introduced such plans voluntarily.
- removing the proposals to make territorial authorities "Waste Control Authorities", bound - among other things - to operate a system of licenses that

would require commercial collectors and transporters of MSW and all operators of MSWM facilities to be licensed.

- removing mandatory target dates and industry requirements for waste reduction goals, and reducing the Act's emphasis on prohibiting the disposal of waste that could be reused or recycled.
- "encouraging" rather than "requiring" waste minimization.

Even with all the amendments, the resulting legislation was still considered to be a significant shift in approach to waste management in New Zealand.

The key elements which were retained in general principle from the original Bill, include:

- a definition of "waste",
- creation of a Waste Disposal Levy,
- creation of a product stewardship scheme,
- creation of a Waste Minimization Fund,
- provision of local authority waste management and minimization plans and bylaws,
- regulations and information gathering provisions, and
- creation of Waste Advisory Board.

However, some of the removed proposals in the original act resulted in a lesser outcome as a result of the implementation and adoption of the act. Had the original act been enacted then it should have impacted better on waste management sector, due to the proposed system of licensing for all waste management operators. This licensing if handled appropriately should have made operators answerable to municipal authorities and hence this obligation should have provided an opportunity for a better data collection and monitoring system.

4.2 National Legislative Outlook

Some of the domestic legislation relating to waste management are framed in accordance with New Zealand's commitments under relevant international agreements (e.g., the Stockholm Convention, the Waigani Convention, and the 1989 Basel Convention) (Table 3.3) while others are developed to address more local circumstances at the time of their enactment.

One of the first international agreements that were signed by New Zealand was the London Dumping Convention on the prevention of marine pollution resulting from the dumping of waste in 1975. In line with that commitment, the Maritime Transport Act 1994 prohibiting the dumping of waste in the sea was enacted. Table 4.1 lists some of the local legislation and the corresponding international agreement.

Table 4.1: National legislation in New Zealand and corresponding international agreement

National Legislation	Relating International Agreement
Resource Management Act 1991	Earth Summit (Agenda 21)
Maritime Transport Act 1994	London dumping convention on the prevention of marine pollution by dumping of waste
Ozone Layer Protection Act 1996	Montreal Protocol on substances that deplete the ozone layer
Climate Change Response Act 2002	Kyoto Protocol and United Nations Convention on Climate Change
Imports and Exports (Restrictions) Prohibition Order (No 2) 2004	Stockholm Convention
Waste minimization Act 2008	Earth Summit (Agenda 21)
Climate Change (waste) Regulations 2010 (Information on emission calculation)	Kyoto Protocol and United Nations Convention on Climate Change
Climate Change (Unique emissions factors) Amendment Regulations 2010	Kyoto Protocol and United Nations Convention on Climate Change
Climate Change Response (Emissions Trading and other Amendment) Bill 2012	Kyoto Protocol and United Nations Convention on Climate Change

Source: Compiled by the Author from various sources

Other local issues related to protecting the environment and health of citizens drive the rest of the legislation discussed here. Refer to Table 3.2 for details of waste legislation and the problems they are intended to address.

Under some legislation, standards are set, like the National Environmental Standards for Air Quality (NES) which was set under RMA in 2004. These are mandatory environmental technical regulations which have included regulatory empowerment measures that are implemented by agencies and parties identified under the relevant legislation. National environmental standards not only protect people and the environment but also secure a consistent approach and decision-making process throughout the whole country. They create a level playing field. Some of the standards prescribed under the Air Quality Standard, affect the management of waste, such as the prohibition of the practices of burning of waste at landfills, and the operation of incinerators at schools and h (Environment Canterbury Regional Council, 2014).

The New Zealand Waste Strategy is a high level, non-statutory policy statement which is setting a new direction aimed at waste reduction and the improved management of all category of waste (liquid, solid, and gas). The three core goals of the strategy are: (Environment Canterbury Regional Council, 2014):

- to lower the social cost and risk of MSW,
- to reduce the damage to the ecosystems resulting from MSW generation and poor disposal practices,
- to increase the economic benefit or available resources through increased efficiency in the use of available materials.

These goals are consistent with the New Zealand Government's sustainable development objectives and are directly linked to the New Zealand National Energy Efficiency and Conservation Strategy and the New Zealand Government's climate change policies. Both central, regional and local government are all involved in the initiatives being put in place to help in the desire to achieve these goals.

This strategy is currently New Zealand’s principal waste management policy document, but this strategy, unfortunately, does not include national waste management standards. Thus, despite achieving some of the targets set by the waste management strategy, waste minimization, and management practices are still widely variable across local councils, and districts and volume of waste to landfill is still increasing. The challenge for New Zeland in 2006 was to ensure that a consistent and high level of service is provided throughout New Zealand (Ministry for the Environment, 2007c). This challenge remains today in 2016. This thesis aims to provide a potential solution to this issue by providing mechanisms for the collection and measurement of accurate and comprehensive data which can be used to determine the quality of waste management practices and compare practices and their impact regionally within New Zealand.

4.3 Regional Legislative Outlook

From 1920 when poor waste management was first identified as an environmental and health problem, territorial authorities have been empowered to control and manage waste in their domain. The various sections of the legislation give that authority to every local government and district and equally the authority to make by-laws for the purpose of managing waste. The RMA provides a framework to manage the environmental and social effects of waste management (Environment Canterbury Regional Council, 2014).

In addition to the authority to make by-laws, the WMA required the territorial authorities to have waste management and minimization plans (WMMPs) by 1 July 2012, which must have regard to New Zealand waste strategy.

Before preparing a WMMP, it is a requirement that the territorial authority must undertake a waste assessment which will provide the necessary background information for the territorial authority to work out a logical set of priorities and report its activities appropriately. The principal behind this local approach is to allow the various districts and territorial authorities draw up their WMMP in response to local needs. The outcome is though that there is no comprehensive or integrated statutory framework covering the management of waste and hazardous waste. Instead, there is a complex array of disparate statutes, by-laws and regulations, policy documents and waste management plans.

4.4 How has MSWM fared under the Present Legislative Structure?

According to WMA which is the major legislative tool governing MSWM in New Zealand, "the purpose of this Act is to encourage waste minimization and decrease in waste disposal to:

- protect the environment from harm; and
- provide environmental, social, economic, and cultural benefit" (New Zealand Legislation, 2008).

The legislative framework as described puts the primary responsibility of MSWM on local authorities. Part 4 of the Act stipulates the responsibilities of territorial authorities, for waste management and minimization, which includes the adoption of a waste management plan which must provide for the following:

(a) objectives and policies directed towards achieving effective and efficient waste management and minimization within the territorial authority's district

(b) the methods for achieving effective and efficient waste management and minimization within the territorial authority's district; including:

  (i) the collection, recovery, recycling, treatment, and disposal services for the district to meet its current and future waste management and minimization needs (whether provided by the territorial authority or otherwise); and

(ii) any waste management and minimization facilities provided, or to be provided, by the territorial authority; and

(iii) any waste management and minimization activities, including any educational or public awareness activities, provided, or to be provided, by the territorial authority:

The Act also recommends the adoption of Waste Management Hierarchy which consists of the following principals, in descending order of importance; reduction; reuse; recycling; treatment and disposal. The strategy adopted should also have regard to the New Zealand Waste Strategy, or any government policy on waste management and minimization that in the future replaces the strategy.

Section 45 recommends that territorial authorities prepare and adopt the same plan. While Section 48 in part recommends the only conditions on which the central government may interfere with the plan of any territorial authority namely, that "**2(a)** the territorial authority's waste management and minimisation plan is inadequate to promote effective and efficient waste management and minimisation within its district; or **2(b)** the proposed changes to the waste management and minimisation plan will achieve or assist in achieving the New Zealand Waste Strategy, or any government policy on waste management and minimisation that replaces the strategy". Section 49 indicates that the Minister may set performance standards, for territorial authorities, for the implementation of waste management and minimization plans.

Although territorial authorities have powers to make bylaws to help them develop and implement waste management and minimization plans, including a collection of data for more effective monitoring of waste within their areas of jurisdiction, many territorial authorities have not taken advantage of these powers to enforce reporting and data collection. For example, as far as this research was able to ascertain, Section 51 on requirements for waste assessment has not been fully implemented by any territorial authority because of a lack of suitable data, because the only available waste data available is disposal data from landfills based on collected levies. Forecasts related to waste management services (collection, recycling, recovery, treatment, and disposal) are made based on assumptions and incomplete, inaccurate, disparate, high level and often poorly estimated data. This lack of data is a reoccurring theme in various government reports (Ministry for the Environment, 1997a, 2007b), but no effort has been made to correct it. One possible solution to this data issue might be to introduce legislation similar to that of Singapore (Chua, 2012).

One major hindrance to improved data availability is ‘commercial sensitivity’ (Ministry for the Environment, 2007a, 2007d) and lack of awareness of the importance of waste tracking from its source. Therefore, waste generation information has been focused on data collected at disposal sites using the Waste Assessment Protocol (WAP). The WAP is a set of guidelines for the local authorities on how to measure and analyse waste. Since 1993 some local authorities have used the WAP to survey their solid waste stream (Ministry for the Environment, 1997b). Recently, the data collected related to waste disposal has improved through the use of a waste disposal levy which can be used as a source of information (Ministry for the Environment, 2012).

While this may have provided a small improvement in the data collected this data does not include the full waste disposal lifecycle and therefore does not reflect recent events in local waste management practices. For example, the transportation of waste from Gisborne to Tirohia landfill (about 320km) is occurring, because of a bylaw prohibiting the disposal of ‘out of district waste’ at (Taupo) which would be a closer location (Environment Waikato, 2007). This is obviously a major setback in achieving clean environment and greatly changes the dynamics of the waste management system because of the additional emissions resulting from a greater distance for transportation contributes to the environmental impact of waste management. The ban on the collection of ‘out of territory waste’ at Taupo is not consistent with some of the New Zealand national policies like the Clean Air Legislation and the general content of the WMA. This ban is, however, consistent with the provision of Section 56(1) of WMA authorizing Territorial Authorities to regulate access to waste management facilities provided, owned or operated by the Territorial Authority. The situation of Gisborne’s waste illustrates the complex web of, sometimes contradictory, the legislative environment in which local authorities are operating as essentially independent/isolated authorities.

The problem of Gisborne dumping their waste within their territory may be linked to the issue of economic of scale. Therefore, it is not viable to maintain a landfill where the total volume of waste to landfill is only about 13000 tonnes per annum. It is cheaper to transport the waste to the nearest available landfill, which is Tirohia landfill, because of the standing rule at Taupo.

4.5 Conclusion

It is a general requirement for each territorial authority to have a waste management plan that is within the scope of New Zealand waste strategy (New Zealand Legislation, 2008, p. 25). That provides a disintegrated waste management targets at national level, as no specific target is set. While some of the territorial authorities have no target or direction in their plan because of a lack of suitable performance indicators (Horowhenua District Council, 2012), others have created ambitious targets. For example, Auckland Council is targeting a zero waste situation by 2040 through various targeted strategies, but of course, the measurements used to establish whether or not these targets are met are reliant on inadequate data. Auckland Council and Waikato District Council are aiming to reduce their per capita waste to landfill by 33 percent by 2022, and this target may result in possible restrictions on the disposal of recyclables and organics (Auckland Council, 2011; Waikato District Council, 2012). Other authorities provide some policy statements and methods, but no targets (Nelson City and Tasman District Council, 2012).

Some local by-laws while beneficial locally may not be good for the national waste management strategy, WMA or our New Zealand's commitment to international treaties as exemplified by the banning of 'out of district waste' in Taupo landfill and this bans impact on the waste of neighbouring districts Gisborne and Waikato (Waikato Regional Council, 2007).

Therefore, developing a national waste management target is necessary if New Zealand intends to meet its waste management strategy target and meet its obligation in international treaties which have relation with waste management.

Although there have been considerable improvements in access to recycling services, and environmental controls around disposal facilities, MSWM and minimization practices still vary around the country, and further improvements can be made (Ministry for the Environment, 2010). Research has continued to highlight the value of recycling (European Environment Agency, 2011; European Recyclers, 2012; R. W. Beck Inc, 2001; US EPA, 2002). However, the environmental and economic costs of collection and transportation of materials can be high in a non-integrated form, especially in a situation like New Zealand scenario where the population can be very small and dispersed.

Because waste generation and volume of waste to landfills have continued to increase it is reasonable to argue that this consequently indicates the current non-sustainability of

New Zealand's waste management systems. Therefore, policy initiatives at the central and regional levels need to work together towards a more sustainable solid waste management infrastructure (Wakim, 2004) and in a more unified form.

Efforts such as the introduction of the kerbside recycling collection have contributed significantly to reduce waste to landfill, although overall the general trend has been a continuous increase in the volume of waste to landfill on a per capita basis. This trend is true not just for Auckland, but for the whole of New Zealand (Auckland Council, 2011). One of the key challenges to reducing waste to landfill is the fact that there are no legal obligations imposed on the commercial waste industry to "promote effective and efficient waste management and minimization" (Auckland Council, 2011, p. 2). Over 30 per cent of material disposed of in landfills could potentially be diverted to beneficial use as in recycling or composting, but there are very few direct incentive for the private waste industry to take further action to recover the materials and reduce waste.

The New Zealand Waste Strategy, whose major themes are – reducing harm and improving efficiency – provides the direction to local government, businesses (including the waste industry), and communities on where to focus their efforts to deliver environmental, social and economic benefits to all New Zealanders.

While territorial authorities such as Auckland Council recognize the harmful effects of waste in landfills such as the emission of harmful GHGs resulting from waste decomposition, and toxic leachate escaping into the ground, many do not incorporate other critical factors such as transportation as contributors to emissions and their environmental impacts. This thesis attempts to develop a framework that provides a more holistic comprehensive approach to understanding and assessing MSWM.

CHAPTER FIVE

RESEARCH METHODOLOGY

5.0 Introduction

Interest in sustainability research has grown significantly since the 1990s, but most especially since the beginning of the 21st century, due primarily to rapid global environmental changes which have been linked to exponential population growth, loss of biodiversity arising from deforestation, climate change, rising inequality, and global financial crises. Along with this increased research comes an increasing need for more reliable scientific data. However, the core scientific methodologies necessary to achieve required results in sustainability research are often undermined because of poor data quality to deal with the complex sustainability problems (Jaeger, Tàbara, & Jaeger, 2011).

Popa, Guillermin, & Dedeurwaerdere argue that addressing issues of sustainability require decisions based on values that require civic participation and the building of social legitimacy for the proposed transitional pathways from the ‘business as usual’ to a sustainable society (Popa, Guillermin, & Dedeurwaerdere, 2015). To achieve high-quality outcomes, many leading researchers and policy makers are calling for the re-conceptualizing of the role of experts, practitioners and citizens in the production and use of scientific knowledge (Backstrand, 2003; European Commission, 2009).

In municipal solid waste management (MSWM), making good decisions towards achieving sustainability is becoming increasingly challenging. This is because MSWM (and of course, all waste management systems) comprise of several complex parts and functions which interact with each. These complex parts and functions include collection, transportation, storage, disposal, treatment, technology, human resources, legislation, waste composition, institutional capacity, political will, safety, and environment, among many others. To understand the waste management system requires an understanding of the complex relationships between these various parts, hence having insight on how they are affecting each other’s dynamics. Therefore, to adequately represent these different areas in a complex waste management system in an attempt to measure the level of sustainability requires a paradigm shift from the single component approach as discussed in section 4.8, to methods that are able to capture, as much as possible, the whole waste management system.

In this research, a *mixed-methodological* approach, which is sometimes termed *pluralist* approach, is adopted. This research also involves a transdisciplinary research approach. Brandt et al. (2013) in that it involves multiple scientific disciplines (interdisciplinary) focusing on a shared problem and considers the work of practitioners from outside academia. In waste management, the sharing of problems is only possible through in the appropriate interaction or consideration of stakeholders and decision makers.

5.1 A Mixed Methodology

A mixed methodology approach in research design incorporates techniques from *qualitative* and *quantitative* methods to answer the research questions (Byrne & Humble, 2007). A mixed methodology may involve different combinations of qualitative and quantitative methods, depending on the goals of the research and the expected outcomes. A mixed method approach can combine individually separate and distinct techniques within one of these families of methods, for example, a study can employ two or more quantitative methodological approaches predicated on fundamentally different assumptions and parameters or feature two or more types of qualitative analyses (Sauro, 2015). On a higher level, it is possible for mixed methodological research to incorporate models or techniques from different disciplines (Hall, 2003, 2007). The most common mixed methodology designs tend to combine some form of qualitative research with some statistical analysis or other computational techniques which Ahmed and Sil (2012) refer to as formal models. Hence providing methodological pluralism where qualitative and quantitative methods are valuable and complementary tools. As a methodology, the mixed method includes philosophical assumptions that guide the direction for the collection and analyses of data and the mixture of qualitative and quantitative data in a single study or series of studies (Creswell & Plano Clark, 2007). It is this form of mixed methodology that is adopted in this research and therefore is the focus of this discussion.

The rationale for mixing these two methods is that neither quantitative nor qualitative methods are sufficient by themselves to capture the complexity of the issue being researched. When used together, both methods complement each other and allow for a complete analysis (Bennett, 2013; Fearon & Laitin, 2008; Henry & Collier, 2004).

The implication of this is that a mixed methodology is not just a pragmatic option for dealing with different elements of a research program or research with practical challenges that arose in the course of the study rather, it is emerging as a 'best practice' resulting from the expectation that a single research endeavour will produce better research result when two or more methods are used systematically in executing the research. In the context of this thesis, a quantitative method was used to assist in corroborating the worldviews established by the researcher as a result of a systematic, qualitative review of the literature and relevant public policy documents For example in this thesis we suggest that the inclusion of the Zero Waste policy as part of the Waste Management and Minimization Plan (WMMP) and closing all landfills within the boundaries of a Territorial Authority, is contrary to developing a sustainable waste management scenario. And the researcher asserts that this is true because the quantity of waste generated or disposed of may not have been affected just the problem shifted to another territorial authority. It was argued that the shift of burden achieved in this instance from one territorial authority to another is not a sustainable achievement. However, unless the effect of such policy implementations can accurately be measured this assertion cannot be considered to be a ground truth. One way of establishing the truth of the effect of this scenario on the environment and on sustainability targets can only be proven through the development and use of a quantitative model such as an LCA-based calculation of for example Emission Ratio (ER) per tonne of waste. Such a measurement would quantify the carbon footprint of a tonne of waste from each Territorial Authority in relation to any set standard whether or not the waste was discarded in another Territorial Authority's region.

The exploratory aspects of adopting a mixed methods approach meant that previously unknown aspects of MSWM could be explored, for example it was only through an examination of secondary data that it was discovered just how inadequate New Zealand's data related to MSWM was and this lead to the hypothesis that using an LCA approach and LCT that an ontology or framework for collecting appropriate data could be established and that this framework should include some kind of quantitative emission model. If such a framework is developed, then it needs to be evaluated. Due to inadequate data, an ontology would need to be evaluated using an expert review of the ontology to establish its coverage and adequacy. Additionally, any emissions model would need to be evaluated, and its effectiveness in estimating emissions from the processes in an MSWM system would need to be benchmarked against other existing models. In order to evaluate these emissions models, suitable data would need to be gathered for selected case study areas and the model's output(s) quantitatively compared with that of the benchmark emissions models. The sections that follow give further justification for this mixed methods approach and provides a discussion for each of the adopted methods in turn.

The review of academic literature relating to waste management research showed that it is common practice to combine *primary* and *secondary data*. This approach was used by both Mallak et al. (2015) and Wang et al. (2015). Wang et al. used document analysis to collect secondary data while they used data acquired from field work to generate primary data. A method of *document analysis* to collect secondary data, which was then the subject of statistical analysis, was adopted by Mallak et al. (2015). As changes in waste management largely result from policy instruments (as suggested by Ekvall & Malmheden, 2014) these documents are considered to be major drivers towards achieving sustainable waste management (as discussed by Finnveden et al., 2013) it is not surprising that much of the academic literature in the area is founded on secondary data. For example, secondary data was collected and analysed in order to perform further cost-benefit analysis of a number of different MSWM scenarios (Jamasb & Nepal, 2010) and Massarutto's systematic literature review of fifteen years of thermal treatment of solid waste in sustainable waste management systems also used secondary data sources (2015).

In other disciplines, usually, qualitative research methods are employed to answer exploratory questions about unknown aspects of a phenomenon, while quantitative research methods tend to be used to answer specific research questions and test hypotheses. Combining qualitative and quantitative methods has the advantage of being able to frame confirmatory and exploratory research questions and hence generate and verify theory in the same study. Providing stronger inferences and a greater assortment of divergent views are two other benefits of a mixed method approach (Teddie & Tashakkori, 2009).

There is little literature currently available related directly to research methods for use in waste management studies, however, Medina (2010) recommended the use of mixed methods in studies of waste management systems in developing countries. The argument for using a mixed methods approach was that formal waste collection in developing countries is inadequate and not centralised and therefore there is less information/data available. However as this research will demonstrate, and has demonstrated in earlier chapters, although developed countries have better formal waste management, not all decisions and practices are governed centrally, and many practices are considered to be commercially sensitive as a result, the data available is not sufficient for decision making.Other advantages gained when adopting a mixed method approach include the ability to provide stronger inferences and the ability to consider a greater range of divergent views (Teddie & Tashakkori, 2009). Therefore, for these reasons, it is clear that a mixed methods approach are also appropriate for a study of MSWM in a developed country.

5.2 Research Phases

The major influences on the choice of research design and method are generally accepted to be based on the resources available, the length of time available to complete the study and the expected outcomes. One of the main factors which will influence this research is the availability and quality of data related to MSWM in New Zealand. Because most of the data is actually embedded within publically available governmental and Territorial Authority reports much of the data will need to be extracted and collated from these reports. So in order to gather the data a systematic document analysis will need to be undertaken. But before data can be extracted an understanding of the basic assumptions in MSWM and relevant legislation and policy were required in order to identify the data required in order to undertake this research. Additionally, it was essential to understand the basic assumptions being made in MSWM and review current practice to develop an understanding of the limitations of these practices in order to fully develop the research questions.

5.2.1 Phase 1

The first method adopted within this research was a qualitative *document analysis* which involved a review of legislation, pacts, and agreements, drawn waste management policies and plans, journal papers, reports, etc. Premises were extracted through document analysis; the deductive reasoning was used to reach conclusions regarding the position and practices in MSWM in New Zealand. Reflections on the relationships between the principles of sustainability and the various practices, ideologies and targets in New Zealand in the 2010's led to the development of research questions and provided insights that were used to develop a waste management scenario for New Zealand.

According to Bowen (2009, p. 1), "document analysis is a systematic procedure for reviewing or evaluating documents—both printed and electronic (computer-based and

Internet-transmitted) material”. As for other analytical methods in qualitative research, it is a requirement in document analysis that the researcher examines and interpret the data available in documents and from that data elicit meaning, gain understanding, and develop empirical knowledge (Corbin & Strauss, 2008; Rapley, 2007). These Documents may take a variety of forms (Bowen, 2009). Non-technical literature such as reports and internal correspondence are all potential sources of data for case studies (Mills, Bonner, & Francis, 2006). Merriam (1988, p. 118) also pointed out that that documents of all types can help in uncovering meaning, developing understanding and discovering insights to the research problem. For the purpose of this thesis, documents include books, past thesis, legislative documents, reports, journals, policy documents, public records, etc.

Document analysis yields data in the form of excerpts (which may be either text or numeric), quotations, or entire passages. These excerpts– that are then organised into major themes categorised and case exemplified into individual cases through content analysis (Labuschagne, 2003).

This analytic procedure involves finding, selecting, appraising, and synthesizing data contained in these documents, and extracting opinions from the documents. Hence, deductive reasoning is applied from the rationalist philosophy, to make conclusions on the level of sustainability of the waste management system.

As a research method, document analysis is particularly applicable to qualitative case studies intended to produce rich descriptions of a single phenomenon, event, organisation or program (Stake, 1995; Yin, 1994).

The document analysis phase of this research was the most crucial. Because it not only provides vital data (including waste volumes, waste composition, emission factors) used for implementing and developing a new MSWM emissions mode (the *CEQ-Model* which is detailed later in this thesis) but also related metadata and background information relevant to the model’s implementation and evaluation.

During document analysis, the focus is on descriptions; hence, the analysis is carried out on data and theories are conceptualized. As such, the interpretation of data is an interactive process linked to the researchers own worldview or paradigm (Ng & Hase, 2008, p. 2). It is, however, important to acknowledge the relationship between the researcher and the analysis of the data and the development of theoretical propositions. A guiding principle in document analysis is that such theories are allowed to emerge from the data as part of the research process, rather than being forced onto the data as a result of preconceptions (Kelle, 2005).

But there is a need for the investigator to identify the boundaries of the research focus, which are continually kept in focus. The ability to understand the complexity of the behaviour pattern of the bounded system helps in identifying the needed data and also be able to develop a theory on which to interpret the outcome of the research.

The concluding view from the arguments presented above is that researchers should avoid using preconceived theoretical frameworks, hence approaching the scenario with an open mind and allow evidence to accumulate and dictate the emergence of a theoretical agenda. Although Goulding (2002) is of the opinion that researchers should venture into the undertaking of the study with limited knowledge, this is not possible in reality. It is common to have background knowledge which provides a level of sensitivity to the t data and information being extracted from the documents. Moreover, it is important the researcher is aware of the influence that their personal bias or beliefs might have on the outcome of a document analysis and to as a result of that awareness avoid influencing the outcome of the analysis and theory development. It is with this awareness that the researcher undertook this study.

5.2.2 Phase 2

The second methodological approach involved a *quantitative* analysis of data and its varied temporal and spatial characteristics using simple descriptive statistics. Trend analysis was carried out using variables such as waste disposal volumes, and composition, which was extracted in the first phase. The data was sourced from governmental agencies responsible for data collection, management, and reporting, including territorial authorities, and the Ministry for the Environment. As a result of this analysis phase, it became evident that the data available was not comprehensive enough for critical policy and legislation to developed and monitored based on currently reported data.

5.2.3 Phase 3

This phase of the research adopts a *pragmatist* approach to the reflexivity of the problem's framing (policy and data) and the problem's solution (a model) (Popa et al. , 2015). As a result of an evaluation of the suitability of the existing waste management plans in the document analysis phase, the need for a suitable more comprehensive measure of the environmental impact of the MSWM system became evident. The outputs of emission models are instrumental in decision making and policy decisions in MSWM. Emission models in waste management typically provide estimates of carbon dioxide (CO_2), methane (CH_4) and sometimes also other gases released by waste management activities (Dalemo et al., 1997; Diaz & Warith, 2006; Harrison et al., 2001; Kirkeby et al., 2006).

One potential solution is to develop a greenhouse gas emissions model which is tailored to estimate emissions resulting from the MSWM system. Such a model is considered to be in line with New Zealand's current policy directive "reducing harm and improving efficiency" (Ministry for the Environment, 2010a)and with current legislative frameworks based the premises of: "(a) protecting the environment from harm, and (b) providing environmental, social, economic, and cultural benefits to the people" (New Zealand Legislation, 2008, p. 6).

Once the emissions model was developed is then need to be evaluated. The estimated emissions level and a number of gases targeted are considered to be indicative of the performance of the model.

To evaluate this novel model a comparative quantitative analysis with selected existing emissions estimation models is undertaken. These existing models are chosen based on the components of quantification, the availability of suitable data for model implementation and whether or not sufficient details of the model are publically available. Moreover, the element of quantification of the selected models must be the same as at least one of the elements of the proposed model.

The estimated emissions are obtained as numeric output, which is of course highly dependent on the quality of the input data. Because typically the components considered in emissions models vary, the output of these models also varies. Therefore, an examination of the relationship between the variables in the models to the observed outputs of the model will be made. To perform this evaluation, a *case study* method is adopted.

According to Yin (2014, p. 16), "a case study is an empirical inquiry that investigates a contemporary phenomenon (the case) in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". Moreover, "The case study method is particularly appropriate when the research question starts with: How? Or Why?" (Yin, 2014, p. 10). The Robert Wood Johnson Foundation (2008) sees case studies as a research strategy as well as an evaluation method.

Sustainability issues (which are arguably the theme focus of this research), are usually characterized by a plurality of decision-makers, pervasive uncertainties, spatial and intertemporal externalities, the interplay of human and natural components and an evolving understanding of policy objectives (Boulanger & Brechet, 2005). One of the strengths of a case study approach in research is that it is a powerful tool when investigating complex environmental problems confronting individuals and organizations, including issues of sustainability (Scholz, Lang, Wiek, Walter, & Stauffacher, 2006). Laws et al. (2004, p. 259) posited that sustainability is a "problem field that presents both practical and conceptual challenges." Roland et al. (2006) suggested that a case study approach is suited for studies related to sustainable development problems. Embedded in this complex nature of sustainability research is a necessity for transdisciplinarity research, which requires integration of a knowledge of science and society (Burger & Kamber, 2003; Scholz, Mieg, & Oswald, 2000; Thompson et al., 2001). Brandt et al. (2013) noted specifically the transdisciplinary nature of mixed methodology research in the domain of sustainability research. Adger, Brown, Fairbrass, and Seyfang (2003) concluded that case study approach, sustainability development study, and transdisciplinarity are all strongly interrelated. Scholz et al. (2006) referred to this type of case study as a *transdisciplinary case study* which goes beyond a purely qualitative approach as it allows the researcher to integrate quantitative aspects in their methods. These interlinked aspects constitute what may be termed the *normative background* of the *transdisciplinary case study* research approach.

So in summary, case study areas were selected from Territorial Authorities located on the north island of New Zealand. The data related to MSWM gathered for these case study areas is then used as input to the various *Comprehensive Emissions Quantification*. Other information gathered in the MSWM of the case study areas as well as the output from the *CEQ-Model* quantifications, forms descriptive scenarios which are studied to create the holistic and meaningful characteristics of the waste management systems within the selected Territorial Authorities. As a result of this analysis, evaluation, and conclusions, the usefulness and applicability of the developed *CEQ-Model* as an assessment tool in sustainability measurement is established.

5.2.4 Phase 4

Phase 4 involved the development of a conceptual waste collection system with the aim of simplifying existing waste management system frameworks and make MSWM and monitoring of waste data collection easier. The end result is a framework or *ontology* which municipal authorities can use to inform improved data collection. This, in turn, provides a better decision support system, hence producing a more sustainable MSWM system.

A qualitative expert evaluation of the ontology is carried out using experts in waste management and environmental planning. Summaries of the ontology design, implementation, and evaluation methods are presented in this section.

5.2.4.1 Ontology Development and Evaluation

One major problem identified in phase 2 of the research is a lack of data from within the waste management system. This is also indicative of the need for future research. To prepare the groundwork for meeting the future need in data collection, an ontological framework was conceived.

Ontologies are the backbone of application development (Fensel et al., 2003) and are increasingly becoming a fundamental data structure for conceptualizing knowledge. It is possible to build many different ontologies conceptualizing the same body of knowledge (Brank, Grobelnik, & Mladenic, 2005). No matter the strategy adopted in the ontology development, It is necessary to be able to define how far an ontology suits some predefined standards. This definition is established through evaluation.

Brewster et al. (2004) categorized ontology evaluation methods into two groups – qualitative and quantitative approaches to evaluation. The steps adopted in evaluating the suitability of any ontology depends on what kind of ontologies that are being evaluated and the purpose of the ontology. Typically, evaluation of ontologies uses one of the following methods:

- Evaluation based on comparison with a standard, which itself may be an ontology – 'golden standard' based; e.g. Maedche and Staab (2002);
- Evaluation based on using a conceptualized ontology in an application and analysing the results – *application based*; e.g. Sabou et al. (2007); Clarke et al. (2013);

- Evaluation based on comparisons with a source of data about the domain to be covered by the ontology – *data-driven*; e.g. Brewster, Alani, Dasmahapatra, and Wilks (2004);
- Evaluation based on the human *expert review*. Expert reviewers assess how well the conceptualized ontology meets a set of predefined criteria, standard, requirements, etc. (Brank et al., 2005), e.g. Lozano-Tello and Gómez-Pérez (2004).

In order to justify the choice of the human *expert-review evaluation method* in this study the previously mentioned techniques 1) to 3) are considered here:

1) The development of ontology over the years has made the possibility of reuse possible (Staab, Gomez-Perez, & Noy, 2005). In the field of knowledge engineering and artificial intelligence, including different applications of computer science and semantic web, ontologies have been widely used in knowledge building (Dokas, 2007). The level of ontology use in waste management theory design is not the same (Pongrácz, Phillips, & Keiski, 2004). The application of ontologies in waste management is still evolving. Hence, there are no existing ontologies to compare the developed framework. Therefore, it is not possible at this stage to compare the ontology developed in this research against a 'golden standard';
2) Due to the time limitations and the practical obstacles to developing and implementing the system, it is not possible to test the system using the output of the system within the scope of this research;
3) Suitable source data does not exist. Thus a data-driven quantitative approach is not possible. Hence, the only option available is the utilization of human expert reviewers a method laid out in Brank et al. (2005).

A qualitative approach involves the use of experts to evaluate the whole or part(s) of an ontology. Brewster et al. (2004) highlighted one issue with the expert reviewer method namely choosing the right reviewers. It is vital that the right choice of professionals is made and that they have not only sufficient expertise but also the ability to evaluate the ontology based on appropriate criteria. For example, they experts may over-value or under-value an ontology regarding its 'sensibility', 'coherency', or 'correctness', for instance.

The quantitative data-driven evaluation where a fit is checked while providing a more objective evaluation method is generally preferable when possible and removes subjectivity. An expert review approach is largely subjective however with the right expert reviewers it is reasonable to be confident that the ontology represents the reality of the ‘real’ system. With a data-driven approach, the evaluation could be determined by inaccurate data or compared with a ‘golden standard’ that is poorly designed

The selection of an appropriate evaluation approach can also be driven by the stage or level of development of the ontology which will provide relevant details and information to make evaluation worthwhile. Plinere and Borisov (2014) and Brank et al. (2005) quoting different authors, defined the various levels of development of an ontology as:

- Lexical, vocabulary, or data layer;
- Hierarchy or taxonomy;
- Other semantic relations;
- Context or application level;
- Syntactic level;
- Structure, architecture, design.

Table 5.1 shows the evaluation approaches that may be adopted at different levels of the ontological development. An ontological framework (architecture) is developed in this thesis. Therefore, according to Plinere and Borisov (2014), the evaluation of the ontology at this architectural level is only possible by using human experts. Obviously, at the other levels, the ontology can only be developed due to the pragmatic reasons related to a lack of data and ‘golden-standard.'

Table 5.1: Evaluation procedure at the various levels of ontology conceptualization

Level	**Golden standard**	**Application-based**	**Data-driven**	**Human expert**
Lexical, vocabulary, data layer	✓	✓	✓	✓
Hierarchy or taxonomy	✓	✓	✓	✓
Other semantic relations	✓	✓	✓	✓
Context or Application		✓		✓
Syntactic	✓			✓
Structure, architecture, design				✓

Source: Plinere and Borisov (2014)

5.3 The Conceptual Framework

The adoption of a strategy for the achievement of the aim the thesis required a review of the current waste management scenarios in New Zealand, hence establishing the level of integration and sustainability in the system. To get the ball rolling, Chapter one of the thesis introduced the thesis and cleared the way for the reader to understand the content of the thesis from the beginning.

Chapters two and three reviews various international frameworks and their relationships with MSWM vis-à-vis the impact on waste management in New Zealand. The evolution of New Zealand legislative framework both on the local front and international arena is discussed as a way of understanding the future direction in the legislative formulation to improve the MSWM system.

The systematic review of literature in Chapter four looks critically at all principles that are embedded in the various issues that are raised by this research, and a literature review of works related to core principals and themes in MSWM such as sustainability and integration were presented. This is necessary because to understand the contribution of this research the dynamism and complexities of MSWM must be understood

This literature reviews and document analyses also provided valuable data/information on waste volume, compositions, management policies and other characteristics which are utilised in the development of a *CEQ-Model* and ontology.

What evolved as a result of the document analysis was an understanding that the lack of progress in establishing sustainable and integrated waste management strategies in the Territorial Authorities is largely due to the following factors:

- Continuing increase in volume of waste to landfill
- Inadequate data for proper evaluation of the system
- Lack of relationship between the waste management and minimization plans (WMMP) and waste management practices within the Council
- Absence of achievable targets
- Existing regional by-laws which are contrary to national aspirations

Based on the above discoveries, the researcher conceived some recommendations for implementation in order to bring some changes in the MSWM sector. This includes:

1. Adoption of a *CEQ-Model* as a tool to measure sustainability.
    a. Formulation of a novel and more comprehensive emissions quantification model using LCT.
    b. Evaluation of the new *CEQ-Model* in order to establish its efficacy by developing specific scenarios based on data collected from case study areas.
2. Develop an ontological framework as a strategy for overcoming the shortcomings related to the availability and standards of MSWM data.

5.4 Data Search and Collection

The first attempt at waste data collection was published in the inaugural New Zealand National Data Report in September 1997 (Ministry for the Environment, 1997). Since 1997, new data have been collected through different means and sources. But much of this data are not available for assessment. Lack of availability is attributed to commercial sensitivity in New Zealand because critical parts of the MSWM system are contracted out to private companies. Efforts to access data from commercial waste management contractors, by the researcher, were not fruitful. It is not clear what data, if any, is collected by these third parties and currently there is no legislation requiring these third parties to fully disclose either their operational practices and processes or environmental monitoring data. Therefore, all the data used in this research was accessed through internet searches, because waste management data in New Zealand are not well organized, and collected or owned by different governmental or regional agencies. Hence, these documents and their associated data (buried inside these documents) are difficult to locate. As at 2016, there is no centralised and dedicated data warehouse for waste management data.

A lack of standardisation was also encountered during the data search and collation phase. Often the result was that conflicting values of the same data were obtained from different sources. Because of this attribute, Ministry for the Environment (2013a) recommended that disposal information before the Waste Minimization Act 2008 (WMA) should not be compared with those after the WMA.

Regional data are non-existent in many cases, and some other cases the waste contractors refused access to the data on the grounds of commercial sensitivity. The non-disclosure of data due to commercial sensitivity was also reiterated as a problem in the Auckland Waste Stocktake & Strategic Assessment report 2009 (Wilson, Middleton, Purchas, & Crowcroft, 2009). Therefore, all information and data used in this research were sourced in publications by the Ministries for the Environment (MoE) and Ministry of Health (MoH), and the Auckland Regional Council (ARC).

5.4.1 Waste Disposal Volume

Solid waste generation data is a major factor in the computation of emissions from solid waste management. Since the introduction of WMA, and its associated waste disposal levy, the amount of waste to landfill has been calculated using the annual sum of money collected as the waste disposal levy rather than the previous system of estimates based on guess work (Ministry for the Environment, 2011c). The value of MSW disposal to landfills as published by MoE (2014c) (Table 5.2) is used in this research.

Waste composition data which is also required in emissions quantification in the various models adopted for comparison with the new formulated emissions model is also accessed through a systematic search online. The value of the waste composition is as shown in Tables 5.3 and 5.4.

Table 5.2: 1996 to 2014 National and Auckland regional waste disposal volumes

Year	* Annual National Tonnage to Landfill (Tonnes)	** National Population	Annual per Capita (Tonnes)	*** Auckland Regional Population	Auckland Annual Disposal
1996	3,041,673	3733900	0.815	1,115,800	908,942.05
1997	2,903,347	3782600	0.768	1,146,700	880,123.02
1998	2,765,020	3815800	0.725	1,169,000	847,085.38
1999	2,829,265	3837300	0.737	1,184,800	873,560.36
2000	2,893,510	3860200	0.750	1,201,500	900,614.54
2001	2,957,755	3886700	0.761	1,218,300	927,118.87
2002	3,022,000	3951200	0.765	1,255,800	960,474.69
2003	3,074,837	4027700	0.763	1,297,600	990,617.10
2004	3,185,995	4088700	0.779	1,326,000	1,033,245.13
2005	3,170,998	4136000	0.767	1,348,900	1,034,177.76
2006	3,156,000	4185300	0.754	1,373,000	1,035335.10
2007	2,999,750	4226200	0.710	1,390,400	986,903.70
2008	2,843,500	4262000	0.667	1,405,500	937,714.51
2009	2,687,250	4304900	0.624	1,421,700	887,468.54
2010	2,531,000	4353000	0.581	1,439,600	837,038.27
2011	2,461,000	4386300	0.561	1,459,600	818,930.67
2012	2,425,022	4410700	0.550	1,476,500	811,786.11
2013	2,595,840	4446700	0.584	1,493,200	871,681.99
2014	2,797,104	4513000	0.620	1,526,900	946,354.55

Sources: * (Ministry for the Environment, 2007, 2013b, 2013c, 2015), ** (Statistics New Zealand, 2014b), *** (Statistics New Zealand, 2014a)

5.4.2 Waste Composition Data

An understanding of what materials are in the waste stream helps in identifying to what degree valuable natural resources are being thrown away rather than reused, recycled or recovered to create other products, materials, or energy. The proportion of materials in a waste stream is an indication of the composition. Waste composition information can then be used tp help develop waste minimization policies, target waste minimization programmes and improve recycling schemes. As an example, local authorities can use waste composition information to target reuse or recycling schemes for materials that make up a large part of the waste stream in their area. An improved understanding of the makeup of our waste stream can also lead to important economic, environmental and social benefits (Ministry for the Environment, 2007c) which include reductions emissions (GHGs).

The environmental and health impacts of waste are driven by waste type because different materials produce different amounts of GHGs as they decompose in a landfill. Better waste composition information can improve our understanding of these impacts and aid in the management of high-impact waste types (Ministry for the Environment, 2009c).

The accuracy of waste composition data is affected by the number of classifications or segregations and the methodological approach in achieving the segregation. Though, this is dependent on the purpose of the composition study. Stephen (2007) in a review of waste composition in the United Kingdom (UK) identified 12 categories of waste using household dwellings. Burnley et al. (2007) identified 37 categories while Kirkeby et al. (2006) segregated the waste into 48 material fractions.

In New Zealand, the MoE developed the Waste Analysis Protocol (WAP) in 1992 to guide the collection of statistically robust information on waste composition. This was reviewed in 2002 and renamed Solid Waste Analysis Protocol (SWAP) (Ministry for the Environment, 2002). Waste materials were classified into one of 12 categories as shown in Table 5.3. Based on the SWAP, the MoE instituted a baseline programme to provide solid waste composition information at four indicator sites selected from around New Zealand (made up of three landfills and one transfer station) to provide a basis for designing and interpreting SWAP surveys throughout New Zealand (Ministry for the Environment, 2008). Because only four indicator sites were used, a level of uncertainty to be expected in generalising these values either across New Zealand as a whole or to other sites.

The SWAP identified two stages for the waste classification process − at the source and at the disposal facility (Ministry for the Environment, 2002). Waste assessment in New Zealand is carried out through sampling at disposal sites (Auckland Council, 2011; Morrison Low, 2011) or by sampling the waste in disposal vehicles (Christchurch City Council, 2013; MWH, 2013) or by sampling waste samples at the transfer station (Christchurch City Council, 2013). No TA has opted to classify waste at the source, as recommended in SWAP, despite the fact that recording at the source is considered to be a better representation of the actual waste composition.

Due to the missing and sporadic nature of waste composition data for New Zealand waste disposal, the available data on waste composition used for this thesis is derived from the assessment as carried out by Waste Not Consulting (2011) (Table 5.3). This choice is because of the Waste Not Consulting assessments adhering to the SWAP classification system (as shown in Table 5.3 and 5.4). The gap in data between 2008 and 2010 is an indication of the sporadic nature of the waste assessment reports in the New Zealand waste management sector. Even though MSW assessment is an expensive venture, the biggest barrier to data availability is a lack of the political will to undertake the process.

Table 5.3: The bases of waste composition as specified in SWAP

WAP primary classification	SWAP secondary classification	Description
Paper	Paper	Recyclable paper, such as newspaper and cardboard, and non-recyclable paper, such as milk containers and waxed paper
	Nappies and sanitary	Disposable nappies, feminine hygiene products and paper towels
Plastic	Plastic	Both recyclable and non-recyclable plastics
Organic	Putrescible	Kitchen/food waste, green waste, other organic waste such as food processing waste
Metal	Ferrous metal	Metal products predominately made from steel
	Non-ferrous metal	Other metal, such as aluminium, copper, lead
Glass	Glass	Recyclable glass, such as bottles and jars, and other products including glass, such as televisions and computer monitors
Construction and demolition	Rubble	Concrete, rocks, plasterboard, and ceramics
	Timber	Timber lengths, furniture, sawdust
Other	Textiles	Clothing, carpet
	Rubber	Tyres, foam mattresses
Potentially hazardous	Potentially hazardous	Material with potentially toxic or ecotoxic properties or having properties requiring special disposal techniques (includes sewage sludge, paint, medical waste, solvents, asbestos, and oil)

Source: Waste Not Consulting (2011)

Table 5.4: 2010 Auckland regional domestic kerbside waste composition

SWAP Primary Category	Annual Tonnage	% of total waste
Paper	18,831	10.4%
Plastics	21,153	11.7%
Putrescible	96,439	53.4%
Ferrous metals	3,215	1.8%
Non-ferrous metals	1,249	0.7%
Glass	3,716	2.1%
Textiles	6,999	3.9%
Nappies & Sanitary	22,283	12.3%
Rubble	3,405	1.9%
Timber	1,529	0.8%
Rubber	271	0.2%
Potentially hazardous	1,578	0.9%
Total	**180,668**	**100.0%**

Source: Auckland Council (2011).

Table 5.5: New Zealand national waste composition average between 1995 and 2008

Waste Category	National Waste Composition					
	1995 *	1997-2000 *	2002 *	2003 *	2004 **	2007/2008 ***
Paper	19.0	22.8	20.3	11.6	15	7
Organics	28.2	55.0	23.1	24.7	23	28
Plastics	7.8		8.5	6.8	9	8
Glass	2.7	2.8	3.9	2.7	2	4
Ferrous metal	5.0	2.3	4.8	4.7	5	4
Non-ferrous metal	2.8	0.7	3.9	1.1	1	0.5
Nappies and sanitary	0.0	0.0	1.2	1.5	3	3
Textiles	0.5	1.7	4.5	3.8	4	4
Rubbles and Concrete	21.2	5.0	16.1	16.6	12	16
Rubber	0.5	0.0	1.3	0.9	1	1
Timber	7.1	0.1	8.2	13.0	14	11
Potentially hazardous	5.3	0.1	4.2	11.6	11	14

Sources: * = (Ministry for the Environment, 2009b), ** & *** = (Ministry for the Environment, 2013c)

5.4.3 Landfill Scenario Data

Landfill scenario data is the regional disposal data attached to the landfills where the waste are disposed as reported by the MoE. This scenario data includes the landfill gas management plan, average distance from the source of waste to landfill, average annual volume of waste accepted at the landfill, landfill design height, and density of waste in the landfill. The Centre for Advanced Engineering (2000) made recommendations for standard design specifications and appropriate site selection for landfills. The values adopted for this research are from consent reports for the Hampton Downs landfill (Waikato Regional Council, 2003) which is located in the Waikato Region but accepts about 35 percent of the total volume of waste from the larger Auckland Region (Auckland Regional Council, 2011). These data are used in the models which require landfill scenario data.

5.4.4 Collection and Transportation Data

Waste collection is one of the first steps in waste management activities. Collection involves the movement of waste from the point of generation to transfer stations, material recovery facilities, waste treatment facilities, and then landfill.

Lack of detailed data related to waste transportation and destination means that it is currently impossible to have complete information that would allow for waste movement to be traced through the MSWM chain. Therefore, the rate of recovery and details of what materials are recovered is not available at any level (Auckland Council, 2011; Eunomia

Research & Consulting Ltd and Waste Not Consulting Ltd, 2014). But this data is vital for measuring the environmental impact of MSWM when taking an LCT approach. The only available data on transported waste is linked to the residual waste that is disposed of in landfills. Because transportation data is missing, and because a comprehensive emission quantification should take into account transportation factors. The average distance from the case study areas city centres to relevant landfill sites is used for the purposes of assessing the novel *CEQ-Model* which takes into account the environmental cost of transportation in MSWM.

Transportation and collection activities hinge on fuel consumption. To measure a more ground truth cost the amount of fuel consumed would be the most appropriate data rather than distance to landfill or some form of calculation of fuel consumption based on distances travelled. This conclusion is founded on two reasons: firstly in a city where there are many transfer stations from which waste is sent landfills, and there are no records of the amount and composition of waste from each of the transfer stations to the landfills it is difficult to estimate fuel consumption accurately where the load each truck is carrying is unknown; and secondly, there are no rules on the pattern of movement, i.e. which landfill accepts waste from which transfer stations. So it is impossible to obtain accurate data on the 'real' distance travelled. However, in the future, either through legislation influence or with the cooperation of waste collectors and transporters, more reliable fuel consumption data could be obtained.

Transportation of waste, like any road transportation, emits mainly CO_2, NOx, CO and NMVOCs and also a smaller amount of N_2O, CH_4, and NH_3. CO_2 as a GHG is a product of the amount of fuel used. Emissions of the remaining gases depend on the type of fuel used and are also affected by the way the vehicle is driven (e.g. the speed, acceleration and load on the vehicle), the vehicle type, the fuel used and technology used to control emissions (e.g. catalysts) (Eggleston & Walsh, 2000). But the amount of fuel used is equally directly proportional to the distance travelled. That justifies the use of average distance and transport emission factors (Tables 5.5 and 5.6) as a means of determining the emissions from this management process.

5.4.5 Fuel Consumption Rate

The level of fuel consumption in a system where fossil fuel is used is directly related to the frequency of vehicular use and the consumption rate per unit distance. Since environmental, the economic and social implication of vehicular movement is to a large extent linked to fossil fuel usage; it becomes necessary to determine the consumption rate within a system. Therefore, the determination of fuel consumption rate is determined both on road probation where the vehicle is in real motion or in a laboratory constructed conditions which allow the simulation of any load on the contrived stand (Kortas, 2014). Fuel consumption, as used in EASEWASTE (the Euro3 efficiency level), is adopted as the standard for transportation of waste on the road using conventional trucks. This is the acceptable limits for exhaust emissions of new vehicles sold in the EU as defined by European Union (1998) and should be equally applicable to New Zealand.

5.4.6 Emission Factors

An emissions factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., kilogrammes of particulate emitted per megagram of coal burned). Such factors facilitate the estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality and are assumed to be representative of long-term averages for all facilities in the source category (i.e., a population average) (US EPA, 2014b). The emission factors have been developed and compiled from source test data, material balance studies, and engineering estimates (Ministry for the Environment, 2009a, 2011a; US EPA, 2014a, 2014b).

5.4.7 Other Important Data Sets

To establish the level of reliability of the outputs resulting from the use of the *CEQ-Model,* some existing MSWM models are computationally evaluated and compared with the results from the use of *CEQ-Model.* The selection criteria for the models are based on similarity in data needs and accessibility to the models.

The following models are evaluated and compared:

1. US EPA LandGEM (The United States) (US EPA, 2005)

2. IPCC Tier II FOD Emission Model (Switzerland) (IPCC, 2006b)
3. Integrated Solid Waste Management Tools (IWM) (Canada) (Environmental and Plastics Industry Council(EPIC)/Corporations Supporting Recycling (CSR), 2000)
4. EASEWASTE Model (Denmark) (Kirkeby et al., 2006)
5. NV Afvalzorg Multiphase Landfill Gas Generation and Recovery Model (The Netherlands (NV Afvalzorg, 2014).

Hence, the necessary data useful for the evaluation and comparison of the models includes:

a. Emission composition (in terms of ratio of methane to carbon dioxide)
b. Emission dissimilation rate (DOC_f)
c. Rate of methane oxidation (OX)
d. Value of degradable organic carbon (DOC)
e. Potential Methane generation rate (Lo)
f. Waste fraction decay rate (k)
g. Lag time before decay
h. Global Warming Potential (GWP)
i. Regional rainfall data

The values of these parameters are applied to the various models as required to quantify the MSW emissions.

5.5 Other Emissions

Other emissions that are considered to make an emission inventory a comprehensive one include emissions from refrigeration/cooling, emissions from electricity consumption and emissions from other activities that utilizes fossil fuel.

Refrigeration/cooling produces ‘direct’ emissions that are related to the loss of refrigerant through leakage, during maintenance or end-of-life decommissioning. There is also ‘indirect’ emissions from refrigeration/cooling resulting from the power system used to run the refrigeration/cooling. In most situations, it is the indirect energy-related emission that dominates the overall GHG emissions from refrigeration/cooling systems as leakages and decommissioning are rare.

Table 5.6: 2012 New Zealand transport emission factors (based on distance travelled)

Vehicle size/ class	Unit	Emission factor total CO_2-e (kg CO_2-e/unit)	Emission factor CO_2 (kg CO_2/unit)	Emission factor CH_4 (kg CO_2-e/unit)	Emission factor N_2O (kg CO_2-e/unit)
Car – small (<1600 cc)	km	0.177	0.174	0.00103	0.00117
Car – medium (1600-<2500 cc)	km	0.230	0.227	0.00134	0.00152
Car – large (≥2500 cc)	km	0.301	0.297	0.00175	00199
Car – default*	km	0.230	0.227	0.00134	0.00152

* The default emission factor used if a vehicle's size class is unknown –
Source: Ministry for the Environment (2014a)

The emissions generated from the consumption of electricity are estimated based on the type of power generation, transmission, and distribution. Information on the source of electricity (fossil fuel, coal, waste, etc) gives detail of the emission factor which will be used to determine the emission level. The emissions are released during the combustion of fossil fuels, such as coal, oil, and natural gas, to produce the electricity. Therefore, CO_2 makes up the vast majority of the emissions from the consumption of electricity, with smaller amounts of CH_4 and N_2O. A negligible amount of GHG emissions from the sector also come from sulphur hexafluoride (SF6), an insulating chemical used in electricity transmission and distribution equipment (US EPA, 2014d).

5.6 Emissions Quantification in Waste Management

For a better understanding of the rationale behind the choice of a carbon trading emission quantification method as the basis for the development of a quantification model, it is necessary to review other quantification methods.

The four main types of emission quantification methods in waste management are (Friedrich & Trois, 2011; Gentil, Christensen, & Aoustin, 2009) the:

3. National accounting method (with reference to the IPCC method)
4. Corporate level accounting method (including local government, i.e. municipalities) as part of annual reporting on environmental issues and social responsibility

5. Life cycle assessment (LCA) method as an environmental basis for assessing waste management and technologies
6. Carbon trading method.

5.6.1 National Emission Accounting Method

The National Emission Accounting Method is employed to calculate the sum of all emissions estimates from the various source categories as specified in the International Panel on Climate Change (IPCC) guidelines for GHG Inventories (IPCC, 1996, 2006a). These source categories include:

1. Energy
    a. Fuel Combustion Activities
    b. Fugitive Fuel Emission
2. Industrial Processes
3. Solvent and Other Product Use
4. Agriculture
    a. Enteric Fermentation
    b. Animal Waste
    c. Rice Cultivation
    d. Agricultural Soils
    e. Prescribed Burning of Savannahs
    f. Field Burning of Agricultural Residues
5. Land-Use Change/Forestry
    a. Changes in Forest and Other Woody Biomass Stocks
    b. Forest and Grassland Conversion
    c. Abandonment of Managed Lands
    d. CO_2 Emissions and Removals from soil
6. Waste

The ultimate objective being to develop a system on which stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system can be achieved. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner (US EPA, 2014c). On this basis country and territories compute their national GHG (Ministry for the Environment, 2014b; US EPA, 2014c).

The IPCC guidelines (IPCC, 1996) give two approaches for estimation of emissions from solid waste disposal. The methods include the default method where emissions from Solid Waste Disposal Sites (SWDSs) are based on a mass balance approach without incorporating any time factors hence all potential emissions are released from the waste in the year the waste is disposed of. The other approach is a first order kinetics method which takes into account the fact that emissions are emitted gradually over an extended period. The first order kinetic approach takes into account the various factors which influence the rate and extent of emission generation and release from SWDSs. Some countries where historical data are available to have adopted this method (Aitchison et al., 1996; Borjesson et al., 2009).

5.6.2 Corporate Level Accounting Method (Including Municipalities)

According to Kauffmann, Less, and Teichmann (2012), there is a growing demand for companies to disclose environmental information resulting from their activities. Some mandatory or voluntary government schemes have emerged which, together with emerging non-governmental initiatives, require or encourage enterprises to measure and report their GHG emissions. These requirements are part of environmental and other non-financial disclosure requirements of policy instruments that put in place a carbon price, such as carbon taxes and emission trading schemes; or of listing requirements of stock exchanges.

To promote broad adoption and comparability in GHG accounting, an internationally acceptable GHG accounting and reporting standards were launched in 1998. The launching of the GHG accounting and reporting standards lead to the emergence of GHG Protocol which categorises emission sources in corporate reporting into Scopes 1, 2 and 3 as follows: (World Resources Institute and World Business Council for Sustainable Development, 2004, 2007):

- Scope 1: Direct GHG emissions which must be reported. These emissions occur from sources within the direct operational boundaries of the company. For example, emissions from combustion of fuel in machinery and vehicles owned or controlled by the enterprise.

- Scope 2: Indirect emissions are occurring as a result of purchased electricity that is consumed by the operation of the company. Indirect emission like this is also required to be reported by GHG Protocol and ISO 14064-1.
- Scope 3: Indirect GHG emissions are occurring as a result of the activities of the company but generated from sources not owned or controlled by the enterprise (e.g., emissions from air travel). Under the current reporting framework, it is optional for businesses to report this type of discharge.

This GHG Protocol Corporate Standard provides standards and guidance for corporations preparing a GHG emissions inventory. It covers the accounting and reporting of the six GHGs covered by the Kyoto Protocol — carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6).

The GHG Protocol is a standard developed jointly by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) while the ISO 14064-1 standard is published by the International Standards Organisation (ISO). Both standards provide comprehensive guidance on the core issues of GHG monitoring and reporting at an organisational level, including:

- Principles underlying monitoring and reporting
- Setting corporate boundaries setting operational boundaries
- Establishing a base year
- Managing the quality of a GHG inventory
- The content of GHG reports.

For corporations to implement these reporting standards, they require methods for converting data they gather about activities in their organisation and services into relevant emission estimates (measured in tonnes of carbon dioxide (CO_2) equivalent). These methods involve using the emission factors as contained in the GHG Protocol.

The emission factor stipulates the quantity of emission release from a specified resource consumption level or a particular unit of activity data. An emission factor allows GHG emissions to be estimated from a unit of available activity data (e.g., emission per litres of fuel consumed or emission per flight distance embarked for business purpose).

For governments, the primary motivation to request GHG emission information from companies is to induce companies to reduce their GHG emissions and to facilitate access to this information. The information itself is used for different purposes by governments, for example, to support emission trading schemes (where they exist), as a complement to domestic climate change policies, and to refine national GHG inventories. Most government GHG reporting regimes (in particular those linked to emission trading schemes) mainly ask companies to disclose GHG emissions. Some systems go further and invite companies to report on emission reduction targets and other climate change related information (Kauffmann et al., 2012).

Sunar and Plambeck (2011) demonstrated the application of corporate emission accounting in climate policies. For example, an importer can be made to pay tax in proportion to the GHG emissions caused by the imported product. Policy makers in the E.U., U.S. and elsewhere, see this system as a means of avoiding loss of domestic manufacturing, garnering support for climate policy from local manufacturers, raising revenue, and as an incentive towards an export rather than an import-oriented economy (Fischer & Fox, 2011).

Besides the legal constraints of mandatory government reporting schemes, companies measure and report GHG emissions to identify opportunities to reduce emissions and save energy and to increase awareness about potential and future climate change-related risks. It may also be a way of demonstrating their corporate social responsibility, through which companies seek to attract clients/customers because of the growing proportion of the population who choose to go ‘green’ and support local and environmentally friendly products. For many leading companies, GHG emission reporting to government and non-governmental schemes has become part of their overall business strategy. For other, less motivated companies, government reporting systems provide guidance on what to measure, how to do it, and how to disclose the information.

5.6.3 Life Cycle Assessment Method

Life Cycle Assessment (LCA) was initially implemented for product analysis but has been applied to waste management for some years. Studies investigating LCA have been widely published (Rigamonti, Falbo, & Grosso, 2013; Harri, Liamsanguan & Gheewala, 2008; Jan-Olov, & Asa, 2007; den Boer, den Boer, & Jagar, 2007; Muñoz et al., 2004; Clift, Doig, & Finnveden, 2000; Ekvall & Finnveden, 2000; Finnveden, 1999). LCA is a holistic approach to emission quantification that quantifies all environmental burdens. In this way, all environmental impacts throughout the life cycle of products or processes are quantified (Rebitzer et al., 2004).

LCA is a methodological approach developed to evaluate the mass balance of inputs and outputs of systems and to organise and convert those inputs and outputs into environmental themes or categories about resource use, human health and ecological areas (Andrae, Itsubo, & Inaba, 2007).

LCA is not an exact scientific tool, but a science-based assessment method for the impacts of a product or system on the environment (Winkler & Bilitewski, 2007). It is increasingly being utilised for solid waste management systems especially in the decision-making process and in strategic planning.

Waste management LCA, unlike product LCA, is a system aimed at assessing the environmental performance of interconnected waste management technologies based on a particular waste compositions and from the point of generation of the waste to its final disposal. Waste management is defined by all activities from the collection, transportation, handling, treatment, material and energy recovery and disposal of waste. LCA are often mathematically linked to the emissions.

To help practitioners in the application of LCA in waste management, some LCA models have been developed targeting waste management. The models include:

- NV Afvalzorg Multiphase Landfill Gas Generation and Recovery Model - NV Afvalzorg (2014)
- MSW – DST - Thorneloe, Weitz, and Jambeck (2007); Solano, Dumas, and Harrison (2002a, b)
- Weitz et al. (1999)
- LCA – IWM - Den Boer, Den Boer, and Jager (2007); Den Boer, Den Boer, and Jager (2005); Den Boer et al. (2005)
- WASTED - Diaz and Warith (2006)
- EASEWASTE - Kirkeby et al. (2006)
- IWM - Haight (2004)
- WRATE - Thomas and McDougall (2003.); Gentil et al. (2005); Coleman (2006)
- IPCC Tier II FOD Emission Model - IPCC (2006b)
- LandGEM - US EPA (2005)
- SSWMSS - Tanaka, Matsui, and Nishimura (2004)

- WARM - US EPA (2002)
- ISWM DST – Solano et al. (2002)
- ONWARE - Eriksson et al. (2002.); Dalemo et al. (1997)
- IWM-2 – McDougall et al. (2001)
- EPIC/CSR - Haight (1999)
- WISARD - Ecobilan (1997)

The GHG accounting results differ significantly between these models and methods based on what is included and what is left out. The choice of GHG accounting mechanism depends on the scope of the reporting, but all rely on the same basic operational data generated by the individual waste management technologies (Gentil et al., 2009). As a result, there is a need to investigate the relationship between the accounting tools used for GHG emissions from municipalities and the actual processes/technologies which give rise to these emissions.

In this research, the combination of life cycle thinking and carbon trading approach is adopted to produce a comprehensive emission output.

5.6.4 Emission Trading Method

Emission trading was initially referred to as carbon trading by the US EPA because only CO_2 was regulated (Watanabe & Robinson, 2005) (Watanabe & Robinson, 2005). However, after the adoption of the Kyoto Protocol, other GHG were included, and countries outside the United States joined in carbon reporting as a way of meeting their commitments, and the Emission Trading Scheme (ETS) was conceived. The recognition of the waste sector as one of the contributors of GHG led to the inclusion of the waste management sector in the ETS as a way of incentivising better waste management systems. In New Zealand, ETS was extended to included waste disposal facility operators (DFOs) in three stages; (Ministry for the Environment, 2011b)

- From the 1st of January 2011, DFOs may voluntarily report information about their methane emissions
- From the 1st of January 2012, DFOs must collect and report this information
- From the 1st of January 2013, DFOs must surrender New Zealand Units (NZUs) to match their emissions.

Emission trading (cap and trade) is a market-based approach used to control pollution by providing economic incentives for achieving reductions in the emissions of pollutants (Stavins, 2001). The government sets a limit or cap on the amount of pollutants that may be emitted. The limit or cap is allocated or sold to firms in the form of emissions permits which represent the right to emit or discharge a specified volume of pollutant. Therefore, businesses that need to increase their volume of emissions must buy permits from those who require lower emission permits or are involved in emission saving activities.

To estimate the emissions from MSW, the regulations how participants in the ETS will meet their reporting requirements, require landfill operators to use the equation below: (Ministry for the Environment, 2011b)

$$E = (A - B) \times C \qquad \text{Eq.5-1}$$

Where: E is the emissions in tonnes of CO_2-e

A is the gross tonnage of waste entering a site in the year

B is the tonnage of waste diverted in the year

C is the emissions factor

The MoE (2010b), using a default waste composition, has determined the default value of C as 1.10 tonnes of CO_2-e per tonne of waste. If the landfill operator does not intend to account for either non-default waste composition or methane collection, this ‘default emissions factor’ or DEF is always used, and no further calculation is needed. The required reporting of each year’s emissions return only consists of the tonnages (A and B) and is entered using an online reporting tool. The reported emission is based on mass balance hence estimating the emission potential, rather than the actual emissions based on a standard emissions factor and the waste disposed of in the period under review (IPCC, 2013).

5.7 Conclusion

There is no doubt of the complexities and dynamic in the status of sustainability, especially in MSWM. To create a system to support the realization of a waste management system is not a straightforward thing. That justify the need to develop a robust strategy to support the idea. It is only a consistent and continuous monitoring that can direct the way to achieve sustainability. But one thing is fundamental; all stakeholders must be carried along, and all possible alternative waste management process is given equal chance of providing some level of solution to the problem that is integration.

The involvement of different professionals and processes calls for an interdisciplinary approach to achieving the needed result in this research. Interdisciplinary approach means the adoption of mixed methods which calls for flexibility and goal oriented in the research to achieve sustainability.

The major strength of this research plan includes:

- The case study approach adopted to represent a methodological framework for handling complex real-world problem in human environmental systems
- The interdisciplinary (mixed-methods) approach accounts for a framework to cope with the contextualization of complex, real-world problems
- A mixed-method framework is chosen in order to tackle a messy and real-world problem.

The reporting of the emissions from waste management sector as prescribed in IPCC Guidelines identifies only the direct emissions of post-consumer waste management such as landfilling and incineration. Post-consumer waste is all waste resulting from anthropogenic activities. Even within this post-consumer waste management scheme, emissions are not reported consistently. For example, in reporting of GHG emissions from waste incineration without energy recovery, all GHG emissions, are reported under the IPCC waste sector. And all emissions from open burning is included in the AFOLU sector (Agriculture, Forestry, Other Land Use) (IPCC, 2006a) even when the open burning results from burning of waste. However, for waste incineration with energy recovery, generated emissions are accounted under the IPCC energy sector (E. Gentil et al., 2009). Similarly, transportation of waste is not reported under the waste sector, but under the energy (fuel combustion activities) (IPCC, 2006a).

Even the use life cycle assessment model which has the advantage of incorporating the emissions from waste management processes like transportation and energy consumption, still result in the omission of some critical steps in waste management sector regarding emission quantification, particularly in the recovery operations.

For emissions calculation under carbon reporting, the assumption of a single emission factor without consideration to waste composition is an imprecise representation of the real life situation. Waste composition is a major determinant of the level of emission and the type of discharge that will be generated at the waste disposal site.

This research is looking at emission reporting differently, especially now that waste management is tailored to sustainable resource management. Just as waste generation is seen as a representation of inefficiency in resource utilization, this research attempts appropriately to recognise the efficiency and sustainability of the waste management sector as a description of the level of emission generated by the system as a whole (system and processes). Hence, a modified emission reporting model which captures the waste management in a near-real-life represents the scenarios is developed. This will help in monitoring the progress made in achieving the goals of RMA, WMA, and the commitments of New Zealand government to Kyoto Protocol and similar agreements which are targeted to environmental protection, effective resource utilization, and social security.

CHAPTER SIX

COMPREHENSIVE EMISSION QUANTITIFICATION MODEL (*CEQ-Model*)

6.0 Introduction

Waste generation, management, and disposal have become increasingly prominent in the environmental arena, both from policy, economic and social perspective (J. Bogner et al., 2007; UNEP, 2009). Hence, Miller (2005), identified waste reduction and management as intractable environmental issues to be resolved.

Apart from this issue, the inconvenient truth about the unprecedented challenge of climate change has created observable changes in various weather patterns and drawn extensive concerns from the public, climate panels and policy makers (Schiermeier, 2011; Solomon et al., 2007). The waste management sector has been identified as a contributor to climate change and is estimated to be accountable for 3-5 percent of total GHG emissions resulting from human activities at a global scale in 2005 (J. Bogner et al., 2008; UNEP, 2010). Even though this may be seen as minor in quantity (ISWA, 2009), the waste sector is capable of contributing to the increase in emissions if no action is taken. For example, in the year 2000, developing countries were responsible for about 29 percent of these emissions, and this share is predicted to increase to 64 percent in 2030 and 76 percent in 2050 with landfills being the major contributor to this increase (Monni et al., 2006).

In developed countries, series of initiatives were highly successful and showed that large reductions in emissions are possible. For example, the contribution of the EU municipal waste sector decreased from 69×10^6 tonnes CO_2-e in 1990 to 32×10^6 tonnes CO_2-e in 2007 and further reductions are projected (ISWA, 2009). Emissions factors for different emissions/gases are often converted to and reported in terms of CO2-e (CO_2-equivalent). This common equivalent is used because it enables the same unit to be used allowing comparisons between different gases.

In New Zealand, emission resulting from MSW disposal to landfill has dominated the amount of emissions from the waste sector between 2003 and 2013 (Table 6.1). The quantity of emission from waste to landfill accounted for 81.2 percent of emissions from waste management sector in 2003, reduced marginally to 67 percent in 2011, and reaching the peak of 92.1 percent in 2013. These statistics are represented in Table 6.1 were produced at a time during which there have been claims of a decrease in waste disposal to landfill (Ministry for the Environment, 2014c).

Current GHG scenarios for New Zealand, and at the global level, follow the IPCC Guidelines for national GHG reporting (IPCC, 2006a) which capture only emissions from disposal sites.

Table 6.1: Summary of emissions from waste management sector in New Zealand (2003 to 2013)

Year	**Waste Sector Emission Compare to all GHG Emission (%)**	**Emission from MSW Disposal to Landfill (Gg CO_2-e)**	**Percentage of Emission from Landfill in Waste Sector Emission (%)**	**Source**
2003	2.3	1425.48	81.2	Ministry for the Environment (2005)
2004	2.5	1509.12	82.0	Ministry for the Environment (2006)
2005	2.4	1460.7	79.1	Ministry for the Environment (2007b)
2006	2.4	1475.4	79.4	Ministry for the Environment (2008)
2007	2.4	1438.0	78.9	(Ministry for the Environment, 2009a)
2008	2.2	1278.4	76.5	Ministry for the Environment (2010b)
2009	2.9	1398.6	69.3	Ministry for the Environment (2011a)
2010	2.8	1345.5	67.6	Ministry for the Environment (2012)
2011	2.7	1331.1	67.0	Ministry for the Environment (2013a)
2012	4.7	3120.5	86.8	Ministry for the Environment (2014c)
2013	6.2	4600.3	92.1	Ministry for the Environment (2015)

Note: Sources for the emissions are stated in column five of the table

It is clear that emissions are produced at all stages of waste management – collection, recovery, treatment, and disposal. Table 6.2 does not include emissions from other stages in the waste management flow. It represents only emissions from waste management at disposal sites. The inclusion of emissions from other stages of waste management would paint a more realistic picture of the waste management situation. It is expected that this more comprehensive view of emissions would show that GHG levels produced from waste management sector are much higher than currently recorded.

An emissions quantification, reporting, and verification system is an essential core tool for any action or commitment on GHG emissions. Such a tool is also an essential basis to allow comparisons between the waste sector and other industrial sectors by comparable reporting principles. It aims at giving support to waste management plant managers for preparing their GHG emissions inventory. Monitoring the level of emissions in the waste management sector in a comprehensive manner considering all the processes in an integrated manner is also advocated as a means of showing the level of sustainability in the system

Table 6.2: Emissions associated with various waste management activities at disposal sites

Activity	GHG Emissions source
Collection	Fuel consumption
Transportation	Fuel consumption
Storage	On-site fuel consumption (include electricity), air-conditioning and refrigeration)
Management (recovery/ treatment)	On-site fuel consumption (include electricity) by machinery, tools, air-conditioning and refrigeration.
Disposal	Waste decomposition On-site fuel consumption (include electricity) by machinery, tools, air-conditioning and refrigeration.

Source: Compiled by the author from various sources

This research aims to develop a model to estimate emissions from waste management in a manner that encompasses all emission from all the stages in the MSWM process. This holistic representation of waste management is represented in the novel *CEQ-Model* presented in this chapters. The Emissions Trading Scheme (ETS) model, which forms the basis of the *CEQ-Model* follows the policy framework of the IPCC. The ETS model is also discussed in detail.

6.1 Review of Components of IPCC Emission from Waste Disposal Sites

According to IPCC (2013), “the IPCC was set up by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risk, and options for adaptation and mitigation.” The IPCC meet its obligation through the provision of reports and guidelines covering the scientific, technical and socio-economic information relevant to the understanding of the scientific basis of risk of human-induced climate change. One such guideline is related to various emissions factors (IPCC, 1996, 2006a) and it is this which forms the basis for the *CEQ-Model.*

The IPCC guidelines (IPCC, 2000) provide two methods for quantifying CH_4 emissions from landfill: the default method (Tier 1) and the First Order Decay (FOD) method (Tier 2). The main difference between the methods is that the FOD method presents a time-dependent emission profile, reflecting the true pattern of the degradation process over time, while the default method presents the annual value of emissions on the assumption that all emissions are released in the same year that the waste is disposed to the landfill.

The decision on the method to adopt for the *CEQ-Model* was based on the availability of data. While the FOD method is more accurate, it requires good historical data and knowledge of the composition of and decomposition rates of the waste in the landfills. Decomposition rates are dependent on spatial data as well as accurate data about landfill management practices, soil chemistry, hydrogeology of the area, and weather conditions. Unfortunately, such detailed spatiotemporal data is not available for New Zealand landfills.

The situation in New Zealand (Ministry for the Environment, 2007a, 2007d) means that there is only sufficient data for the adoption of the default (Tier 1) method (Eq. 6-2). In the models, all emissions are assumed to be generated by biodegradable waste components of MSW.

The IPCC (2000) MSW emission model for disposal sites allows the computation of a specific emission factor for a disposal site. But this is only possible if the site can produce accurate data such as annual waste composition and depth of fill of the landfill. Although the default equation is based on the same principle, the default equation assumes that all landfills have the same characteristics.

The value of L_{CH4} is based on the following factors (or variables) for Auckland (2007/2008 disposal year):

1 **MSW disposed at the landfill (MSW_D):** Before the enactment of WMA in 2008, the value of waste disposal to landfills was only estimated. Since 2010, the figure has improved (Ministry for the Environment, 2011b) as it is now based on waste disposal levy (Ministry for the Environment, 2014d). Although due to commercial sensitivity, some metadata values are not available (Auckland Council, 2011), it is an improvement over the situation before 2008. Using the available values with the population of the country gives an acceptable value for per capita waste to landfill.

2 **Methane Correction Factor (MCF):** This is based on the condition of the SWDS as stipulated in (IPCC, 2000, p. 5.9) (Table 6.1). Managed landfills are considered to be a secure environment, protecting all waste that is disposed of in the landfill. Therefore, 100 percent of the disposed waste is covered in the landfill. There are no scavenging or recovery activities allowed. In the other categories of landfills, some percentage of the deposited waste is removed through scavenging, recovery or burning.

Table 6.3: SWDS classification and methane correction factors

Type of Site	Methane Correction Factor (MCF)
Managed	1.0
Managed – semi-aerobic	0.5
Unmanaged – deep (≥ 5 m waste)	0.8
Unmanaged – shallow (< 5 m waste)	0.4
Uncategorized SWDS	0.6

Source: IPCC (2000)

New Zealand is categorized as a country with managed landfills. Hence it has an allocated MCF of 1.0. Therefore, the gas released is the total amount without consideration for any loss from the system through the burning of waste, scavenging or other similar practices.

3 **Degradable Organic Carbon (DOC):** is the percentage of organic carbon that is accessible to biochemical decomposition in a particular waste stream and the value is expressed in units of Gigagram (Gg) of C (Carbon) per Gg of waste (IPCC, 2000).

Table 6.4: IPCC default DOC values for major waste streams

	Waste Stream	Percent DOC (by weight) in wet (fresh) MSW
A	Paper and Textile (% portion in MSW)	40
B	Garden and Park Waste and other (non-food) organic putrescible (% portion in MSW)	17
C	Food Waste (% portion in MSW)	15
D	Wood and straw waste (% portion in MSW)	30

Source: IPCC (1996)

IPCC Guidelines (IPCC, 1996) approved default values for major waste streams as shown in Table 6.4.

Table 6.5 gives the default DOC values for New Zealand. as the percentage DOC in each waste stream.

Table 6.5: New Zealand default DOC values for major waste streams

Waste Stream	DOC Fraction
Garden waste	0.20
Nappies	0.24
Food	0.15
Paper	0.40
Sewage Sludge	0.05
Wood	0.43
Textiles	0.24

Source: Ministry for the Environment (2010a)

4 **The fraction of Degradable Organic Carbon Dissimilated (DOC_f):** This fraction estimated, using a theoretical model, which depends on the temperature of the anaerobic zone in the landfill and represents the fraction of carbon that is degraded and released from landfills. The fraction which is not degradable is a reflection that some organic carbons deposited in landfills are sequestered (National Council for Air and Stream Improvement, 2013). IPCC (2000), recommends using DOC_f values of 0.5 to 0.6. New Zealand adopted (Ministry for the Environment, 2010a) and still adopts a value of 0.5.

5 **The fraction of Methane in Landfill Gas (F):** According to US EPA (2000), landfill gas contains mostly CH_4 and CO_2, with traces of H_2S and Non-Methane Organic Compounds (NMOC). Agency for Toxic Substances & Disease Registry (2001) citing Tchobanoglous, Theisen, and Vigil, (1993) and EPA (1995) puts it precisely as in Table 6.6:

Table 6.6: Typical landfill gas components

Gas	Percentage by Volume
Methane (CH_4)	45-60
Carbon Dioxide (CO_2)	40-60
Nitrogen	2-5
Oxygen (O_2)	0.1-1
Ammonia (NH_3)	0.1-1
NMOCs	0.01-0.6
Sulfides	0-1
Hydrogen	0-0.2
Carbon Monoxide (CO)	0-0.2

Source: EPA (1995)

The F value for New Zealand is 0.5 (Ministry for the Environment, 2010a). This, therefore, puts carbon dioxide at 50% of the generated gas.

6 **Global Warming Potential (GWP):** The GWP for CH_4 is 25 (Table 6.8). GWP is required so that the values of CH_4 can be represented in CO_2-e for comparison sake.

7 **Oxidation Factor (OX):** This is a reflection of the CH_4 oxidised in the soil or other materials covering the waste. Zero oxidation means that there is no oxidation while one oxidation value is indicating 100% of CH_4 is oxidised. Methane oxidation is a result of a reaction of methane and other volatile hydrocarbons with oxygen caused by microbes in the soil. The estimation of OX is recognised as one of the main sources of uncertainty in estimating CH_4 emissions from landfills (American Society of Agronomy, 2009). A value of 0 to 10% oxidation has been recommended by the IPCC Guidelines for national GHG inventories. Currently, for regulatory purposes, the US EPA has recommended a default value for landfill cover CH_4 oxidation of 10% due to the uncertainty involved and the lack of a standard method to determine oxidation rate. While there are variations in OX value used the IPCC (2000) also considered 10 percent to be acceptable.

8 **Molecular weight ratio, methane/carbon (16:12):** This value is required for the calculation of CO_2-e.

9 **Molecular weight ratio, Carbon dioxide/carbon:** This value is also required for the calculation of CO_2-e.

6.2 The *CEQ-Model*

This research is aimed at policy re-orientation in MSWM in New Zealand and around the world, using comprehensive emissions resulting from the whole waste management scenario as a means of measuring performance. This emission measurement is possible and reliable because every stage of the management situation produces its part of the emissions into the environment. New Zealand waste management system rely more on landfilling as a means of disposal. Inadequate availability of data has made it impossible for the authorities to measure actual performance indicators. But through systematic, comprehensive emission measurement of the scenario, the performance can be measured.

A comprehensive emission quantification model *CEQ-Model* which is similar to the New Zealand emissions estimation model for New Zealand Emissions Trading Scheme (NZETS) for waste management sector is developed.

NZETS was established by the Climate Change Response Act 2002 (CCRA) (New Zealand Emission Unit Register, n.d; NZ Parliamentary Library, 2001). The Emission Trading Scheme (ETS) is a way of putting a price on emissions and creating an incentive for people and businesses to change their behaviour towards emission reduction (Ministry for the Environment, 2010c). Under ETS, operators of waste disposal facilities including landfills have been required to report their emissions since the 1 January 2012 using a default formula (Tonkin & Taylor Ltd, 2010). The model that is employed for ETS reporting is based on Eq.1 (Section 5.5.4). But since there is no resource recovery activity in New Zealand landfills, the model makes use of a quantity of waste disposed of to landfill and emission factor.

$$E_A = 1.1454 \times A_A \qquad \text{Eq.6-1}$$

Where:

A_A is the annual tonnes of waste disposed to the landfill

E_A is the emissions in tonnes of carbon dioxide equivalent ($t CO_2$-*e*) for the year

1.1454 is the combined emission factor (*EF*) for disposed waste composition as determined by the Ministry for the Environment.

The *EF* is determined by the Ministry for the Environment using a combination of a default waste composition for New Zealand and default emission generation potential for each waste fraction as indicated in the IPCC Guidelines.

In formulating the *CEQ-Model*, the Life Cycle Thinking (LCT) principle is integrated into the ETS model, and the emissions generated at critical stages of the MSWM system are captured. In applying the LCT principles, LCA principles are observed, but without all the analytical/scientific complexities involved in the implementation of a full LCA. In that sense, the basic idea of multiplying EF with the quantity of a fraction of waste composition in the waste stream is repeated at all stages of the waste flow chain from collection to disposal. Therefore, the framework of the *CEQ-Model* is as follows:

$$Emission\ (Total) = \sum [AD \times EF_1] + [E(T_r) \times EF_2] + E(E_n) \times EF_3] + E(E_r) \times EF_4$$

Eq.6-2

Where:

AD is the activity data showing the volume of waste to landfill

EF_1 is the emission generation rate of the landfill as determined from waste composition data and the various emission potential of composition fractions. The value of EF_1 will change based on the frequency of waste assessment. Each waste assessment is expected to produce a new waste composition because of changes in consumption pattern.

$E(T_r)$ is the activity data for fuel consumption in waste transportation. The value is generated through average disposal distance and the fuel consumption rate of trucks per tonne of waste disposed

EF_2 is the emission factor of fuel used in transporting the waste

$E(E_n)$ is the activity data on energy (electricity) used throughout the waste management process

EF_3 is the emission factor related to electricity

$E(E_r)$ represents the emissions from refrigeration and air conditioning units. This factor is based on the assumption that emissions will only be generated if leakages from the units occur and release the relevant gas into the environment.

EF_4 is the emission factor for the relevant gas.

6.2.1 Background of the ETS Model

To understand the relationship between the *CEQ-Model* and the ETS model, it is necessary to review the ETS model. The ETS model provided for the volume of diverted waste from landfill. But in New Zealand waste management system, all waste entering the landfill are covered. There is no opportunity for any attempt to salvage any material. Therefore, no data on the volume of diverted waste in New Zealand. The only available data is the amount of waste that is deposited in the landfill, which is the parameter A in Eq.5-1.The second parameter is the emission factor, C, which is the expected emission potential of the waste stream as deposited in the landfill. The value of C is determined by the Ministry for the Environment and handed to the landfill operators to use in the quantification of their emission release. In that case, the ETS model is transformed from Eq. 5-1 Eq.6-2.The emission factor, C, is calculated as (Ministry for the Environment, 2010d)

$$C = [MCF \times DOC_f \times FCH_4 \times \frac{16}{12} \times GWP \times DOC] \times [1 - OX] \qquad \text{Eq.6-3}$$

Where:

MCF is Methane Correction Factor for aerobic managed landfill. It has been allocated the value of 1.0 by the IPCC (Table 6.3).

DOC_f is the fraction of Degradable Organic Carbon (DOC) that degrades to emit landfill gases. IPCC recommends between 0.5-0.6 of carbon content degrade, and the default value for New Zealand is 0.5 (Ministry for the Environment, 2010a).

FCH_4 is the fraction of landfill gas (by volume) that is methane. The Agency for Toxic Substances & Disease Registry (2001) puts the composition of landfill gas as in Table 6.2, but the default value for New Zealand landfills is 0.5. That means that 50 percent of gases generated in landfills is CH_4.

$16/12$ is the molecular unit weight ratio of CH_4 to CO_2.

GWP is the global warming potential of methane which is 25. GWP is required in order to convertCH_4 quantity to a CO_2-Equivalent (CO_2-e)

(1-OX) is an adjustment of the methane oxidation resulting The assumption is that 10 percent of CH_4 generated is oxidized therefore not contributing to emissions)and therefore the carbon dissimilation factor OX is equal to 0.1 and 1-OX must, therefore, be 0.9.

DOC is the degradable organic carbon which is calculated from the waste fractions that degrade to generate the gases.

So that;

$$Emission\ Factor\ (C) = [1 \times 0.5 \times 0.5 \times \frac{16}{12} \times 21 \times DOC] \times 0.9 = 6.30 \times DOC$$

Eq.6-4

DOC was calculated based on Solid Waste Analysis Protocol (SWAP) 2004 national average and the IPCC DOC value for each waste category as in Table 6.7.

$$DOC = [(0.15 \times 0) + (0.2 \times 0.233) + (0.4 \times 0.149) + (0.43 \times 0.139) + (0.24 \times 0.039) + (0.24 \times 0.027) + (0.05 \times 0)] = 0.18181$$ Eq.6-5

So that;

$$\mathrm{C} = 0.18181 \times 6.30 = 1.145403\ (\text{t } CO_2\text{-e})$$[1] Eq.6-6

Therefore, 1.145403 is the default emission factor which will be integrated into the *CEQ- Model* developed as part of this research and Eq.6-7 is used to calculate for a specific waste disposal sites the emissions released by that site.

$$\text{Emission (E)} = \text{volume of waste to landfill (A)} \times 1.145403$$ Eq.6-7

Table 6.7: Waste composition and DOC value

Waste Stream	**IPCC DOC**	**SWAP 2004**	**DOC**
Food	0.15	0.0%	0.0
Garden	0.2	23.3%	0.0466
Paper	0.4	14.9%	0.0596
Wood	0.43	13.9%	0.05977
Textile	0.24	3.9	0.00936
Nappies	0.24	2.7%	0.00648
Sewage sludge	0.05	0.0%	0.0
Total			0.18181

Source: Ministry for the Environment (2010d)

[1] t CO_2-e is the unit of measurement – tonnes CO2-equivalent

6.2.2 Summary of the *CEQ-Model*

The framework of the *CEQ-Model* represented in Eq.6-2 represents the components of the model. In this Section, each of the components is discussed.

6.2.2.1 Emissions from waste disposal sites

It can be seen in Table 6.6, that CH_4 and CO_2 are the two main emissions from typical waste disposal sites, and represent 45-60% and 40%-60% of emissions by volume respectively. The next highest source of emission Nitrogen contributes significantly less (up to 5% by volume). Therefore, for estimating the emissions from a waste disposal site (AD) only CH_4 and CO_2 emissions are c are considered an assumption is made that these two gases alone as sufficient for estimation purposes. Moreover, because such data is more readily available than for the other lesser gases, the *CEQ-Model* is considered to be more immediately practical. Therefore separate calculations are required in order to quantify both CH_4 and CO_2 which then combined represent AD.

CH_4 quantification in the *CEQ-Model* is based on the IPCC (2000) estimation model as follows:

$$\mathrm{Emission}_{CH_4}(\mathrm{Gg/yr}) = \left[\sum_{i=1}^{n}\left(\mathrm{MSW_D} \times \mathrm{L}_{CH_4}\right) \times (1 - \mathrm{OX})\right] \quad \text{Eq.6-8}$$

$$\mathrm{L}_{CH4} = \mathrm{CH_4\ generation\ potential} = \left[\mathrm{MCF} \times \mathrm{DOC} \times \mathrm{DOC_f} \times \mathrm{F} \times \mathrm{GWP} \times \frac{16}{12}\right] \quad \text{Eq.6-9}$$

Where:

MSW_D = Municipal Solid Waste disposed to landfill in tonnes

L_{CH4} = Emission (CH_4) generation potential

MCF = Methane correction factor (fraction) = 1. See Table 6.1

DOC = Degradable organic carbon (fraction)

DOC_f = Fraction of DOC dissimilated

F = Fraction of CH_4 in landfill gas by volume

OX = Oxidation factor = 0.10 i.e. 10% of CH_4

GWP = Global warming potential (converts CH_4 to CO_2-e)

$\frac{16}{20} = \frac{CH_4}{C}$ = The molecular weight ratio of CH_4 and C (Carbon)

n = Number of landfills starting from i=1

Gg/yr = Gigagram per year

The model for the CO_2 emissions calculation can be derived based on the CH_4 emission estimation (Eq. 6-8) as follows:

$$\text{Emission}_{CO_2}(\text{Gg/yr}) = \left[\sum_{i=1}^{n}[(\text{MSW}_D * L_{CO_2})] * (1 + OX)\right] \qquad \text{Eq.6-10}$$

So that,

$$L_{CO_2} = \left[\text{MCF} * \text{DOC} * \text{DOC}_f * F * \frac{44}{12}\right] \qquad \text{Eq.6-11}$$

And,

MSW_D = Municipal Solid Waste disposed to landfill in tonnes

L_{CO_2} = Emission (CO_2) generation potential

MCF = Methane correction factor (fraction) = 1.0. See Table 6.1

DOC = Degradable organic carbon (fraction) which depends on the decomposable waste fractions in the mass volume of waste disposed of.

DOC_f = Fraction of DOC dissimilated (fraction of DOC that can decompose) = 0.5

F = Fraction of CO_2 in landfill gas by volume = 0.5

OX = Oxidation factor = 0.10 i.e. 10% of CH_4

$\frac{44}{12} = \frac{CO_2}{C} =$ The molecular weight ratio of CO_2 and C (carbon)

n = the number of landfills

Note that the oxidation factor (1-OX) in Eq.6-8 is a reflection of the percentage of CH_4 oxidised in the cover soil of the landfill to CO_2. The same fraction of CO_2 is gained by volume in Eq.6-10, hence the (1+OX) term.

6.2.2.2 Emissions from waste transportation

Emission from transportation can be estimated from total fuel consumption or total distance travelled (Weigel et al., 2009). Data on fuel consumption for waste transport does not exist. Distance travelled is used here because it can be estimated. The basis of Eq.6-12 as adopted for emission from transportation is from IPCC (2006b). The emission quantification covers the three major gases from transportation processes.

$$\text{Transport emission} = \sum\nolimits_{a,b,c,d}\left[\text{Dist} \times \left(\text{EF}_{\text{CO}_2} + \text{EF}_{CH_4} + \text{EF}_{\text{N}_2\text{O}}\right)\right] \qquad \text{Eq.6-12}$$

Where:

Dist. = Distance travelled at stabilized engine operational phase (km)

EF_{CO2} = CO_2 emission factor for the fuel type

EF_{CH4} = CH_4 emission factor for the fuel type

EF_{N2O} = N_2O emission factor for the fuel type

a = Fuel type (diesel, gasoline, natural gas, LPG)

b = Vehicle type

c = Emission control technology (such as an uncontrolled catalytic converter, etc.)

d = Operating conditions (e.g. urban or rural road type, climate or other environmental factors

(Note: The EFs are as given in Tables 5.6 and 5.7. The emission is expressed as CO_2-e (kg))

The uncertainties in the values from the quantification of the emission from transportation results from the necessary estimation of distance travelled and the values of the variables in the calculation of each of the emission factors. The distances may be overestimated or underestimated. Also, the emission factors are based on certain characteristics of the vehicles and fuel used, which may change over time. The possible variation in the characteristics of the fuel and vehicle affects the consumption per kilometre travelled.

6.2.2.3 Electricity as an Indirect Emission factor

The volume of emission from electricity depends on the source of electricity (e.g. coal, natural gas, petroleum or alternative renewable sources). The emissions from the electricity sector come from the generation, transmission and distribution of electricity. While CO_2 makes up the majority of emissions from electric power, other emissions like CH_4 and N_2O are also produced in small quantities. The emissions from electricity are usually attributed to the sector where the power is used rather than the supplier as follows:

$$\text{Emissions (kg)} = \text{EP (kWh)} \times \text{EF} \times \text{GWP} \qquad \text{Eq.6-13}$$

Where:

EP = Purchased electricity in kWh

EF = Emission factor

GWP = Global warming potential (equals 1 for CO_2)

Since GWP for CO_2 is 1, Eq.6-13 is simplified to:

$$\text{Emissions (kg } CO_2 - \text{e)} = \text{EP (kWh)} \times \text{EF}$$

Eq.6-14

6.2.2.4 Refrigeration emission

The emissions resulting from refrigeration and cooling in the waste management sector might contribute relatively little to the overall emissions from MSWM systems. However, in the future, it may become necessary to report them because some HCFCs and HCFs have very high global warming potentials (GWP) (Table 6.8).

Direct release of HCFCs and HFCs may occur during the servicing or disposal of refrigeration and cooling equipment. However, such a release of HCFCs or HFCs is not very common, especially in waste management facilities and efforts are being made to replace these refrigerants with alternative gases that have very lower or near zero GWPs (DEFRA, 2012). Since the amount of emission is the amount of gases released, the emission in CO_2-e is the product of the amount of gas and the GWP:

$$\text{Total Refrigeration Emissions} = \sum[\text{GWP (IE + S + DE)}] \qquad \text{Eq. 6-15}$$

Where:

IE = Emissions resulting from refrigerants used during installation of equipment

S = Emissions resulting from refrigerants used during the servicing of equipment

DE = Emissions from refrigerants from disposed of with equipment

GWP = the 100-year global warming potential of the HFC and HCFC refrigerants used in the system

Therefore, the C*EQ-Model* is a combination of all the emissions as presented:

$$CEQ - Model\ (\mathrm{Gg\ CO_2 - e}) = [(\mathrm{Eq.}\ 6-8) + (\mathrm{Eq.}\ 6-10) + (\mathrm{Eq.}\ 6-12) + (\mathrm{Eq.}\ 6-14) + (\mathrm{Eq.} 6-15)] \quad \text{Eq.6-16}$$

Table 6.8: Gases and their GWP

Chemical formula	**GWP**
CO_2	1
CH_4	25
N_2O	298
HFC-23	12,200
HFC-32	205
HFC-125	1,100
HFC-134a	435
HFC-143a	1,590
HFC-152a	38
HFC-236fa	7,660
HCFC-22	549
HCFC-123	24
HCFC-124	185
HCFC-141b	220
HCFC-142b	705
HCFC-225ca	37
HCFC-225cb	181

Source: IPCC (2007b)

6.2.3 Implementation of the *CEQ-Model*

In the New Zealand Emissions Trading Scheme (NZETS), the emission factor is derived using a mass balance approach in which emissions are attributed to waste in the year of the disposal at the solid waste disposal site. The waste composition provides the percentage value of each specific waste fraction. The waste composition determines the proportion of the particular waste fraction that contributes to the waste stream aka the estimated DOC (Degradable Organic Carbon).

Landfill gas generation is a function of degradation of the biodegradable fraction which contains the DOC. The landfill gas generation is also influenced by the physicochemical composition of the waste and related environmental factors (Kumar, Mondal, Gaikwad, Devotta, & Singh, 2004). Environmental factors affecting emission generation include pH, temperature, moisture, nutrient, and depth of landfill. Capping and compaction of waste lying in the landfill also affect the rate of gas generation. According to Kumar et al. (2004), the practices of capping and compaction result in aerobic zone variation, and the pH varies with the landfill depth and is an indicator of the level of aerobic (and hence anaerobic) chemical reactions.

As mentioned previously, the ETS model is based on default IPCC method, which does not reflect the variation in degradation period of waste from biogenic sources, hence assumes that all methane is released the year the MSW is disposed of (IPCC, 2000). The default equation also has assigned emission factor ‘C’ which is the emission generation potential for all solid waste disposal sites within the period. Until ‘C’ is recalculated to be a reliable parameter or the solid waste disposal site applies for a unique emission factor (UEF) uncertainty will exist in the *CEQ-Model* as a result of the use of the assigned emissions factor ‘C’. Currently, this value is estimated based on the assumption that all landfill have the same waste composition all over the country and over many years. Thus, the primary limitation of the *CEQ-Model* is related to the lack of available and suitable data. Currently, many of the parameters to the model (and indeed all models) are determined by estimates which are themselves based on inadequate data and have been determined by governing authorities often at an international level.

6.3.2.1 Quantification of Waste Disposal Site Emission

In order to evaluate the *CEQ-Model,* it was used to calculate the emissions for a period 2007 to 2008. The data was comprised of waste disposal data sourced from the former Auckland Regional Council (now the Auckland Council). The choice of the years for implementation was determined by the availability of other related datasets which are required in order to calculate the *CEQ-Model* emission estimate. In years prior to 2007, there are gaps in the data which meant that it was difficult to determine whether or not the data was adequate. In the 2007/2007 survey, the total waste to landfill was an estimate of the waste generated in the Auckland region based on waste disposed of at one of the four landfills that were servicing Auckland at the time. The data was largely based on truck weighbridge records or directly by commercial landfill operators to the Auckland Regional Council.

Using the *CEQ-Model* the emission from waste disposal sites are computed substituting the required parameters in Eq. 6-8 to Eq. 6-11 as follows:

> L$_{CH_{42}}$ is calculated by substituting the values of MCF, F, GWP, and DOC$_f$ after computing DOC. The value of DOC is calculated using the waste composition data in Table 6.9 and the percentage organic carbon ascribed to each waste fraction as in Table 6.5. The waste fractions contributing to the DOC in the 2007/2008 waste assessment are paper, food, textiles, nappies, and timber.

So that;

$$\text{DOC} = [(3/100 \times 0.24) + (19.1/100 \times 0.15) + (10.4/100 \times 0.40) + (13.7/100 \times 0.43) + (3/100 \times 0.24)] \quad \text{Eq.6-17}$$

$$\text{DOC} = (0.0072 + 0.02865 + 0.0416 + 0.05891 + 0.0072) = 0.14356 \quad \text{Eq.6-18}$$

Substitute the value of DOC, F, GWP, DOC$_f$ and MCF in Eq. 6-9, where;

MCF = 1 as in Table 6.3

F = 0.5 as in Ministry for the Environment (2010a, pp. 14-16)

GWP = 25 as in Table 6.8

DOC$_f$ = 0.5 as in Ministry for the Environment (2010a, pp. 14-16)

$$L_{\text{CH}_4} = (1 \times 0.5 \times 0.5 \times 25 \times 0.14356 \times 16/12) = 1.19633 \quad \text{Eq.6-19}$$

Therefore, the Emission Factor (EF) for CH_4 is:

$$\text{EF}_{CH_4} = 1.19633 \times 0.9 = 1.0767$$

So that;

$$\text{CH}_4 \text{ Emission (Gg)} = 1{,}396{,}432/1000 \times 1.0767$$
$$= 1503.54 \text{ Gg CO}_2 - \text{e}$$

For CO_2, changes will be in the GWP, molecular weight ratio, and oxidation factor which will be 1.0, $\frac{44}{12}$, and 0 respectively. The oxidation factor of CO_2 is zero because

CO_2 is a stable gas (Widory, Proust, Bellenfant, & Bour, 2012) and hence is released fully when produced by the decomposing MSW.

So CO_2 is computed using Eq.6-17 to calculate the DOC which is then substituted into Eq.6-10

Therefore, according to Eq.6-17, the DOC is calculated to be 0.14356

$$L_{CO_2} = \left(MCF \times DOC \times DOC_f \times F \times \tfrac{44}{12}\right) = (1.0 \times 0.5 \times 0.5 \times 3.667) \times DOC \quad \text{Eq.6-20}$$

$$\therefore L_{CO_2} = (0.91667 \times 0.14356) = EF_{CO_2} = 1.1316 \quad \text{Eq.6-21}$$

$\therefore CO_2$ Emission = (1,396,432/1000 ×1.1316) = 183.77 Gg $CO_2 - e$

Table 6.9: Auckland region waste composition, 2007 - 2008

SWAP Primary Classification Category	Tonnes/year	% of total
Paper	145,015	10.4%
Plastics	124,646	8.9%
Putrescible (Food)	266,249	19.1%
Ferrous metals	55,874	4.0%
Non-ferrous metals	9,482	0.7%
Glass	31,939	2.3%
Textiles	41,787	3.0%
Nappies & Sanitary	41,465	3.0%
Rubble	121,539	8.7%
Timber	191,592	13.7%
Rubber	17,309	1.2%
Potentially hazardous	349,535	25.0%
Total	**1,396,432**	**100.0%**

Source: Auckland Council (2011, p. 28)

6.3.2.2 Quantification of Transportation Emissions

According to Zielinska, Sagebiel, McDonald, Whitney, and Lawson (2012), the composition of emissions from petrol and diesel combustion depends on the type of fuel (diesel or petrol), the state of the vehicle, the ambient condition or engine temperature. As mentioned earlier, emissions can be quantified based on fuel consumption or the travelled distance. According to the IPCC (2006b), fuel based quantification is appropriate for CO_2 while the distance based approach is better for CH_4 and N_2O. However, a country's situation and data availability largely determine the approach that can be adopted. Countries with fuel consumption data are required to use that data as it is a better representation of the emission because the emission is based on the carbon content of the fuel. In this research, the distance-based approach is adopted because of inadequate data availability.

The accurate quantification of CH_4 and N_2O is more difficult than CO_2 because those emission factors depend on vehicle technology, fuel and operating characteristics which are not typically recorded (IPCC, 2006b). MSW transportation when considered in depth is more complicated than it may seem as a result of;

- The dynamic and changing network of movement of vehicles (and hence waste)
- The types of vehicle used (engine size and weight etc.)
- The different types and quality of the fuel used
- The weight of the solid waste transported per vehicle and per trip.

With eighteen transfer stations located at various locations across Auckland and four landfills receiving MSW from the transfer stations, without a record of the transportation routes/network, it’s hard to calculate accurate transportation distances as travelled by the various trucks to deliver their waste to the landfill. Kirkeby et al. (2006), assumed a standardised vehicle approach (using the Euro3 or Euro2 vehicle standards and standard tonnage per trip) as a way of overcoming these complexities. The actual distance may not be accurately established because of the array of sources of the waste, the types of vehicle and many other scenarios. Therefore, a baseline has to be established. Since in Auckland, there is a better record of the quantity of the waste that is transported from the transfer stations, for this calculation the transfer station is used as the starting destination for waste transportation.

Table 6.10 provides a summary of waste disposal in 2007/2008 as reported in the Auckland Council assessment (2011, p. 25) on which the emissions quantification is based.

Table 6.10: Waste to landfill, distances, and waste volumes in Auckland by landfills servicing the Auckland region for 2007 to 2008 period

Landfill	Average Distance[2] (km)	Est. volume (tonnes)
Redvale Landfill (Transpacific Industry)	30	717,000
Hampton Downs (Envirowaste)	68	478,782
Whitford Landfill (Waste Disposal Services)	21	200,000
Claris Landfill (Auckland Council)	11	650
	Total estimated tonnes	**1,396,432**

Source: Auckland Council (2011, p. 25)

The equation for transportation emission quantification is based on the IPCC (2006a) Tier 3 emissions equation (Eq.6-12). Fuel consumption depends on many different parameters such as type and size of the vehicle of transportation, volume weight of the material, capacity use, combustion technologies of the engine, and traffic conditions on the transportation route. Kirkeby et al. (2006) aggregated all these parameters into a single parameter for measuring fuel consumption.They also defined the distance travelled for waste transportation as the length of the route travelled in km from where the collection was completed to the point of unloading. Fuel consumption is typically expressed as a unit of fuel consumption corresponding to the amount of fuel used for transporting one tonne of waste over a distance of one km (Technical University of Denmark, 2012).

The quantified emissions are calculated based on substituting emission factors in Table 5.6, waste volumes and distance travelled in Table 6.10, in Eq .6-12 are shown in Table 6.11. Each run of the waste truck is measured as a round trip to the landfill from the transfer station. The number of runs is derived based on the total waste volumes reported and based on an average load of 25 tonnes.

$$no. of\ runs = \frac{total\ waste\ volume}{25}$$

The total distance is calculated as $no. runs\ \times Distance\ (km)$ where the distance is a round trip to/from the landfill and the emission quantity for each gas is given by the $total\ distance\ \times\ EF_{gas}$ and is given in Table 6.11.

[2] Average distance from source to landfill is estimate from assumed city centre to solid waste disposal site

Table 6.11: Quantified Auckland regional emissions from transportation, 2007 - 2008

Landfill (1)	**Distance (km) (2)**[3]	**Total Waste Volume (tonnes) (3)**	**Volume Per Run (tonnes) (4)**[4]	**No of Runs (5)= [(3)/(4)]**	**Total Distance (6)= [2x(2)x(5)]**	**EF(7)**	**Emission (8) (kg)**
						CO_2 kg/unit	CO_2
						CH_4 (CO_2-e)	CH_4
						N2O (CO_2-e)	N_2O
Redvale	30	717,000	25	28,680	1,720,800	0.227	390621.6
						0.00134	2305.9
						0.00152	2615.6
Hampton Downs	68	478,782	25	19,151.28	2,604,574.08	0.227	591238.3
						0.00134	3490.1
						0.00152	3959.0
Whitford	21	200,000	25	8,000	336,000	0.227	76272.0
						0.00134	450.2
						0.00152	510.7
Claris	11	650	25	26	572	0.227	129.8
						0.00134	0.8
						0.00152	0.9
Total emission (kg) CO_2-e 1,071,594.9							

Source: Compiled by the author

6.3.2.3 Electricity Indirect Emission

Emissions from electricity consumption is an indirect emission computed based on the total purchased electricity in kWh and the EF as shown in Table 6.12. The total power consumption is the value of power used for site maintenance, lighting, cooling and heating. The emission factor in CO_2-e is multiplied by the quantity of purchased energy and GWP as in Eq.6-14 to generate the emission.

Table 6.12: Emission factor for purchased electricity

Emission source	**Unit**	**Emission factor total (kg CO_2-e/unit)**
Purchased electricity	kWh	0.165

Source: Ministry for the Environment (2014a)

The amount of emissions from purchased electricity could not be established because of a lack of availability of data. Metre readings, if publically available or as part of new reporting requirements, from the appropriate sites would provide this information.

[3] Average distance from transfer stations to landfills
[4] Average load of waste trucks from transfer station to landfills is 25 tonnes

6.3.2.4 Refrigeration Emissions

Emissions of hydrofluorocarbons (HFCs) result from unintentional leaks and spills from cooling units and heat pumps. The quantity of HFC leakages associated with MSWM facilities may be small, but HFCs have very high global warming potentials (between 1300 to 3300 times more potent than CO_2) (Table 6.8) (Ministry for the Environment, 2014a).

Emissions from refrigeration and cooling may be quantified using Eq.6-15 (Ministry for the Environment, 2014a; World Resource Institute, 2005). Because of inadequate data, this emission cannot be quantified for Auckland MSWM. The ability to include emissions from refrigeration and cooling would make the quantification more complete.

6.3.2.5 Combined Emissions Computed using the *CEQ-Model*

With the above, the combined model for comprehensive emissions as a result of waste disposal activities is:

$$\text{Total Emission (Gg) CO2} - \text{e} = \Big\{\Big[\textstyle\sum_{i=1}^{n}\big(\text{MSW}_{\text{D}} \times \text{L}_{\text{CH}_4}\big)\,(1-\text{OX})\Big] + \Big[\textstyle\sum_{i=1}^{n}(\text{MSW}_{\text{D}} \times \text{L}_{\text{CO}_2})(1-\text{OX})\Big] + \Big[\textstyle\sum_{i=1}^{n}[\text{Dist}\,\big(\text{EF}_{\text{CO}_2} + \text{EF}_{\text{CH}_4} + \text{EF}_{\text{N2O}}\big)]\Big] + \Big[\textstyle\sum_{i=1}^{n}[(\text{EP} \times \text{EF}) \times \text{GWP}]\Big] + \Big[\textstyle\sum_{i=1}^{n}[(\text{IE} + \text{S} + \text{DE}) \times \text{GWP}]\Big]\Big\} \qquad \text{Eq.6-22}$$

A summary of the total emission is shown in Table 6.13. The highest quantified volume of CH_4 (1,305 Gg CO_2-e) is produced by the landfill itself, while the transportation factor produced the highest amount of CO_2 at 1058.3 Gg CO_2-e. The N_2O volume from transportation is a relatively small 7.1 Gg CO_2-e. All of these individual gases produced contribute to the amount of waste disposed of in each landfill.

Table 6.13: Summary of quantified emissions for the combined Auckland landfills

Emission Source	**gas**	**Volume (Gg CO_2-e)**	**Total Volume (Gg CO_2-e)**
Landfill	CH_4	1,305.0	1,475.9
	CO_2	183.8	
Transportation	CO_2	1058.3	1071.6
	CH_4	6.2	
	N_2O	7.1	
Purchased electricity	-	0 [unknown]	
Refrigeration	-	0 [unknown]	
		Total *CEQ-Model* estimate	**2,560.4 Gg CO_2-e**

6.3.3 Analysis of Standard Parameters

The assigning of standard values to some of the parameters used in the model is in part responsible for the inherent limitations of the *CEQ-Model* and contributes a level of uncertainty in the final calculated values of the quantified emissions. The following discussion of these issues helps in understanding the standards and how improvements can be achieved. The adoption of these values are based on the submissions as determined by the Inter-Academic Council (IAC) of the (IPCC, 2012) and approved through the relevant working groups.

6.3.3.1 Gas Correction Factor (GCF)

The IPCC Guidelines approved the adoption of Gas Correction Factor (GCF), which can be used for CH_4, CO_2 or any other gas (as the case may be), as '1' representing 100% of disposed waste in a particular solid waste disposal site (SWDS). The implication of this is that the quantity of waste disposed on the site is still complete onsite without any percentage loss through scavenging, fire or any other form. And 100% of the biodegradable waste will decompose to yield gases during the year the waste is disposed of (IPCC, 2006c). Hence, at managed landfills, all the quantity of waste disposed of are accounted for in the correct proportion, unlike in the unmanaged SWDS. Unmanaged-shallow landfills (< 5m waste depth) can lose up to 60 percent of waste via unaccounted for waste, and this would increase the error using the *CEQ-Model* an adjustment would, therefore, be required for countries where landfills are unmanaged. In New Zealand where all landfills are considered for emissions quantification purposes to be managed, the value is '1' and any error would be close to zero.

In an unmanaged SWDS, less production of landfill gas (LFG) is observed than for managed landfills because of the increased aerobic decomposition of the top layer of the landfill, (IPCC, 2006a). Therefore, the correction factor at managed landfills is an indication of the level of decomposition through anaerobic managed landfills to semi-aerobic managed environment where the disposed waste is not compacted well, to an unmanaged aerobic situation where air circulation and water within the body of the SWDS reduce the generation of LFG. Therefore, the classification of waste sites may change over time depending on the waste management policies implementation and the scenario in a particular SWDS. The value of '1' for New Zealand scenario can be justified, but some of the landfills that incorporate recovery facilities in their management may not account for recovered waste. Hence, in situations where the records of landfill conditions and operations are kept and reflected in the data system of the landfill, the level of error in the final output of the *CEQ-Model* should be very low. Table 6.14 gives the range of uncertainty in MCF suggested by IPCC Guidelines.

Table 6.14: MCF uncertainty range

Methane Correction Factor (MCF)	**IPCC Default Uncertainty Range**
1.0	-10%, +0%
0.8	±20%
0.5	±20%
0.4	±30%
0.6	-50%,+60%

Source: IPCC (2006a)

6.3.3.2 Degradable Organic Carbon (DOC)

The percentage of DOC is a major determinant of the level of decomposition over time of a waste sample in a landfill. However, the uncertainty level in establishing the DOC for a group of waste types/materials (paper, food, etc.), is normally high. This is due to lack of specific research in this area of waste management (IPCC, 2006a). Different types of waste/material (paper, food, wood and textiles) can have very different DOC values (Table 6.15). These values can vary from country to country and even within a country. The rate of decomposition is affected by many factors including the composition of the waste stream (which is further affected by the chemical composition of the waste fractions).

Table 6.15: Summary of different decay rates from different models and literature

Type of waste	**IPCC[1]**				**De la Cruz and Barlaz (2010)**	**US EPA (2004)**
	Default		Range			
	Dry	Wet	Dry	Wet		
Paper/textiles	0.04	0.06	0.03-0.05	0.05-0.07	0.06[a]	0.10[c]
Wood/Straw	0.02	0.03	0.01-0.03	0.02-0.04	0.03	0.03[d]
Food waste	0.06	0.185	0.05-0.08	0.1-0.2	0.14	0.29
Other[2]	0.05	0.1	0.04-0.06	0.06-0.1	0.2[b]	0.33
Bulk waste	0.05	0.09	0.04-0.06	0.08-0.1	0.04	0.08

[1] these values are based on a boreal and temperate climate
[2] (non-food) organic putrescible/garden and park waste
[c] Mean value for newsprint, coated paper and office paper
[b] Mean value for branches, leaves, and grasses
[c] Mean value for less, newspaper, office paper, magazines and corrugated cardboard
[d] Mean value for grass, leaves and brush

Sources for the table are as stated in the table.

Other factors which influence the rate of decay of these materials include, the water content of the waste, climatic conditions of the site where the landfill is located, landfill condition (e.g., degree of moisture and depth of waste disposal), and landfill management processes (which determines the level of compaction, for instance) (Thomson, Sawyer, Bonam, & Valdivia, 2009). The higher the value of the decay rate, the higher the volume of gas produced. The uncertainty in DOC estimations because of the difficulties in obtaining data related to the actual conditions at a landfill could be reduced if suitable data was available. Moreover, uncertainty in the waste composition affects estimates of total DOC in the SWDS. Waste composition varies widely even within countries (for example, between urban and rural populations, between households on different incomes, and between seasons) as well as between countries.

Just as the accuracy of waste composition data is affected by the number of classifications or segregations and the methodological approach, the resultant impacts on outputs from its application are not in doubt. Though, this is dependent on the application of the composition study. But whatever the purpose may be, the results based on Burnly (2007) 12 segregation, Burnley et al. (2007) 37 categories or Kirkeby et al. (2006) 48 material fractions, cannot yield the same result. The variation in waste segregation can be said to be one of the reasons for different decay rate in different waste management model as shown in Table 6.15.

6.3.3.3 Fraction of DOC which Decomposes (DOC_f)

The uncertainty in DOC_f is high due to the difficulty in replicating the real life scenarios in SWDS during experimental studies (IPCC, 2006a). As for DOC, the variation in the chemical composition of waste samples and composition even within landfills, including weather and other environmental conditions, compounds the level of uncertainty. The composition of materials from landfill mining (Hogland, Marques, & Nimmermark, 2004; van der Zee, Achterkamp, & de Visser, 2004) gives some indication of the impact of chemical composition, temperature, moisture, pH, and other environmental condition in the level of decomposition and hence carbon storage or sequestration.

Oonk and Boom (1995) used a DOC_f of 0.5-0.6 for calculating emissions from landfills in the Netherlands. The authors concluded that in their opinion values above this range are too high. Similar values, to that of Oonk and Boom's, are suggested for developed countries (IPCC, 2000). The IPCC default DOC_f value, adopted in this research, of 0.5 is expected to have an uncertainty range of ±20% (IPCC, 2006c)

6.3.3.4 Oxidation Factor (OX)

As stated in section 1.1, the OX reflects the amount of CH_4 and other gases that are oxidized in the soil and other materials used as landfill cover. According to the IPCC (2000), sanitary (modern engineered) landfills tend to have higher oxidation levels than unmanaged SWDS. The nature and thickness of covering materials are considered to be major factors in determining the oxidation level. The difficulties in consistently maintaining set conditions for covering materials, make it equally difficult to maintain a fairly uniform standard of oxidation level. For example, thick cover materials that are well aerated produce a different OX than SWDS without cover or than SWDS with a cover that can crack and allow gases to escape. The Centre for Advanced Engineering (2000, p. 45) recommends a combination of compacted clay layer about 600mm thick and a compacted soil layer of about 150mm on top of the clay as the final cover in New Zealand. The consistency of landfill operators to meet this cover material specification over the whole landfill cannot be guaranteed.

Atmospheric conditions and climate, the rate of flow of the LFG are both factors that will determine the level of oxidation. Laboratory determination will normally use uniform and homogenous soil layers and may lead to over-estimation of oxidation level in a landfill.

The default oxidation value given in the IPCC Guidelines is zero (IPCC, 2000). Due to variations in field and laboratory conditions, observations are expected to yield a wide range of values. Expert advice from the IPCC (2000) therefore suggests that values higher than 0.1 will probably be too high. This level of oxidation is justified because only a fraction of the CH_4 generated will diffuse through a homogeneous layer, another fraction will escape through cracks or via lateral diffusion without being oxidised. Therefore, results from field observation cannot be homogenous, and laboratory studies may lead to overestimations of oxidation in landfill cover soils.

6.3.3.5 Fraction of CH_4 in landfill gas (F)

LFG is made up of mainly CH_4 and CO_2 plus minor other gases. The default value is taken as 0.5, but acceptable values range between 0.4 and 0.6 (IPCC, 2000) depending on several factors including waste composition. An uncertainty range of -0%, +20% is prescribed by (IPCC, 2000, 2006c).

6.3.3.6 Recovered Landfill Gas (R)

Recovered LFG is the gas that is extracted and flared or used for energy recovery. The default value for R is zero if there is no LFG recovery facility within the system. Recovered LFG should be subtracted from the amount of gas generated according to the oxidation factor (OX). The use of LFG in this manner is beneficial as collected gases are not subject to oxidation in the upper layer of the landfill where the waste meets the cover materials.

6.3.3.7 Distance from Transfer Station to Landfill

The quantification of transport emission using the amount of fossil fuel utilization is the most accurate since this can be quantified to a better accuracy of waste collection and transportation companies cooperate with researchers in this direction. In this research, however, the average distance is used which is a factor in the uncertainty level of the result. The uncertainty can, however, could be improved if landfills were zoned to a particular transfer station through the implementation of proximity ratio, where transfer stations dispose waste to the closest landfill.

6.3.3.8 Summary of Uncertainty Evaluation

The cost of all the uncertainties discussed above demonstrates the importance of having suitable data available which is of good quality in order to estimate emissions, and relevant parameters, more reliably. The activity data in the waste sector includes limited information regarding waste generation, composition, and management. The highest contributor to uncertainty is the waste composition is the main factor used to determining the values of DOC and DOC_f.

The uncertainty level is also dependent on the manner or method of collecting and recording the data. In the case of New Zealand, only 'four indicator sites' are used to determine the national waste composition value for the country (Ministry for the Environment, 2009b). It is highly likely that this is not a good representation of waste composition and volume for New Zealand, or for the greater Auckland region, due to the large local variations in demographics, socioeconomic conditions, and primary industries.

The number of segregations in the waste composition used is another major contributor of uncertainty. The SWAP method adopted twelve categories as shown in Table 5.3, for the purpose of determining the DOC values. For example, the adoption of DOC fraction of 0.40 for paper, covering newspaper, cardboard, office paper, packaging paper, etc., (Ministry for the Environment, 2009b). But the variation in the chemical composition and carbon content of the various categories of paper does affect their DOC.

In New Zealand, the default emission factor for landfill emission quantification has been the same for several years pending a review by the Technical Advisory Group (TAG) for waste (Ministry for the Environment, 2010d) which has yet to be undertaken. This also impacts on the accuracy of any calculations of the DOC which in turns add uncertainty to the values estimated for DOC_f and $L_{CO2.}$ Improvement in the accuracy of DOC could be realised by either using regional values or even better landfill specific values.

In general terms, therefore, current uncertainties on emissions and mitigation potentials could be reduced by more consistent national definitions, coordinated data collection, standardized methods of data analysis, field validation of used models, and uniform application of LCA tools and fossil fuel offsets.

6.4 Validation of the Model

Since the early 1990s, it was realized that a dedicated decision support tool was needed to aid policy makers and waste management practitioners in the planning, design, and selection of appropriate waste management strategies (Clavreul, Guyonnet, & Christensen, 2012). As a result of the need for such support, several models have been developed to support waste management decisions, using a variety of tools and methods. According to Morrissey and Browne (2004, p. 297), the tools and methods include "risk assessment, environmental impact assessment, cost-benefit analysis, multi-criteria decision making and life cycle analysis". The type of tool selected for use depends on the decision that is expected to be made and the decision maker (EEA, 2003; Zopounidis & Doumpos, 2002).

The use of different types of models for the simulation of physical processes has significantly affected our approach to engineering and science. These models are used to analyse the results and perform "what-if" studies (Hills & Trucano, 1999). Whether these models are used with the aid of computers or through physical computation, the question that is always asked is – how accurate is the model?

Models are abstractions, simplifications and interpretations of reality (Refsgaard et al., 2006). The completeness of a model's structure is a function of physical phenomena that are not entirely obvious or that are known, but due to their complex nature, are not represented well in the model. This incompleteness contributes to the series of systematic bias and uncertainty in the output of the model (Atamturktur & Stevens, 2014). The level or the amount of this incompleteness determines whether the model is accepted or rejected. The validation process is, therefore, meant to show the degree of consistency between the physical processes represented in the model and the model output. Validation can also help in the modification of the model to reduce the systematic biases and uncertainties resulting from the structural imperfections of the model (Thacker et al., 2004; Trucano et al., 2006; Van Buren et al., 2012). Atamturktur and Stevens (2014) view validation as a fine-tuning of the model.

One challenge faced in many implementations or applications of models is that predictions are required beyond the range of available observations. Beck (2005), pointed to predictions for a natural system, such as ecosystems that are likely to undergo structural changes, as one example. The same issue is relevant to predictions in waste management systems, where a lot of unpredictable variables are involved and where the system us undergoing constant structural change. The result of emissions, as modelled in this study, is a combination of waste composition (which can never be the same from household to household or from landfill to landfill, or even within the same house on different days), conditions in the landfills, whether condition, the nature of landfill cover materials, the compaction level of the disposed waste, etc. Hence, uncertainty in model structure is recognised by different authors as the major source of error in model predictions (Dubus, Brown, & Beulke, 2003; Linkov & Burmistrov, 2003)

Models are tested against experimental data whenever possible. In such cases, the validation experiment is repeated several times to enable the measurement of any errors that may be a result of the validation experiment. Thereby, arriving at acceptable experimental values which are in turn evaluated using rigorous statistical methods. Validation is based on comparing the output from deterministic simulation and output from single or repeated experiments. In deterministic simulation validations of models, the presence of uncertainty is not considered. This approach, where the physical experiment has to be repeated a sufficient number of times, may be difficult to adopt for many applications, due to the cost and time commitment required (Chen et al., 2004).

Recent model validation approaches propose a shift of efforts to allow for the propagation of uncertainty in model outputs. However less work has been done in this area (Hills & Trucano, 1999; Oberkampf & Trucano, 2002; Sargent, 2013)

Uncertainties in model inputs and parameters have also been used to measure the correctness of computational models. The complexity of the MSWM data and quantification of process outputs contribute to the uncertainties which result from the data. The uncertainty in the model results from input data, model parameter values, or the structure of the model.

Even though some default uncertainty ranges have been suggested by the IPCC (2006a), based on the Norwegian scenario, the same may not apply to New Zealand. Hence, that uncertainty range may not fit well with the data available for this research, and therefore it is difficult to quantify the uncertainty in the model with any confidence.

6.4.1 Validation method

Chen et al. (2004) categorised model validation approaches as either subjective comparisons of x-y plots, showing the trend in data over time and space or quantitative comparisons of model outputs and experimental observations. Quantitative comparison techniques adopt statistical inference methods such as an X^2 test on residuals between the estimated values (model) and actual/measured values (Gregoire & Reynolds, 1988). The determination of coefficient (R^2) can be used to evaluate the model's goodness of fit. The higher the value ($0 < R^2 < 1$), the better is the output from the model (Fakruddin, Mazumdar, & Mannan, 2011)

Model validation is a complex undertaking especially when so much uncertainty exists in the actual data and therefore in the parameters to the model. In this research, a quantitative comparison of the *CEQ-Model* with other selected waste emission quantification models is undertaken. These models were chosen because of the similarity in characteristics with *CEQ-Model*. They are all based on LCA/LCT frameworks. Therefore, process emission, especially transportation are considered in their emission quantification. These models are also ones which are available and have enough detail for them to be replicated in this research.

For the purpose of this comparison, the data used is Auckland waste disposal data from 1996 to 2015(Table 6.16), the emission factors as in Section 6.3.2.1 and Section 6.3.2.2.

Table 6.16: Auckland waste disposal, 1996 to 2015

Year	Auckland Population*	Auckland Annual Waste Disposal (tonnes)**
1996	1115800	909404.8
1997	1146700	880455.9
1998	1169000	847263.0
1999	1184800	870972.1
2000	1202500	901948.3
2001	1218300	928600.2
2002	1255800	961131.5
2003	1297600	990740.1
2004	1326000	1033548.5
2005	1348900	1034703.1
2006	1373000	1035508.3
2007	1390400	987464.5
2008	1405500	938198.8
2009	1421700	887942.9
2010	1439600	826924.1
2011	1459600	849856.8
2012	1476500	819531.4
2013	1493200	872592.4
2014	1526900	947373.4
2015	1569900	1054485.2

Source: * Statistics New Zealand (2015); ** Ministry for the Environment (2016); Ministry for the Environment (2007c, p. 9); Ministry for the Environment (2013b); (Ministry for the Environment, 2013c); Ministry for the Environment (2014b)

6.4.2 Landfill Emission Models

A landfill methane model is a tool for the projection of methane generation over time from a mass of waste. In its simplest form, the model predicts emission generation or recovery from a single batch of waste, landfilled over a given point of time. Landfill emission models are changing as better landfill data are becoming available for modelling.

The following models were considered:

1. US EPA LandGEM (The United States)
2. IPCC Tier II FOD Emission Model (Switzerland)
3. Integrated Solid Waste Management Tools (IWM) (Canada)
4. EASEWASTE Model (Denmark)
5. NV Afvalzorg Multiphase Landfill Gas Generation and Recovery Model (The Netherlands)

6.4.2.1 Model Specifications

All these models share a common methodological background and aim to quantify emissions. However, they vary due to the countries waste management systems and have been developed for that local context. Therefore each model's difference in terms of scope, inputs and input format, and even the type/format of the output. The five models can be categorised into two as:

1. LCA modelling tools – EASEWASTE Model and Integrated Solid Waste Management Tools
2. Gas Generation and Recovery Models – US EPA LandGEM, IPCC Tier II Emission Model and NV Afvalzorg Multiphase Landfill Gas Generation and Recovery.

The following subsections provided details of the models. The details of the actual implementation of each model are provided in Appendices (I-V) and a summary of the assumptions made during the implementation of each model is provided in Section 6.4.3. The results of modelling for all five models as well as the *CEQ-Model* are provided in Section 6.4.4.

6.4.2.1.1 US EPA LandGEM

This model is based on the following first order decomposition model (US EPA, 2005a):

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} \mathrm{K} L_o \left[\frac{M_i}{10}\right] e^{-Kt_{ij}} \qquad \text{Eq.6-23}$$

Where:

Q_{CH4} = Methane generation rate at time t (year of the calculation), m^3/yr

L_o = Methane generation potential, m^3 CH4/Mg waste

M_i = Mass of waste accepted in the i^{th} year (Mg)

t_{ij} = age of the jth section of waste mass M_i received in the i^{th} year (decimal year, e.g., 3.2 years)

n = *year of calculation – first year of waste acceptance*

e = Base log, unit less

k = Waste decay rate, yr^{-1}

j = 0.1 year time increment

i = 1-year time increment

The model treats MSW disposed of as a homogeneous waste with one decay rate (k). Hence, there is no provision of waste composition values. In reality, component-specific decay rates are required to more accurately reflect the effects of changes in waste composition on methane generation. LandGEM values for k is in the range of 0.02 to 0.7 units pre year depending on the average precipitation level of the region where the landfill is located, using 0.04 as a default value for a conventional landfill (Table 6.17).

Table 6.17: Value of k as used in US EPA LandGEM model

Methane Generation Rate, k (year^{-1})	**Regional Description**
CAA (Clean Air Act) Conventional region	0.05
CAA Arid area	0.02
Inventory conventional	0.04
Inventory arid	0.02
Inventory wet	0.07
User specified	Provide where available

Source: (US EPA, 2005b)

The k value increased more rapidly (as the landfill continues to receive waste) and decreased rapidly after the closure of the landfill. The k value is also referred to as the methane generation rate constant since the decay rate determines the rate of emission release by the waste sample. The value of k is affected by waste depth, density, pH, and other environmental conditions (Garg, Achari, & Joshi, 2006; Machado, Carvalho, Gourc, Vilar, & do Nascimento, 2009). It controls the predicted time over which methane is generated from the specified waste stream.

L_o describes the amount of methane (m^3) that could be produced per mass of waste (Mg). It is related to the waste composition. The values for L_o were determined experimentally in a laboratory, and ultimate methane yields were measured for each waste component. The L_o values reported in the literature vary from 6 m^3Mg^{-1} to 270 m^3Mg^{-1}, depending on the composition of the waste stream and the ultimate methane yield of each component (Oonk, 2010; US EPA, 2008). LandGEM sets the value of L_o at 170 m^3Mg^{-1} to represent a conventional landfill (for reporting under Clean Air Act) and 100 m^3Mg^{-1} for a standard methane estimation (US EPA, 2005a, p. 17) (Table 6.18). The time horizon for waste intake is 80 years while emission quantification terminates after 140 years. Details of the emissions modelling using LandGEM are provided in Appendix I.

Table 6.18: Values emission generation potential (Lo) as used in US EPA LandGEM model

Potential Methane Generation Capacity (L_o)	**Regional Description**
Inventory Wet Area	96
Inventory Arid Area	100
Inventory Conventional	100
CAA Arid Area	170
CAA Conventional	170
User Specific	Provide where available

Source: (US EPA, 2005b)

6.4.2.1.2 Integrated Waste Management Model for Municipalities (IWM)

The IWM model provides a tool for environmental and economic evaluation of municipal waste. It employs life cycle principles to quantify the energy consumed and the emissions released from a user-specified waste management system (EPIC and CSR, 2000). For the purpose of this research, only the environmental performance of the waste management system is used to enable the comparison of the model output to those of other models in this study.

To enable the efficient evaluation of pollutant loadings for a specified waste management strategy, IWM covers a system which includes waste collection, waste transfer, recycling, and recovery, composting, energy recovery and landfilling. The pollutant loads are categorized as air emissions, water discharges, and residual waste. This study is only interested in the air emission from landfilling as a residual waste. The IWM has a time horizon of 100 years for waste emission discharge from disposal sites Finnveden (1995).

The IWM model does not address the management of all waste streams. Specifically, it does not cover the management of white goods and textiles because in the Canadian municipalities there are separate collections of these items (EPIC and CSR, 2000). The following waste categories are included in the IWM model:

- Paper
  - Newspaper
  - OCC (Old Corrugated Containers)
  - Telephone Directories
  - Boxboard
  - Mixed Paper
- Glass
- Ferrous Metals
- Aluminium
- Plastics
  - PET (polyethylene terephthalate)
  - HDPE (high-density polyethylene)
  - LDPE (low-density polyethylene)
  - PP (polypropylene)
  - PS (polystyrene)
  - PVC (polyvinyl chloride)
- Organics
  - Food Waste
  - Yard Waste
- Other Waste

In order to implement this model, the Auckland waste data must be reclassified according to the IWM model's waste streams. This reclassification of waste may impact on the accuracy of the model, in the Auckland context, and limit the degree to which comparisons can be made to the results of the other models. The modelling is detailed in Appendix II.

6.4.2.1.3 NV Afvalzorg Multiphase Landfill Gas Generation and Recovery Model

This is a First Order Decay (FOD) model based on IPCC equations and default parameters resulting from Luchien and Oonk (2011), Gebert, Huber-Humer, Oonk, and Scarff (2011), and IPCC (2006c). The model incorporates different decay rates for different types of degradable carbon but treats the municipal waste as a bulk quantity without provision for waste composition. The volume of waste being treated is viewed as solely household waste with percentage fractions classified as having fast, moderate, slow degradability, respectively or non-degradable organic carbon content (NV Afvalzorg, 2014).

The non-degradable, inert, carbon content used in this model was based on the work of Steketee, Cuperus, and Jacobs (2011) and Luchien and Oonk (2011). Steketee et al. (2011) and Luchien and Oonk (2011) also established that under Dutch conditions CH_4 oxidation varies between 20 and 30 percent. However, the lower limit of 20 percent was adopted for use in this model. This model is a formula (Eq. 6-24) for calculating methane generation (G).

$$G = WL_o\left[F_{(f)}\left(K_{(f)}e^{-K_{(f)}\left(t-t_{(1)}\right)}\right) + F_{(s)}\left(K_{(s)}e^{-K_{(s)}\left(t-t_{(1)}\right)}\right)\right] \quad \text{Eq.6-24}$$

Where:

G = Methane generation (million cubic meters per year)

W = Waste disposed of (Tonnes)

Lo = Methane yield potential (cubic meter per tonne of waste

T = Time after waste placement (year)

T_1 = lag time (between placement and start of gas generation)

$K_{(f)}$ = First-order decay rate constant for rapidly decomposing waste

$K_{(s)}$ = First-order decay rate constant for slowly decomposing waste

$F_{(f)}$ = Fraction of rapidly decomposing waste

$F_{(s)}$ = Fraction of rapidly decomposing waste

This model has the following parameters and characteristics:

- Time horizon is 100 years
- Oxidation is between 20 percent to 30 percent (Luchien & Oonk, 2011; Steketee et al., 2011), 20 percent is the default
- Landfill surface area is required for oxidation determination of individual landfills
- Waste composition consideration is limited when compared with the other models used in this research. Although the model recognises that waste component

degrades at different rates there is not enough detail to determine the actual composition of the waste in each of the following models specified waste categories:

- Soil and soil decontamination residues
- Construction and demolition waste
- Commercial waste
- Shredder waste
- Street cleansing waste
- Sludge and composting waste
- Waste from refuse-derived fuel (RDF)
- Household waste
- Vegetable, fruit and garden waste
- Wood

- Assumes that emissions are released one year after waste deposition
- Assumes that methane is 50 percent of landfill gas
- Assumes that dissimilated landfill gas is 70 percent

The details of the implementation of the model are given in Appendix III.

6.4.2.1.4 The IPCC Models

IPCC Guidelines (IPCC, 2006a) approved two models depending on the level of data availability.

The default IPCC model (Eq.6-25) which is based on the theoretical gas yield and assumes that all gas yields are released at the year of waste disposal (mass balance equation).

$$Q_{CH_4}\left(\frac{Gg}{yr}\right) = (MSW_F \times MCF \times DOC \times DOC_F \times F \times 16/12 - R) \times (1 - OX)$$

Eq.6-25

Where:

MSW_F = Waste disposed to solid waste disposal sites

MCF = methane correction factor

DOC = degradable organic carbon (fraction) (kg C/kg SW)

DOC_F = fraction of DOC dissimilated

F = fraction of CH_4 in landfill gas

16/12 is ratio for the conversion of carbon to methane (C to CH_4)

R = recovered methane (Gg/yr)

OX = oxidation factor (fraction)

The IPCC Guidelines provide default values for countries where site specific values do not exist.

The Tier 2 first order decay (FOD) model (Eq.6-26) for countries with more reliable data.

$$Q_{CH_4} = \sum_{x=x_o}^{t} [K \times MSW_{F(x)} \times MCF_{(x)} \times L_{o(x)}] \times e^{-k(t-x)} \times F \qquad \text{Eq.6-26}$$

Where:

Q_{CH4} = the amount of methane generated in the current year from waste disposed of in the year x

t = the current year (year of emission estimate) (Gg/yr)

x = the total historical years of disposal of MSW quantities

Lo(x): DOC× DOC_F for the year x (Gg CH_4/Gg waste)

k = methane generation rate constant (also reflected as decay rate) (1 yr^{-1})

$MSW_{(x)}$, $MSW_{(F)}$, and F are the same as for the default model.

The difference between the two models is the reflection of time variation of solid waste disposal and the degradation process in the FOD model. The timing of actual emissions is therefore reflected in FOD model whereas the default model assumes total emissions released in the year of disposal. The FOD model estimates the mass of methane generated in a particular year by combining the waste landfilled in that year with the predicted methane produced from the waste landfilled in previous years.

The default model provides for the provision of specific DOC for a particular waste fraction which is an equivalent to the impact of the k value (also referred to as degradation rate) in FOD model as both are the main indicators of the rate emission from the waste stream. Both models require waste disposal data as input data including information on the composition of the waste and the conditions at the landfill. But the default model requires this data only for the inventory year, whereas the FOD model requires historical data. Like the other models, IPCC adopted its waste composition modalities following eight fractional parts, each having a range of degradable organic carbon (DOC) and methane generation rate (Table 6.19).

Including first order reaction in the FOD model means that the year of the disposal is not a major factor in the amount of CH_4 generated each year. It is the total mass of decomposing material currently in the SWDS that matters. Hence, the FOD model takes account of the amount of waste contributing to the DOC deposited each year and the amount remaining from previous years.

Table 6.19: The relationship between waste composition and k value as used in IPCC model

Waste Fraction	Degradable Organic Carbon (DOC)		Methane Generation Potential (k)	
	Range	Default Value	Range	Default Value
Food waste	0.08-0.20	0.15	0.1-0.2	0.185
Garden waste	0.18-0.22	0.2	0.06-0.1	0.1
Paper	0.36-0.45	0.4	0.05-0.07	0.06
Wood and straw	0.39-0.46	0.43	0.02-0.04	0.03
Textiles	0.20-0.40	0.24	0.05-0.07	0.06
Disposable nappies	0.18-0.32	0.24	0.06-0.1	0.1
Sewage sludge	0.04-0.05	0.05	0.1-0.2	0.185
Industrial waste	0.0-0.54	0.5	0.08.0.1	0.09

The CH_4 generation potential as a key input in the model is a product of the DOC, the CH_4 concentration in the gas (F) and the molecular weight ratio of CH_4 and carbon. Details of the modelling are provided in Appendix IV.

6.4.2.1.5 EASEWASTE Model

The EASEWASTE model is an LCA model it covers all impacts associated with waste management both upstream and downstream of the waste management system. It provides a framework in which users can define all necessary data related to waste composition, collection, treatment, recovery, and disposal, building a life cycle inventory to evaluate the environmental impact of the entire system.

EASEWASTE allows users to segregate waste composition into 48 material fractions or less, according to the needs of the user (Christensen et al., 2007). EASEWASTE makes use of distance travelled, height or depth of landfill, waste composition, and the volume of waste disposed of, and sorting efficiency /sorting categories in the modelling of waste management (Kirkeby et al., 2006). While the model is supplied as a software application, the actual details of model constructs are not provided or publically available. Details of the modelling are supplied in Appendix V.

However, the 48 waste composition material fractions in EASEWASTE is modified to 7 by choosing the appropriate fractions similar to the material fractions defined in Afvazorg, LandGEM, IWM and IPCC models. Hence the New Zealand waste composition data is made suitable for use in EASEWASTE model.

6.4.2.1.6 CEQ-Model Quantification of the Auckland Scenario

The use of *CEQ-Model* to calculate the emissions for the purpose of the comparison with other emission models was undertaken using the emission factors in Sections 6.3.2.1 and 6.3.2.2. The details of the quantification can be found in Appendix VI

6.4.3 Summary of the Models' Assumptions

In the face of the different waste management scenarios existing around the world, it is not surprising to see that this is reflected in the various model that have been used in this work. The application of varying scenarios in the formulation of these models would have made it impossible to compare the results from these models if they were not adjusted in some way to make them comparable. To make it possible to compare outputs from the models, a standard is necessary to allow for either data conversion or impact evaluation which reflects the variability across boundaries. The will make interpretability of results to be simple for users to draw the right conclusion.

The various assumptions as adopted by the developers of the different models are summarized in Table 6.20.

The IPCC model (IPCC, 2006a) is a more general model which can model several waste types at the same time, but it cannot be used to model/quantify CO_2 emissions. LandGEM model, EASEWASTE model, and IWM model can be used to model both CO_2 and CH_4. However, the IPCC model considers more site-specific data and is, therefore, likely to produce a more accurate result. Moreover, the IPCC allows a lot of adjustments and general assumptions that can be adapted to varying conditions which should mean it is more readily adjusted for New Zealand use.

The LCA models incorporate emissions generated from other activities in the waste management system, not just landfilling. EASEWASTE and the EPIC/CSR IWM model both quantify the emissions from transportation and energy consumption. But the

EPIC/CSR model also takes into account the emissions from transportation of recycling material, landfilling and waste to energy separately, where these activities are part of the modelling process.

Table 6.20: Summary of the parameters and assumptions in the models

	EASEWASTE	**Afvalzorg**	**LandGEM**	**IWM**	**IPCC**	***CEQ- model***
Time Horizon (yrs)	100	100	140	100	80	-
Oxidation (%)	-	20	10	-	10	10
Dissimilation (%)	-	70	-	-	50	50
K Value (CH_4 generation rate)	-	3 default values – 0.187, 0.099 and 0.030 (for fast, moderate and slow decay rate respectively)	0.04	-	Specific value for waste tractions (0.03 to 0.185)	-
Fraction of CH_4 in emission (%)	-	50	50	-	50	50
Lag time (months)	-	12	12	12	6	-
Composition Parameter (no. of fractions)	7 (modified)	3 (default) – Based on decay rate, fast, moderate and slow	1	8	7	7
DOC	-	-	-	-	Varying values based on % of composition between 0.05 and 0.43	Varying values based on % of composition between 0.15 and 0.43
L_0 (CH_4 potential generation capacity)	-	-	100	-	-	Based on DOC
Conversion factor (Carbon to methane)	-	-	-	-	1.33	1.33
Surface area of landfill (m^2)	-	13300	-	-	-	-
Height of landfill (meter)	10	-	-	-	-	-
Average precipitation at disposal site (mm)	-	-	100	100	-	-
Bulk density at disposal site (t/m^3)	1.8	-	-	-	-	-

Source: Compiled by the author from various sources

Defining the active life of a landfill is another area of difficulty which resulted in varying temporal components for the different models. This time, the frame is an estimation of the time it takes a waste disposed of in a disposal site to reach a pseudo steady state after which changes are no longer noticeable as at the beginning (Finnveden, 1995). The various models adopted different length of the frame. The periods of 80 years are adopted in the IPCC models, 140 years in the LandGEM model, while Easewaste, Afvalzorg, and IWM models adopted 100 years.

The varying results as shown in Table 6.21 is, therefore, may be a reflection of varying data input into the models over the same waste volume disposed over the same number of years (18,578,645.1 tonnes between 1996 and 2015).

6.4.4 Summary of Results

The results from the various models are shown in Table 6.21 and Figure 6.1. The status of the various results is a reflection of the varying assumptions and the similarities in the parametric contents of the models. LandGEM and IWM models have similar assumptions, and that is shown in the closeness of their results. Though, the plotting is done with 100 years emissions resulting from LandGEM so that the conditions are similar to the rest.

The IPCC model and the modified model are the same parameters in CH4 quantification, only varying in the inability of the IPCC model to compute the value of CO2. The level of variation in the result is more visible between Afvalzorg model and IWM model where the difference of over 1200 percent is observed in the value of CH4. For CO2, the modified model and IWM model showed the highest variation of about 26 percent. The variations are a reflection of the following:

- Different models adopt different waste composition definition modality
- Country specific waste characteristics are utilized in the assumptions
- Different models assume different waste morphology resulting in various number of waste fractions in the modelling process
- Carbon sources are defined differently in the models
- Some models (like EASEWASTE) consider the water and energy (BTU) content of the waste samples while in others; they are not important
- The percentage of CH4 oxidized at the cover material as adopted by different models affects the volume of actual methane quantified by the models

- A model like Afvalzorg model is a multi-phase model, adopting three decay periods for the waste streams modelled. The decay period affects the emission rate parameters between it and other models that are single phased hence assuming a single decay rate for the waste in the landfill.

Table 6.21: Summary of emission output from the models

Model	CH4 (kg CO2-e)			CO2 (kg)		
	Collection	Transportation	Disposal	Collection	Transportation	Disposal
CEQ		79665200	2000362300		13495529800	2444887800
EASEWASTE	4204232.5	13849235	3037293005	101025034	332788347.2	413950416
Afvalzorg			49570972			
LandGem			30876572500			3386674800
IWM	1726975000		35156200000		54453000	3879283000
IPCC			2088698000			

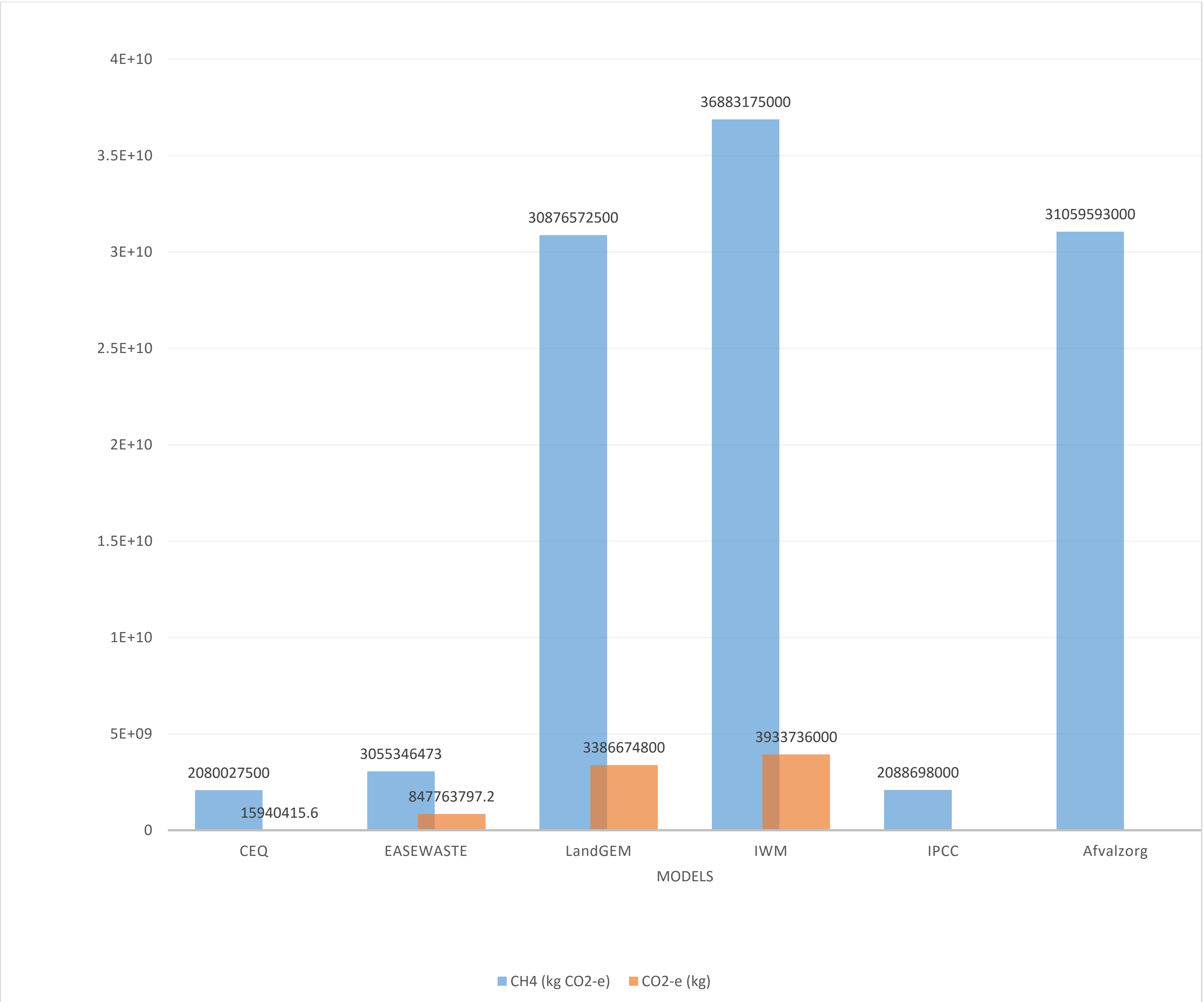


Figure 6.1: Emission quantification results from the six models evaluated. Source: Drawn by the author based on calculation from Table 6.21

6.5 Justifying the Use of Emission Potential as a Measuring Criteria

Recently the number of engineered landfills have increased leading to high rate of landfill gas collection for economically viable use for power generation or treatment to reduce the negative environmental impact. But even the most efficient gas collection systems, do not collect all of the landfill gas generated (Barlaz, Chanton, & Green, 2009). The high methane content of landfill gas (LFG) makes the uncollected (fugitive) emissions to be a major threat to the environment (Abichou et al., 2011a; Abichou et al., 2011b; Jung et al., 2011; Lizik et al., 2013).

The LFG emissions are driven by pressure (advection) and concentration (diffusion) gradient. Figure 6.2 provides a conceptual representation of a typical landfill gas generation, collection, and emissions into the atmosphere.

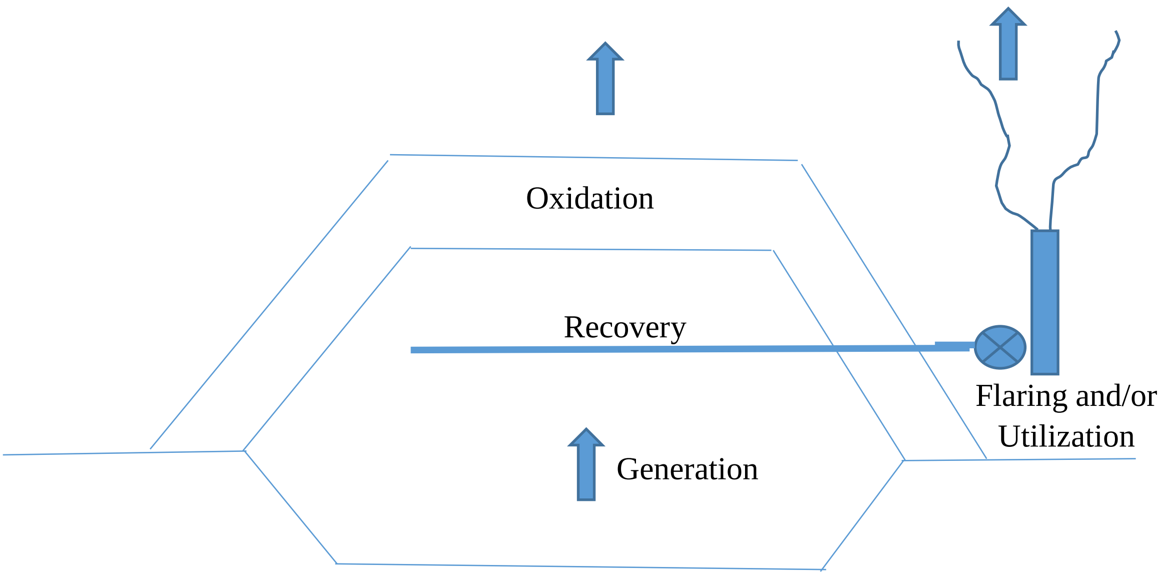


Figure 6.2: Landfill gas mass flow

There is no one "perfect" landfill emission generation estimation method because:

1. various available models use different degradation rates, dissimilation factors, lag times and conversion factors
2. Site-specific conditions cause process kinetics to deviate from the national average

3. Activity data standard definitions differ from country to country or even from city to city. Hence, different models adopt different modes for defining biodegradable carbon content
4. Oxidation value varies according to field conditions and has been proven to be higher than 0.1 as applied in IPCC model

The only way out of the complex situation is to agree on an acceptable model with adjustable parameters based on proven scientific proof. Variation should be allowed for across regional boundaries, taking into account geographical variation and changing consumption habits.

On transportation, the emissions resulting from the consumption of the fuel type can always be quantify using the relevant emission factor, likewise refrigeration/cooling, and power consumption. Therefore, the emission is a measurable quantity which is produced at all stages of the waste management process.

6.6 Conclusion

The values of L_o as applied in the various model are based on laboratory tests. The accuracy of applying results from laboratory studies to landfill modelling under different environmental conditions has not been determined (Amini, Reinhart, & Mackie, 2012).

The LandGEM model was reported to underestimate gas production (Ogor & Guerbois, 2005; Thomson et al., 2009). If this is true, then the results from this research (Figure 6.1 and Table 6.21) are an indication that while some models underestimate it is likely that other models tend to overestimate landfill emissions.

Adopting a default value for k which reflects the value of the rate of degradation for a homogeneous MSW stream is a major problem. Waste components degrade at a different rate (Machado et al., 2009). In their study, De la Cruz and Barlaz (2010) established that decay rate for leaves, grass and branches are 327%, 645% and -63% of IPCC value for garden and park category as defined in IPCC Guidelines (IPCC, 2006).

The review of a variety of laboratory and field investigations for landfill CH_4 oxidation indicates an average of 35 ± 6 percent for landfill cover soils with different characteristics and seasonal variability (Chanton, Powelson, & Green, 2009). Some other literature has emphasized the dependence of emission oxidation on cover soil thickness and texture, microbial oxidation rates of the methane gas which varies spatially and temporally with seasonal climatic trend (Bogner, Spokas, & Burton, 1997; Jones & Nedwell, 1990;

Kightley, Nedwell, & Cooper, 1995; Klusman & Dick, 2000; Maurice & Lagerkvist, 2003; Scheutz et al., 2009).

It is recognized that waste management industry plays an increasing role in climate change mitigation (IPCC, 2007c; Ragossnig & Hilger, 2008). But with different reporting mechanism requesting for different GHGs reporting systems, leading to different reporting accuracies, the goals of climate change mitigation in waste management system may not be realized soon. For instance, the Kyoto Protocol (United Nations Framework Convention on Climate Change (UNFCCC), 2008) requires the reporting of six gases (CO_2, CH_4, N_2O, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and SF6). The EpE Protocol includes only the most relevant gases to the sector, CO_2, CH_4, and N_2O (Entreprises Pour I ' Environment (EpE), 2008), while the European Emission Trading Scheme trades on CO_2 gases only (Ellerman & Joskow, 2008). National inventory reports also include the reporting on non-methane organic compounds (NMVOC) (Gentil, Christensen, & Aoustin, 2009).

Companies, cities, and countries are reporting how waste management contributes to global GHG emissions, and policies are being developed for improving their current environmental performance (Gentil et al., 2009), but these reports and policies are largely founded on inaccurate data and inadequate estimation models. Waste disposal is recognised as one of the major sources of anthropogenic emissions generated from human activities. Landfills account for about 10-19% of annual global CH_4 emissions (Kumar et al., 2004a; US EPA, 2006a). The volume of emission generated depends not only on the biogenic carbon content of the waste in the waste in the landfill but also on the material fractions which contain carbon (Manfredi et al., 2009). Different reporting purposes request a different level of accuracy in emission measurement as reflected in (US EPA, 2005). Thus, the true reflections of these emissions may never be established without establishing a common standard which can be compared across boundaries.

CHAPTER SEVEN

CASE STUDIES APPLYING THE *CEQ-MODEL* IN SUSTAINABILITY ASSESSMENT

7.0 Introduction

Emission Ratio (ER) is the ratio of total emission from a waste management system to the total tonnes of waste disposed of in that system. Therefore, ER is the total emissions divided by the total waste disposed of in tonnes. ER can also be measured relative to the size of the population generating the disposed waste. Hence, it is possible to measure the amount of emission each person has contributed to the waste disposal system. The emission measurement is known as per capita emission and is calculated using the total emissions divided by the population generating the waste per year. Through any of these ways, the efficiency or performance of the system over some years can be measured to establish the level of improvement or otherwise. Also, the performance of different metropolitan waste management systems can be measured and compared to determine their relative performance.

In this thesis, a novel MSWM emissions model has been developed called the *CEQ-Model*. The work in this chapter adopts case studies as a means of demonstrating the functionality and efficacy of this *CEQ-Model* in waste management systems.

The criteria for selecting the case study areas were that one or more of the following attributes differed:

- Population,
- Area,
- Distance to Landfill,
- Regional or Local Waste Management Practices and Policy,
- Land use practices.

Although the proximity of landfill to waterways affects the sustainability level of waste management systems, this aspect is not considered as a case selection criteria or indeed discussed in this thesis for the following two reasons:

1. Landfill Guidelines provide the site selection criteria to be followed by a Territorial Authority when granting landfill consent (Centre for Advanced Engineering, 2000). These guidelines include avoiding places that are near to watercourses, within water supply catchments, estuaries, marshes, and wetlands. These guidelines have been followed in all the cases under consideration.
2. All the managed and monitored landfills in New Zealand are modern engineered landfills with liner systems to prevent leachate leakage to underground surfaces, and presumably, this means that groundwater pollution is unlikely.

Four case study areas were selected, namely; Auckland Region, Waikato District, Rotorua District and Opotiki District. The selection was made in such a way as to represent varied scenarios in Municipal Solid Waste Management (MSWM) in New Zealand and to reflect stakeholder and decision-maker expectations. For example, Opotiki District transports its waste to Tirohia landfill over 216 km away. What is the significance of transporting a small quantity of waste, generated by a rural district, this distance for a small quantity of waste? How does the Opotiki District scenario compare to a more urban area such as Waikato District where larger amounts of waste are transported shorter distances for disposal?

Auckland Council is not doing much in the way of recycling. Auckland recycles household items including plastic bottles and containers, glass bottles and jars, and tins and cans. Only some areas in Auckland are able to recycle paper products. Plastic bags are not recycled, and there is currently no recycling collection for organic waste though the council is due to implement urban organic waste collections during 2016. This current low recycling level in Auckland is reflected in the composition of the disposed waste stream where 49.9 percent of the waste are organic waste which can easily have been managed in a composting project. Different scenarios exist in other councils where the organic fraction varies from seven percent at Rotorua District, 25 percent at Waikato District and 19 percent at Opotiki District, because of their organic waste collections and recycling efforts and local residents reuse culture. The emission footprint per tonne of waste can be used to measure the level of sustainability, irrespective of the local waste management policies in place. Such that the *CEQ-Model* can be expressed as:

$$\frac{TE}{TWD} = ER$$ Eq.7-1

So that;

$$\frac{TE + \Delta TE}{TWD + \Delta TWD} = ER + \Delta ER$$ Eq.7-2

$$TE = f(T_w, WC, LFG_m, S_e, S_c, WMP, TWD)$$ Eq.7-3

Where;

ER = Emission Ratio

TE = Total Emission

T_W = Waste Transportation mode

WC = Waste Composition

LFG_m = Landfill Gas Management Plan

S_e = Waste Management System Efficiency

S_c = Waste Management System Configuration

WMP = Waste Management Policy or Plan

TWD = Total Waste Disposal

ΔTE = Increase in TE as a result of changed scenario

ΔTWD = Change in value of TWD

ΔER = Change in value of ER

The limitations of this application of the *CEQ-Model*, are the omission of purchased power consumption, and cooling/refrigeration emissions. Additionally, the transportation emission does not include emissions produced by movements made during collection of the waste. The inclusion of these emissions will provide more accurate and complete quantification of total emissions generated by any waste management system. To establish methods for estimating or collecting these missing values for an emissions quantification calculation would require further research beyond the scope of this thesis. In the next section, each case study area's geospatial features and spatial attributes are described including population, local, and regional waste management practices and policies.

7.1 Description of Case Study Areas and Data

The areas selected for this exposition are four Territorial Authorities – Auckland Council, Waikato District Council (Ngaruawahia), Rotorua District Council, and Opotiki District Council, located in three regions in New Zealand. A total of six landfills is used by the four councils – Claris landfill, Redvale landfill, Whitford landfill, Hampton Downs landfill, Tirohia landfill, and Rotorua District landfill.

Auckland is a regional council comprising of twenty-one local boards. Waikato District Council is in the Waikato Region, while Rotorua District Council and Opotiki District Council are located in the Bay of Plenty Region. An evaluation of the WM scenarios for each case was undertaken. The results of this evaluation are summarised in Figures 7.1 and 7.2 and Table 7.1

The data is based on the waste disposal data from 2011. (Auckland Council, 2011; Opotiki District Council, 2011, 2012; Waikato District Council, 2011, 2012; Waikato Regional Council, 2012; Zero Waste New Zealand, 2012). Waste disposal volumes are as reported by the various councils while the average disposal distances are estimated average distances from the city or town centre to the landfills (since waste sources within the same city are many. The population data are sourced from New Zealand population census estimates as provided by Statistics New Zealand (Statistics New Zealand, 2016). The number of landfills in use by a city's waste management system is as reported, but this data may not be accurate due to waste diverted out of the region.

Figure 7.1 is a graphical representation of Table 7.1 illustrating the variations in population, waste disposal volume and travel distance for waste disposal. It also shows the per capita waste disposal which the amount of waste disposed of by a citizen of a year, derived from total waste disposal divided by the population. The number of landfills is necessary for the understanding of the basis for the disposal travel distance. For Auckland where four landfills are used, the travelled distance is attached to each landfill.

Table 7.1: Summary of WM scenario at Territorial Authorities

Council	**Auckland**	**Rotorua**	**Waikato**	**Opotiki**
Population	1459600	68800	65400	9070
Total waste disposal (Tonnes)	2415022	29796	45000	1450
Per Capita Waste Disposal (kg)	1661.43	654.07	455.60	159.90
Average Waste disposal Travel Distance (km)	61	32	44	216
Number of Landfill in Use	4	1	1	1

Figure 7.1 also provides a visual representation of the case study areas in a single map showing the location of the cities – Auckland, Rotorua, Waikato and Opotiki – the landfills and the movement patterns in moving the waste. The coloured rings are representing buffers showing the distances from the cities to the landfills. While the arrows are indicating the direction of movement from each city to the landfill.

For a better idea of the landfill areas, site visits were performed. Though, because of restrictions on the sites, access was not granted except Tirohia landfill. But the visits were still good as the approximate distance of landfill to the nearest residential community were estimated and the land use pattern around the area established.

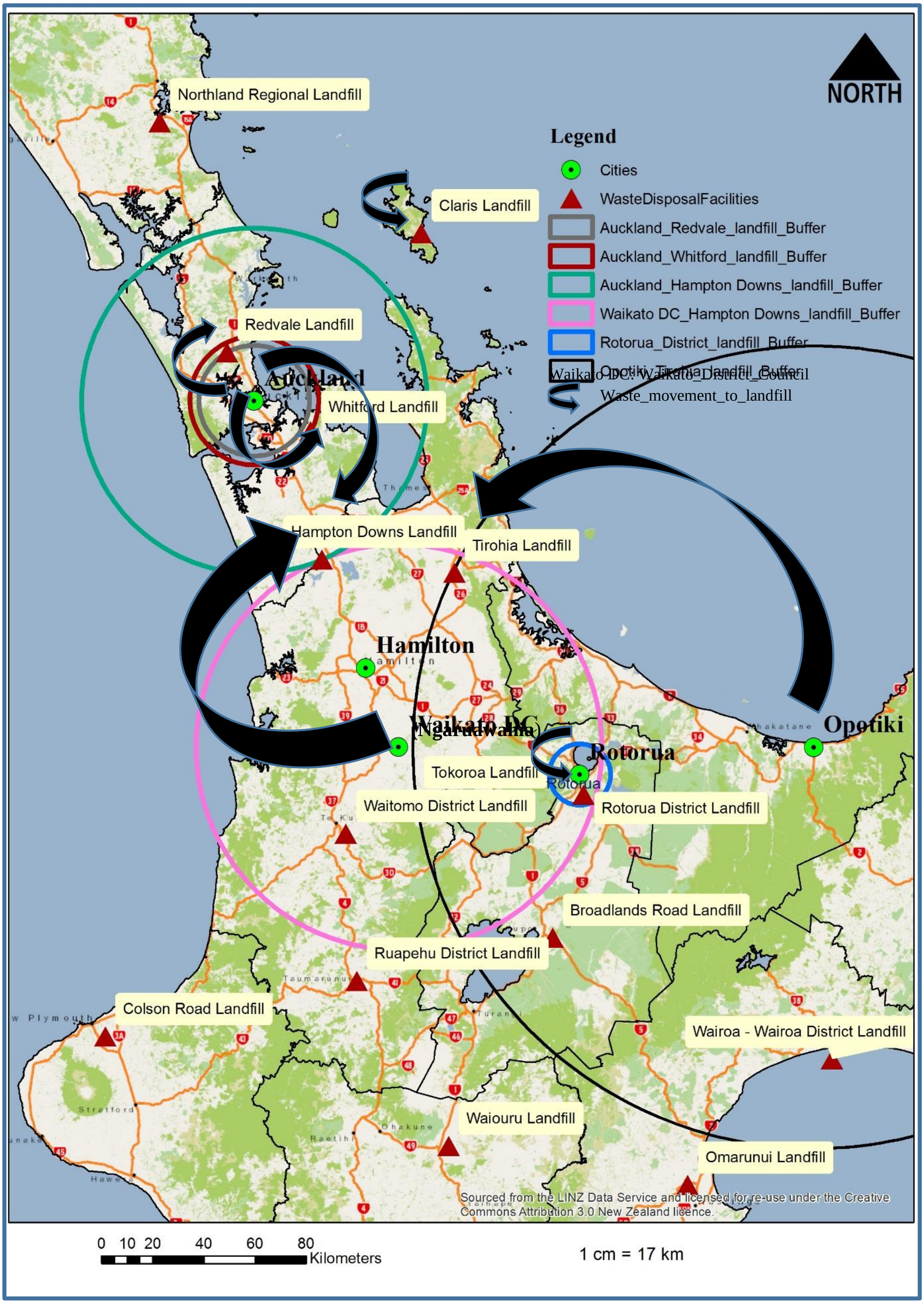


Figure 7.1: Geographic overview of the study areas **7.1**

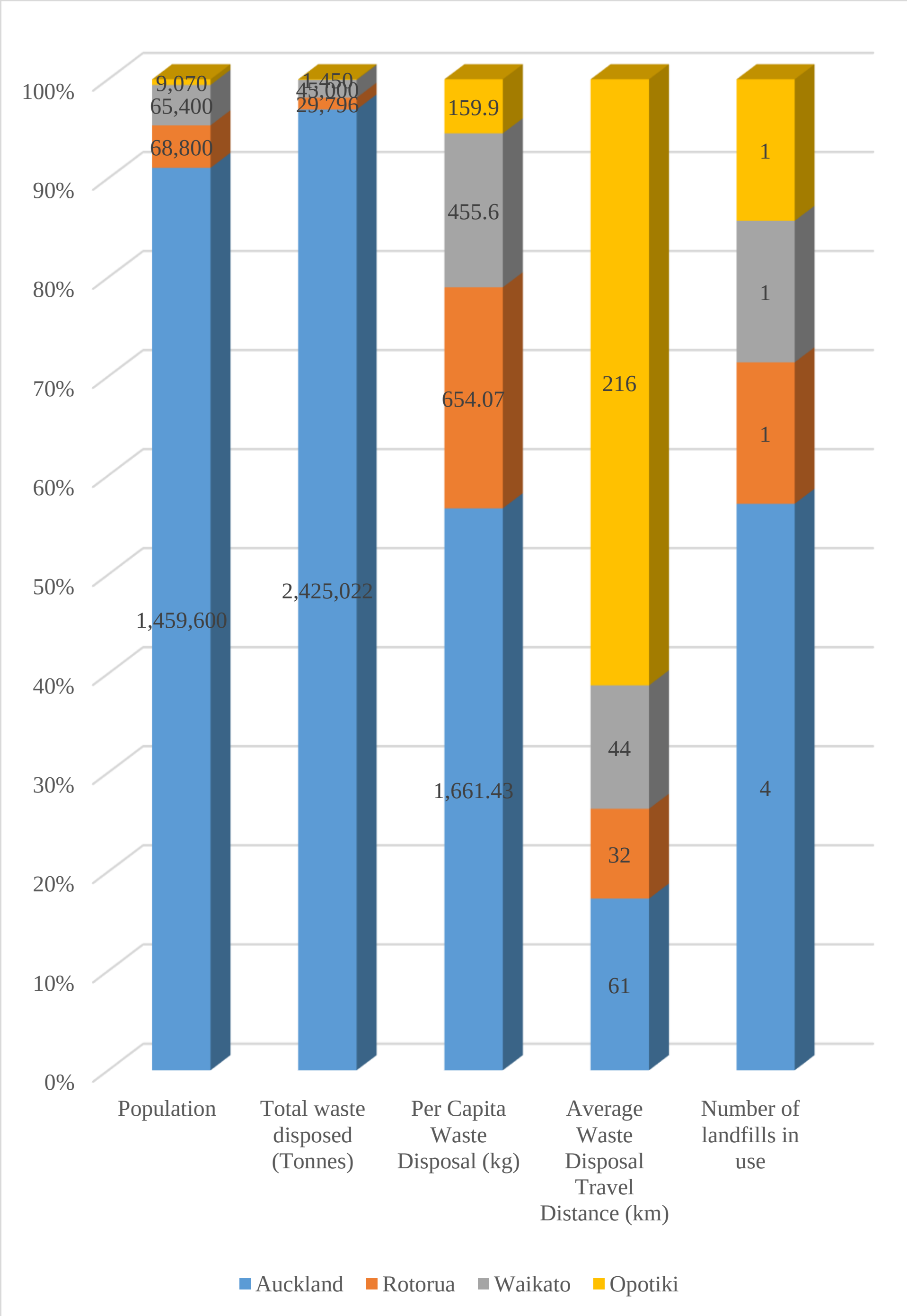


Figure 7.2: Summary of WM scenario by local council

7.1.1 Opotiki District Council

Opotiki is one of the districts within Bay of Plenty Region, located at 38° 00′ 20.77″S and 177° 17′ 15.92″ E. It is a coastal, rural District Council bordered to the south by Gisborne and to the east by Whakatane Districts respectively (Figure 7.3).

As of 2011, Opotiki had a population of 9070 people (Statistics New Zealand, 2015a). Its waste management policy is geared towards Zero Waste (ZW) to landfill. Zero Waste New Zealand (2012), reported that in November 1998 Opotiki was the first Territorial Authority to adopt ZW in New Zealand. The Opotiki ZW policy is a combination of a kerbside recycling scheme and resource recovery facilities with the primary objective of encouraging waste volume reduction via reuse and recycling. This ZW initiative has reduced the amount of waste disposed by the Opotiki District from 10,000 tonnes in 1998 to about 5,000 tonnes in 2000 and today to about 1,450 tonnes per annum (Opotiki District Council, 2011; Zero Waste New Zealand, 2012). The population of the district has been on a steady decline from 9610 people in 2000 to 8870 people in 2012 and, to 8810 people in 2015 (Statistics New Zealand, 2015c). It is likely that this population decline has also contributed to the reduction in the volume of waste disposal.

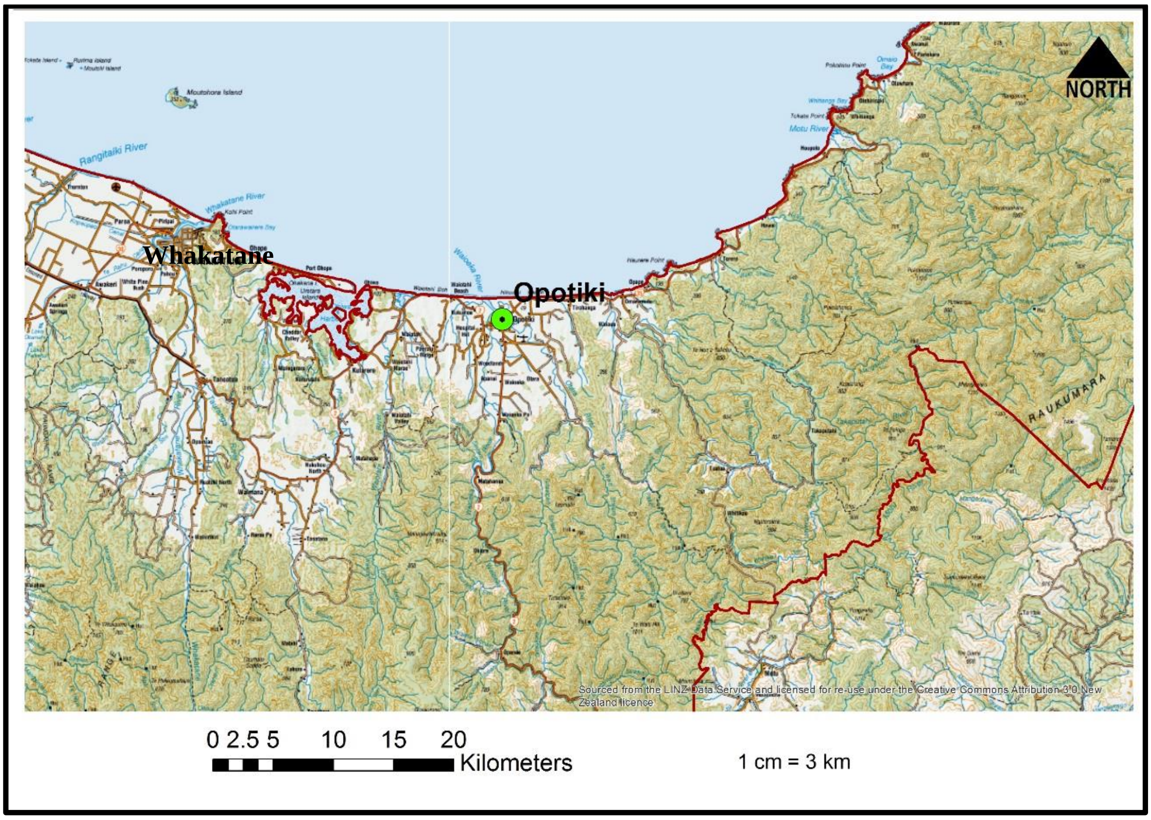


Figure 7.3: Geographic map of Bay of Plenty showing the location of Opotiki

A review of the population and waste disposal between 1998 and 2011, showed a constant population between 1998 and 2000 while waste disposal is reduced 10,000 tonnes to 5,000, a

50 percent reduction. But from the year 2000 to 2011, the population had a 5.6 percent reduction from 9610 people to 9070 people, while waste disposal is reduced from 5,000 tonnes to 1450 tonnes, a 29 percent reduction.

The reduction in waste volume between 1998 and year 2000 was an indication of a successful waste reduction strategy while the reduction between the year 2000 and 2011 was a combination of population reduction and successful reduction strategy.

The reduction in the volume of waste to landfill is also a reflection of the effectiveness of the recyclable material collection centres at Opotiki Township, Hikutaia/Woodlands area and the Resource Recovery Centres (RRC) at Opotiki Township, Te Kaha, and Waihau Bay.

The economy of the district is driven by mainly by agricultural, forestry and horticulture (Opotiki District Council, 2011). The rural nature of the region is evident in the map given in Figure 7.3. Because of the organic nature of the waste from the agricultural sector which is often re-introduced farms f as manure, waste generated in this sector are very difficult to account for. Hence, the impact on the o organic generated waste is not significant to MSWM in this region.

Opotiki District Council (2011) is projecting an increase in population resulting from an expected seaport expansion, which has yet to eventuate, as larger vessels begin to berth at Opotiki port the council, has also predicted an increase in the number of tourists visiting the area. These activities will bring increased pressure on the waste management system.

There is no existing landfill within this Council’s boundaries. Hence, residual waste is sent to landfill at Tirohia. The last landfill in the region, at Woodlands Road, was closed in July 2004, and the Council has no immediate plans for a new landfill (Opotiki District Council, 2012).

The choice of Opotiki District Council as one of the cases is based on the rural nature of the town, without landfill and as a result transports the residual waste to Tirohia landfill, about 216 km, for disposal.

7.1.1.1 Tirohia Landfill

This was the first modern landfill to service the waste disposal needs of communities in Eastern Waikato, Western Bay of Plenty, Thames Valley and the Coromandel Peninsula. It was opened in 2001 and is located in closed pits created by stone quarrying. The landfill site is located about 7 km south of the small town of Paeroa.

On a visit to the site, it was observed that Tirohia landfill site has some good characteristics. Active parts of the landfill are located between high rising rocks. This reduces odour dispersal as the site is well-shielded from the wind. The nearest neighbours are located more than 2 km away on the Hauraki Plains. Different views of the landfill as captured by the researcher are shown in Figures 7.4 to 7.9.

Figure 7.4: Photo view of part of the active section of Tirohia landfill showing refuse collection truck and compactor in action

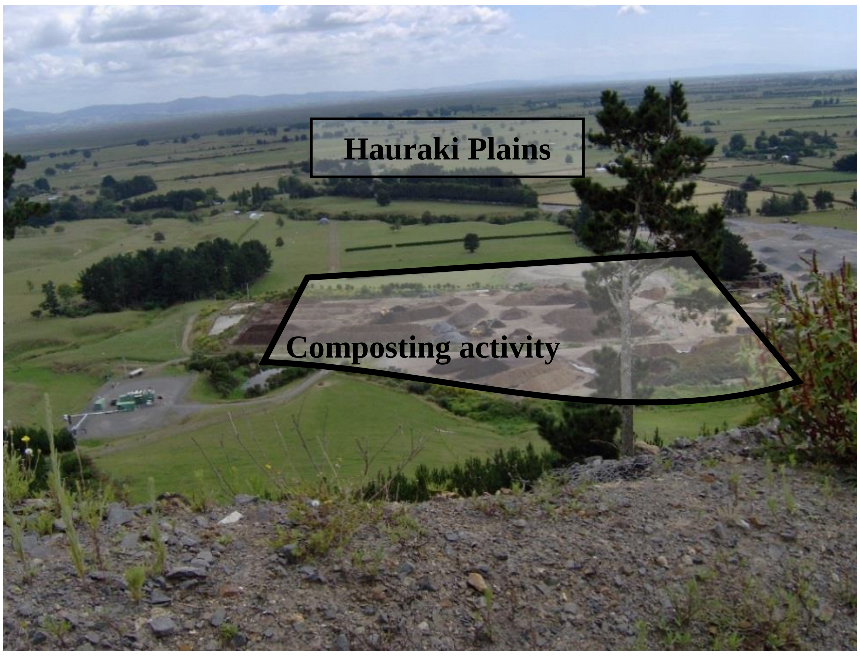


Figure 7.5: Composting activities at Tirohia landfill overlooking Hauraki plains

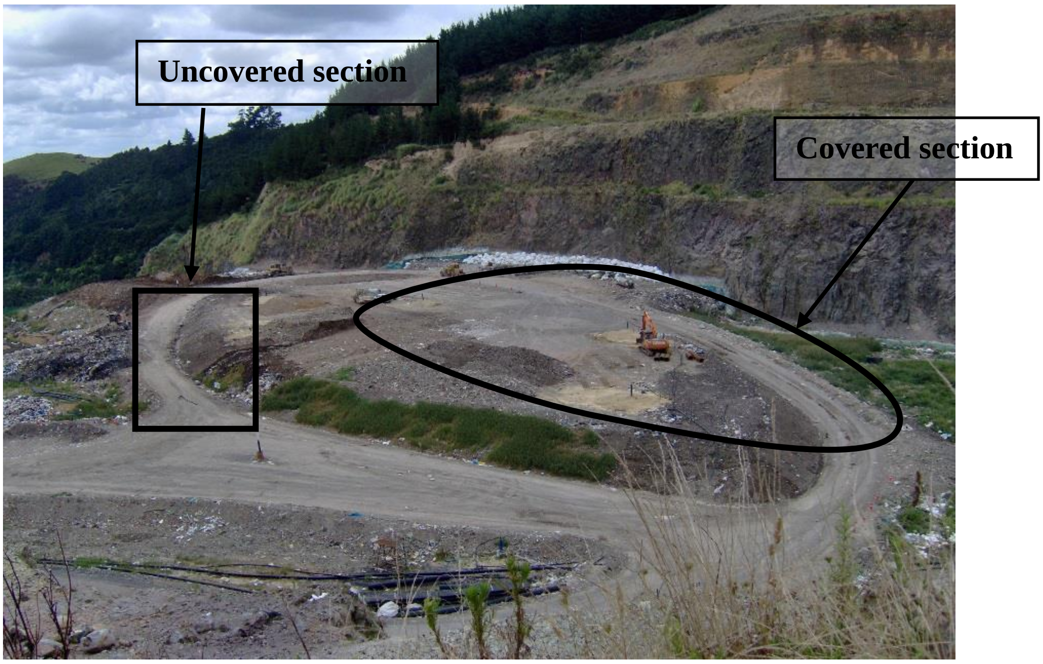


Figure 7.6: Section of Tirohia landfill showing the covered section of the landfill

According to the management of Tirohia landfill, the landfill has the capacity for about 4 million cubic metres of waste. This is expected to take about 25 years of active life. The landfill receives waste from the Hauraki Plains, Coromandel, Tauranga, and the Western

Bay of Plenty (which includes Opotiki, and Gisborne). The immediate neighbours to the landfill are farms as can be seen in Figure 7.5

Figure 7.7: The Managing Director of Tirohia landfill, Mr Eric Souchon, explaining the landfill operations to the researcher

Figure 7.8: Hauraki Plains at the background from a position at Tirohia landfill

Figure 7.9: The Managing Director of Tirohia landfill, Mr Eric Souchon and the researcher

7.1.2 Waikato District Council

Waikato District Council is located between Auckland to the North and Hamilton to the south on latitude 37° 40′ 10.28″S and longitude 175° 9′ 3.75″E. Located on the eastern side of the district are the Hauraki and Matamata-Piako Districts while Port Waikato is located to the district’s west (Figure 7.10).

Major towns in the region include Ngaruawahia, which is the district headquarters, Huntly, Raglan, and Te Kauwhata. The land use patterns in the district cut across industries and agriculture. The 2011 population estimate, puts the number of people living in the Waikato District Council area at 65,400 (Statistics New Zealand, 2015c).

A substantial amount of waste generated is agricultural waste which is often re-introduced to the farms as manure. The U.K Environment Agency (2001) suggested that this can be ignored, provided that the waste is generated within the farm where the re-introduction took place.

Some farm waste is likely to be illegally buried or burnt on the farms and cannot be accounted for in the MSW reporting system, in most cases. This is one factor that impacts the total waste disposal volume recorded for the area of 29,796 tonnes for a population 65,400. Moreover, this factor is highly likely to be the primary reason that a lower per capita waste generation is recorded than for Rotorua, which has almost the same population (Table 7.13).

Because of the strategic location of Waikato District Council as shown in Figure 7.10, being close to the two largest cities in the Northern Island - Auckland and Hamilton - it is benefiting economically and as a consequence is developing its waste management sector. It is the site of several major waste management facilities that serve the North Island population centres. These centres include Auckland, Hamilton, and cities in Bay of Plenty Region.

As part of the greater Waikato Region, Waikato District Council is included in regional plans focusing on the sustainable management of resources and improved quality of the environment to improve air and water quality. This is one the drivers for the sustained efforts to reduce waste generation and devise a good strategy in managing the residual waste in the area. But like other Councils, Waikato Regional Council have not devised a good strategy for managing the resulting data/information or for monitoring and reporting of MSWM.

Under the current Waste Management Plan, the Waikato district has a ZW management policy. The policy targets a zero waste to landfill by 2020 (Waikato District Council, 2011).

There is one disposal facility within the boundaries of Waikato District Council, which is North Waikato Regional Landfill (Hampton Downs Landfill). There are several closed landfills in the townships of Huntly, Ngaruawahia, Raglan, Te Kauwhata and Horotiu.

To help in achieving the ZW target, the Waikato District Council combines the kerbside collection services with an annual free inorganic rubbish collection including the services of recycling stations and transfer station.

In 2011, a total of 29,794 tonnes of residual waste was disposed to landfill (Waikato District Council, 2011). This quantity and the composition is adopted in this emission quantification.

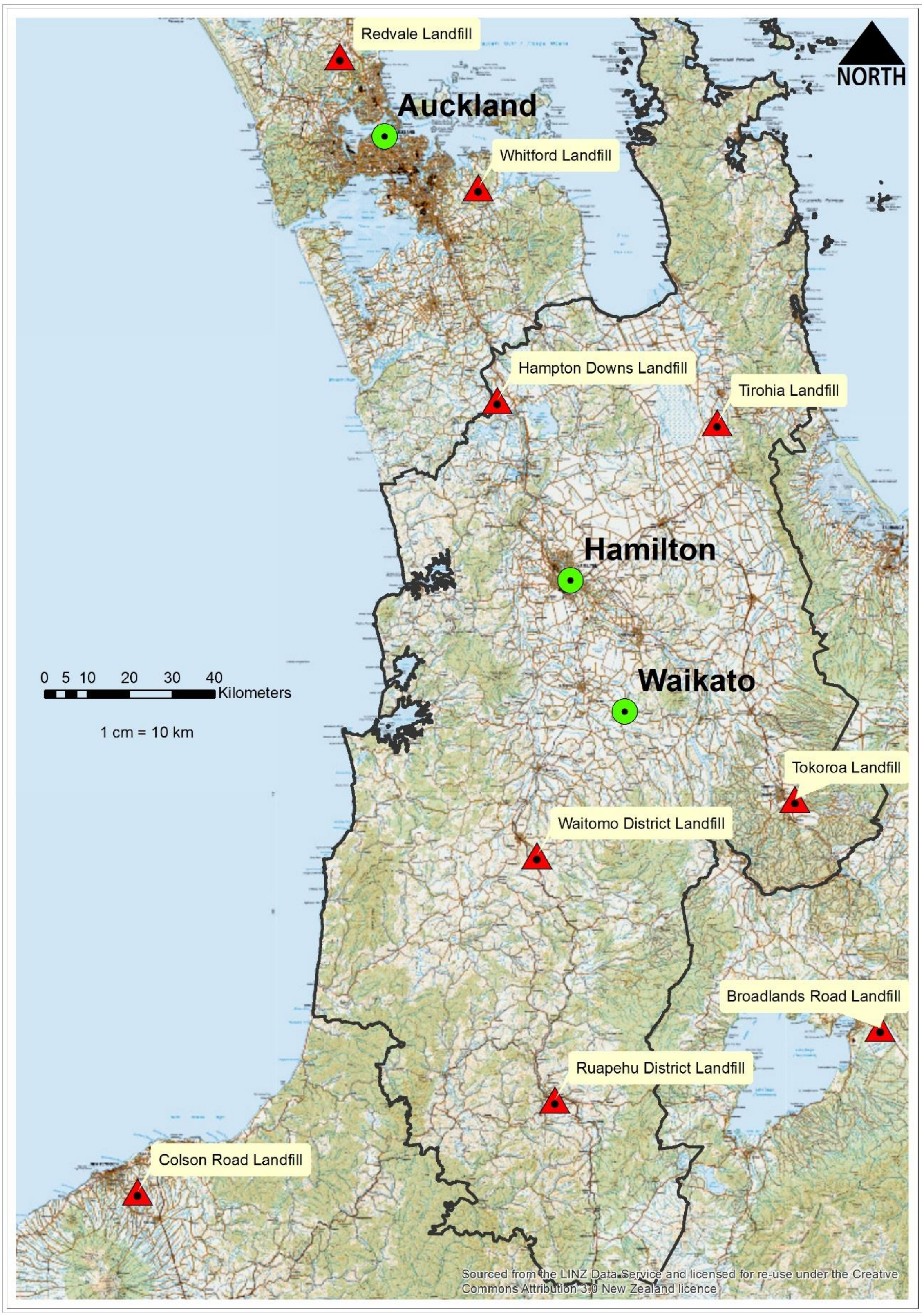


Figure 7.10: Geographic map of Waikato Region showing the location of Waikato District

7.1.2.1 Hampton Downs Landfill

Hampton Downs is the largest of the five active landfills in Waikato Region. Other landfills include Taupo, Te Kuti, Tirohia, and Tokoro. Hampton Downs is on 386 hectares of ex-farmland. The capacity of the landfill is 30 million cubic metres with consent for 25 years of operation.

Hampton Downs landfill is situated in rural northern Waikato, about 70 km from Auckland on the Waikato Expressway. It is near the Meremere drag strip and the Hampton Downs Motorsport Park (Figure 7.11). Hampton Downs Motorsports Park is located just down the hills of a covered waste of the capped portion of the landfill.

The immediate surrounding area consists of agricultural parcels with the nearest human settlement located more than 5 km away. Hampton Downs landfill serves Auckland Regional Council, Waikato District Council and Hamilton City Council.

Figure 7.11: Photo view of the location of Hampton Downs landfill. Map data: Google, DigitalGlobe (Google Earth, 2015)

7.1.3 Rotorua District

Rotorua is located in the central North Island, about 234 km from Auckland at 38º 8′ 12.65″S and 176º 14′ 59.09″E. Rotorua is one of the Bay of Plenty Territorial Authority to the north of Taupo, bounded on the west by South Waikato, Tauranga on the North and Whakatane at the East (Figure 7.12).

In 2011, the Council and its 68,800 residents disposed of about 45,000 tonnes of waste to landfill. This quantity has been steady since 2010 and is expected to reduce, under the current waste management plan (Rotorua Lakes Council, 2015).

The waste management Strategy includes:

- Waste reduction through education and information,
- Promoting reuse and recycling through drop-off centres,
- Recovery of material and energy from waste,
- Sustainable treatment and disposal of residual waste.

Rotorua District Council provides a range of services which include rubbish collection, recycling drop-off centres, green waste diversion, and concrete crushing. The system consists of four transfer stations, a disposal facility at Atiamuri Landfill and six recycling drop-off locations. The waste minimization plan is targeted at “achieving sustainability through the consideration of the impact of the waste management system on the economy, society, and environment” (Rotorua Lakes Council, 2015).

7.1.4 Auckland Council

Auckland is the largest city in New Zealand with a rapidly increasing population. In 2016, New Zealand's population is estimated to be increasing by one person about every 6 minutes, the majority of these new residents chose to live in Auckland. According to Statistics New Zealand (2015b). In the 2013 census, 1,459,600 people were resident in the city. In 2014 the population was estimated to be around 1.53 million.

Auckland is located at latitude 36o 50′ 54.45″S and longitude 174o 45′ 47.99″E, lying between the Hauraki Gulf of the Pacific Ocean to the east, the low Hunua Ranges to the south-east, the Manukau Harbour to the south-east, and the Waitakere Ranges and other smaller ranges to the west and north-west (Figure 7.13).

Figure 7.12: Geographic map showing the location of Rotorua District Council

In 2011, the city threw away 2,425,022 tonnes of waste to landfill. This represents about 1.7 tonnes of waste per capita in that year. According to Auckland Council (2011), while Auckland generates more waste than any other Territorial Authority in the country, Auckland Council has less direct control over the waste and the MSWM infrastructure than any other Territorial Authority in New Zealand. This is a lack of control is attributed to the general overall poor performance of Auckland's waste management system.

The nature of the city life of Auckland and being a major tourist destination, are some of the major reasons for the high rate of waste disposal. However, there is a lack of data available to actually measure the true performance of the system.

Auckland Regional Council is serviced by four landfills:

1. Claris landfill which is located on Great Barrier Island
2. Redvale landfill located at Diary Flat
3. Whitford, landfill in South Auckland, and
4. Hampton Downs landfill in the Waikato Region.

Each of landfill receives a percentage of Auckland Regional waste. On average, Redvale landfill receives more than 50 percent of all disposed waste in Auckland. This is closely followed by Hampton Downs landfill which receives about 35 percent. Whitford landfill receives about 15 percent while Claris, which takes all waste from Great Barrier Island, takes about 0.05 percent of Auckland Regional waste. These landfills are supported by 23 transfer stations and recycling centres.

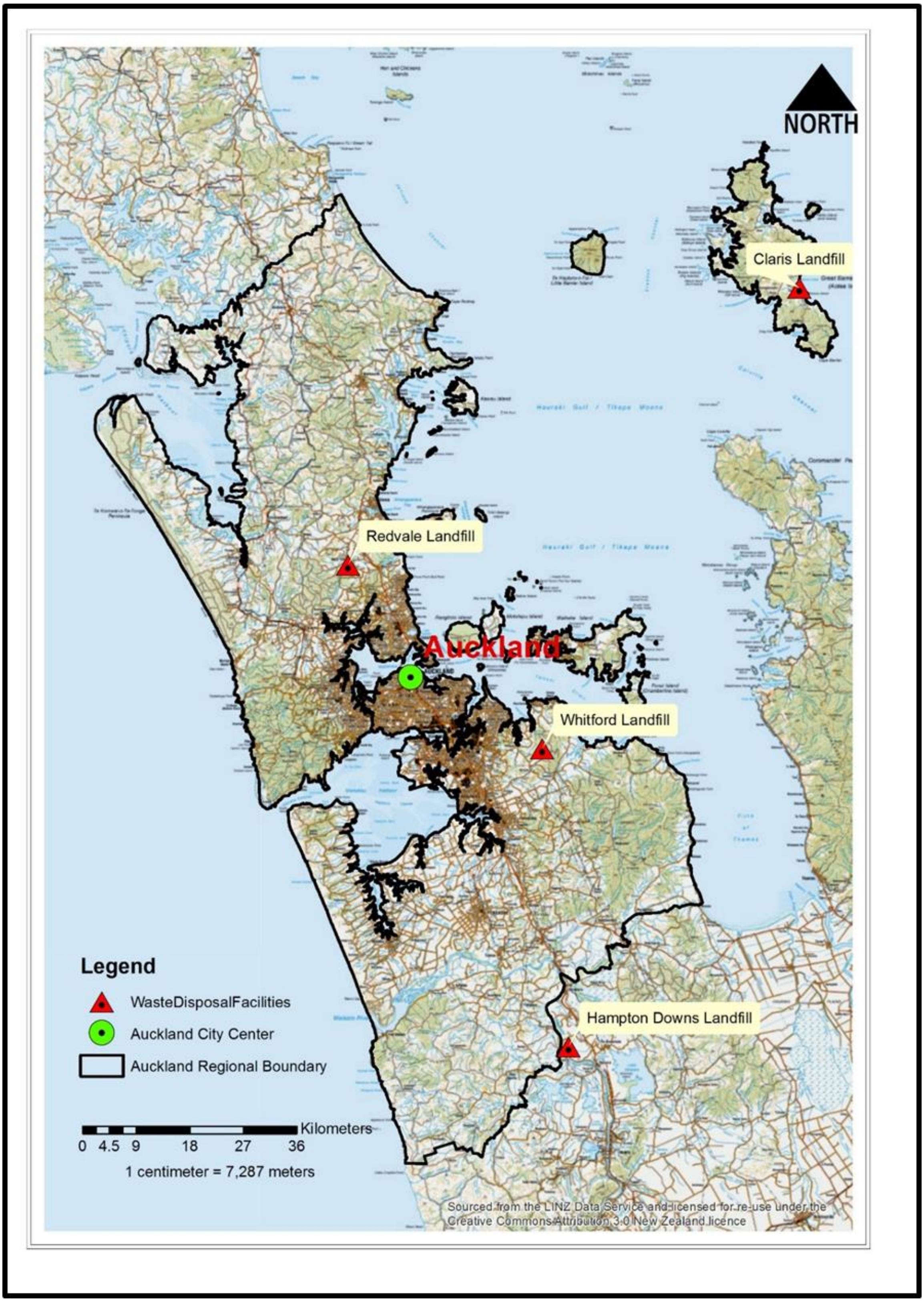


Figure 7.13: The Geographic map showing Auckland Council Region and its landfill locations

7.1.4.1 Claris Landfill

Claris landfill is located on Great Barrier Island, which lies in outer Hauraki Gulf to the north about 100 kilometres north-east of central Auckland. Great Barrier Island has an area of about 285 square kilometres (Figure 7.15).

The Island was first exploited for its minerals and timber (kauri) with a few limited agricultural activities taking place on the island. According to the 2015 population estimate, the island was inhabited by 980 people (Statistics New Zealand, 2016) mostly making a living from farming and tourism (Auckland Council, 2016).

Figure 7.14: Photo view of Great Barrier Island showing the location of Claris landfill. Map data: Google, DigitalGlobe (Google Earth, 2015)

Claris landfill is located north-west of the Great Barrier Island Aerodrome, close to Kaitoke Creek. As the only landfill for the island, Auckland Council waste management minimization plan on the island is aimed at extending the life of the landfill. This waste minimisation policy is achieved through a producer(user) pays system which was introduced in 2013 to encourage more recycling and less waste to landfill. The reduction in waste is expected to reduce the volume of waste to landfill by 30 percent by 2018. However, there again continues to be a lack of data with which to assess the impact of strategies and for future planning.

7.1.4.2 Whitford Landfill

Whitford landfill is a key element in Auckland Council's solid waste management infrastructure. It is located on Whitford-Maraetai Road, opposite Clifton Road, East Tamaki South Auckland. As can be seen in Figure 7.16, the nearest residents to the landfill are located more than 3 km, and immediate vicinities are farm parcels.

The landfill has operated with a modern engineering and management system since 1994 and is a now a state-of-the-art infrastructure serving major urban areas in the southern part of Auckland. Like Tirohia landfill, it was established as a means of filling the burrows created as a result of quarry activities in the area (Figure 7.16). The landfill is an engineered landfill with clay and geomembrane liner systems. The footprint covers about 52 hectares to contain up to 12 million cubic metres of waste. This is estimated to last for 20 years assuming a rate of filling of approximately 200,000 tonnes of refuse per annum.

It may be said that the landfill satisfies the sustainable waste management policy of Auckland Region, but it may be contributing to the poor air quality and some level, ground water pollution from emissions and leachate leakages. These environmental impacts have not been proven because no monitoring system has been put in place. This is where the *CEQ-Model* and measurement should prove useful.

Figure 7.15: Photo view of part of the active section of Whitford landfill

The current gas management process at Whitford landfill is to collect and flare gases to reduce odorous load and environmental pollution.

7.1.4.3 Redvale Landfill

The Redvale Landfill was developed as a large modern landfill for the disposal of non-hazardous waste. It was opened in August 1993 and is located 1 km west of State Highway 1 (SH1 or Diary Flat Highway), about 6 km south of the Silverdale community of Diary Flat. It is approximately 25 km north of Auckland City and has a footprint covering an area of about 59 hectares (Figure 7.17).

Auckland Council (2014), quoting from the consent application, describes the topography of the landfill site as "ranging in elevation". It also noted that "the site is enclosed by higher elevated land to the west and north, with the highest point, RL130m, located atop stockpile four, adjacent to the site. The landform around the southern and eastern parts of the site is flat; however, the eastern slope of the completed landform forms a noticeable change". The wider catchment, however, is characterised by low rolling country with the more elevated and dissected land being separated by broad valleys.

The vegetation throughout the rural landscape covering the north, east, and south of the landfill is characterised by predominantly exotic species used as shelterbelts, small woodlots and specimen trees. This vegetation combined with significant amenity planting associated with rural households as represented in Figures 7.17 and 7.18, creates a lush character to the valley and significantly enhances the rural amenity of the area (Figure 7.19).

The initial land use consent for the landfill had a 30 years duration which was to expire in 2023. But due to a slower rate of waste placement than originally anticipated, an application for the extension of the consent was made in July 2014. If approved, the life of the landfill will be extended to 2049 (Auckland Council, 2014). Currently, the landfill takes more than 1900 tonnes of waste every day (Auckland Council, 2011, p. 25).

Like other landfills, details of the activities and data from Redvale landfill are not in the public domain. Hence, it is difficult to complete carry out an assessment of the performance of the landfill in line with sustainable waste management policies. However, the plan to incorporate landfill-gas-to-energy as an added facility within the gas management plan (Waste Management, 2016) improves the sustainability profile of the landfill.

Figure 7.16: Photo view of the location of Redvale landfill and Diary Flat Highway (SH1). Map data: Google, DigitalGlobe (Google Earth, 2015)

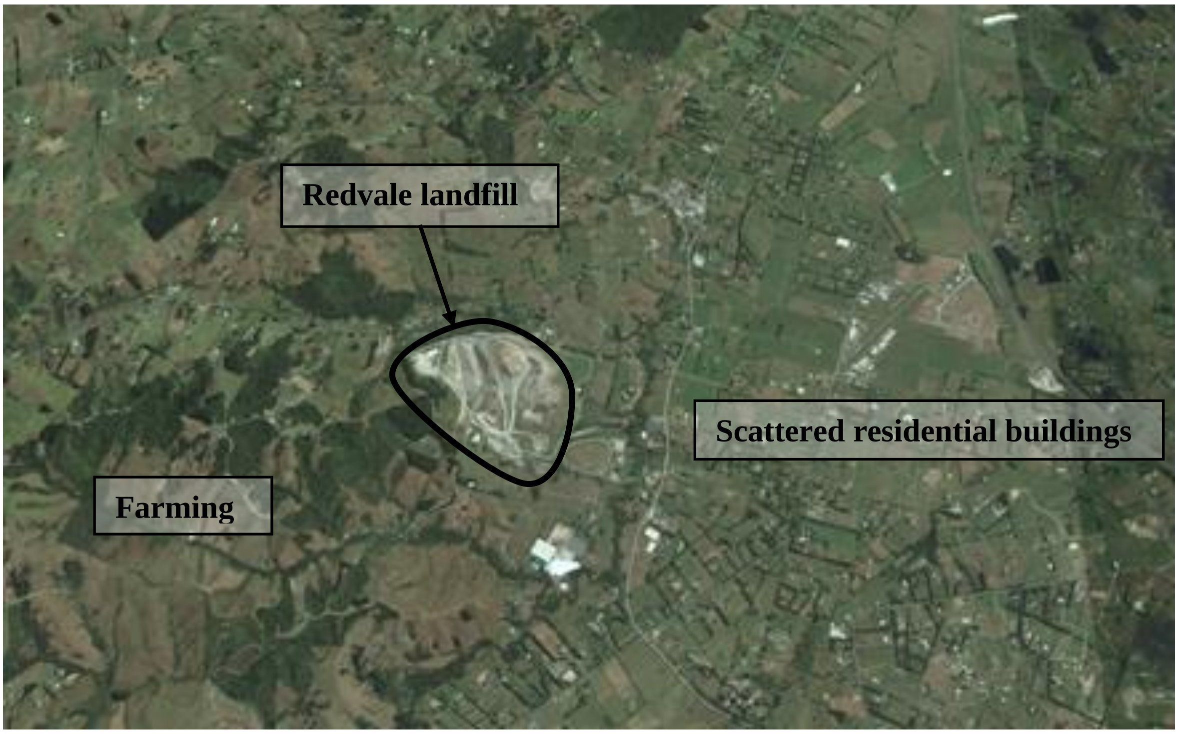


Figure 7.17: Aerial view of Diary flat showing the location of Redvale landfill and adjoining land use activities. Map data: Google, DigitalGlobe (Google Earth, 2015)

Figure 7.18: Photo view of Diary Flat showing the location of Redvale landfill. Source: Tonkin & Taylor (2016)

7.2 Emissions Quantification of Waste Management Systems

The waste composition, dwelling population, estimated average distance from the transfer stations to landfills, emissions factors and other characteristics of the scenarios, are applied to the *CEQ-Model*.

7.2.1 Opotiki District Council

7.2.1.1 Opotiki District Council Emission from Disposal Site

The waste composition at Opotiki District in 2011 (Table 7.3) and the value of DOC in Table 6.7 (Chapter Six) are used in Eq.7.4 to calculate the CH_4 and CO_2 potentials of the waste stream L_{CH4} and L_{CO2} respectively. The CH_4 and CO_2 potentials are then used to compute total CH_4 and total CO_2, respectively.

Table 7.2: 2011 Opotiki waste composition

Waste Fraction	**Volume (%)**	**Volume (tonnes)**
Organic	19	275.5
Timber	23	333.5
Paper / Cardboard	5	72.5
Textiles	6	87
Rubble	14	203
Soil	23	333.5
Metals	10	145
Total	**100**	**1450**

Source: Compiled from Opotiki District Council (2012) and Opotiki District Council (2011)

$$L_{CH_4} = \left[\left(MCF \times DOC_f \times F_{CH_4} \times \frac{16}{12} \times GWP \times DOC\right) \times (1 - OX)\right] \quad \text{Eq.7.4}$$

$$L_{CH_4} = \left[\left(1 \times 0.5 \times 0.5 \times \frac{16}{12} \times 28 \times DOC\right) \times (1 - 0.1)\right] \quad \text{Eq.7.5}$$

$$L_{CH_4} = [(1 \times 0.25 \times 1.3333333333 \times 28 \times DOC) \times (0.9)] \quad \text{Eq.7.6}$$

$$\therefore L_{CH_4} = \left[\left(9.\dot{3} \times DOC\right) \times (0.9)\right]$$

And,

$$\text{DOC} = \left[\left(\frac{19}{100} \times \frac{0.2}{1}\right) + \left(\frac{5}{100} \times \frac{0.4}{1}\right) + \left(\frac{23}{100} \times \frac{0.43}{1}\right) + \left(\frac{6}{100} \times \frac{0.24}{1}\right)\right] \quad \text{Eq.7.7}$$

$$\therefore \text{DOC} = [(0.038) + (0.02) + (0.0989) + (0.0144)] = 0.1713$$

And,

$$L_{CH_4} = 9.3333 \times 0.1713 \times 0.9 = 1.43892 \quad \text{Eq.7.8}$$

$$\therefore CH_4 = 1.43892 \times 1450 = 2086.434\ (Gg\ CO_2 - e)$$

Similarly,

$$L_{CO_2} = \left[\left(0.25 \times \frac{44}{12}\right) \times (1 - 0) \times (DOC)\right] \quad \text{Eq.7.9}$$

$$\therefore L_{CO_2} = [(0.91666666667) \times (1) \times (0.1713)] = 0.157025$$

So that;

$$CO_2 = 0.157025 \times 1450 = 227.69\ (Gg\ CO_2 - e)$$

7.2.1.2 Opotiki District Council Transportation Emission

The estimated disposal distances, Emission Factors (EF) as represented in Table 6.7 and volume of disposed waste, are substituted in Table 7.3 to compute the emission quantities of the three major transportation emissions – CO_2, CH_4, and N_2O.

Table 7.3: 2011 Opotiki District Council waste transportation emission

Distance to Landfill (km)	Total Disposed waste (Tonnes)	Volume Per Run (Tonnes)	Number of Runs	Total Distance	gas	EF	EF units	Emission (kg)
216	1450	25	116	25056	CO_2	0.227	Kg/unit	5687.712
					CH_4	0.00134	CO_2-e	33.57504
					N_2O	0.00152	CO_2-e	38.08512
							Total	**5759.37216**

7.2.2 Waikato District Council

7.2.2.1 Waikato District Council Emission from Disposal Site

The waste composition at Waikato District in 2011 (Table 7.4) and the value of DOC in Table 6.7 are used in Eq.6-10 and Eq.6-11 to calculate the CH_4 and CO_2 potentials of the waste stream L_{CH4} and L_{CO2} respectively.

Table 7.4: 2011 Waikato District Council waste composition

Waste fraction	**Volume (%)**	**Volume (Tonnes)**
Garden	25	7449
Putrescible	13	3873.48
Paper	11.2	3337.152
Building	4	1191.84
Metals	5	1489.8
Plastic	13.8	4111.848
Textiles	7	2085.72
Glass	5	1489.8
Potentially hazardous	1	297.96
Nappies and Sanitary	8	2383.68
Timber	10	2979.6
Rubber	1	297.96
Total	100	29796

Data source: Waikato District Council (2012)

$$\mathrm{DOC} = \left[\left(\frac{25}{100}\times\frac{0.20}{1}\right)+\left(\frac{11.2}{100}\times\frac{0.40}{1}\right)+\left(\frac{7}{100}\times\frac{0.24}{1}\right)+\left(\frac{1}{100}\times\frac{0.05}{1}\right)+\left(\frac{8}{100}\times\frac{0.24}{1}\right)+\left(\frac{10}{100}\times\frac{0.43}{1}\right)+\left(\frac{13}{100}\times\frac{0.15}{1}\right)\right]$$

$$\therefore \mathrm{DOC} = [(0.05)+(0.0448)+(0.0168)+(0.0005)+(0.0192)+(0.043)+(0.0195)] = 0.1938$$

So that;

$$L_{CH_4} = 9.33333333333 \times 0.1938 \times 0.9 = 1.62792$$

$$CH_4 = 1.62792 \times 29796 = 48505.50432\ (Gg)$$

Thus,

$$L_{CO_2} = \left[\left(0.25\times\frac{44}{12}\right)\times \mathrm{DOC}\right] = 0.9167 \times \mathrm{DOC} = 0.9167 \times 0.1938 = 0.1776$$

And,

$$CO_2 = 17765 \times 29796 = 5293.2594\ (Gg\ CO_2 - e)$$

7.2.2.2 Waikato District Transportation Emission

The estimated disposal distances, Emission Factors (EF) as represented in Table 6.7 and volume of disposed waste, are substituted in Eq.6-10 to compute the emission quantities of the three major transportation emissions – CO2, CH4, and N2O and represented in Table 7.5.

Table 7.5: 2011 Waikato District Council waste transportation emission

Distance to Landfill (km)	**Total Disposed waste (Tonnes)**	**Volume Per Run (Tonnes)**	**Number of Runs**	**Total Distance**	**gas**	**EF**	**EF units**	**Emission (kg)**
44	29796	25	1192	104882	CO_2	0.227	Kg/unit	24035.214
					CH_4	0.00134	CO_2-e	140.542
					N_2O	0.00152	CO_2-e	159.421
							Total	**24335.18**

7.2.3 Rotorua District Council

7.2.3.1 Rotorua District Council Emission from Disposal Site

The waste composition at Rotorua District in 2011 (Table 7.6) and the value of DOC in Table 6.7 to calculate the CH_4 and CO_2 potentials of the waste stream L_{CH4} and L_{CO2} respectively. The CH_4 and CO_2 potentials are substituted into Eq.6-10 and Eq.6-11 respectively to compute total CH_4 and total CO_2.

Table 7.6: 2011 Rotorua District waste composition

Waste fraction	Volume (%)	Volume (Tonnes)
Garden	7	3150
Putrescible	17	7650
Paper	9	4050
Building	15	6750
Metals	4	1800
Plastic	11	4950
Textiles	2	900
Glass	3	1350
Potentially hazardous	14	6300
Nappies and Sanitary	3	1350
Timber	15	6750
Rubber	0	0
TOTAL	100	45000

$$DOC = \left[\left(\frac{7}{100}\times\frac{0.20}{1}\right)+\left(\frac{9}{100}\times\frac{0.40}{1}\right)+\left(\frac{3}{100}\times\frac{0.24}{1}\right)+\left(\frac{14}{100}\times\frac{0.05}{1}\right)+\left(\frac{2}{100}\times\frac{0.24}{1}\right)+\left(\frac{15}{100}\times\frac{0.43}{1}\right)+\left(\frac{17}{100}\times\frac{0.15}{1}\right)\right]$$

$$\boldsymbol{DOC} = [(0.014) + (0.036) + (0.0072) + (0.007) + (0.0048) + (0.0645) + (0.0255)]$$

$$\mathrm{DOC} = 0.159$$

So that;

$$L_{CH_4} = 9.33333333333 \times 0.159 \times 0.9$$

$$L_{CH_4} = 1.3356$$

$$CH_4 = 1.3356 \times 45000$$

$$\mathrm{CH_4} = 60102.000 \text{ Gg}$$

Also;

$$L_{CO_2} = \left[\left(0.25 \times \frac{44}{12}\right) \times (DOC)\right]$$

$$L_{CO_2} = 0.9167 \times DOC$$

$$L_{CO_2} = 0.9167 \times 0.159$$

$$L_{CO_2} = 0.1457553$$

$$CO_2 = 0.1457553 \times 45000$$

$$\mathrm{CO_2} = 6558.9885$$

7.2.3.2 Rotorua District Council Transportation Emission

The estimated disposal distances, Emission Factors (EF) as represented in Table 6.7 and volume of disposed waste, are substituted in Table 7.7 to compute the emission quantities of the three major transportation emissions – CO_2, CH_4, and N_2O.

Table 7.7: 2011 Rotorua District Council waste transportation emission

Distance to Landfill (km)	**Total Disposed waste (Tonnes)**	**Volume Per Run (Tonnes)**	**Number of Runs**	**Total Distance**	**gas**	**EF**	**EF units**	**Emission (kg)**
64	45000	25	1800	230400	CO_2	0.227	Kg/unit	52300.8
					CH_4	0.00134	CO_2-e	308.736
					N_2O	0.00152	CO_2-e	350.208
							Total	**52959.744**

7.2.4 Auckland Council

6.2.4.1 Auckland Council Emission from Disposal Site

The waste composition at Auckland Regional Council in 2011 (Table 7.8) and the value of DOC in Table 6.7 are used to calculate the CH_4 and CO_2 potentials of the waste stream L_{CH4} and L_{CO2} respectively. The CH_4 and CO_2 potentials are used to compute total CH_4 and total CO_2.

Table 7.8: 2011 Auckland Council waste composition

Waste fraction	**Volume (%)**	**Volume (Tonnes)**
Organics	49.9	1210085.978
Paper	11.8	286152.596
Demolition	4.5	109125.99
Metals	2.5	60625.55
Plastic	10.6	257052.332
Textiles	3.9	94575.858
Glass	3.6	87300.792
Potentially hazardous	1.2	29100.264
Nappies and Sanitary	9.8	237652.156
Timber	2	48500.44
Rubber	0.2	4850.044
TOTAL	**100**	**2425022**

$$\mathrm{DOC} = \left[\left(\frac{49.9}{100}\times\frac{0.20}{1}\right)+\left(\frac{11.8}{100}\times\frac{0.40}{1}\right)+\left(\frac{9.8}{100}\times\frac{0.24}{1}\right)+\left(\frac{1.2}{100}\times\frac{0.05}{1}\right)+\left(\frac{3.9}{100}\times\frac{0.24}{1}\right)+\left(\frac{2}{100}\times\frac{0.43}{1}\right)\right]$$

$$\therefore \mathrm{DOC} = [(0.0998)+(0.0472)+(0.02352)+(0.0006)+(0.00936)+(0.0086)] = 0.18908$$

So that;

$$L_{CH_4} = 9.33333333333 \times 0.18908 \times 0.9 = 1.588272$$

$CH_4 = 1.588272 \times 2425022 = 3.851594.542$ (Gg)

Also;

$$L_{CO_2} = \left[\left(0.25 \times \frac{44}{12}\right) \times (DOC)\right] = 91670 \times DOC$$

$$L_{CO_2} = 91670.\times DOC = 0.9167 \times 0.18908 = 0.173329636$$

$$CO_2 = 0.173329636 \times 2425022 = 420328.181 \text{ Gg}$$

7.2.4.2 Auckland Council Transportation Emission

The estimated disposal distances, Emission Factors (EF) as represented in Table 6.7 and volume of disposed waste, are used to compute the emission quantities of the three major transportation emissions – CO_2, CH_4, and N_2O as in Table 7.9.

Table 7.9: Auckland regional waste transportation emissions

Landfill		**Redvale**	**Hampton Downs**	**Whitford**	**Claris**	
Average Distance to landfill(km)		30	68	21	11	
Total disposed waste (Tonnes)		1,245,248.80	831,540.04	347,263.15	970.01	
Est. volume per run (Tonnes)		25	25	25	25	
Number of Runs		49,810	33,262	13,891	39	
Total Distance		2,988,600	4,523,632	583,422	858	
EF	CO_2 (kg/unit)	0.227	0.227	0.227	0.227	
	CH4 (CO_2-e)	0.00134	0.00134	0.00134	0.00134	
	N_2O (CO_2-e)	0.00152	0.00152	0.00152	0.00152	Total
Emission (kg CO_2-e)	CO_2	52,300.8	1,026,864.464	132,436.794	194.766	1,211,796.824
	CH_4	308.736	6,061.667	781.79	1.150	7,153.343
	N_2O	350.208	6,875.921	886.802	1.304	8,114.235
					Total	**1,227,064.402**

7.3 Results and Discussion

The measurement of a sustainable society within a waste management system or a sustainable waste management system can be undertaken using any of the following criteria, among others:

1. The volume of waste generated per person per year which is known as per capita waste generation
2. Changes in the position of waste management on Waste Management Hierarchy. This is not part of this discussion as there is no historical data showing changes in waste composition and management strategies
3. The volume of emission resulting from the system. As practiced now, this is taken as emission from landfill
4. The comprehensive emission resulting from the system. This is where we are going as recommended in this thesis.
5. Reduction in the volume of waste to landfill. This will also not be part of this discussion because historical data was not used in this case.

The general idea is to measure the influence of paradigm shifts from the 'Business As Usual' (BAU) practices to the new WM scenarios on the environment. Measurable indices need to be established and adopted to facilitate this process of policy and MSWM change

In the cases presented in this section and the analysis of the cases in the next section, a comparison between TAs is undertaken using criteria that are common to all of them and the emissions estimates provided by the *CEQ-Model*.

Where comparisons are made, to determine which of the territorial authority is performing better, a system of ranking from (1) to (4) has been adopted. (1) represents the best performance while (4) the worst performance. Matrices of the performance levels of the four Territorial Authorities are created in each case. The sums of these matrices indicate the final performance level of the Territorial Authorities relative to each other.

7.3.1 Per Capita Waste Generation

Per capita waste generation is the quantity of waste generated by an average resident over a period, normally one year. The volume of emission produced by a disposal site is determined by the type of waste that is placed in the landfill. This is reflected in the composition of the waste stream. The composition of the waste stream is a reflection of the speed of decomposition and the percentage of the waste stream that will decompose, that is, the decomposable waste fractions in the mass volume of waste disposed of. This is known as Degradable Organic Carbon (DOC). The higher the percentage content of DOC in a waste stream, the higher the expected emission. This is computed and represented in Table 7.10 and captured in Figure 7.20.

Table 7.11 represents the sum of all the values categories of emissions considered in this study as computed in section 7.2 to section 7.2.4.2. Examining Table 7.12, the volume of waste to landfill is proportional to the size of the settlements. Auckland, which is the most populous, has the highest volume of waste to landfill and therefore would be also expected to have the highest volumes of emissions attributed to waste.

The waste composition represented in Table 7.14 shows that 49.9 percent of Auckland disposals are composed of organic waste, is a good representation of the result of the waste disposal habits of inner city dwellers There is no indication of the make-up of the organic waste in Auckland, but it is most likely from garden trimmings and leaves, flowers and vegetable garden maintenance.

Rotorua and Waikato are similar in size and MSWM scenarios. But Rotorua has a higher per capita disposal level than Waikato DC; this difference is most likely due to tourism. Rotorua is a major tourist destination because of its thermal activity and geysers.

Overall, Auckland is the most wasteful city of the four centres investigated, disposing of 2,125,022 tonnes of waste or 1661.43 kg per capita in 2011. Opotiki District Council, as a rural settlement, has a per capita disposal of 159.9 kg while Rotorua District and Waikato District have 654.07 kg and 455.60 kg respectively (Table 7.13).

7.3.2 Volume of Per Capita Emission

Per capita emission is the total emission divided by the population of the Council. This is divided into various areas for easy understanding. In general, the emission is a function of the amount of DOC in the waste stream which is the percentage value of the waste stream which can decompose and produce gases (Bo-Feng et al., 2014). Since Auckland residents throw away more waste than residents of other cities, their emission follows that same trend.

7.3.3 Volume of Emission per Tonne of Waste

The DOC value calculated for the cities and towns captured in this case study are given in Table 7.10. Table 7.10 and Figure 7.20 indicate that the same volume of waste from different cities produces a different amount of emission. Waikato District produces more emission per tonne of waste than others, followed by Auckland, Opotiki, and Rotorua respectively. Hence, Waikato District Council has the highest emission per tonne of waste as shown in Table 7.13 (hence scoring the maximum of (4) points on the scale). Waikato is closely followed by Auckland where each tonne of waste produces 1.762 $GgCO_2$-e, while Opotiki and Rotorua produce 1.6 $GgCO_2$-e and 1.4814 $GgCO_2$-e respectively. This result is a function of the waste composition in Table 13 where the total percentage of waste contributing to the emissions are shown.

7.3.4 Variation in the value of per Capita Emission and Emission per Tonne of Waste

Interestingly, the scaled position of the cities in per capita emission is not the same as emission per tonne of waste (Table 7.13). The simple explanation for the difference is shown made clearer in Table 7.11 which indicates that Waikato District has the least emissions due to transportation because of a shorter distance to landfill and a good level of per capita waste disposal, see Table 7.12. When compared with the rest of the territorial authority, Opotiki has the lowest per capita disposal but transports waste a longer distance, hence raising the per capita emissions contribution.

Tables 7.13 and 7.16 show that Waikato has the best per capita emission ratio, followed by Opotiki, Rotorua, and finally Auckland.

Comparing the various outputs and population and one tonne of waste shows the territorial authority that is the most sustainable in their SWM strategy.

Opotiki which has the smallest per capita waste disposal, each resident in Opotiki disposing of less than one-quarter of their counterpart in Rotorua, is contributing an equal amount of cumulative emission or 24.45 percent of the waste volume. This is, almost inevitably, a result of the unsustainable waste handling at Opotiki, transporting their waste over 216 km to Tirohia.

7.3.5 General Sustainability Position of the Territorial Authorities

Currently, all Territorial Authority concentrate on the reduction of waste to landfill without considering the implication of other decisions on both the local ecosystem and national environment. For example, Rotorua and Tokoroa do not accept 'out of district' waste in their landfill as a way of ensuring healthy environment locally. But on the other hand, they are contributing to environmentally detrimental practices resulting from the transportation of waste from Gisborne and Opotiki to Tirohia landfill. The practice of restricting waste acceptance in the landfill within their territory is supported by section 56(e) of the Waste Minimization Act 2008.

In general, however, looking at the performance of the Territorial Authorities in various aspect of the waste management as analysed and represented in Table 7.13, Opotiki District has the most sustainable system. This is arrived at by summing up the score of each territorial authority on a scale of 1 to 4, which showed Opotiki having a total of 5 points, compare to 6 points for Rotorua, 7 points for Waikato and 10 points for Auckland.

This is achieved because of the level of recycling and reuse in Opotiki, leading to a very low volume of waste to landfill and lowest DOC contributing waste fraction – 53 percent (Table 7.14). Because of the small amount of waste that is transported over the long distance from Opotiki to Tirohia landfill, the environmental impact of the transportation on the overall scale position compare to other territorial authorities is not too bad.

Rotorua District has an appreciable amount of per capita waste to landfill standing at 654.07 tonnes per capita per year (Table 7.12), but due to the proximity of the landfill to the transfer station and to the people – averaged 33 km – the performance on the scale compare to the rest of the cities is good at second position. Also, the other important contributing factor to the good showing of Rotorua District is the level of total waste volume contributing to the DOC, which is 60 percent, compare to 74.2 percent for Waikato District and 78.6 for Auckland Region (Table 7.14).

Waikato District with an average distance of 44 km to the landfill is in the third position because of the percentage level of DOC in the waste stream (Table 7.5 and Table 7.14). Therefore, it is important for Waikato District to improve on its recycling efforts and sensitise citizens to reduce the per capita waste generation and reduce the amount of per capita waste to landfill.

Auckland has the most unsustainable waste management system among the pack. This is resulting from poor level of recycling leading to high DOC, high level of disposal and the distance to Hampton Downs Landfill which is accepting a good percentage of Auckland

Table 7.10: Value of DOC of territorial authority's waste streams

Territorial Authority (ordered north to south)	**DOC Value**	**Rank according to the Relative Level of Emission Potentials**
Auckland	0.18908	(3)
Rotorua	0.15900	(1)
Waikato	0.19380	(4)
Opotiki	0.17130	(2)

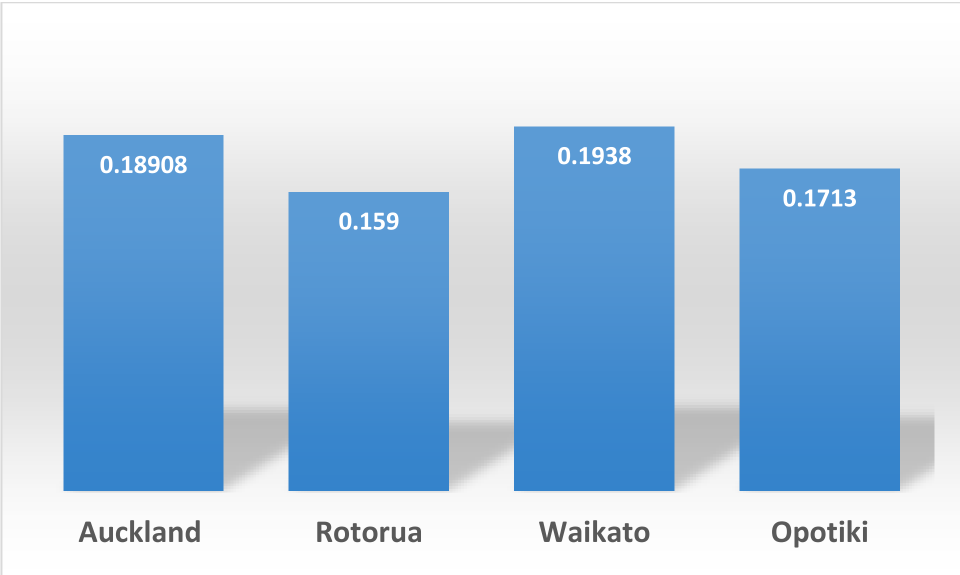
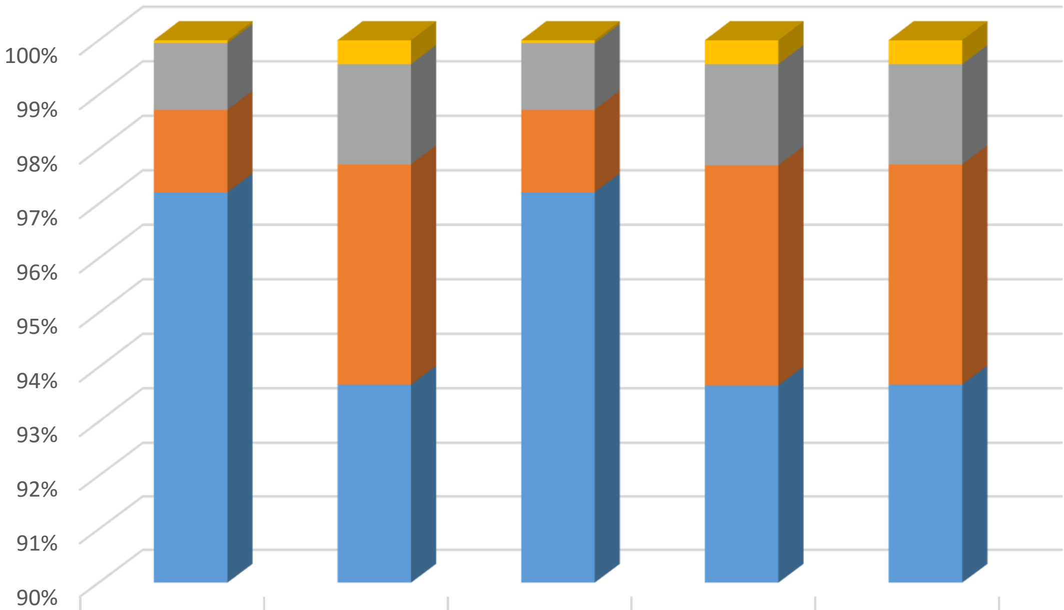


Figure 7.19: Visual depiction of the DOC value for each of the cities or township studied

Table 7.11: Summary of the CEQ-Model emission quantification results

Territorial Authority	**CH_4**		**CO_2**		**N_2O**
	Landfill (Gg CO_2-e)	Transport (kg CO_2-e)	Landfill (Gg CO_2-e)	Transport (kg CO_2-e)	Transport (kg CO_2-e)
Auckland	3,851,594.54	7,153.35	420,328.18	1,211,796.84	8,114.24
Rotorua	60,102.00	308.74	6,558.99	52,300.80	350.21
Waikato	48,505.50	140.54	5,293.26	24,035.22	159.42
Opotiki	2,086.44	33.58	227.69	5,687.71	38.09



	(Gg CO2-e) Landfill CH4	(kg CO2-e) Transport CH4	(Gg CO2-e) Landfill CO2	(kg CO2-e) Transport CO2	(kg CO2-e) Transport N2O
Opotiki	2,086.44	33.58	227.69	5,687.71	38.09
Waikato	48,505.50	140.54	5,293.26	24,035.22	159.42
Rotorua	60,102.00	308.74	6,558.99	52,300.80	350.21
Auckland	3,851,594.54	7,153.35	420,328.18	1,211,796.84	8,114.24

Figure 7.20: Specific emission quantities resulting from each territorial authority's solid waste management system

Table 7.12: Summary of emission ratio output based on per capita waste disposal

Territorial Authority	**Population**	**Total Waste Volume (tonnes)**	**Per Capita Waste Disposal (kg) value (rank)**	**Emission Ratio Per Tonne of Waste (Gg CO_2-e) value (rank)**	**Emission Per Capita (Gg CO_2-e) value (rank)**	**TAs overall value (rank)**
Auckland Region	1,459,600	2,425,022	1,661.43 (4)	1.762 (3)	2.93 (3)	10 (4)
Rotorua District	68,800	45,000	654.07 (3)	1.4814 (1)	0.969 (2)	6 (2)
Waikato District	65,400	29,796	455.60 (2)	1.806 (4)	0.823 (1)	7 (3)
Opotiki District	9,070	1,450	159.90 (1)	1.6 (2)	0.969 (2)	5 (1)

Positional matrix of Territorial Authorities performance using per capita waste disposal, emission ratio per tonne of waste and emission per capita resulting from Table 7.11 is shown below:

$$\begin{bmatrix} Auckland \\ Rotorua \\ Waikato \\ Opotiki \end{bmatrix} = \begin{bmatrix} 4 & 3 & 3 \\ 3 & 1 & 2 \\ 2 & 4 & 1 \\ 1 & 2 & 2 \end{bmatrix} = \begin{bmatrix} 10 \\ 6 \\ 7 \\ 5 \end{bmatrix} = \begin{bmatrix} 4 \\ 2 \\ 3 \\ 1 \end{bmatrix}$$

[A] [B1] [C1] [D1]

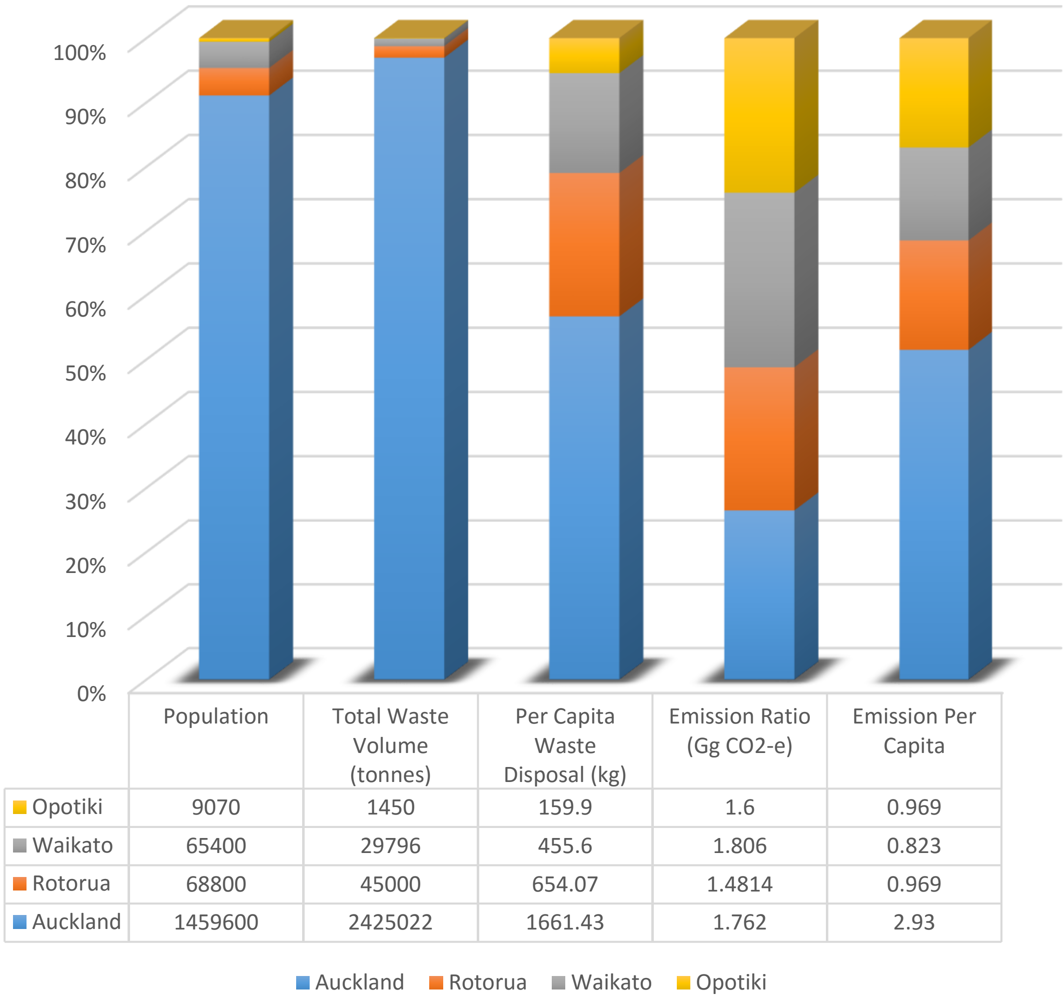
Where;

[A] is the matrix of the councils

[B1] is the matrix containing the relative ranked performance level of the councils

[C1] is the within matrix summation of the rows in matrix [B1]

[D1] is rank of the councils on a scale of 1 to 4 based on matrix [C1]



	Population	Total Waste Volume (tonnes)	Per Capita Waste Disposal (kg)	Emission Ratio (Gg CO2-e)	Emission Per Capita
Opotiki	9070	1450	159.9	1.6	0.969
Waikato	65400	29796	455.6	1.806	0.823
Rotorua	68800	45000	654.07	1.4814	0.969
Auckland	1459600	2425022	1661.43	1.762	2.93

Figure 7.21: Relationship between the emission, waste volumes, and population

Table 7.13: Relative position of Territorial Authority emission ratio at landfills

Territorial Authority	Auckland	Rotorua	Waikato	Opotiki
Population	1,459,600	68,800	65,400	9,070
Total Volume of Waste Disposed (Tonnes)	2,425,022	45,000	29,796	1,450
CH_4 Resulting from Landfill (Gg CO_2-e)	3,851,594.54	60,102.00	48,505.50	2,086.44
CH_4 Per Capita (Gg CO_2-e)	2.64 (4)	0.87 (3)	0.74 (2)	0.23 (1)
CH_4 Per Tonne of Waste (Gg CO_2-e)	1.59 (3)	1.34 (1)	1.63 (4)	1.44 (2)
CO_2 Resulting from Landfill (Gg CO_2-e)	420,328.18	6,558.99	5,293.26	227.69
CO_2 Per Capita (Gg CO_2-e)	0.29 (4)	0.10 (3)	0.08 (2)	0.03 (1)
CO_2 Per Tonne of Waste (Gg CO_2-e)	0.17 (2)	1.15 (4)	0.18 (3)	0.16 (1)
Territorial Authority Position on Scale value (rank)	13 (3)	11 (2)	11 (2)	5 (1)

So that the matrix of the relative position of the Territorial Authority emissions ratio at the landfill is as shown below:

$$\begin{bmatrix} Auckland \\ Rotorua \\ Waikato \\ Opotiki \end{bmatrix} = \begin{bmatrix} 4 & 3 & 4 & 2 \\ 3 & 1 & 3 & 4 \\ 2 & 4 & 2 & 3 \\ 1 & 2 & 1 & 1 \end{bmatrix} = \begin{bmatrix} 13 \\ 11 \\ 11 \\ 5 \end{bmatrix} = \begin{bmatrix} 3 \\ 2 \\ 2 \\ 1 \end{bmatrix}$$

[A] [B2] [C2] [D2]

Where:

[A] is the matrix containing the councils

[B2] is the matrix containing the relative performance levels

[C2] is the within matrix summation of rows in [B2]

[D2] is the ranking based on the values in [C]

Figure 7.22 is representing the performance of the each Territorial Authority using only emission resulting from landfills where their waste is disposed.

Figure 7.22: Territorial Authority relative performance level using landfill emission only

Table 7.14: Percentage of Territorial Authority waste composition components contributing to DOC

Territoria Authority	**Timber (0.43)**	**Paper (0.40)**	**Nappies and Sanitary (0.24)**	**Textile (0.24)**	**Organic Waste (0.20)**	**Garden Waste (0.20)**	**Putrescible (Food waste) (0.15)**	**Potentially Hazardous (0.05)**	**Total DOC Fraction (%)**
Auckland	2	11.8	9.8	3.9	49.9	-	-	1.2	78.6
Rotorua	15	9	3	2	-	-	17	14	60.0
Waikato	10	11.2	8	7	-	25	13	-	74.2
Opotiki	23	5	-	6	19	-	-	-	53

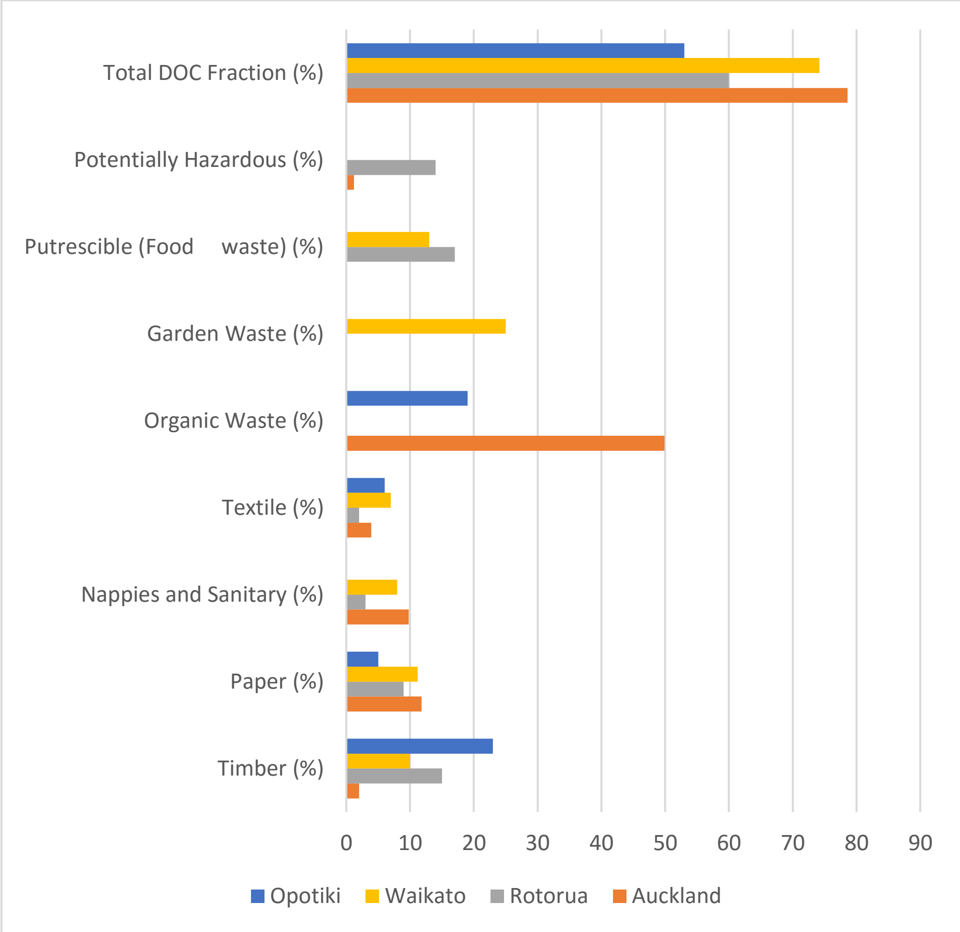


Figure 7.23: Percentage of Territorial Authority's waste components contributing to DOC

Table 7.15: Average distance to disposal site being used and average distance to the nearest disposal site

Territorial Authority	**Disposed Waste Volume (Tonnes)**	**Average Distance to Actual Disposal Site**		**Average Distance to Nearest Disposal Site**	
		Landfill	km	Landfill	km
Auckland	2425022	Hampton Downs	61	Hampton Downs	61
Rotorua	45000	Rotorua District Landfill	32	Rotorua District Landfill	32
Waikato	29796	Waikato District Landfill (Waitomo)	44	Waikato District Landfill (Waitomo)	44
Opotiki	1450	Tirohia Landfill	216	Rotorua District Landfill	148

Table 7.16: Per capita emission ratio of individual emission components relative to territorial authorities position

Territorial Authority	**CH_4**		**CO_2**		**N_2O**	**Territorial Authority positonal value (rank)**
	Landfill (Gg CO_2-e) value (rank)	**Transport** (kg CO_2-e) value (rank)	**Landfill** (Gg CO_2-e) value (rank)	**Transport** (kg CO_2-e) value (rank)	**Transport** (kg CO_2-e) value (rank)	
Auckland	2.64 (4)	0.005 (3)	0.29 (4)	0.83 (4)	0.006 (4)	19 (4)
Rotorua	0.87 (3)	0.005 (3)	0.10 (3)	0.76 (3)	0.005 (3)	15 (3)
Waikato	0.74 (2)	0.002 (1)	0.08 (2)	0.37 (1)	0.002 (1)	7 (1)
Opotiki	0.23 (1)	0.004 (2)	0.03 (1)	0.63 (2)	0.004 (2)	8 (2)

The matrix of the relative position of each council is formed as below:

$$\begin{bmatrix} Auckland \\ Rotorua \\ Waikato \\ Opotiki \end{bmatrix} = \begin{bmatrix} 4 & 3 & 4 & 4 & 4 \\ 3 & 3 & 3 & 3 & 3 \\ 2 & 1 & 2 & 1 & 1 \\ 1 & 2 & 1 & 2 & 2 \end{bmatrix} = \begin{bmatrix} 19 \\ 15 \\ 7 \\ 8 \end{bmatrix} = \begin{bmatrix} 4 \\ 3 \\ 1 \\ 2 \end{bmatrix}$$

[A] [B3] [C3] [D3]

Where;

[A] is the matrix of the councils

[B3] is the matrix of the relative level of the emission ratios in a scale of 1 to 4

[C3] is the within rows matrix summation of [B3]

[D3] is the relative/ranked level of the council's performance based on [C3]

The contents of Table 7.16 provides a summary of all the emission ratios whose ranks are determined to produce a final assessment indicating the general performance of the Territorial Authorities. Waikato District Council, waste management scenario, is the most sustainable system, followed by Opotiki District Council. Rotorua District Council and Auckland Regional Council are in third and fourth positions respectively.

7.4 Conclusion

The quantifications and analyses of the results, to produce the answers to the question of sustainability level in waste management systems, is performed at Territorial Authority level. This is because waste management is the responsibility of Territorial Authorities. This results of the case studies provide confidence of the adaptability and efficacy of the *CEQ-Model* for MSWM emissions evaluations at a local level. The model provides an estimated measure of emissions generated and allows analysis of components within each Councils MSW systems that may be contributing to emissions. The CEQ-Model provides a platform for comparison based on parameters that are common to all the Territorial Authorities under investigation. *Because the CEQ-Model* has empirical foundations, it should prove to be, therefore, a useful tool for achieving unbiased assessment.

Moreover, the same principle can be applied to a single Territorial Authority where historical data is available to evaluate the performance of the Territorial Authority over a period. In this case, the aim will be to establish whether the waste management system is improving over the period under review or otherwise.

The evaluation of the performance level of each Territorial Authority with improved data will be an eye opener for all stakeholders on the true contribution level of the waste management sector to the degradation of the environment and the ecosystem and will help in good policy evaluation and review.

This is a good performance measurement system that will spur each Territorial Authority to improve on its position on the scale relative to other Territorial Authorities. This is an indicative research which will impact on the waste management system in New Zealand and any country where it is applied. Therefore, *CEQ-Model* is recommended for adoption, replacing the current system of waste reduction and emission from landfill as used in New Zealand.

CHAPTER EIGHT

STRATEGIC DATA AVAILABILITY AND STANDARDS

8.0 Introduction

In section 4, some of the setbacks in the New Zealand waste management system were discussed. These included a lack of data, poor policy implementation, inadequate or outdated legislation, conflict of interest among stakeholders and a lack of data standards. Improved performance, required the system to be strengthened and a more robust policy statement built. To pave the way, while avoiding potential loopholes, for improved policies a holistic framework encompassing data, data collection and analysis standards and methods is required.

A holistic waste management approach allows the leverage of valuable waste streams to find innovative solutions for difficult waste fractions. Therefore, finding a solution for all waste fractions within the waste management system. The holistic approach to waste management is only possible with up-to-date and historical data, which will make it possible to track all waste within the waste management system and measure successes in waste reduction and waste diversion policies and implementation.

The inadequacy of waste data means that there is a need for processes and standards to be established. This research, as part of its contribution to waste management, aims to develop an ontological framework to facilitate easy waste management data collection. The ontological framework is intended to simplify the complex MSWM system and make data collection an easy venture. The system implementation achieved through the ontological framework is also expected to ensure data standardization so that the MSWM data is comparable across stakeholders.

8.1 Ontological Framework

There is an increasing need for MSWM data for research and to inform decision making. Even where these data exist, the reliability is questionable, and many assumptions have to be made in interpreting the data (Bogner & Mathews, 2003). Many of the assumptions are due to some epistemological thinking that waste management scenarios are too complex to be mapped and reduced to numerical data. This thinking is as a result of the uncoordinated nature of waste movement which makes it look complicated and impossible to track. Waste generation data and composition do not have the same standard of representation within the same country or even municipality (Mertins et al., 1999). And since many other related data or information resulting from waste management depends on generation and composition, the uncertainties resulting from their values as determines today, leads to unreliable results from analyses carried out for the purpose of decision making. Although efforts are being made around the world regarding the systemic and syntactic heterogeneity in waste management data (University of Illinois at Urbana-Champaign, 2009), the problem has persisted.

The increasing number of sources of waste and changing composition/characters coupled with the increasing demand for more p advanced monitoring and control systems are making waste management and disposal an even more complex venture. Hence, decision makers and practitioners are confronted by many challenges, among them are data extraction, data integration, the modalities to be adopted in collecting these data and the form the data will take to make it useful in the system.

To bring together existing data sources into an adequate information and computational system, it is necessary to exploit their semantic relationship. An ontological framework that captures these relationships and permits the use of valid combinations of scientific resources for the production of new data is, therefore, being advocated. The ontology is a phonological perspective which makes it possible to quantify the series of abandoned measurements which are existing but neglected over the years. Therefore, it is an attempt to establish an organised system of data collection that will enable these data to be collected and represented in a standardized format. Figure 8.1 is a schematic representation of the material flow scenario created by the waste management environment which enables adequate data collection. The detailed architecture is presented in the ontology as represented in Figure 8.2.

8.1.1 Description of the Ontology Design Concept

The core design of the ontology is based on zoning waste generation, management and disposal within a municipal area in such a manner as to be able to monitor the flow of waste. Each zone has an activity level from 1 to 4, depending on whether waste is generated at a reuse/recycling centre (RRC), recovered/reused or managed in a material recovery facility (MRF), treated in a waste treatment facility (WTF), bailed in a transfer station (TS) or disposed at a waste disposal site (WDS) as in Table 8.1.

Table 8.1: Activity levels (hierarchy) in the designed ontological framework

Activity		Level
Waste Generation		1
Transfer Station Material Recovery Facility Recycling/Reuse Facility	Management / Recovery	2
Waste Treatment Facility		3
Waste Disposal Site		4

All activities at the same level have aspects in common (Table 8.1). None or all four levels of activity may exist within a zone, depending on the size of the zone. If any of the four activity levels are missing in a zone, the waste flow system modelled allows the system to cross over to a designated zone in order to facilitate or access the activity or facility that is absent in the originating zone (Figure 8.1). In this way, the destination of all waste from one level to the other is pre-determined within the ontological system as represented in Figure 8.2. As a result of this zonal activity transfer process, metadata related to out-of-zone movement is one item of data that should be collected when adopting the ontological framework depicted in Figure 8.2.

In the future innovations in waste tagging and tracking would improve the availability of data and assist in the collection of the data specified by the ontology. The introduction of a decision support system is possible through the definition of a tagging system in a proper ontology, providing the vocabulary that will be used in encoding the solid waste flow or other operational knowledge-based information to help in the decision-making rules.

In this way, an ontological framework that captures the relationships between the various nodes in the MSWM system is defined. The ontology allows the inference of their valid combinations as a scientific resource for the generation of unique new data as a solution to the present numerous unanswered questions. The ontological framework implements a multiplicity of resources in a data system. Hence developing a data standard which is not currently existing.

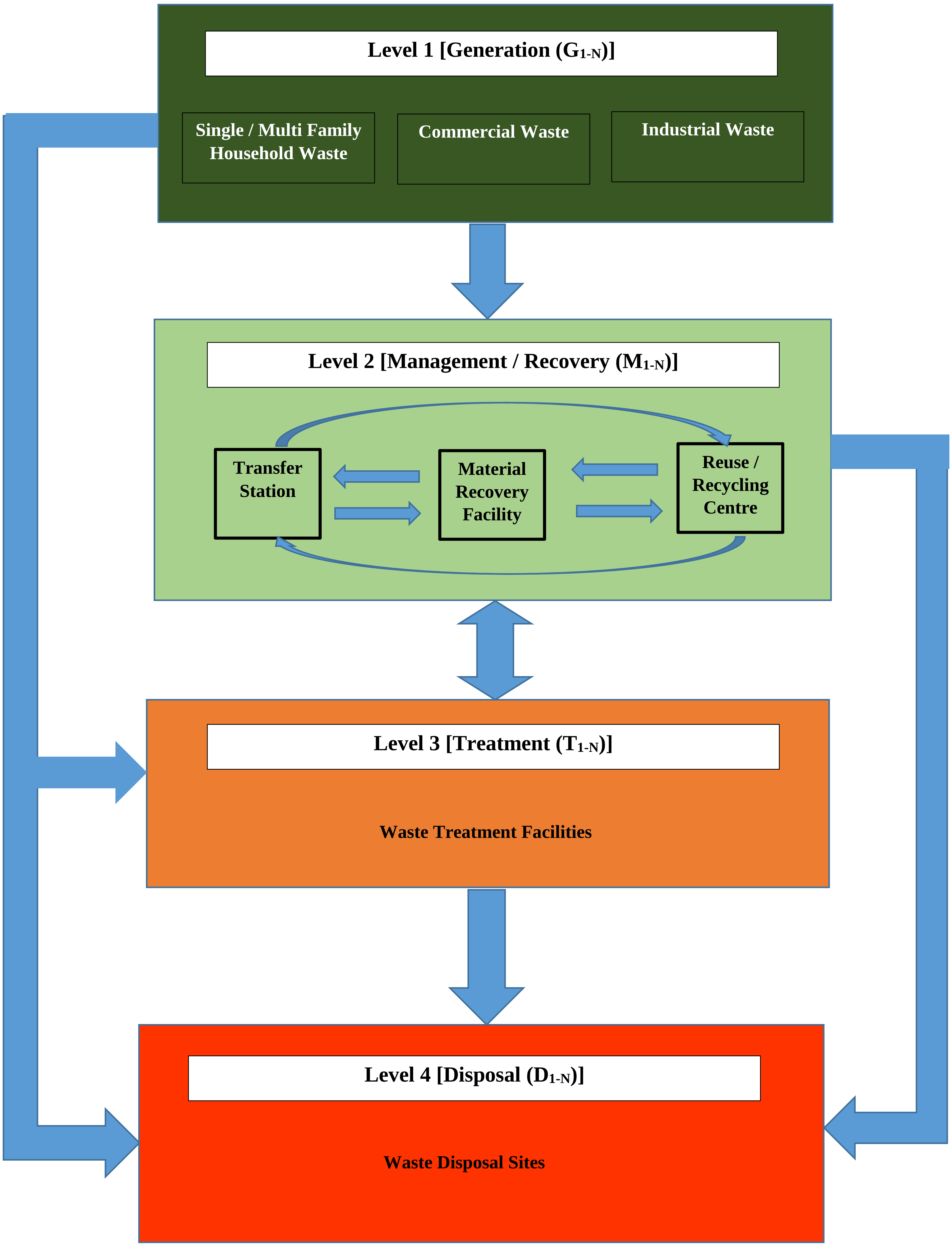


Figure 8.1: Material flow architecture for waste generation, recovery, treatment and disposal, defining the activity levels where waste characteristics are formed and changed

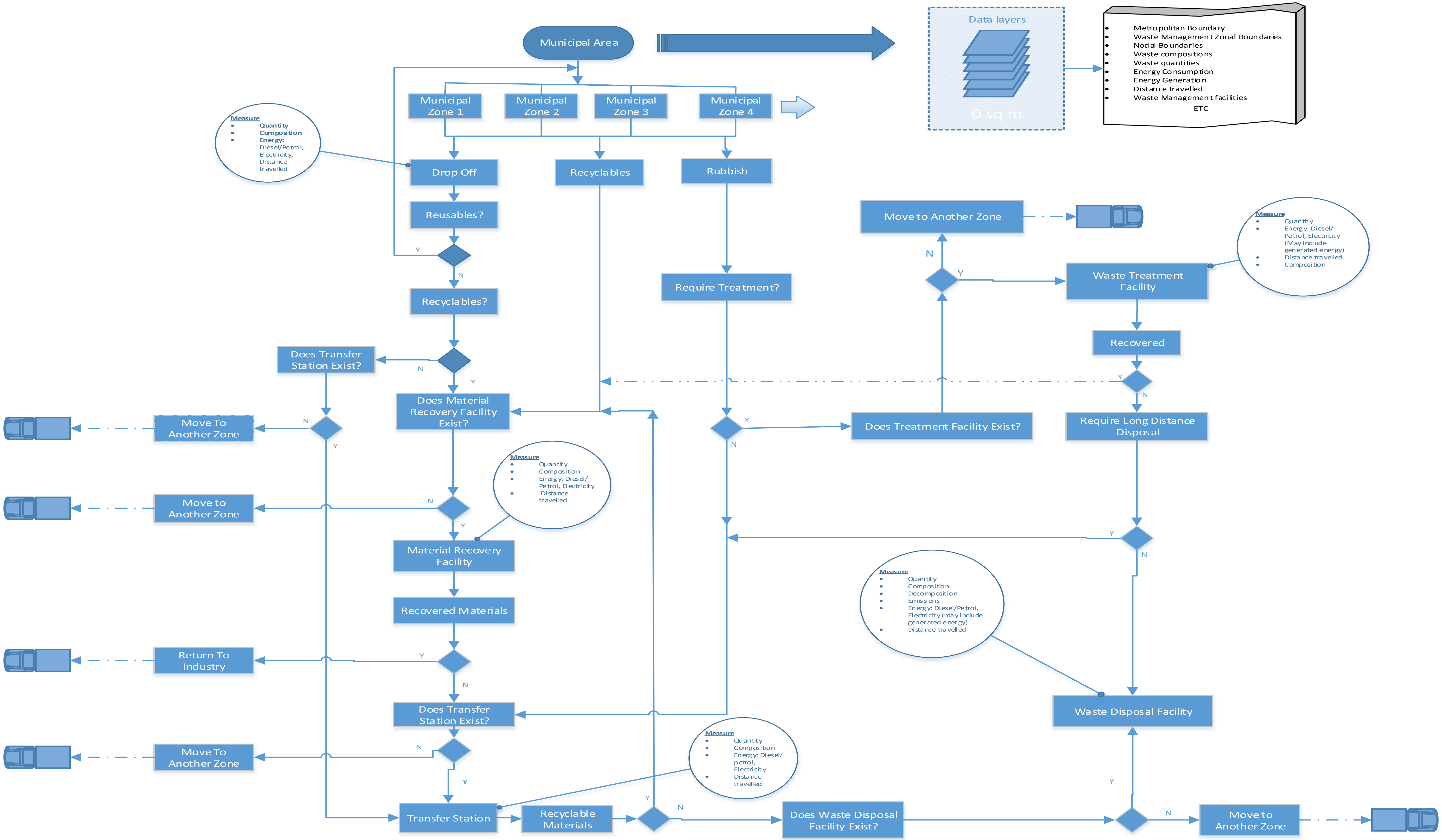


Figure 8.2: The ontological framework

In the ontology, each node represents a particular point of activity within a zone. The node can be defined by a point (using a pair of geographic coordinates) or polygon (using series of geographic coordinates), depending on the level of activity within the node. There are many nodes within a zone. For example, at the level of waste generation, household waste and commercial waste may be defined as a polygon because many addresses are combined in a collection process and data may be collected by the truckload rather than by household bins. In the case of industrial waste, this may be defined by a point depending on whether the industry is large in waste generation. This decision is taken because the volume of waste from a company may be of such a volume to warrant moving straight from the industrial site to any of the nodes in level 2, Level 3 or Level 4 (TS, MRF, WTF or WDS), as the case may be.

These nodes are the centre of the MSWM activities and where the data standards are defined. The nodes are interconnected through a network of movement through which waste is moved. The final destination is the disposal or treatment node. Data standards define the type and quality of data collected at each nodal point and how the data are collected. In this way, the level of waste generation are monitored and recorded at each point and level, and the level of waste recovery or changes from one node to the other are monitored and can be ascertained. The main questions are:

1 What is the position or characteristics of the waste on arrival at a node
2 How is it leaving the node regarding quantity, quality (composition/types) and form?
3 Where did the waste come from and where is the waste going?
4 How did the waste arrive the node?

The definition of how these various data are reported to make comparability possible among zones, nodes, and levels, is very important.

8.1.2 Definition of Coding Terminologies

In Figure 8.1, $G_{1\text{-}N}$, $M_{1\text{-}N}$, $T_{1\text{-}N,}$ and $D_{1\text{-}N}$ is the coding system which is adapted to identify the location of waste data on the hierarchy.

'G' represents 'Generation' and 1-N are the numbers which are assigned to various waste generation points which are defined by a polygon (a set of residential buildings or commercial entities) or a point location (an industrial establishment generating a high volume of waste which are transported to WDS, TS or MRF).

‘M’ represents ‘Management’ and 1-N is the number of facilities within this hierarchy or group (TS, MRF, RRC)

‘T’ represents ‘Treatment’ and 1-N is the number of treatment facilities existing at various locations.

‘D’ represents ‘Disposal’ and 1-N represents the number of WDS existing at various locations.

Figure 8.3 and Figure 8.4 provide examples of a data standard specification for waste collection and transportation. The attributes are defined below to show how data collection standards can be specified. The specification of data helps stakeholders in knowing what to collect and how to collect it:

$S_{1\text{-}N}$ = Defined zones of waste sources

H1 = Defined household MSW sources located in S_1

C1 = Defined Commercial waste sources located in S_1

I1 = Defined industrial waste sources located in S_1

P1 = Waste from S1 (Level 1) moved by petrol-operated vehicles to Level 4 (D1-N)

D1 = Waste from S_1 (Level 1) moved by diesel-operated vehicles to Level 4

P2 = Waste from Level 1 to Level 2 that are moved by petrol-operated vehicles

D2 = Waste from Level 1 to Level 2 that are moved by diesel-operated vehicles

P3 = Waste from Level 2 to Level 1 moved by petrol-driven vehicles

D3 = Waste from Level 2 to Level 1 moved by diesel-driven vehicles

P4 = Waste from Level 2 to Level 3 moved by petrol-driven vehicles

D4 = Waste from Level 2 to Level 3 moved by diesel-driven vehicles

P5 = Waste from Level 3 to Level 2 moved by petrol-driven vehicles

D5 = Waste from Level 3 to Level 2 moved by diesel-driven vehicles

P6 = Waste from Level 3 to Level 4 moved by petrol-driven vehicles

D6 = Waste from Level 3 to Level 4 moved by diesel-driven vehicles

P7 = Waste from Level 4 to Level 3 moved by petrol-driven vehicles

D7 = Waste from Level 4 to Level 3 moved by diesel-driven vehicles

P8 = Waste from Level 1 to Level 3 moved by petrol-driven vehicles

D8 = Waste from Level 1 to Level 3 moved by diesel-driven vehicles

P9 = Waste from recycling/reuse facility to transfer station moved by petrol-driven vehicles

D9 = Waste from recycling/reuse facility to transfer station moved by diesel-driven vehicles

D10 = Waste from MRF to TS moved by diesel-driven vehicles

D10 = Waste from MRF to TS moved by diesel-driven vehicles

P11 = Waste from TS to MRF moved by petrol-driven vehicles

D11 = Waste from TS to MRF moved by diesel-driven vehicles

P12 = Waste from TS to RRC moved by petrol-driven vehicles

D12 = Waste from TS to RRC moved by diesel-driven vehicles

P13 = Waste from RRC to MRF moved by petrol-driven vehicles

D13 = Waste from RRC to MRF moved by diesel-driven vehicles

P14 = Waste from MRF to TS moved by petrol-driven vehicles

D14 = Waste from MRF to TS moved by diesel-driven vehicles

The diesel and petrol used by the waste management companies can also be quantified through the purchase and utilisation inventory.

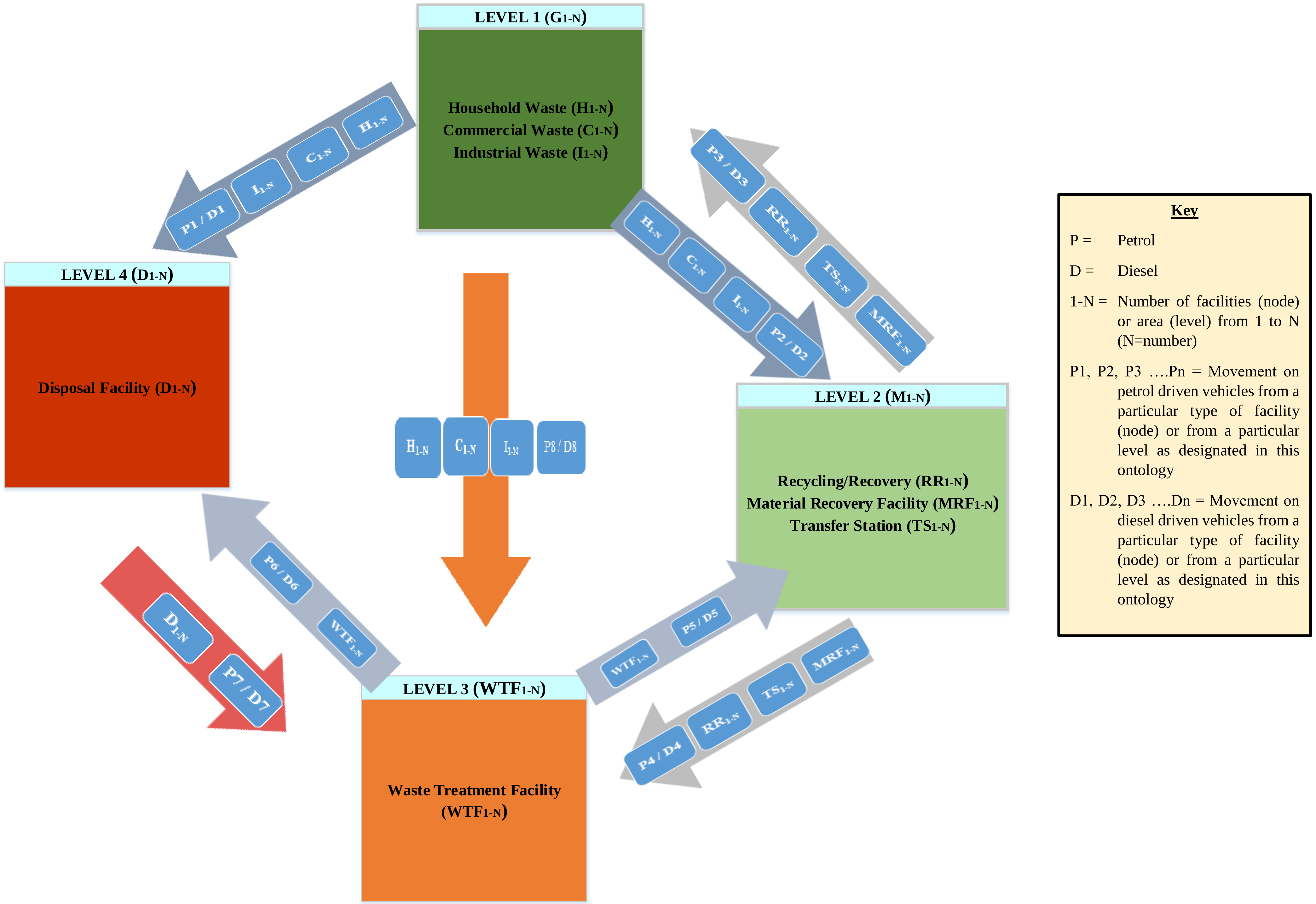


Figure 8.3: Task-specific ontology for waste transport subsector showing movement between levels and possible data tagging for fuel consumption

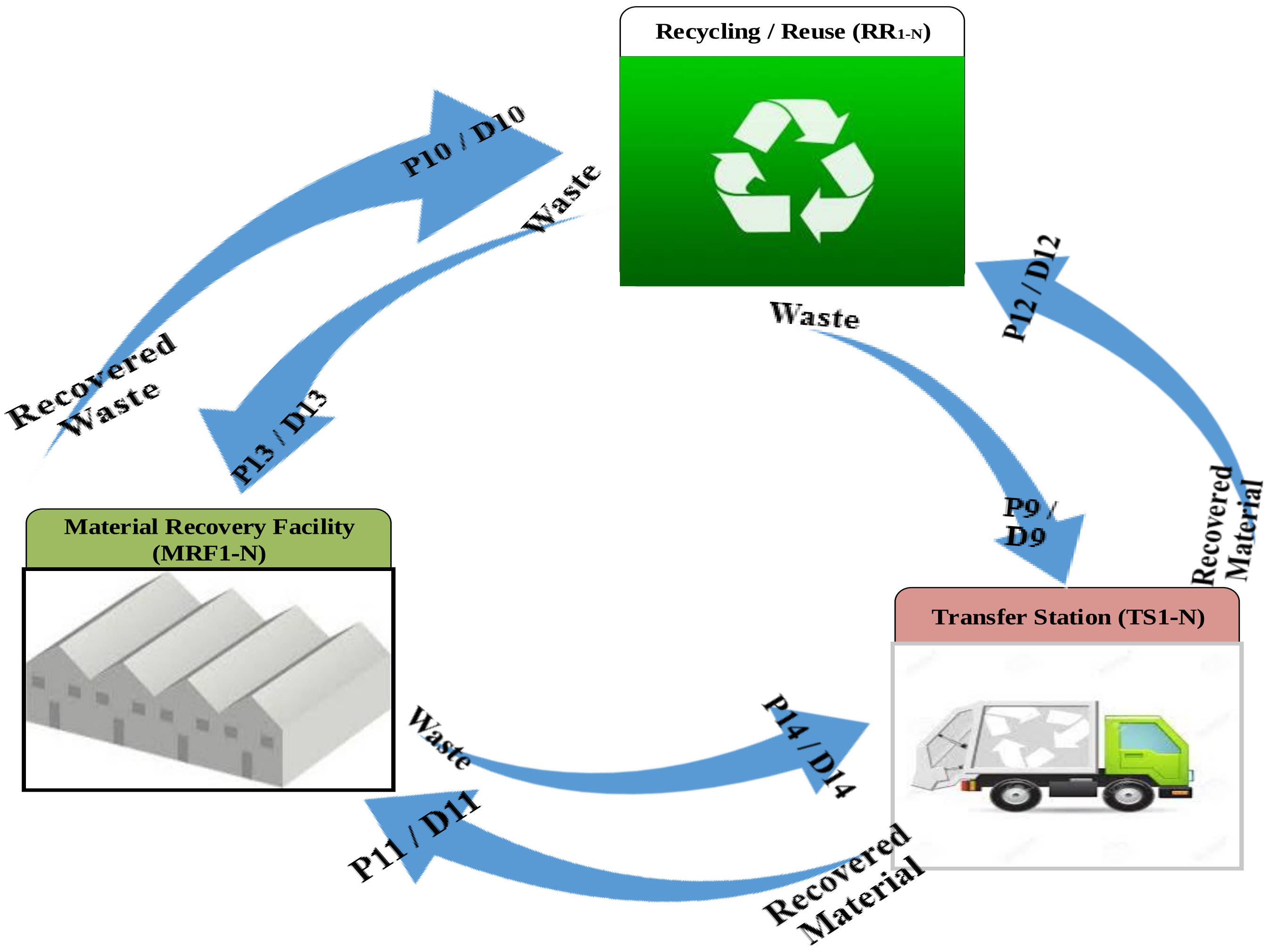


Figure 8.4: Task-specific ontology showing the flow between nodes within level 2 of Figure 8.1

8.1.3 Data Expectation

The volume of data that will be generated at the various nodes from the activities will require an adoption of a new computer-based information system capable of storing a structured data and the automation of the various activities which can only be possible through an ontological based knowledge management framework capable of modelling generic structures in a defined waste data standard. The new data structure is a shift of paradigm from the current system that is based on a broad range of imposed assumptions that results to series of undecided questions of uncertainties.

To simplify the system will require consistent research efforts to establish standards and metadata at the nodes to feed the new system database. The data may be generic in nature as a strategy to creating long-term data and information base.

8.1.4 Implementation

To implement this proposal requires the following:

1. Mapping the municipal area for zoning purpose and facility location
2. Documentation of all stakeholders: waste collectors and all facilities for tagging purpose
3. Monitoring for review
4. Legislation tailored towards ameliorating identified problems

8.1.5 Evaluation Task

This ontological concept is applied to the several physical notions making up the data, such as spatial location, road network, time that are encountered in the various geospatial, environmental and other metadata within the system. The ontological foundation of this knowledge provides a good framework for inferring valid combinations of available scientific resources regarding concrete environmental problems like waste management.

As a requirement for ensuring that the ontological framework meet some universal standard in the field of waste management, expert evaluation was carried out using selected expert. The choice of human experts for evaluation is based on the following:

1. There is no existing ontology similar to the constructed ontology which can be compared (Dokas, 2007) as a system of evaluation

2. At the stage of the ontology, no data can be applied to data based evaluation as in Patel, Supekar, Lee, and Park (2003).

The evaluation required was based on the criteria obtained from the literature on the qualities of a good ontology (Gangemi, Catenacci, Ciaramita, & Lehmann, n.d; Gomez-Perez, 2004; Gruninger & Fox, 1995; Obrst, Ceusters, Mani, Ray, & Smith, 2007). This approach is not infallible, however, and Vrandecic (2009) noted that a good ontology might not necessarily perform well across all the criteria in an expert review.

The following questions were provided to the expert reviewers within the criteria, extracted from the literature as provided below:

Accuracy

1 Does the ontology capture and represent correctly aspects of the real world?

2 Do the axioms comply with the expertise of one or more users within the domains?

Adaptability

3 Is the ontology anticipatory in its applications?

4 How will the ontology react to changes in the axioms?

5 Does the ontology comply with procedures for extensions, integration, and adoption?

6 Is the ontology expandable to include more domain area?

7 Is the ontology looking flexible to adapt to different scenarios?

Clarity

8 Does the ontology communicate effectively the intended application?

Completeness

9 Is the domain of interest appropriately covered?

10 Does the ontology include all relevant concepts and their lexical representation?

Computational efficiency

11 How easy can the usual reasoning services (instance classification, querying, etc.) be applied to the ontology?

Conciseness

12 Does the ontology include irrelevant axioms with regards to the domain to be covered?

13 Does the ontology impose a minimal ontological commitment?

14 How weak are the assumptions regarding the ontology's underlying philosophical theory about the reality?

Consistency

15 Are the formal and informal description of the ontology consistent, i.e. does the documentary description match the architecture?

Implementation

16 Is the ontology easily deployable within real life scenarios?

For ease of evaluation, the questions were arranged in a tabular form with options on a scale of 1 to 10 (Appendix 7). The evaluation scale of '1' represents very poor while '10' represents excellent.

The justification for the use of human experts was given in Section 5.1.4.2.

8.1.6 Evaluation Feedback

Eight professionals some from industry and some from academia were approached and asked to review the ontology. Of these eight experts, four responded. Background information about these fours reviewers, in anonymised form, and their expertise is given in this section.

1. Kate: - A senior academic at a leading American university. Her major area of interest is in landfill gas generation (specifically CH4 emissions), transportation, and emission processes. She has published extensively in the field of waste management and its related greenhouse gas emissions.
2. Jill: - Is the Solid Waste Assets Manager in a small New Zealand district council. She is responsible for MSW collections, resource recovery programs and transfer station operations. Her background as a landfill manager and a site engineer inform her expertise in MSWM practices and processes in New Zealand.
3. David - is the founder of a not-for-profit organisation promoting zero waste initiatives in the UK. David has been involved in waste management for many

years firstly in a local council and later an environmental charity organisation before focusing his interests in the area of the promotion of waste management and reduction.

4. Ian - is a senior environmental and urban planner in a New Zealand City Council. He is involved in consent approval and overseas the implementation of monitoring programs. He over ten years of experience in waste consent application assessment, approval, and monitoring.

The following comments were also made by the reviewers

1 While one reviewer agreed that the ontology was comprehensive and appropriate, concern was expressed regarding the cost of implementation of a data collection program informed by the ontology.

2 One amendment was recommended by Jill. She observed that MSW resulting from MRF might need treatment before disposal or before moving to TS. This observation has been incorporated into a revised version of the framework. The revised ontology is represented in Figure 8.5. The thick orange line indicated the possible new route of movement if the waste from material recovery facility needs to be treated. The orange dotted line was the original path which did not consider treatment prior to recovery.

3 David responded saying– "I think you have hit on a real problem area for the waste industry, which is good data for both business analysis and the collection of data for trends by others. I find data to be patchy, inconsistent, and unstandardized. So your proposals for methodology and data sets have a lot of merits although clearly, more work will need to be done by others. And I fear there is a huge mountain to climb actually to get the lower end of the waste industry to accept this, which they may see as a burden to comply with."

4 Ian sent the following comments in his feedback –

A The ontology diagram captures what I would expect in a municipal waste management process.

B I think the method regarding adaptability could be easily be used in different municipalities.

C While the intention is well understood, I am of the view that complexities should be reduced. For example following the flow sequences below

Municipal 1 on the ontology diagram, I would have thought that the materials that get to the transfer station should go straight to waste disposal as they have already gone through the process of sorting for recyclable and recovery. So why do they have to come out as recyclables again and possibly get back to the recovery facility?

D From my experience, the model is not far from how municipal waste is processed. At least, I have been to two waste collection facilities in Hamilton and could see waste coming into the facilities being sorted. The materials that were not separated from the heap as recyclables were prepared for transportation off the facilities to final disposal, which I guess was to a landfill.

E I think the waste management process and the assumptions are fine. However, a more detailed explanation as to how the criteria relate to and their relevance to the ontology would be appreciated."

8.1.6.1 Response to the Feedback from Experts

The ontology is developed following the general waste management system representation obtainable in a municipality involved in waste management. The various waste management activities include; collection, transportation (from one point of activity to another), recycling, recovery, treatment, and disposal. The level of coverage of these various waste management activities varies from municipality to municipality, depending on the waste management policy, the level of technology implementation, and the level of commitment of stakeholders in observing and implementing sustainable principles. Therefore, there is no abstract introduction in the ontology.

The concerns of the expert reviewers can be summarised under the following:

(i) **The cost of implementation:** It is worthy of note that the implementation of a new system can increase or reduce the cost of running the system. The resultant impact on cost will, however, depend on the cost of initial implementation of the new system and the continuous maintenance of the system, compared to the cost of maintaining the old system. However, there are some factors which must be considered when counting the cost of the new system. A new policy initiative which is implemented through the introduction of a new technology may bring some benefits such as improvement in service delivery or transparency through integration. Hence, it is the cost-benefit analysis that will point to the worthiness of the new system.

The cost of implementing a technology may appear to be expensive at the initial stage of implementation but may save money in the long run. The practices in waste management are currently disjointed, each municipality doing their thing not minding what is happening in other cities. The ontological framework is an integrated system, promoting data sharing and partnership. The principle of integration will save money for the stakeholders and increase efficiency.

(ii) **Resistance from some stakeholders:** Resistance to the implementation of a new policy can be linked to the existence of some 'blind-spots' and attitudes which some stakeholders may have because of their preoccupation with the technicalities of the new system. Resistance to change may be linked to fear of loss of long-term investment in certain routines which some stakeholders may not want to give up. Resistance can also be linked to fear of extra cost in executing certain aspect of the business which will affect profit. Therefore, Quast (2012), suggested that decision makers need to:

- Try and understand what the specific change entails, that is, what are the new things inherent in the new system?
- What are the impacts on the stakeholders?
- What are the possible reasons for resistance?

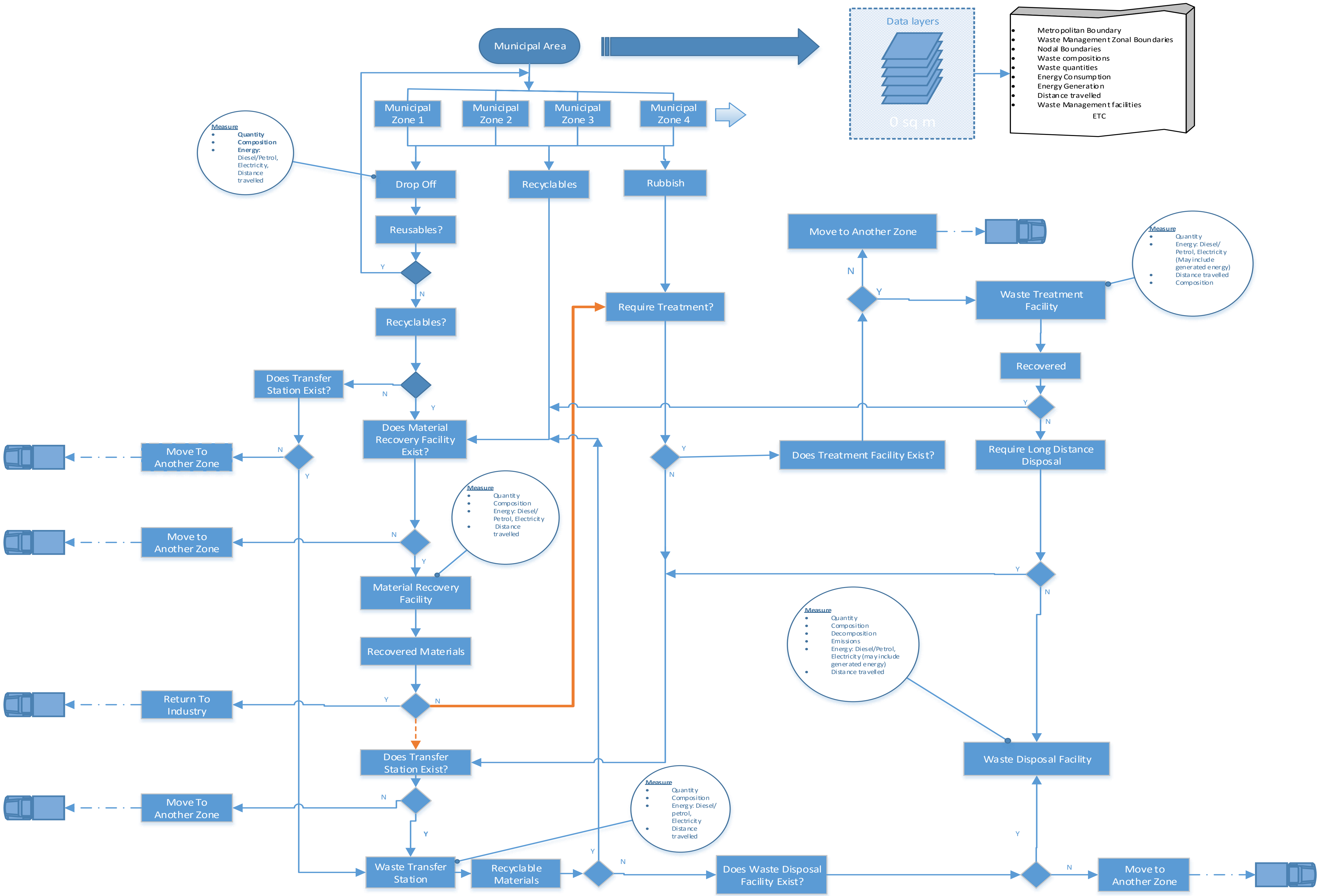
Being aware of these issues will help in implementing a new system with less resistance. In the case of the implementation of this ontological framework, everything is revolving around more data collection. Education will be needed to inform stakeholders; legislation will be required to enforce the new data collection modalities.

(iii)**The Complexity of the System and Adaptability:** As stated before, the ontology is a reflection of what happens in a waste management system. There are going to be differences between municipalities. The ontology is intended to be generic enough to apply to most MSWM scenarios while still capturing essential detail/information. Although the ontology may appear complex, it is the researcher's stance that the ontology is a simple as it can be without losing critical information. It is expected that any implementation of data collection guided by the ontology would be a digital system. Such as system could make use of sensors and other automated or semi-automated data collection processes, possibly included procedures such as image recognition. Additionally, it is anticipated that data need only be inputted oat the time the waste flow is at a node as shown in Figure 8.6. The data content at the different nodes includes basic waste data – volume of waste, waste composition, power consumption (simple meter reading), refrigeration and cooling (if leakage is involved), electricity generation (if waste to energy is in place, meters could be used to collect such consumption), petrol and diesel consumption, and distance travelled (recording systems could be establish using onboard boxes which communicate within a wireless sensor network). **Treating Waste from MRF:** This point was a valid point and has been incorporated into the final ontological framework (Figure 8.5).

According to Ceccaroni (2001), an ontology is an explicit formal specification of shared conceptualization. "Ontologies specifies in a standard way, the knowledge that is exchanged and shared between the different systems, and within the systems by the various components" (Vrandecic, 2009, p. 13). It describes the concepts and relationships among the various domain, tasks or application within the waste management system. Therefore, it can be used to share knowledge about specific aspects of the real world (Guarino, 1998) within the MSWM system in an unambiguous way. In this way, Sheth (1999) stressed that capturing commonly agreed on knowledge regarding ontologies is a significant step towards addressing data availability. Hence, semantics interoperability in an information system is solved. Thus, the intrinsic meaning is given to the data within the MSWM system.

8.2 Conclusion

The expectation of this research is a knowledge base integrated waste management system. The result is a combination of spatial and non-spatial data linkages and other relevant technologies, in solving the long-standing problem of waste data collection, standardization, and management. The Structured Query Language (SQL) database of the municipality mapping/address system and MSW information system will be built on an MSW tracker website with an online logging and possibly a wireless sensor network. This tracker website system makes it possible for a data feed from various data link (waste management companies and municipal authorities), data retrieval and downloads.



Municipal Area
Data layers
0 sq m
Metropolitan Boundary
Waste Management Zonal Boundaries
Nodal Boundaries
Waste compositions
Waste quantities
Energy Consumption
Energy Generation
Distance travelled
Waste Management facilities
ETC
Municipal Zone 1
Municipal Zone 2
Municipal Zone 3
Municipal Zone 4
Measure
Quantity
Composition
Energy: Diesel/Petrol, Electricity, Distance travelled
Drop Off
Recyclables
Rubbish
Reusables?
Move to Another Zone
Measure
Quantity
Energy: Diesel/ Petrol, Electricity (May include generated energy)
Distance travelled
Composition
Waste Treatment Facility
Require Treatment?
Recyclables?
Recovered
Does Transfer Station Exist?
Does Material Recovery Facility Exist?
Move To Another Zone
Does Treatment Facility Exist?
Require Long Distance Disposal
Measure
Quantity
Composition
Energy: Diesel/ Petrol, Electricity
Distance travelled
Move to Another Zone
Material Recovery Facility
Measure
Quantity
Composition
Decomposition
Emissions
Energy: Diesel/Petrol, Electricity (may include generated energy)
Distance travelled
Recovered Materials
Return To Industry
Does Transfer Station Exist?
Waste Disposal Facility
Measure
Quantity
Composition
Energy: Diesel/ petrol, Electricity
Distance travelled
Move To Another Zone
Waste Transfer Station
Recyclable Materials
Does Waste Disposal Facility Exist?
Move to Another Zone

Figure 8.5: Final ontological framework based on feedback from expert reviewers

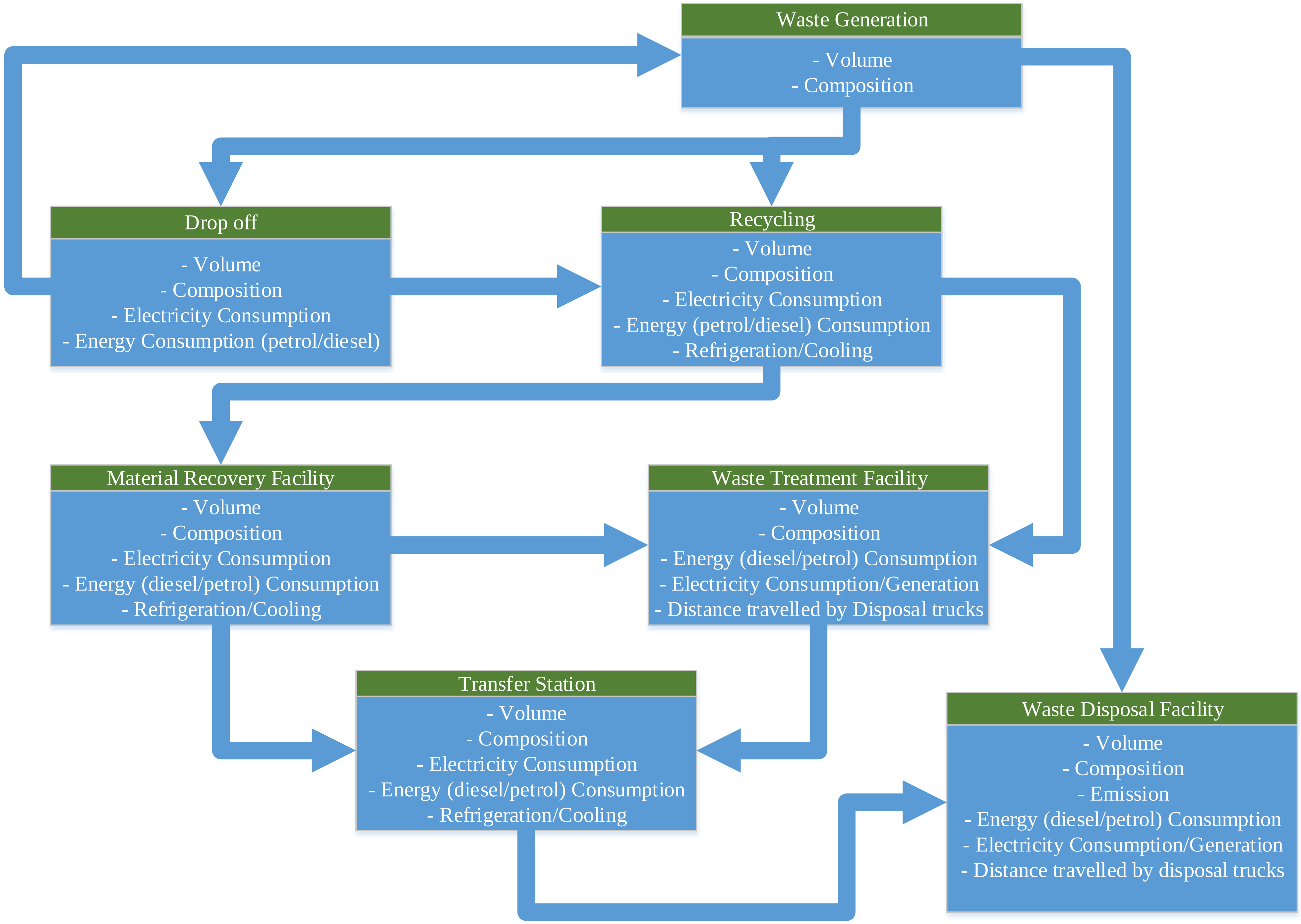


Figure 8.6: Waste data flow diagram indicating the data collection nodes and the type of data expected

CHAPTER NINE

CONCLUSIONS

One word that could be used to define the theme underpinning the research presented in this thesis is 'change'. The researcher comes from a philosophical stance which advocates for changes in waste management policy that will improve the quality of our environment. Poor waste management has been identified as a major contributor to the current state of the environment. Current waste disposal methods have led to environmental pollution, global warming, and poor human health. But changing a policy is not always easy, as Pierson (2000) noted that public policies and institutions are not easily changed. Capoccia and Kelemen (2007, p. 341) identified "critical junctures" as one major thing policy makers wait for before introducing policy change. Critical junctures may be a period of crises. Once a country has set a particular policy path, changing this path is difficult and costly because the actors and the policies become institutionalized (Cerna, 2013). Waiting for a critical juncture can lead to policy change being an expensive venture. Globally the environment is at a critical juncture due to the impacts of climate change. As a result, any systems seen to contribute to global warming are being targeted for remediation. MSW is one of these contributors. A review of waste management policies to reduce emissions and other negative environmental impacts of the current MSWM practices is essential as the world reaches this critical juncture.

This research began with a comprehensive review of MSWM and policies, tracing the historical evolution of waste management practices, evolving legislation, and driving factors. This review revealed that the costs of waste and of managing waste have historically dictated society's attitude to waste. The cost of waste includes poor environmental aesthetics, epidemics and disease, and air pollution to mention but a few. The financial burden of waste management has been on the increase worldwide. The World Bank (2012) estimated the global cost of MSWM at US$205.4 billion. This is expected to increase to US$375 billion by 2025 (World Bank, 2012). To reduce waste to landfill and the cost of MSWM, new legislative initiatives have been introduced. These legislative initiatives include New Zealand Waste Minimisation Act 2008 which provide for:

- **generator-pay policies** −where residents are charged according to the amount of waste they generate in the waste management system,\and
- **product stewardship policies** − where entrepreneurs contribute into the management of the waste resulting from the consumption of their products and services.

Such policies should result in companies rethinking and redesigning their products and services to reduce waste. Consumers are becoming aware of the need to reduce their waste generation and of the type of waste they generate. The new legislation and MSWM policies in New Zealand and other OECD countries have resulted in the introduction of new technologies. For instance, new waste-to-energy technologies have emerged to solve the problem of pollution resulting from incineration (Crawford, 2013; Stringfellow, 2014; Plastic New Zealand, 2012). Legislation has also driven the development of technology and methods for monitoring and measuring the impact of waste and to minimise the environmental impact of waste management practices (European Union, 2008; New Zealand Legislation, 2008).

One major aspect of the research presented in this thesis was related to emission quantification models. A review of emissions models pointed to a number of critical issues in the models. One of these issues was the use of expert determined parameter values rather than those based on ground truth data. Secondly, was the lack of consistency in the definition of waste streams between regions which means that emissions cannot be compared with confidence. Data adequacy is another major issue. These issues point to a lack of standards for data in waste management. Another critical issue in MSWM models is that the time frame for total emission release from the waste disposal site is a point of conflict. The number of years ranges from 80 years in the IPCC model to 100 years in EASEWASTE, Afvalzorg and LandGEM models and 140 years in the IWM model. In the *CEQ-Model*, developed as part of this thesis research, all emissions are released in the year preceding disposal.

In general, other emissions models define waste management emissions as emissions from disposal sites. This thesis research viewed emissions from waste management as consisting of emissions from all processes in the management chain from the collection, transportation, all management processes, and equipment, to disposal. Therefore, in developing a comprehensive emission quantification model, the *CEQ-Model*, which is one of the contributions of this research, the emissions is categorized into emission from the disposal site, emissions from transportation, emissions from purchased electricity, and emissions from refrigeration/cooling. The emissions from purchased electricity and refrigeration could not be quantified because of a lack of data. However, provision is made in the *CEQ-Model* for such factors to be included when the data is available.

In the case studies, computation of emissions using the *CEQ-Model* was undertaken with the knowledge that the quantity calculated does not directly include emissions resulting from waste collection process due to a lack of ground truth data. Instead, the distance travelled by vehicles transporting waste from transfer stations to disposal site was used. This distance is not fully representative of the transportation factors but is a pragmatic choice based on the data available at the time of this research. Obviously, any evaluation of emissions models is limited by the data, but the quantifications from different models can be compared because they were all implemented using the same data.

One approach to addressing the issue of data adequacy is to design and specify data standards. Such a system should define:

- Data collection methods
- Data dictionary
- Data storage
- Reporting guidelines

A major barrier encountered in the course of this research was data availability and the accompanying resistance to monitoring. Waste management contractors proved unwilling to release relevant data on the grounds of commercial sensitivity. This illustrated the lack of transparency and openness which is commonly encountered in the waste management sector. Transparency and openness encourage partnership and cooperation which in turn helps guide the move towards sustainable practices. It is the viewpoint of this researcher that in part because of this resistance, waste data collection system, and management practices should be provided for in legislation. As part of this legislation, all contractors would be required to be registered. The registration or licensing process would then have provisions for education and training, along with on-site reviews, to ensure monitoring and processes adhere to best practices and standards. In this way, a level of commitment is assured and monitoring integrated into the MSWM system.

In this research, a data collection system is proposed and developed through an ontological framework intended to cover MSWM scenarios. The ontology creates a better understanding of MSWM system and the points in the cycle where data collection is necessary as well as what data should be collect at each point. In the ontology designed as part of this research Geographic Information System (GIS) principles are adopted to manage the spatial and temporal data component of the waste management scenario. The data specified by the ontology includes:

i. Municipal boundaries
ii. Waste management zonal boundaries
iii. Categorized waste management facilities mapping (generation points, material recovery facilities, waste treatment facilities, and disposal facilities)
iv. Waste generation quantity
v. Quantity of waste treated for recovery, reuse or disposal
vi. Quantity of waste recovered
vii. Quantity of waste reused
viii. Quantity of waste disposed
ix. Waste composition data
x. Energy consumption: Petrol and diesel
xi. Electricity consumption
xii. Refrigeration/cooling gas release
xiii. Electricity and heat generation in waste-to-energy (where applicable)
xiv. Mode of transportation
xv. Distance travelled

As these data are collected at different points designated as nodes in the ontology, all stakeholders would need to be aware of their level of involvement and commitment for such a system to be viable. The ontological framework formulated in this research is intentionally generic in nature so that it can, in principle, apply to any waste management system. This ontology has not been implemented in terms of data collection. For the ontology to be implemented a policy change is required.

In New Zealand, many territorial authorities claim that they are achieving sustainability in their waste management system without convincing evidence of the outcomes of their practices. The *CEQ-Model* could be adopted as an unbiased sustainability measurement tool. In this research, an evaluation of the *CEQ-Model* was undertaken. It was used to assess four territorial authorities. The findings suggest that the *CEQ-Model* is useful and is sufficient to explain a territorial authority's MSWM practices. For an example, of the four case study areas, Opotiki had the lowest percentage DOC volume but Rotorua had the lowest emissions according to the *CEQ-Model* quantification. This a reflection of the different MSWM scenarios for the territorial authorities. Opotiki's higher *CEQ-Model* emission value compared with Rotorua which actually had a higher percentage Degradable Organic Carbon volume, was a reflection of the long distance travelled to dispose of the waste outside of Opotiki. Auckland had the highest emissions, a result that can be explained by lower rates of recycling, larger waste volume generation, and the relatively long transportation distance to the primary landfill, Hampton Downs. In the course of this research the following research questions were considered:

RQ 1: Is it possible to develop a framework to improve data quality and availability?

This is the overall encompassing research question, and the answer is yes. It is possible to develop a framework to improve data quality and availability. Such a framework should ideally include environmental impact models and data standards as well as encompass all MSWM processes. The review of the literature, legislation, and data currently available presented in this thesis clearly illustrates current limitations on data availability and adequacy. Indeed the lack of standardised data collection is recognised as a major problem for waste management (Mertins et al., 1999). Any monitoring being undertaken at the current point in time is flawed due to a limited view of the waste management cycle in emissions quantification models and a lack of standards for data. Clearly, there is scope for improvement. This research has developed a more comprehensive emissions quantification model than existing models and conceptualised a new ontology for MSWM. Both of these artefacts have the potential to improve the information currently available to decision and policy makers. Additionally, the ontology provides a starting point for further discussions and standards specifications aimed at improving the data available for decision and policy making, monitoring, and reporting purposes.

RQ 1.1: What are the historical drivers influencing municipal waste management in New Zealand?

The thesis identified the historical drivers of waste management to include:

The cost of management which was the driver of waste management from history. 'Out of sight is out of mind' was the basic guide, when waste was dumped in waterways, on the roads and drainages, without minding the repercussion. This practice led to poor city aesthetics, pollution and contamination, flood as a result of drainage blockage and many other problems.

Closely following this driver is the value of recycled materials (economic value of waste). Waste which is still valuable in any form, are not likely to be disposed of. Therefore, the public perception of what is waste, was and is still a major driver. The perception and value of the waste determine the way the waste is managed.

The characteristics of the waste stream (content of waste composition) determine the management procedure. This is also influenced by the available technology. The value of land determines whether there will be land for disposal purpose. Therefore, how easy is it to convert land to a disposal site? Before the emergence of legislation to control the way waste is managed, creating a disposal site was quite easy. It is not that easy today. In 2017, waste is being treated as resource and source of energy.

RQ 1.2: What ontological framework could be developed to improve the quality of municipal solid waste management?

The establishment of the position of data in sustainable waste management resulted in a critical evaluation of MSWM systems to identify possible improvement. It was determined that an ontology encompassing the entire waste management scenario or life cycle which was general enough to be adapted to differing local scenarios was required and could be developed.

RQ 1.3: What Factors influence the viability to model a municipal solid waste management system?

In chapter six of this thesis, the *CEQ-Model* was conceived. To determine the reliability of the results produced by *CEQ-Model,* some existing waste management models were selected and used to model the same scenario and the results compared with the results produced by *CEQ-Model*. Table 6.21 and Figure 6.1 represent the results from the various models. The IPCC model produced the nearest result to the result of *CEQ-Model*. The review of parameters and assumptions used in other models (Table 6.20) points to variation in data and parametric standards being a major problem and hindrance to the efficient modelling of emissions from MSWM. This issue is exacerbated by the uncertainty in specified values for some parameters in emissions models which are set by authorities or based on assumptions or on laboratory simulation or experimentation rather than ground truth data (De la Cruz & Barlaz, 2010; US EPA, 2004). In the Auckland

Council 2010 waste composition survey, the Council and private waste companies reported conflicting waste composition data (Auckland Council, 2011). A lack of data standards is likely to be one of the reasons for this reporting discrepancy. In examining the major threats to the viability of modelling MSWM the notion of an ontological framework to resolve data issues was conceived.

As a result of this work during the literature review, data acquisition/search phase and model implementation phase of this research a number of factors were identified which are barriers to modelling MSWM systems including:

- Lack of Data Standards
- Lack of consistent data collection and monitoring procedures
- Resistance to monitoring – privatisation of the sector
- Inadequate legislation and policies
- Costs of system change
- Ongoing cost of improved monitoring and data collection standards
- Lack of "real" ownership of MSWM by some stakeholders

To achieve sustainability and integration, an MSWM system requires coherent policy development, financing, technology and infrastructure, and clear stakeholder roles and responsibilities.

RQ 1.4: What factors constrain the efficacy of current models?

The external factors which constrain the efficacy of the models are essentially the same as those which affect the viability of the models.

The ontology was evaluated using expert reviews due to the lack of available data. This evaluation was limited by the small number of responses received. However, the expertise of the reviewers meant that feedback was obtained that resulted in an improvement to the ontology. However, the efficacy of the model has not been proven empirically, and the ontology stands as a conceptual contribution which requires a data-driven evaluation in the future when adequate information allows this evaluation.

The *CEQ-Model* is based on the assumption that appropriate measurements and data collection are conducted at all stages of the waste management system. In order to fully evaluate the efficacy of the model better data is required.

9.1 Policy Implication of implementing the research results

The global aspiration is to achieve zero waste situation in cities around the world. This is the target of New Zealand through the Waste Minimisation Act of 2008 and New Zealand Waste Strategy of 2010. This is reflected in the waste management and minimisation plans produced and implemented at territorial authorities level. The achievement of the various targets of the waste management and minimisation plans are hampered by the level of data collection and the standard of the available data. Hence planning for service delivery monitoring become impossible.

The implementation of the ontology as developed in this thesis will help cities in New Zealand and governments around the world to collect reliable waste management data. The up to date data collection will help in system monitoring and policy update. Currently, data inconsistency is a major problem. The ontology will facilitate the establishment of data standards leading to consistency and comparability within and across borders. Waste data collection will be given its prime of place in waste management policy implementation.

The understanding of the waste management performance through close monitoring and evaluation will point to where policy review is needed, directing scarce resources where it is most needed. For instance, reduction in the volume of waste to landfill is not guaranteed under a sustainable system but is depending on the prevailing composition and management strategy. Therefore, this understanding will trigger policy review. In New Zealand, this may lead to waste management and minimisation fund being channelled to handling a particular waste fraction as a strategy to reducing the emission output and composition.

Implementing the outcome of this thesis will also impact on the planning/design of emerging cities around the world. The zoning of city's waste management system is a new concept which, if integrated into the planning and design of new cities, will change the general infrastructural development. Waste management facilities and infrastructures should be considered as important as sewers, power lines and water distribution network. This will change the way we see our cities.

To achieve the above goals, however, New Zealand and countries around the world will require doing the following:

a. New town planning laws and policy will need to be put in place, recognising the importance of waste management infrastructures and the need to incorporate them at the onset of the city conception. At present, waste management planning and implementation come last after the city is taken up by residents.

b. New legislation will be required to register all waste management entrepreneur and service providers. This registration is to facilitate easy data collection, setting data standards, monitoring of policy implementation and highlighting the responsibility of all stakeholders. It may be necessary to recommend the frequency of policy review due to the dynamic nature of waste management.

9.2 Future Work

One obvious avenue of future work is a data-driven evaluation of the ontology conceptualised in this thesis. In order to undertake such an evaluation ground truth data would need to be acquired and processes and instrumentation for real-time monitoring of such data would need to be identified and implemented in the field. Additionally, tools for representing and evaluating the ontology itself, such as OWL (Hitzler, Krötzsch, & Rudolph 2009) could be investigated.

If ground truth data is collected for evaluating the ontology or using the ontology to collect the data then the *CEQ-Model* could also be evaluated in a more rigorous manner with accurate empirical data related to waste composition, transportation etc. Such an evaluation would require instrumentation and data logging processes to measure and record the amount and composition of gases emitted from the landfill and relevant recycling facilities in order to be able to compare expected with observed values to determine the accuracy of the estimates.

Integration of aspects of deterministic physiochemical based emissions models with the CEQ-*Model* may improve the reliability of emissions quantification models and help account for longer term trends. Such an avenue of research requires a long-term view as historical data would be required in order to be able to evaluate such a models’ ability to predict trends or project into the future.

References

Abichou, T., Clark, J., Tan, S., & Chanton, J. (2011a). Reporting central tendencies of chamber measured surface emission and oxidation. Waste Management, 31(5), 1002-1008.

Abichou, T., Mahieu, K., Chanton, J., Romdhane, M., & Mansouri, I. (2011b). Scaling methane oxidation: From laboratory incubation experiments to landfill cover field conditions. Waste Management, 31, 978-986.

Adams, K. T., Phillips, P. S., & Morris, J. R. (2000). A radical new development for sustainable waste management in the UK: the introduction of local authority Best Value legislation. Resources, Conservation and Recycling, 30(3), 221-244. doi:http://dx.doi.org/10.1016/S0921-3449(00)00061-6

Adger, W. N., Brown, K., Fairbrass, J., & Seyfang, G. (2003). Governance for sustainability: Towards a 'thick' analysis of environmental decision making Environment & Planning A, 35(6), 1095-1110. doi:10.1068/a35289.

Adhikari, B., Dahal, K. R., & Khana, S. N. (2014). A Review of Factors Affecting the Composition of Municipal Solid Waste Landfill Leachate. International Journal of Engineering Science and Innovative Technology (IJESIT), 3(5), 273-281.

Agency for Toxic Substances & Disease Registry. (2001). Chapter 2: Landfill Gas Basics. In Landfill Gas Primer - An Overview for Environmental Health Professionals. Retrieved from http://www.atsdr.cdc.gov/HAC/landfill/html/ch2.html

Ahmed, A., & Sil, R. (2012). When Multi-Method Research Subverts Methodological Pluralism—or, Why We Still Need Single-Method Research. Perspectives on Politics, 10(4), 935-953. doi:10.1017/S1537592712002836

Aitchison, E. M., Meadows, M. P., Wenborn, M. J., Marlowe, I. T., Mikkelson, M., Milton, M., . . . Pocock, R. (1996). A Methodology for Updating Routinely the Annual Estimate of Methane Emissions from Landfill Sites in the UK. ETSU, AEA Technology, Report RYWA/18678001/R4.

Amini, H. R., Reinhart, D. R., & Mackie, K. R. (2012). Determination of first-order landfill gas modeling parameters and uncertainties. Waste Management, 32(2012), 305-316. doi:10.1016/j.wasman.2011.09.021

Arena, U., Mastellone, M. L., & Perugini, F. (2003). The environmental performance of alternative solid waste management options: a life cycle assessment study. Chemical Engineering Journal, 96(1-3), 207-222. doi:10.1016/j.cej.2003.08.019

Assamoi, B., & Lawryshyn, Y. (2012). The environmental comparison of landfilling vs. incineration of MSW accounting for waste diversion. Waste Management, 32(5), 1019-1030. doi:10.1016/j.wasman.2011.10.023

Atamturktur, S., & Stevens, G. (2014). Validation of Strongly Coupled Models: A Framework for Resource Allocation. In H. S. Atamturktur, B. Moaveni, C.

Papadimitriou, & T. Schoenherr (Eds.), Model Validation and Uncertainty Quantification, Volume 3. New York: Springer.

Auckland Council. (2011). Auckland Council waste assessment (Produced under the auspices of the ATA) Notified October 2011. Auckland. Retrieved from http://www.aucklandcouncil.govt.nz/EN/environmentwaste/rubbishrecycling/wastemanagementandminimisationplan/Documents/wasteassess-report.pdf

Auckland Council. (2012). Solid Waste Bylaw 2012. Auckland. Retrieved from http://www.aucklandcouncil.govt.nz/EN/licencesregulations/Bylaws/SolidWaste/Documents/solidwastebylaw2012.pdf

Auckland Council. (2014a). Auckland Air Emissions Inventory 2006: Technical Report 2014/015 (TR2014/015). Auckland. Retrieved from http://www.aucklandcouncil.govt.nz/SiteCollectionDocuments/aboutcouncil/planspoliciespublications/technicalpublications/tr2014015aucklandairemissionsinventory2006.pdf

Auckland Council. (2014b). Report on an application for resource consent (Application No.: LAN61338, REG61341, REG61342, REG61343, and REG61544). Retrieved from http://www.aucklandcouncil.govt.nz/SiteCollectionDocuments/aboutcouncil/hearings/redvalelandfillhrgrpt20140722.pdf

Auckland Council. (2016). Great Barrier Local Board - About the Great Barrier area. Retrieved 29 February 2016, from http://www.aucklandcouncil.govt.nz/EN/AboutCouncil/representativesbodies/LocalBoards/GreatBarrierlocalboard/Pages/about.aspx

Australian Government Department of the Environment. (n.d-a). International hazardous waste conventions. Retrieved 20 February 2014, from http://www.environment.gov.au/topics/environment-protection/hazardous-waste/conventions

Australian Government Department of the Environment. (n.d-b). Stockholm Convention on Persistent Organic Pollutants (POPs). Retrieved 22 February 2014, from http://www.environment.gov.au/topics/environment-protection/chemicals-management/pops

Avfall Sverige. (2009). Swedish Waste Management. Malmö, Sweden. Retrieved from http://www.avfallsverige.se/fileadmin/uploads/Rapporter/SWM.pdf

Avfall Sverige. (2010). Swedish Waste Management 2010. Malmö, Sweden. Retrieved from http://www.avfallsverige.se/fileadmin/uploads/Statistikfiler/SWM2010.pdf

Avfall Sverige. (2011). Swedish waste management. Retrieved from http://www.avfallsverige.se/fileadmin/uploads/Rapporter/Utveckling/Rapporter_2011/SAH_eng111219.pdf

Avfall Sverige. (2013a). Swedish waSte management. Retrieved from http://www.avfallsverige.se/fileadmin/uploads/Rapporter/SWM_2013.pdf

Avfall Sverige. (2013b). Towards a greener future with Swedish waste-to-energy: The world's best example. Retrieved from http://www.avfallsverige.se/fileadmin/uploads/forbranning_eng.pdf

Ayalon, O., Avnimelech, Y., & Shechter, M. (1999). Issues in designing an effective solid waste policy: the Isreali experience. In T. Sterner (Ed.), The market and the environment: the effectiveness of market based instruments for environmental reform. UK: Edward Elgar.

Backstrand, K. (2003). Civic Science for Sustainability: Reframing the Role of Experts, Policy-Makers, and Citizens in Environmental Governance. Global Environmental Politics 3(4), 24-41. doi:10.1162/152638003322757916

Barton, J. R., Issaias, I., & Stentiford, E. I. (2008). Carbon - Making the right choice for waste management in developing countries. Waste Management, 28(4), 690-698. doi:org/10.1016/j.wasman.2007.09.033

Beck, M. B. (2005). Environmental foresight and structural change. Environmental Modelling & Software, 20(2005), 651-670. doi:10.1016/j.envsoft.2004.04.005

Beloff, B. R., Beaver, E. R., & Massin, H. (2000). Assessing societal costs associated with environmental impacts. Environ. Qual. Manage., 10(2), 67-82. doi:10.1002/1520-6483(200024)10:2<67::AID-TQEM8>3.0.CO;2-B

Bennett, A. (2013, 16 December). Where the Model Frequently Meets the Road: Combining Statistical, Formal, and Case Study Methods. presented at the meeting of the Annual meeting of the American Political Science Association, Marriott, Loews Philadelphia, and the Pennsylvania Convention Center, Philadelphia, PA. Retrieved from http://citation.allacademic.com/meta/p152866_index.html

Bilitewski, B. (2008a). From traditional to modern fee systems. Waste Management, 28(12), 2760-2766. doi:10.1016/j.wasman.2008.03.032

Bilitewski, B. (2008b). Pay-as-you-throw – A tool for urban waste management. Waste Management, 28(12), 2758. doi:10.1016/j.wasman.2008.08.001

Binder, C. R., & Mosler, H.-J. (2007). Waste-resource flows of short-lived goods in households of Santiago de Cuba. Resources, Conservation and Recycling, 51(2), 265-283. doi:10.1016/j.resconrec.2006.04.001

Bo-Feng, C., Jian-Guo, L., Qing-Xian, G., Xiao-Qin, N., Dong, C., Lan-Cui, L., . . . Zhan-Sheng, Z. (2014). Estimation of Methane Emissions from Municipal Solid Waste Landfills in China Based on Point Emission Sources. Advances in Climate Change Research, 5(2), 81-91. doi:10.3724/SP.J.1248.2014.081

Bogner, J., Ahmed, M. A., Diaz, C., Faaij, A., Gao, Q., Hashimoto, S., . . . Zhang, T. (2007). Waste Management. In B. Metz, Davidson, O.R., Bosch, P.R., Dave, R., & Meyer L. A (Ed.), Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. Retrieved from http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter10.pdf

Bogner, J., & Mathews, E. (2003). Global methane emissions from landfills: New methodology and annual estimates 1980 - 1996. Global Biogeochemical Cycles, 17(2), 1065. doi:10.1029/2002GB001913

Bogner, J., Pipatti, R., Hashimoto, S., Diaz, C., Mareckova, K., Diaz, L., . . . Gregory, R. (2008). Mitigation of global greenhouse gas emissions from waste: conclusions and strategies from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. Working Group III (Mitigation). Waste Management & Research, 26(2008), 11-32.

Bogner, J. E., Spokas, K. A., & Burton, E. A. (1997). Kinetics of methane oxidation in landfill cover materials: Major controls, a whole-landfill oxidation experiment, and modeling of net methane emissions. Environmental Science & Technology, 31(9), 2504-2514. doi:10.1021/es960909a

Borjesson, G., Samuelsson, J., Chanton, J., Adolfsson, R., Galle, B., & Svensson, B. H. (2009). A national landfill methane budget for Sweden based on field measurements, and an evaluation of IPCC models. Tellus B, 61(2), 424-435. doi:10.1111/j.1600-0889.2008.00409.x

Botanic Gardens Conservation International. (1999). Agenda 21: Programme of Action for Sustainable Development. Retrieved 21 February 2014, from http://www.bgci.org/worldwide/article/0011/

Boulanger, P.-M., & Brechet, T. (2005). Models for policy-making in sustainable development: The state of the art and perspectives for research. Ecological Economics, 55(3), 337-350. doi:10.1016/j.ecolecon.2005.07.033

Bovea, M. D., Ibáñez-Forés, V., Gallardo, A., & Colomer-Mendoza, F. J. (2010). Environmental assessment of alternative municipal solid waste management strategies. A Spanish case study. Waste Management, 30(11), 2383-2395. doi:10.1016/j.wasman.2010.03.001

Bovea, M. D., Powell, J. C., Gallardo, A., & Capuz-Rizo, S. F. (2007). The role played by environmental factors in the integration of a transfer station in a municipal solid waste management system. Waste Management, 27(4), 545–553. doi:10.1016/j.wasman.2006.03.020

Bowen, G. A. (2009). Document Analysis as a Qualitative Research Method. Qualitative Research Journal, 9(2), 27-40. doi:10.3316/QRJ0902027

Bozec, A. L. (2008). The implementation of PAYT system under the condition of financial balance in France. Waste Management, 28(12), 2786-2792. doi:10.1016/j.wasman.2008.03.028

Brandt, P., Ernst, A., Gralla, F., Luederitz, C., Lang, D. J., Newig, J., . . . Wehrden, H. v. (2013). A review of transdisciplinary research in sustainability science. Ecological Economics, 92, 1-15. doi:10.1016/j.ecolecon.2013.04.008

Brank, J., Grobelnik, M., & Mladenic, D. (2005). A Survey of Ontology Evaluation Techniques. In Proceedings of 8th Int. multi-conf. Information Society (pp. 166-

169). SiKDD 2005. Retrieved from http://ailab.ijs.si/dunja/sikdd2005/papers/BrankEvaluationSiKDD2005.pdf

Brewster, C., Alani, H., Dasmahapatra, S., & Wilks, Y. (2004). Data driven ontology evaluation. In Proceedings of Int. Conf. on Language Resources and Evaluation (LREC 2004). Lisbon, Portugal, 24 - 30 May. Retrieved from http://oro.open.ac.uk/20045/1/

Broitman, D., Ayalon, O., & Kan, I. (2012). One size fits all? An assessment tool for solid waste management at local and national levels. Waste Management, 32(10), 1979-1988. doi:10.1016/j.wasman.2012.05.023

Brunner, P. H. (2010). Recycling and Sustainability. Keynote speech given at the International Solid Waste Association (ISWA) Annual Conference., Hamburg, Germany, 15-17 November 2010.

Burger, P., & Kamber, R. (2003). Cognitive Integration in Transdisciplinary Science: Knowledge as a Key Notion. Issues in Integrative Studies, 21, 43-73.

Burgess, J. (2013, 19 September). Sweden has Run out of Rubbish for Waste-to-Energy Industry. Retrieved 30 May 2014, from http://oilprice.com/Latest-Energy-News/World-News/Sweden-has-Run-out-of-Rubbish-for-Waste-to-Energy-Industry.html

Burling, S. (2000, 29 April). Ash from Khian Sea is on the move again. The 14-year-old Philadelphia waste, dumped in Haiti 12 years ago, is on its way to be disposed of in Louisiana. Retrieved 12 August 2016, from http://articles.philly.com/2000-04-29/news/25592602_1_khian-sea-ash-waste-management

Burnley, S. J. (2007). A review of municipal solid waste composition in the United Kingdom. Waste Management, 27(10), 1274-1285. doi:10.1016/j.wasman.2006.06.018

Burnley, S. J., Ellis, J. C., Flowerdew, R., Poll, A. J., & Prosser, H. (2007). Assessing the composition of municipal solid waste in Wales. Resources, Conservation and Recycling, 49(3), 264-283. doi:10.1016/j.resconrec.2006.03.015

Byrne, J., & Humble, A. M. (2007). An Introduction to Mixed Method Research. Retrieved from http://www.msvu.ca/site/media/msvu/MixedMethodologyHandout.pdf

Capoccia, G., & Kelemen, D. (2007). The study of critical junctures: theory, narrative, and counterfactuals in historical institutionalism. World Politics, 59(3), 341-369.

Ceccaroni, L. (2001). ONTOWEDSS-An ontology-based environmental decision-support system for the management of wastewater treatment plants (Unpublished doctoral dissertation, Universitat Polit`ecnica De Catalunya, Barcelona, Spain). Retrieved from http://www.cs.upc.edu/~luigi/thesis.pdf

Centre for Advanced Engineering. (2000). Landfill Guidelines. Christchurch: University of Canterbury. Retrieved from https://www.mfe.govt.nz/sites/default/files/funding/docs/4139_landfill.pdf

Cerna, L. (2013). The Nature of Policy Change and Implementation: A Review of Different Theoretical Approaches. Retrieved from https://www.oecd.org/edu/ceri/The%20Nature%20of%20Policy%20Change%20and%20Implementation.pdf

Chanton, J. P., Powelson, D. K., & Green, R. B. (2009). Methane Oxidation in Landfill Cover Soils, is a 10% Default Value Reasonable? Journal of Environmental Quality, 38(2), 654-663. doi:10.2134/jeq2008.0221

Chaturvedi, B. (2007). Privatization of Solid Waste Collection and Transportation in Delhi : The Impact on the Informal Recycling Sector. Paper prepared as partial fulfilment of course on Urban Issues in Developing Countries, School for Advanced International Studies. Johns Hopkins University., Washington, DC.

Chen, W., Baghdasaryan, L., Buranathiti, T., & Cao, J. (2004). Model Validation via Uncertainty Propagation and Data Transformations. AIAA Journal, 42(7), 1406-1415.

Cherubinia, F., Bargigli, S., & Sergio, U. (2009). Life cycle assessment (LCA) of waste management strategies: Landfilling, sorting plant and incineration. Energy, 34(12), 2116-2123. doi:10.1016/j.energy.2008.08.023

Christchurch City Council. (2013). Waste Management and Minimisation Plan 2013: Christchurch City Council. Christchurch: Christchurch City Council. Retrieved from http://resources.ccc.govt.nz/files/WasteManagementPlan2013.pdf

Christchurch City Council. (n.d.). Waste Statistics (Statistics on rubbish collection in Christchurch) – Kerbside rubbish Information. Retrieved 12 August 2016, from http:// https://ccc.govt.nz/services/rubbish-and-recycling/learning-resources/waste-statistics

Christensen, T. H., Bhander, G., Lindvall, H., Larsen, A. W., Fruergaard, T., Damgaard, A., . . . Hauschild, M. (2007). Experience with the use of LCA-modelling (EASEWASTE) in waste management. Waste Management and Research, 25(3), 257-262.

Chua, G. (2012, 7 March). Compulsory for large hotels, malls to report waste data Retrieved 30 April 2014, from http://www.zerowastesg.com/2012/03/07/compulsory-for-large-hotels-malls-to-report-waste-data-news/

Clarke, E. L., Loguercio, S., Good, B. M., & Su, A. I. (2013). A task-based approach for Gene Ontology evaluation. Journal of Biomedical Semantics, 4(Suppl 1), S4. doi:10.1186/2041-1480-4-S1-S4

Clift, R., Doig, A., & Finnveden, G. (2000). The Application of Life Cycle Assessment to Integrated Solid Waste Management: Part 1-Methodology. Process Safety and Environmental Protection, 78(4), 279-287. doi:10.1205/095758200530790

Coleman, T. (2006, July 19). Life Cycle Assessment for Municipal Waste: Supporting Decisions. Presented at the meeting of the Resources Recovery Forum, London, UK.

Committee on Pollution of the Environment. (1973). A manual on solid waste disposal in New Zealand. Wellington: Board of Health.

Commonwealth of Australia Productivity Commission. (2006). Waste Management Productivity Commission Inquiry Report No. 38, 20 October 2006. Canberra. Retrieved from http://www.pc.gov.au/__data/assets/pdf_file/0014/21614/waste.pdf

Contreras, F., Ishii, S., Aramaki, T., Hanaki, K., & Connors, S. (2010). Drivers in current and future municipal solid waste management systems: cases in Yokohama and Boston. Waste Management & Research, 28, 76-93. doi:10.1177/0734242X09349417

Contreras, F., Ishii, S., Aramaki, T., Hanaki, K., & Connors, S. (2010). Drivers in current and future municipal solid waste management systems: cases in Yokohama and Boston. Waste Management & Research, 28(1), 79-93. doi:10.1177/0734242X09349417

Corbin, J., & Strauss, A. (2008). Basics of qualitative research: Techniques and procedures for developing grounded theory. Thousand Oaks: SAGE. doi:10.4135/9781452230153

Crawford, G. (2011, 6 June). ISWA white paper on waste and climate change. Presented at the meeting of the ISWA/EESC Workshop: The Future of Waste Management and Climate Change in Europe, Brussels. Retrieved from http://www.iswa.org/uploads/tx_iswaknowledgebase/G_CRAWFORD_EU_meeting_O6O62011_nc.pdf

Crawford, M. (2013). New WTE Technologies Turn Trash into Treasure. Retrieved from http://www.plastics.org.nz/documents/Environmental/Waste%20to%20Energy/Exec%20Summary.pdf

Creswell, J. W., & Plano Clark, V. L. (2007). Designing and Conducting Mixed Methods Research. Thousand Oaks, California: Sage.

CWG. (2006, 1–5 February). Solid waste, health, and the millennium development goals Symposium conducted at the meeting of the CWG-WASH Workshop, Kolkata, India. Collaborative Working Group on Solid Waste Management in Low and Middle Income Countries (CWG). Retrieved from http://www.cwgnet.net/

Dalemo, M., Sonesson, U., Björklund, A., Mingarini, K., Frostell, B., Jönsson, H., . . . Thyselius, L. (1997). ORWARE – A simulation model for organic waste handling system. Part 1: Model description. Resources, Conservation and Recycling, 21(1), 17-37.

Dann, C. (2012a, 13 July). Sewage, water, and waste - Cleaning up dumps. Te Are - the Encyclopedia of New Zealand. Retrieved 12 August 2016, from http://www.TeAre.govt.nz/en/sewage-water-and-waste/page-6

Dann, C. (2012b, 13 July). 'Sewage, water, and waste - Dirt and disease,' Te Ara - the Encyclopedia of New Zealand. Retrieved 12 August 2016, from http://www.teara.govt.nz/en/sewage-water-and-waste/page-2

Dann, C. (2012c, 13 July). 'Sewage, water, and waste - Recycling and waste minimisation,' Te Ara - the Encyclopedia of New Zealand. Retrieved 10 August 2016, from http://www.teara.govt.nz/en/sewage-water-and-waste/page-7

Dann, C. (2012d, 13 July). Sewage, water, and waste - Solid waste. Retrieved 13 July 2016, from http://www.teara.govt.nz/en/sewage-water-and-waste/page-5

Dann, C. (2012e, 13 July). 'Sewage, water, and waste - Solid waste,' Te Ara - the Encyclopedia of New Zealand. Retrieved 17 July 2016, from http://www.teara.govt.nz/en/sewage-water-and-waste/page-5

Dann, C. (2012f, 13 July). 'Sewage, water and waste - Water pollution,' Te Ara - the Encyclopedia of New Zealand. Retrieved 20 July 2016, from http://www.teara.govt.nz/en/sewage-water-and-waste/page-8

Dann, C. (2012g, 13 July). Story: Sewage, water, and waste: Page 1 – Māori and colonial settlements. Te Ara - the Encyclopedia of New Zealand. Retrieved 24 July 2016, from http://www.teara.govt.nz/en/sewage-water-and-waste/page-1

Dann, C. (2013, 12 February). 'Sewage, water and waste - Stinking cities', Te Ara - the Encyclopedia of New Zealand. Retrieved 17 July 2016, from http://www.teara.govt.nz/en/sewage-water-and-waste/page-3

Daskalopoulos, E., Badr, O., & Probert, S. D. (1997). Economic and Environmental Evaluations of Waste Treatment and Disposal Technologies for Municipal Solid Waste. applied Energy, 58(4), 209-255. doi:10.1016/S0306-2619(97)00053-6

Davidson, G. (2011). Waste Management Practices: Literature Review: Office of Sustainability – Dalhousie University Retrieved from http://www.dal.ca/content/dam/dalhousie/pdf/sustainability/Waste%20Management%20Literature%20Review%20Final%20June%202011%20(1.49%20MB).pdf

De Feo, G., & Malvano, C. (2012). Technical, economic and environmental analysis of a MSW kerbside separate collection system applied to small communities. Waste Management, 32(10), 1760-1774. doi:10.1016/j.wasman.2012.05.009

De la Cruz, F. B., & Barlaz, M. A. (2010). Estimation of waste component-specific landfill decay rates using laboratory-scale decomposition data. Environmental Science Technology, 44(12), 4722-4728. doi:10.1021/es100240r

de Swaan, A. (1988). In care of the State: health care, education, and welfare in Europe and the USA in the modern era. USA: Oxford University Press.

DEFRA. (2012a). The Economics of Waste and Waste Policy. London. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69500/pb13548-economic-principles-wr110613.pdf

DEFRA. (2012b). Guidance on Minimising Greenhouse Gas Emissions from Refrigeration, Air-conditioning, and Heat Pump Systems Guidance: F Gas and

Ozone Regulations Information Sheet RAC 7: Alternatives Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/182589/fgas-rac7-alternatives.pdf

Den Boer, E., Den Boer, J., & Jager, J. (2005). Waste Management Planning and Optimisation. Handbook for Municipal Waste Prognosis and Sustainability Assessment of Waste Management Systems. LCA–IWM. Darmstadt, Germany, p. 306.

Den Boer, E., Den Boer, J., & Jager, J. (2007). LCA-IWM: A decision support tool for sustainability assessment of waste management systems. Waste Management, 27, 1032-1045.

Den Boer, E., Den Boer, J., Jager, J., Rodrigo, J., Meneses, M., Castells, F., & Schanne, L. (2005). Deliverable Report on D3.1 and D3.2: Environmental Sustainability Criteria and Indicators for Waste Management (Work Package 3). The Use of Life Cycle Assessment Tool for the Development of Integrated Waste Management Strategies for Cities and Regions with Rapid Growing Economies LCA–IWM. Darmstadt, Germany, p. 198.

den Boer, J., den Boer, E., & Jagar, J. (2007). LCA-IWM: A decision support tool for sustainability assessment of waste management systems. Waste Management, 27(8), 1032-1045. doi:10.1016/j.wasman.2007.02.022

Department of Environment Food and Rural Affairs (DEFRA). (2011). Government Review of Waste Policy in England 2011. London. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69401/pb13540-waste-policy-review110614.pdf

Desmond, M. (2010). Municipal solid waste management in Ireland: Assessing for sustainability Irish Geography, 39(1), 22-33.

Despaisse, M., Ball, P. D., & Evans, S. (2012). Modelling and Tactics for Sustainable Manufacturing: An Improvement Methodology. In G. Seliger (Ed.), Sustainable Manufacturing: Shaping Global Value Creation. Heidelberg New York Dordrecht London: Springer. doi:10.1007/978-3-642-27290-5

Diaz, R., & Warith, M. (2006). Life-cycle assessment of municipal solid wastes: Development of WASTED model Waste Management, 26, 886-901.

Diaz, R., & Warith, M. (2006). Life cycle assessment of municipal solid wastes: development of the WASTED model Waste Management, 26(8), 886-901.

Dokas, I. M. (2007). Ontology To Support Knowledge Representation and Risk Analysis for the Development of Early Warning System in Solid Waste Management Operations In Proceedings of the International Symposium on Environmental Software Systems, May 22 - 25, 2007. Prague, Czech Republic

Dubus, I. G., Brown, C. D., & Beulke, S. (2003). Sources of uncertainty in pesticide fate modelling. The Science of the Total Environment, 317(2003), 53-72. doi:10.1016/S0048-9697(03)00362-0

Dunne, L., Convery, F. J., & Gallagher, L. (2008). An investigation into waste charges in Ireland, with emphasis on public acceptability. Waste Management, 28(12), 2826-2834. doi:10.1016/j.wasman.2008.07.007

Ecobilan. (1997). Life Cycle Research Programme for Waste Management: Inventory Development for Waste Management Operations: Landfill, Final Report. Bristol, UK: Environment Agency.

EEA. (2003a). Assessment of Information Related to Waste and Material Flows—a Catalogue of Methods and Tools (Technical report 96). Copenhagen. Retrieved from http://www.eea.europa.eu/publications/technical_report_2003_96/at_download/file

EEA. (2003b). EEA core set of indicators Retrieved from http://www.unece.org/fileadmin/DAM/env/europe/monitoring/StPetersburg/EEA%20Core%20Set%20of%20Indicators%20rev2EECCA.pdf

EEA. (2004). Consumption Drivers. Retrieved 24 November 2013, from http://epaedia.eea.europa.eu/page.php?pid=409

EEA. (2013). Municipal waste management in Sweden. Retrieved from http://www.eea.europa.eu/publications/managing-municipal-solid-waste/sweden-municipal-waste-management

EEA. (2015). The European Environment - State and Outlook 2015: Synthesis Report. Copenhagen. Retrieved from http://www.eea.europa.eu/soer-2015/synthesis/report/at_download/file

Eggleston, S., & Walsh, M. (2000). Emissions: Energy, Road Transport In Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_3_Road_Transport.pdf

Eisted, R., Larsen, A. W., & Christensen, T. H. (2009). Collection, transfer, and transport of waste: accounting of greenhouse gases and global warming contribution. Waste Management & Research, 27(8), 738-745. doi:10.1177/0734242X09347796

Ekvall, T., Assefa, G., Björklund, A., Eriksson, O., & Finnveden, G. (2007). What life-cycle assessment does and does not do in assessments of waste management. Waste Management, 27(8), 989–996. doi:10.1016/j.wasman.2007.02.015

Ekvall, T., & Finnveden, G. (2000). The Application of Life Cycle Assessment to Integrated Solid Waste Management: Part 2—Perspectives on Energy and Material Recovery from Paper. Sustainable Development, 78(4), 288–294. doi:10.1205/095758200530808

Ekvall, T., & Malmheden, S. (Eds.). (2014). Towards Sustainable Waste Management - Popular Summary Report from a Swedish EPA Research Programme. Stockholm, Sweden: IVL Swedish Environmental Research Institute. Retrieved from http://www.ivl.se/download/18.1acdfdc8146d949da6d659d/1419236358373/C69+TOSUWAMA+report+.pdf

Elcock, D. (2007). Life-cycle thinking for the oil and gas exploration and production industry. Oak Ridge, TN: Argonne National Laboratory. Retrieved from http://www.netl.doe.gov/kmd/cds/disk23/D-Water%20Management%20Projects/Produced%20Water%5CFEW%2049124%5CFEW%2049124%20ANL%20Final%20Rpt.pdf

Ellerman, D. A., & Joskow, P. L. (2008). The European Union's Emission Trading System in Perspective. Arlington, VA: Pew Center on Global Climate Change. Retrieved from http://www.c2es.org/docUploads/EU-ETS-In-Perspective-Report.pdf

Entreprises Pour I ' Environment (EpE). (2008). Protocol for the Quantification of Greenhouse Gases Emissions from Waste Management Activities. Version 3.0. Paris. Retrieved from http://waste.ccac-knowledge.net/sites/default/files/CCAC_images/documents/EpE%20-%20emission%20calculator%20-%20Protocol%20for%20the%20Quantification%20of%20GHG%20Emissions%20from%20MSW%20activities.pdf

Environment Canterbury Regional Council. (2014, 13 February). Waste regulation. Retrieved 23 May 2014, from http://ecan.govt.nz/our-responsibilities/Waste/Pages/waste-regulation.aspx

Environment Protection Agency (TAS). (2013). Measuring Waste Disposal and Recovery. Retrieved 28 May 2014, from http://epa.tas.gov.au/regulation/measuring-waste-disposal-and-recovery

Environment Waikato. (2007). Waikato Regional Waste Infrastructure Stocktake and Strategic Assessment. Hamilton East. Retrieved from http://www.waikatoregion.govt.nz/PageFiles/5481/tr0744.pdf

Environmental and Plastics Industry Council (EPIC)/Corporations Supporting Recycling (CSR). (2000). Integrated Waste Management Model for Municipalities. Retrieved 20 July 2015, from http://environment.uwaterloo.ca/research/iwm/users.html

EPA, U. (2013, 10 September). Global Greenhouse Gas Emissions Data. Retrieved 20 August 2014, from http://www.epa.gov/climatechange/ghgemissions/global.html

EPIC and CSR. (2000). Integrated Solid Waste Management Tools: User Guidance Document. Retrieved from http://environment.uwaterloo.ca/research/iwm/pdfs/env.pdf

Ericsson, K., & Nilsson, L. J. (2004). International biofuel trade—A study of the Swedish import. Biomass and Bioenergy, 26(3), 205-220. doi:10.1016/S0961-9534(03)00122-3

Eriksson, O., & Bisaillon, M. (2011). Multiple system modelling of waste management. Waste Management, 31(12), 2620-2630. doi:10.1016/j.wasman.2011.07.007

Eriksson, O., Frostell, B., Bjorklund, A., Assefa, G., Sundqvist, J.-O., Granath, J., . . . Thyselius, L. (2002.). ORWARE - A simulation tool for waste management. Resources, Conservation and Recycling, 36, 287-307.

ETC/SCP. (2009). Country Fact Sheets on waste policies. Retrieved from http://scp.eionet.europa.eu/facts/factsheets_waste/2009_edition/factsheet?country=SE

Eunomia Research & Consulting Ltd and Waste Not Consulting Ltd. (2014). New Zealand Waste Data Framework: Background Document (Prepared for Waste Management Institute New Zealand). Retrieved from http://www.wasteminz.org.nz/wp-content/uploads/Waste-data-framework-background-Final.pdf

European Commission. (1975). Council Directive of 15 July 1975 on waste (Directive 75/442/EEC). Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:1975L0442:20031120:EN:PDF

European Commission. (2008). Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:EN:PDF

European Commission. (2009). Challenging Futures of Science in Society - Emerging trends and cutting-edge issues (Report of the MASIS Expert Group setup by the European Commission) (EUR 24039 EN). Brussels. Retrieved from https://ec.europa.eu/research/science-society/document_library/pdf_06/the-masis-report_en.pdf

European Commission. (2011). Guidelines on the Interpretation of the R1 Energy Efficiency Formula for Incineration Facilities Dedicated to the Processing of Municipal Solid Waste According to Annex II of Directive 2008/98/EC on Waste. Retrieved from http://ec.europa.eu/environment/waste/framework/pdf/guidance.pdf

European Commission. (2012). Biodegradable Waste. Retrieved 10 November 2013, from http://ec.europa.eu/environment/waste/compost/

European Commission. (n.d). The story behind the strategy: EU waste policy. Retrieved from http://ec.europa.eu/environment/waste/pdf/story_book.pdf

European Communities. (1999a). Council Directive 99/31/EC of 26 April 1999 on the landfill of waste. Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1999:182:0001:0019:EN:PDF

European Communities. (1999b). EU focus on waste management. Retrieved from http://ec.europa.eu/environment/waste/publications/pdf/eufocus_en.pdf

European Communities. (2001). Waste Management Options and Climate Change. Luxembourg. Retrieved from http://ec.europa.eu/environment/waste/studies/pdf/climate_change.pdf

European Communities. (2005). Report from the commission to the Council and the European Parliament on the national strategies for the reduction of biodegradable waste going to landfills pursuant to article 5(1) of Directive 1999/31/EC on the landfill of waste {SEC(2005) 404}. Brussels. Retrieved from

Ghinea, C., Petraru, M., Bressers, H. T. A., & Gavrilescu, M. (2012). Environmental evaluation of waste management scenarios - significance of the boundaries. Journal of Environmental Engineering and Landscape Management, 20(1), 76–85 doi:10.3846/16486897.2011.644665

Gille, Z. (2007). From the Cult of Waste to the Trash Heap of History: The Politics of Waste in Socialist and Postsocialist Hungary. Bloomington, Indiana USA: Indiana University Press.

Gillenwater, M., & Seres, S. (2011). The Clean Development Mechanism: A Review of the First International Offset Program (Prepared for the Pew Center on Global Climate Change. Retrieved from http://ghginstitute.org/wp-content/uploads/2015/04/PEW8037CDMReport.pdf

Global Environment Facility. (2014). Report on the Sixth Replenishment of the GEF Trust Fund (Prepared by the GEF Secretariat & World Bank as Trustee). Retrieved from http://www.unitar.org/cwm/sites/unitar.org.cwm/files/uploads/gef6_strategy_cwm.pdf

Gomez-Perez, A. (2004). Ontology Evaluation. In S. Staab & R. Studer (Eds.), Handbook on Ontologies in Information Systems (First ed., pp. 251-274). Berlin: Springer.

Google Eaarth. (2015, 18 December). Claris Landfill, New Zealand. 36.233194oS , 175.459380oE, Eye alt 6.29 km. Retrieved 29 February 2016, from http://www.google.com/earth/index.html

Goulding, C. (2002). Grounded Theory: A Practical Guide for Management , Business, and Market Resource. Thousand Oaks, CA: Sage.

GreenConduct. (n.d). Sweden is a Model of Sustainable Waste Management. Retrieved 27 May 2014, from http://greenconduct.com/news/2013/08/01/sweden-is-a-model-of-sustainable-waste-management/

Gregoire, T. G., & Reynolds, M. R. (1988). Accuracy Testing and Estimation Alternatives. Forest Science, 34(2), 302-320.

Gruninger, M., & Fox, M. S. (1995). Methodology for the design and evaluation of ontologies. presented at the meeting of the IJCAI95 Workshop on Basic Ontological Issues in Knowledge Sharing, Montreal.

Guarino, N. (1998). Formal Ontology and Information Systems. In N. Guarino (Chair), IOS Press. Symposium conducted at the meeting of the Ist International

Conference on Formal Ontology in Information System, Trento, Italy, 6-8 June 1998.

Guerrero, L. A., Maas, G., & Hogland, W. (2013). Solid waste management challenges for cities in developing countries. Waste Management, 33(1), 220-232. doi:10.1016/j.wasman.2012.09.008

Haider, A., Amber, A., Ammara, S., Mahrukh, K. S., & Aisha, B. (2015). Knowledge, Perception and Attitude of common People towards Solid Waste Management-A case study of Lahore, Pakistan International Research Journal of Environment Sciences, 4(3), 100-107.

Haight, M. (1999). EPIC/CSR Integrated Solid Waste Management Model. Final Report Waterloo, Canada, p. 23.

Haight, M. (2004). Integrated Solid Waste Management Model. Technical Report. University of Waterloo, School of Planning, Waterloo, Canada.

Hall, P. (2003). Aligning Ontology and Methodology in Comparative Politics. In J. Mahoney & D. Reuschemeyer (Eds.), Comparative Historical Analysis in the Social Sciences. New York: Cambridge University Press.

Hall, P. (2007). The Dilemmas of Contemporary Social Science. boundary 2, 34(3), 121-141. doi:10.1215/01903659-2007-018

Hansen, W., Christopher, M., & Verbuecheln, M. (2002). EU waste policy and challenges for regional and local authorities. presented at the meeting of the Background Paper for the Seminar on Household Waste Management “Capacity Building on European Community’s Environmental Policy”, Retrieved from http://www.arctic-transform.eu/files/projects/2013/1921-1922_background_paper_waste_en.PDF

Harri, M., Jan-Olov, S., & Asa, S. (2007, August 27-29). LCA-based decision-support tool for waste management planning – optimal waste management scenarios for the Baltic States. presented at the meeting of the 3rd International Conference on Life Cycle Management, University of Zürich at Irchel. Retrieved from http://www.lcm2007.org/presentation/Wed_2.07-Moora.pdf

Harrison, K. W., Dumas, R. D., Solano, E., Barlaz, M. A., Brill, E. D., & Ranjithan, S. R. (2001). Decision support tool for life-cycle-based solid waste management. Journal of Computing in Civil Engineering, 15(1), 44-58.

Health Protection Agency. (2011). Impact on Health of Emissions from Landfill Sites: Advice from the Health Protection Agency (RCE-18). Retrieved from http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1309969974126

Henry, B., & Collier, D. (Eds.). (2004). Rethinking Social Inquiry: Diverse Tools: Shared Standards. Lanham, MD: Rowman & Littlefield.

Herzog, T. (2005). World Greenhouse Gas Emissions in 2005. WRI Working Paper. Retrieved from http://pdf.wri.org/working_papers/world_greenhouse_gas_emissions_2005.pdf

Hills, R. G., & Trucano, T. G. (1999). Statistical Validation of Engineering and Scientific Models: Background (SAND99-1256). California: Sandia National Laboratories. Retrieved from http://www4.ncsu.edu/~rsmith/Hills-1.pdf

Hinchey, L. (2013, 14 February). Waste Minimisation Act 2008 at a glance: risks and opportunities for New Zealand businesses Retrieved 7 March 2014, from http://www.conferenz.co.nz/content/whitepapers/2013/Luke%20Hinchey%20Paper.pdf

Hitzler, P., Krotzsch, M., & Rudolph, S. (2009). Knowledge Representation for the Semantic Web Part I: OWL 2. Retrieved 3 August 2016, from http://www.semantic-web-book.org/w/images/b/b0/KI09-OWL-Rules-1.pdf

Hogland, W., Marques, M., & Nimmermark, S. (2004). Landfill mining and waste characterization: a strategy for remediation of contaminated areas. J Mater Cycles Waste Manag, 6, 119-124.

Hongyuan, Y. (2008). Global Warming and China's Environmental Diplomacy. New York: Nova Science Publishers, Inc.

Horowhenua District Council. (2012). Horowhenua District Council Waste Management and Minimisation Plan Retrieved from http://www.horowhenua.govt.nz/Documents/Rubbish%20and%20Recycling/Waste%20Management%20and%20Minimisation%20Plan%20Web.pdf

Hughey, K. F. D., Keer, G. N., & Cullen, R. (2010). Public perceptions of New Zealand's environment: 2010. Lincoln, Canterbury: Lincoln University. Retrieved from http://researcharchive.lincoln.ac.nz/handle/10182/3875

Hume, C. (2006, 16 September). Sweden's burning with enthusiasm: Waste-to-energy incineration is clean, efficient and 'absolutely feasible for Toronto,' disposal executives say. Retrieved 30 May, 2014, from http://www.seas.columbia.edu/earth/wtert/sofos/Hume_Sweden's%20burning%20with%20enthusiasm.pdf

iDeck. (2009). Implementation of integrated municipal solid waste management system in Tumkur, Karnataka. Retrieved from http://idd.kar.nic.in/docs/18.Prefea_TSWM.pdf

International Maritime Organization (IMO). (2016, 24 March). Parties to the London Convention and Protocol. Retrieved 26 July 2016, from http://www.imo.org/en/OurWork/Environment/LCLP/Documents/Parties%20to%20the%20London%20Convention%20and%20Protocol%20March%202016.pdf

International Organization for Standardization. (1997). Environmental management - Life cycle assessment - Principles and framework (ISO 14040: 1997(E)). Geneva, Switzerland. Retrieved from http://web.stanford.edu/class/cee214/Readings/ISOLCA.pdf

International Solid Waste Association. (2012). State of the Nation Report: Landfilling Practices and Regulation in New Zealand. Retrieved from https://www.google.co.nz/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=

rja&uact=8&ved=0ahUKEwiNs9b9n5DOAhWDtpQKHYSPCPwQFggcMAA&url=http%3A%2F%2Fwww.iswa.org%2Findex.php%3FeID%3Dtx_bee4mememberships_download%26fileUid%3D168&usg=AFQjCNGkydq3OFZ9cG9y9lT70QFYFuPoTg&sig2=ttcA7u_1Umx-pkEGMvDtzQ

IPCC. (1996). Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reporting Instructions (Volume 1). Retrieved 23 July, 2016, from http://www.ipcc-nggip.iges.or.jp/public/gl/invs4.html

IPCC. (2000). Chapter 5: Waste. In Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventory. Geneva. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/gp/english/5_Waste.pdf

IPCC. (2006a). 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 1 General Guidance and Reporting. Retrieved 23 July, 2016, from http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol1.html

IPCC. (2006b). Chapter 3 - Mobile Combustion. In 2006 IPCC Guidelines for National Greenhouse Gas Inventory, Volume 2, Energy. Geneva. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf

IPCC. (2006c). Chapter 3: Solid Waste Disposal. In 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 5, Waste. Geneva. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_3_Ch3_SWDS.pdf

IPCC. (2006d). IPCC waste model. Retrieved 21 June 2014, from https://www.ipcc.ch/meetings/session25/doc4a4b/ipcc-waste-model.xls

IPCC. (2007a). 2.10.2 Direct Global Warming Potentials. In IPCC Fourth Assessment Report: Climate Change 2007 Retrieved from https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

IPCC. (2007b). Climate Change 2007 Mitigation: Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In M. Bert, Ogunlade, D., Peter, B., Rutu, D., Leo, M (Ed.). New York, NY: Cambridge University Press.

IPCC. (2007c). Climate Change 2007: Synthesis Report. In IPCC Fourth Assessment Report: Climate Change 2007 (AR4). Retrieved from http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

IPCC. (2007d). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC. New York, Cambridge. Retrieved from http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4_wg1_full_report.pdf

IPCC. (2012). IPCC 35th Session, 6-9 June 2012, Geneva, Switzerland: Decisions Taken with Respect to the Review of IPCC Processes and Procedures, Communications Strategy. Retrieved from www.ipcc.ch/meetings/session35/IAC_CommunicationStrategy.pdf

IPCC. (2013a). Climate Change 2013, The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Retrieved from http://www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf

IPCC. (2013b). Climate change 2013: The physical science basis. In T. F. Stocker, D. Qin, G.-K. Plattner, M. M. B. Tignor, S. K. Allen, J. Boschung, A. Nauels, X. Yu, B. Vincent, & P. M. Midgley (Eds.), Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

IRU. (2014). Sustainable Development. Retrieved 20 March, 2014, from http://www.iru.org/en_policy_development

ISO. (2006). ISO 14044 (Environmental management - Life cycle assessment - Requirements and guidelines (First ed.). Geneva, Switzerland: ISO.

ISWA. (2009). Waste and Climate Change. ISWA White Paper. Vienna, Austria: International Solid Waste Association. Retrieved from http://www.iswa.org/fileadmin/user_upload/_temp_/Small_GHG_white_paper_01.pdf

ISWA, & UNEP. (2002). Industry as a partner for sustainable development. Retrieved from www.sustentabilidad.uai.edu.ar/pdf/ing/waste_management.pdf

Jaeger, C. C., Tàbara, J. D., & Jaeger, J. (Eds.). (2011). European Research on Sustainable Development Volume 1: Transformative Science Approaches for Sustainability. Berlin, Heidelberg: Springer-Verlag. doi:10.1007/978-3-642-19202-9

Jamasb, T., & Nepal, R. (2010). Issues and options in waste management: A social cost–benefit analysis of waste-to-energy in the UK. Resources, Conservation and Recycling, 54(12), 1341-1352. doi:10.1016/j.resconrec.2010.05.004

Jensen, J. E. F., & Pipatti, R. (2000). CH4 Emission from Solid Waste Disposal. In P. Boeckx, S. A. Bhide, K. A. Brown, K. Steczko, G. Mauschitz, H. Jiming, P. Hackl, T. Kleffegaard, D. Krueger, & T. Martinsen (Eds.), Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Geneva, Switzerland: IPCC. Retrieved from http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/5_1_CH4_Solid_Waste.pdf

Jibril, D. J., Ibrahim, A. S., Dodo, Y. A., Sheelah, S., & Suleiman, A. S. (2012). Integrated solid waste management as a tool for effective sustainable practice. OIDA International Journal of Sustainable Development, 4(4), 95-104.

Jin-Won, P., & Ho-Chul, S. (2001). Surface emission of landfill gas from solid waste landfill. Atmospheric Environment, 35(20), 3445-3451. doi:10.1016/S1352-2310(01)00118-2

Jones, H. A., & Nedwell, D. B. (1990). Soil atmosphere concentration profiles and methane emission rates in the restoration cover above landfill sites: Equipment and preliminary results. Waste Management and Research, 8(1), 21-31. doi:10.1016/0734-242X(90)90049-S

Jung, Y., Imhoff, P. T., Augenstein, D., & Yazdani, R. (2011). Mitigating methane emissions and air intrusion in heterogeneous landfills with a high permeability layer. Waste Management, 103, 8243-8250.

Kauffmann, C., Less, C. T., & Teichmann, D. (2012). "Corporate Greenhouse Gas Emission Reporting: A Stocktaking of Government Schemes", OECD Working Papers on International Investment, No. 2012/1, OECD Investment Division. France. Retrieved from http://www.oecd.org/investment/internationalinvestmentagreements/50549983.pdf

Kelle, U. (2005). Emergence vs Forcing of Empirical Data? A crucial Problem of Grounded Theory Forum: Qualitative Social Research, 6(2), Art. 27.

Khoo, H. H. (2009). Life cycle impact assessment of various waste conversion technologies. Waste Management, 29(6), 1892–1900.

Kightley, D., Nedwell, D. B., & Cooper, M. (1995). Capacity for methane oxidation in landfill cover soils measured in laboratory scale microcosms. Applied and Environmental Microbiology, 61(2), 592-601.

Kirkeby, J. T., Birgisdottir, H., Hansen, T. L., Christensen, T. H., Bhander, G. S., & Hauschild, M. (2006). Evaluation of environmental impacts from municipal solid waste management in the municipality of Aarhus, Denmark (EASEWASTE). Waste Manag Res, 24(1), 16-26. doi:10.1177/0734242X06062598

Kirkeby, J. T., Birgisdottir, H., Hansen, T. L., Christensen, T. H., Bhander, G. S., & Hauschild, M. (2006). Environmental assessment of solid waste systems and technologies: EASEWASTE. Waste Management & Research, 24, 3-15. doi:10.1177/0734242X06062580

Klusman, R. W., & Dick, C. J. (2000). Seasonal variability in CH4 emissions from a landfill in a cool, semiarid climate. Journal of the Air & Waste Management Association, 50(9), 1632-1636. doi:10.1080/10473289.2000.10464201

Koko toxic waste dump. (2012, 29 December). National Mirror. Retrieved 20 February, 2014, from http://nationalmirroronline.net/new/koko-toxic-waste-dump/

Koné, L. (2010, 14 July). Toxic colonialism: The human rights implications of illicit trade of toxic waste in Africa. Retrieved 20 February, 2014, from http://www.consultancyafrica.com/index.php?option=com_content&view=article&id=473:toxic-colonialism-the-human-rights-implications-of-illicit-trade-of-toxic-waste-in-africa&catid=109:counter-proliferation&Itemid=267

Kong, D., Shan, J., Lacoboni, M., & Maguin, R. S. (2012). Evaluating greenhouse gas impacts of organic waste management opotions using life cycle assessment.

Waste Management & Research, 30(8), 800–812. doi:10.1177/0734242X12440479

Kortas, P. (2014). Methods of determination of the fuel consumption of the locomotive diesel-electric propulsion system for regular operating conditions. Key Engineering Materials, 597(2014), 77-86. doi:10.4028/www.scientific.net/KEM.597.77

Krausz, R. (2012). All for naught? A critical study of zero waste to landfill initiatives. PhD thesis, Lincoln University, Lincoln, New Zealand. Retrieved from http://researcharchive.lincoln.ac.nz/bitstream/10182/5301/3/Krausz_phd.pdf

Kumar, S., Mondal, A. N., Gaikwad, S. A., Devotta, S., & Singh, R. N. (2004). Qualitative assessment of methane emission inventory from municipal solid waste disposal sites: a case study Atmospheric Environment, 38, 4921-4929. doi:10.1016/j.atmosenv.2004.05.052

Labuschagne, A. (2003). Qualitative research: Airy fairy or fundamental? The Qualitative Report, 8(1), 100-1003. Retrieved 8 December, 2015, from http://www.nova.edu/ssss/QR/QR8-1/labuschagne.html

Laws, D., Scholz, R. W., Shiroyama, H., Susskind, L., Suzuki, T., & Weber, O. (2004). Expert views on sustainability and technology implementation. International Journal of Sustainable Development & World Ecology, 11(3), 247-261. doi:10.1080/13504500409469829

Lead International & Lead India. (2014). WHAT IS THE UNFCCC & THE COP? Retrieved 17 February, 2014, from http://www.climate-leaders.org/climate-change-resources/india-at-cop-15/unfccc-cop

Lee, M., Legg, R., Maxwel, l., & Rees, W. (2013). Closing the loop: Reducing greenhouse gas emissions and creating green jobs through zero waste in BC. Retrieved from http://policyalternatives.ca/publications/reports/closing-loop

Lehman, P. K., & Geller, E. S. (2004). Behavior Analysis and Environmental Protection: Accomplishments and Potential for More. Behavior and Social Issues, 13 13-32.

letsrecycle.com. (2010, 23 March). UK achieves average EU municipal recycling rate. Retrieved 30 May, 2014, from http://www.letsrecycle.com/news/latest-news/waste-management/uk-achieves-average-eu-municipal-recycling-rate

Liamsanguan, C., & Gheewala, S. H. (2008). LCA: A decision support tool for environmental assessment of MSW management systems. Journal of Environmental Management, 87(1), 132-138. doi:10.1016/j.jenvman.2007.01.003

Linkov, I., & Burmistrov, D. (2003). Model Uncertainty and Choices Made by Modelers: Lessons Learned from the International Atomic Energy Agency Model Intercomparisons. Risk Analysis, 23(6), 1297-1308. doi:10.1111/j.0272-4332.2003.00402.x

Lizik, W., Im, J., Semrau, J. D., & Barcelona, M. J. (2013). A field trial of nutrient stimulation of methanotrophs to reduce greenhouse gas emissions from landfill over soils. Journal of Air and Waste Management Association, 63(3), 300-309.

Louis, G. E. (2004). A historical context of municipal solid waste management in the United States. Waste Manag Res, 2004(22), 306–322. doi:10.1177/0734242X04045425

Lozano-Tello, A., & Gómez-Pérez, A. (2004). ONTOMETRIC: A Method to Choose the Appropriate Ontology. Journal of Database Management, 15(2), 1-18. doi:10.4018/jdm.2004040101

Luchien, L., & Oonk, H. (2011). Stortgasemissies Duurzaam Stortbeheer. Eindrapport, in opdracht van Ministerie van I&M, Ecofys Project nummer: PSUPNL102132, Utrecht, Nederland.

Ludwig, C., Hellweg, S., & Stucki, S. (2003). Municipal Solid Waste Management Strategies and Technologies for Sustainable Solutions Int J Life Cycle Assess, 8(2), 114.

Machado, S. L., Carvalho, M. F., Gourc, J.-P., Vilar, O. M., & do Nascimento, J. C. F. (2009). Methane generation in tropical landfills: Simplified methods and field results. Waste Management, 29(1), 153-161. doi:10.1016/j.wasman.2008.02.017

Maedche, A., & Staab, S. (2002). Measuring similarity between ontologies. In A. Gomez-Perez & V. R. Benjamins (Eds.), Proceedings of the 13th International Conference on Knowledge Engineering and Knowledge Management: Ontologies and The Semantic Web (pp. 251-263). Berlin Heidelberg: Springer-Verlag. Retrieved from http://link.springer.com/chapter/10.1007%2F3-540-45810-7_24#page-1

Mallak, S. K., Ishak, M. B., Kasim, M. R. M., & Samah, M. A. A. (2015). Assessing the Effectiveness of Waste Minimization Methods in Solid Waste Reduction at the Source by Manufacturing Firms in Malaysia Pol. J. Environ. Stud, 24(5), 2063-2071. doi:10.15244/pjoes/35518

Manfredi, S., Tonini, D., Christensen, T. H., & Scharff, H. (2009). Landfilling of waste: Accounting of greenhouse gases and global warming contributions. Waste Management and Research, 27(8), 825-836. doi:10.1177/0734242X09348529

Maritime Safety Authority of New Zealand. (1999). New Zealand Guidelines for Sea Disposal of Waste - Advisory Circular Part 180: Dumping of waste or other matter (Issue No. 180-1). Wellington. Retrieved from http://www.maritimenz.govt.nz/Publications-and-forms/Environmental-protection/Sea-disposal-of-waste.pdf

Massarutto, A. (2015). Economic aspects of thermal treatment of solid waste in a sustainable WM system. Waste Management, 37, 45-57. doi:10.1016/j.wasman.2014.08.024

Maurice, C., & Lagerkvist, A. (2003). LFG emission measurements in cold climate conditions: Seasonal variations and methane emissions mitigation. Cold Regions Science and Technology, 36(1-3), 37-46. doi:10.1016/S0165-232X(02)00094-0

Mazzanti, M., & Zoboli, R. (2008). Waste generation, waste disposal and policy effectiveness: evidence on decoupling from the European Union. Resources, Conservation and Recycling, 52(10), 1221–1234. doi:org/10.1016/j.resconrec.2008.07.003

McDougall, F., While, P., Franke, M., & Hindle, F. (2002). Integrated Solid Waste Management: A Life Cycle Inventory. Blackwell, UK: Oxford.

McDougall, F., White, P. R., Franke, M., & Hindle, P. (2001). Integrated Solid Waste Management: A Life Cycle Inventory (Second ed.): Oxford, UK.

McDougall, F., White, P. R., Franke, M., & Hindle, P. (2001). Integrated Solid Waste Management: A Life Cycle Inventory (second ed.). UK: Oxford.

Medina, M. (2010). Solid Wastes, Poverty and the Environment in Developing Country Cities - Challenges and Opportunities (Working Paper No. 2010/23). Retrieved from http://re.indiaenvironmentportal.org.in/files/solid%20wastes%20poverty%20and%20the%20environment.pdf

Melosi, M. (1981). Garbage in the Cities, Refuse, Reform and Environment, 1880-1980. College Station, Texas, USA: A&M Press.

Merriam, S. B. (1988). Case Study Research in Education: A Qualitative Approach. San Francisco: Jossey-Bass.

Mertins, L., Vinolas, C., Bargallo, A., Sommer, G., Renau, J., de Catalunya, G., & de Residus, J. (1999). Development and application of waste factors - an overview, Technical Report 37. Copenhagen: European Environment Agency.

Michiel, R. J. D., & Morton, A. B. (1995, February). Estimate of global methane emissions from landfills and open dumps. Retrieved 17 July, 2016, from http://infohouse.p2ric.org/ref/07/06250.pdf

Michikazu, K., & Enri, D. (Eds.). (2009). 3R Policies for Southeast and East Asia: ERIA Research Project Report 2008: No. 6-1. Retrieved from http://www.eria.org/RPR-2008-6-1.pdf

Miliute, J., & Plepys, A. (2009). Driving Forces for High Household Waste Recycling. Lessons from Sweden. . Environmental Research, Engineering & Management, 47(1), 50-62.

Miller, T. (2005). Environmental Waste Management Strategies and Options. Journal of Waste Reduction Research and Management, 2(3), 81-92.

Mills, J., Bonner, A., & Francis, K. (2006). The Development of Constructivist Grounded Theory. International Journal of Qualitative Methods, 5(1), 25-35.

Ministry for the Environment. (1997a). National Waste Data Report. Wellington. Retrieved from http://mfe.govt.nz/sites/default/files/nat-waste-data-report-may97.pdf

Ministry for the Environment. (1997b). The State of New Zealand's Environment 1997. Wellington. Retrieved from http://www.mfe.govt.nz/sites/default/files/ser-1997.pdf

Ministry for the Environment. (2000). The 1998/1999 national landfill census report (ME number 335). Wellington. Retrieved from http://www.mfe.govt.nz/publications/waste/nat-landfill-census-report-98.pdf

Ministry for the Environment. (2002). Solid Waste Analysis Protocol. Wellington: Ministry for the Environment. Retrieved from http://www.mfe.govt.nz/publications/waste/solid-waste-analysis-mar02/chapters-mar02.pdf

Ministry for the Environment. (2003). The 2002 Landfill Review and Audit (ME number: 466). Wellington. Retrieved from http://www.mfe.govt.nz/publications/waste/landfill-review-and-audit-mar03.pdf

Ministry for the Environment. (2004a). Proposed National Environmental Standard to Control Greenhouse Gas Emissions from Landfills: Resource Management Act Section 32. Wellington. Retrieved from http://www.mfe.govt.nz/publications/air/nes-landfill-emissions-analysis/proposed-nes-landfill-emissions.pdf

Ministry for the Environment. (2004b). Review of targets in New Zealand waste strategy. Wellington, New Zealand. Retrieved from http://www.mfe.govt.nz/publications/waste/review-targets-waste-strategy-feb04/review-waste-strategy-targets-feb04.pdf

Ministry for the Environment. (2005). New Zealand's Greenhouse Gas Inventory 1990-2003 (ME 607). Wellington: Ministry for the Environment. Retrieved from http://www.mfe.govt.nz/sites/default/files/nir-apr05.pdf

Ministry for the Environment. (2006). New Zealand's Greenhouse Gas Inventry 1990-2004: The National Inventory Report and Common Reporting Format (ME 746). Wellington: Ministry for the Environment. Retrieved from http://www.mfe.govt.nz/sites/default/files/nir-apr06_0.pdf

Ministry for the Environment. (2007a). The 2006/07 National Landfill Census (ME 842). Wellington. Retrieved from http://www.mfe.govt.nz/publications/waste/2006-07-national-landfill-census-oct07/2006-07-national-landfill-census-oct07.pdf

Ministry for the Environment. (2007b). Environment New Zealand 2007 (ME 847). Wellington. Retrieved from http://www.mfe.govt.nz/publications/ser/enz07-dec07/environment-nz07-dec07.pdf

Ministry for the Environment. (2007c, 17 September). How information is collected. Retrieved 30 April, 2015, from http://www.mfe.govt.nz/issues/waste/waste-data/pilot-how.html

Ministry for the Environment. (2007d). National Waste Data Report. Wellington. Retrieved from http://www.mfe.govt.nz/publications/waste/nat-waste-data-report-may97.pdf

Ministry for the Environment. (2007e). New Zealand's Greenhouse Gas Inventory 1990-2005: The National Inventory Report and Common Reporting Format. Wellington: Ministry for the Environment. Retrieved from http://www.mfe.govt.nz/sites/default/files/nir-jul07.pdf

Ministry for the Environment. (2007f, 24 September). Regulatory impact statement: Towards a Sustainable New Zealand – Measures to Minimise Solid Waste. Retrieved 20 July, 2016, from http://www.mfe.govt.nz/laws/ris/ris-solid-waste.html

Ministry for the Environment. (2007g). Targets in the New Zealand Waste Strategy 2006 Review of Progress. Wellington. Retrieved from http://www.mfe.govt.nz/publications/waste/waste-strategy-review-progress-mar07/waste-strategy-review-progress-mar07.pdf

Ministry for the Environment. (2007h). Targets in the New Zealand Waste Strategy: 2006 Review of Progress (Publication number: 802). Retrieved from http://www.mfe.govt.nz/sites/default/files/waste-strategy-review-progress-mar07.pdf

Ministry for the Environment. (2007i, 17 September). Tools for collecting waste data: Waste data pilot. Retrieved 30 April, 2015, from http://www.mfe.govt.nz/issues/waste/waste-data/pilot.html

Ministry for the Environment. (2007j). Waste. In Environment New Zealand 2007 Retrieved from http://www.mfe.govt.nz/publications/ser/enz07-dec07/chapter-6.pdf

Ministry for the Environment. (2008a). New Zealand's Greenhouse Gas Inventory 1990-2006 (Publication Number: 885). Wellington: Ministry for the Environment. Retrieved from http://www.mfe.govt.nz/sites/default/files/nz-greenhouse-gas-inventory-apr08.pdf

Ministry for the Environment. (2008b, 19 December). Waste: SWAP Baseline Programme. Retrieved from http://www.mfe.govt.nz/issues/waste/waste-data/swap-baseline.html

Ministry for the Environment. (2009a). Calculation and Payment of the Waste Disposal Levy: Guidance for waste disposal facility operators - Version two. Wellington. Retrieved from http://www.mfe.govt.nz/publications/waste/calculation-payment-of-waste-disposal-levy/calculation-payment-of-waste-disposal-levy.pdf

Ministry for the Environment. (2009b). Environmental report card: Solid waste composition. Wellington, New Zealand. Retrieved from http://www.mfe.govt.nz/environmental-reporting/waste/waste-composition-2009/waste-composition.pdf

Ministry for the Environment. (2009c). Guidance for voluntary, corporate greenhouse gas reporting: Data and Methods for the 2008 Calendar Year Wellington. Retrieved from http://www.mfe.govt.nz/publications/climate/guidance-greenhouse-gas-reporting-sept09/guidance-greenhouse-gas-reporting-sept09.pdf

Ministry for the Environment. (2009d). New Zealand's Greenhouse Gas Inventory 1990–2007 (ME 928). Wellington. Retrieved from http://www.mfe.govt.nz/sites/default/files/new-zealands-greenhouse-gas-inventory%202009.pdf

Ministry for the Environment. (2009e). Solid waste composition environmental report card. (INFO 420). Wellington. Retrieved from http://www.mfe.govt.nz/sites/default/files/environmental-reporting/waste/waste-composition-2009/waste-composition.pdf?_ga=1.153378232.1052275520.1401692142

Ministry for the Environment. (2010a). A guide to landfill methane in the New Zealand Emissions Trading Scheme. Wellington: Ministry for the Environment. Retrieved from https://www.climatechange.govt.nz/emissions-trading-scheme/participating/waste/guide-to-landfill-methane-in-nz-ets.pdf

Ministry for the Environment. (2010b). New Zealand's Greenhouse Gas Inventory 1990-2008. Wellington: Ministry for the Environment. Retrieved from http://www.mfe.govt.nz/sites/default/files/greenhouse-gas-inventory-2010%20%281%29.pdf

Ministry for the Environment. (2010c). The New Zealand Waste Strategy: Reducing Harm, Improving Efficiency (ME 1027). Wellington. Retrieved from http://mfe.govt.nz/sites/default/files/wastestrategy.pdf

Ministry for the Environment. (2010d). The New Zealand Waste Strategy: Reducing harm, improving efficiency. Wellington. Retrieved from http://www.mfe.govt.nz/publications/waste/waste-strategy/wastestrategy.pdf

Ministry for the Environment. (2010e, 15 October). Our Kyoto Protocol obligations. Retrieved 11 September, 2014, from http://www.climatechange.govt.nz/emissions-trading-scheme/about/international/kyoto.html

Ministry for the Environment. (2010f). Recommendations for methodologies for ETS landfill gas emission reporting (T&T Ref: 27228). Wellington: Ministry. Retrieved from https://www.climatechange.govt.nz/consultation/waste/recommendations-for-methodologies/recommendations.pdf

Ministry for the Environment. (2011a). A guide to landfill methane in the New Zealand Emissions Trading Scheme. Wellington. Retrieved from http://www.climatechange.govt.nz/emissions-trading-scheme/participating/waste/guide-to-landfill-methane-in-nz-ets.pdf

Ministry for the Environment. (2011b). Guidance for Voluntary Corporate Greenhouse Gas Reporting: Data and Methods for the 2010 Calendar Year. Wellington. Retrieved from http://www.mfe.govt.nz/publications/climate/guidance-greenhouse-gas-reporting-2010/greenhouse-gas-reporting-2010.pdf

Ministry for the Environment. (2011c). A guide to landfill methane in the New Zealand Emissions Trading Scheme. Wellington. Retrieved from https://www.climatechange.govt.nz/emissions-trading-scheme/participating/waste/guide-to-landfill-methane-in-nz-ets.pdf

Ministry for the Environment. (2011d). Measuring up: Environmental reporting - a discussion document (ME 1065). Wellington. Retrieved from http://www.mfe.govt.nz/publications/ser/measuring-up-environmental-reporting/measuring-up-environmental-reporting.pdf

Ministry for the Environment. (2011e). New Zealand's Greenhouse Gas Inventory 1990-2009 (ME 1045). Wellington: Ministry for the Environment. Retrieved from http://www.mfe.govt.nz/sites/default/files/media/Climate%20Change/New%20Zealand%E2%80%99s%20Greenhouse%20Gas%20Inventory%201990%E2%80%932009.pdf

Ministry for the Environment. (2011f, July). Solid Waste Disposal, 2010: Environmental Snapshot. Retrieved 6 September, 2014, from http://www.mfe.govt.nz/environmental-reporting/waste/solid-waste-disposal-indicator/solid-waste-disposal-2011.html

Ministry for the Environment. (2011g, 9 February). Stockholm Convention. Retrieved 20 February, 2014, from http://www.mfe.govt.nz/laws/meas/stockholm.html

Ministry for the Environment. (2011h, 15 March). The Waigani Convention. Retrieved 20 February, 2014, from http://www.mfe.govt.nz/issues/waste/weee-guidelines/exporting-hazardous-waste/waigani-convention.html

Ministry for the Environment. (2011i, 15 March). Waste Stream. In Waste. Retrieved 14 February, 2014, from http://www.mfe.govt.nz/issues/waste/streams/index.html

Ministry for the Environment. (2012a, 17 September). Montreal Protocol. Retrieved 22 February, 2014, from http://www.mfe.govt.nz/laws/meas/montreal.html

Ministry for the Environment. (2012b, 24 July). Multilateral Environmental Agreements. Retrieved 30 January, 2014, from http://www.mfe.govt.nz/laws/meas/

Ministry for the Environment. (2012c). New Zealand's Greenhouse Gas Inventory 1990-2010. Retrieved from http://www.mfe.govt.nz/sites/default/files/greehouse-gas-inventory-2012.pdf

Ministry for the Environment. (2012d). Quantity of solid waste sent to landfill – Indicator update (INFO 654). Retrieved from http://www.mfe.govt.nz/environmental-reporting/waste/solid-waste-disposal-indicator/quantity-solid-waste-landfill.html

Ministry for the Environment. (2012e, 19 November). Questions and answers about the emissions trading scheme. Retrieved 20 June 2014, from http://www.climatechange.govt.nz/emissions-trading-scheme/about/questions-and-answers.html

Ministry for the Environment. (2012f, 3 December). Waste in the emission trading scheme Retrieved 17 January, 2014, from http://www.climatechange.govt.nz/emissions-trading-scheme/participating/waste/

Ministry for the Environment. (2013a, 9 December). National Environmental Standards for Air Quality. Retrieved 20 January, 2014, from http://www.mfe.govt.nz/laws/standards/air-quality/index.html

Ministry for the Environment. (2013b). New Zealand's Greenhouse Gas Inventory 1990-2011 (ME 1113). Wellington: Ministry for the Environment. Retrieved from http://www.mfe.govt.nz/sites/default/files/greenhouse-gas-inventory-2013.pdf

Ministry for the Environment. (2013c, 12 April). Projected greenhouse gas emissions from waste 2008–2012. Retrieved 20 August, 2014, from http://www.mfe.govt.nz/issues/climate/greenhouse-gas-emissions/project-greenhouse-gas-emissions-from-waste.html

Ministry for the Environment. (2013d, 17 July). Quantity of solid waste sent to landfill - Indicator update October 2012 (INFO 254). Retrieved 27 January, 2015, from http://mfe.govt.nz/environmental-reporting/waste/solid-waste-disposal-indicator/quantity-solid-waste-landfill.html

Ministry for the Environment. (2013e, 17 July). Quantity of solid waste sent to landfill indicator update (INFO 654). Retrieved 2 December, 2014, from http://www.mfe.govt.nz/more/environmental-reporting/waste/solid-waste-disposal-indicator/quantity-solid-waste-landfill

Ministry for the Environment. (2013f, 17 July). Quantity of solid waste sent to landfill: Indicator update October 2012 (INFO 654). Retrieved 10 December, 2013, from http://www.mfe.govt.nz/environmental-reporting/waste/solid-waste-disposal-indicator/quantity-solid-waste-landfill.html

Ministry for the Environment. (2013g, 17 July). Solid waste disposal, 2010 environmental snapshot (INFO 610). Retrieved 3 December, 2014, from http://www.mfe.govt.nz/more/environmental-reporting/waste/solid-waste-disposal-indicator/solid-waste-disposal-2010

Ministry for the Environment. (2013h, 24 July). SWAP Baseline Programme. Retrieved 5 December, 2014, from http://www.mfe.govt.nz/sites/default/files/waste/data/reports-stats/swap-results-2004.xls

Ministry for the Environment. (2013i, 18 October). Waste Minimisation Act 2008. Retrieved 20 August, 2014, from http://www.mfe.govt.nz/issues/waste/waste-minimisation.html

Ministry for the Environment. (2014a). Guidance for Voluntary Corporate Greenhouse Gas Reporting - Data and Methods for the 2012 Calendar Year. Wellington: Ministry for the Environment. Retrieved from http://www.mfe.govt.nz/sites/default/files/media/Climate%20Change/greenhouse-gas-reporting-2012%20year.pdf

Ministry for the Environment. (2014b, 11 September). Monthly levy graph. Retrieved 24 November, 2014, from http://www.mfe.govt.nz/waste/waste-disposal-levy/monthly-levy-graph

Ministry for the Environment. (2014c). New Zealand's Greenhouse Gas Inventory 1990 - 2012. Wellington. Retrieved from http://www.mfe.govt.nz/publications/climate/greenhouse-gas-inventory-2014/greenhouse-gas-inventory-2014-year.pdf

Ministry for the Environment. (2014d). Proposed National Environmental Standard to Control Greenhouse Gas Emissions from Landfills (Resource Management Act Section 32- Analysis of the costs and benefits) (ME number: 515). Wellington. Retrieved from http://www.mfe.govt.nz/sites/default/files/proposed-nes-landfill-emissions.pdf

Ministry for the Environment. (2014e). Review of the effectiveness of the waste disposal levy, 2014 - In accordance with section 39 of the Waste Minimisation Act 2008 (ME 1159). Wellington: Ministry for the Environment. Retrieved from http://www.mfe.govt.nz/sites/default/files/media/Waste/waste-disposal-levy-review-2014-pdf.pdf

Ministry for the Environment. (2014f, 17 September). Rotterdam Convention. Retrieved 4 May, 2016, from http://www.mfe.govt.nz/more/international-environmental-agreements/multilateral-environmental-agreements/key-multilatera-13

Ministry for the Environment. (2014g, 3 September). Waste disposal levy. In Waste. Retrieved 17 January, 2015, from http://www.mfe.govt.nz/issues/waste/progress-and-outcomes/waste-disposal-levy.html

Ministry for the Environment. (2015a, 13 February). Monthly levy graph. Retrieved 23 February, 2015, from http://www.mfe.govt.nz/waste/waste-disposal-levy/monthly-levy-graph

Ministry for the Environment. (2015b). New Zealand's Greenhouse Gas Inventory 1990-2013 (ME 1195). Wellington. Retrieved from https://www.mfe.govt.nz/sites/default/files/media/Climate%20Change/national-inventory-report%20updated%2029%20July%202015.pdf

Ministry for the Environment. (2015c, 5 June). Vienna Convention for the Protection of the Ozone Layer and the Montreal Protocol on Substances that Deplate the Ozone Layer. Retrieved 5 May, 2016, from http://www.mfe.govt.nz/more/international-environmental-agreements/multilateral-environmental-agreements/key-multilateral-7

Ministry for the Environment. (2016a, 22 March). Monthly levy graph. Retrieved 15 May, 2016, from http://www.mfe.govt.nz/waste/waste-disposal-levy/monthly-levy-graph

Ministry for the Environment. (2016b, 22 March). Monthly levy graph. Retrieved 2 June, 2016, from http://www.mfe.govt.nz/waste/waste-disposal-levy/monthly-levy-graph

Ministry for the Environment. (2016c, 15 April). United Nations Framework Convention on Climate Change. Retrieved 4 May, 2016, from http://www.mfe.govt.nz/climate-change/international-forums-and-agreements/united-nations-framework-convention-climate

Ministry for the Environment. (n.d-a). Part 1: Understanding wastewater within natural and human systems. In Sustainable Wastewater Management: A handbook for smaller communities. Retrieved from http://www.mfe.govt.nz/publications/waste/wastewater-mgmt-jun03/html/part1-section2.html

Ministry for the Environment. (n.d-b). Part 2: New Zealand’s Response to the Articles of the Stockholm Convention. In New Zealand's National Implementation Plan under the Stockholm Convention on Persistent Organic Pollutants. Retrieved 20 February, 2014, from http://www.mfe.govt.nz/publications/hazardous/stockholm-convention-pops-dec06/html/page5.html

Mitchell, G. (1996). Problems and fundamentals of suatainable development indicators. Sustainable Development, 4(1), 1-11. doi:10.1002/(SICI)1099-1719(199603)4:1<1::AID-SD24>3.0.CO;2-N

Monni, S., Pipatti, R., Lehtilä, A., Savolainen, I., & Syri, S. (2006). Global climate change mitigation scenarios for solid waste management. VTT Publications 603. VTT Technical Research Centre, Finland.

Morgan, S. (2011, 6 December). Illegal dumping costs city $1.2m. Retrieved 19 March, 2014, from www.stuff.co.nz/auckland/local-news/6088449/illegal-dumping-costs-city-1-2m

Morrison Low. (2011). Wellington Regional Waste Assessment (1770). Retrieved from http://www.kapiticoast.govt.nz/documents/downloads/solid-waste/wmmp/regional-waste-assessment.pdf

Morrissey, A. J., & Browne, J. (2004). Waste management models and their application to sustainable waste management. Waste Management, 24(3), 297-308. doi:10.1016/j.wasman.2003.09.005

Morrissey, A. J., & Browne, J. (2004). Waste management models and their application to sustainable waste management. Waste Management, 24(2004), 297-308. doi:10.1016/j.wasman.2003.09.005

Muñoz, I., Rieradevall, J., Doménech, X., & Milà, L. (2004). LCA application to integrated waste management planning in Gipuzkoa (Spain). The International Journal of Life Cycle Assessment, 9(4), 272-280. doi:10.1065/Ica2004.04.156

MWH. (2013). Nelson - Tasman SWAP Studies 2012. Retrieved from http://www.tasman.govt.nz/document/serve/Nelson%20Tasman%20Waste%20Composition%20Survey%202012%20%28Final%29.pdf?path=/EDMS/Public/Other/Services/Rubbish_Recycling/000000262545

National Council for Air and Stream Improvement. (2013). Effects of Recycled Fiber Use on Greenhouse Gas Emissions: Carbon Sequestered in Forest, Products and landfills. Retrieved from http://www.paperenvironment.org/PDF/recycling/greenhouse/R_G_Carbon.pdf

Neilsen, S. G. (2003). Liberalization of Waste Incineration – a Scenario Study of Future Treatment Prices and Amounts of Waste Designated for Combustion in the Region of Öresund (in Danish). Denmark, Roskilde Universitets-center: Institut for Miljø, Teknologi og Samfund. .

Neira, M. (1997). Cholera: a challenge for the 21st century. World Health, 50(1), 9.

Nelson City and Tasman District Council. (2012). Nelson City Council and Tasman District Council Joint Waste Management and Minimisation Plan Retrieved from file:///C:/Users/mmichael/Downloads/Joint%20Waste%20Management%20and%20Minimisation%20Plan-April%202012.pdf

New Zealand Emission Unit Register. (n.d). About the NZEUR. Retrieved 10 September, 2014, from www.eur.govt.nz/about-us

New Zealand Legal Information Institute. (2013a, 7 July). Climate Change Response Act 2002 (2002 No 40). Retrieved 18 January, 2016, from http://www.nzlii.org/nz/legis/hist_act/ccra20022002n40239/

New Zealand Legal Information Institute. (2013b, 7 July). Environment Act 1986 (1986 No 127). Retrieved 19 January, 2014, from http://www.nzlii.org/nz/legis/hist_act/ea19861986n127186/

New Zealand Legal Information Institute. (2013c, 7 July). Hazardous Substances and New Organisms Act 1996 (1996 No 30). Retrieved 20 January, 2014, from http://www.nzlii.org/nz/legis/hist_act/hsanoa19961996n30426/

New Zealand Legal Information Institute. (2013d, 7 July). Health Act 1920 (11 GEO V 1920 No 45). Retrieved 28 January, 2016, from http://www.nzlii.org/nz/legis/hist_act/ha192011gv1920n45141/

New Zealand Legal Information Institute. (2013e, 7 July). Health Act 1956 (1956 No 65). Retrieved 28 January, 2016, from http://www.nzlii.org/nz/legis/hist_act/ha19561956n6596/

New Zealand Legal Information Institute. (2013f, 7 July). Litter Act 1968 (1968 No 134). Retrieved 25 January, 2016, from http://www.nzlii.org/nz/legis/hist_act/la19681968n134126/

New Zealand Legal Information Institute. (2013g, 7 July). Litter Act 1979 (1979 No 41). Retrieved 28 January, 2016, from http://www.nzlii.org/nz/legis/hist_act/la19791979n41126/

New Zealand Legal Information Institute. (2013h, 7 July). Local Government Act 2002 (2002 No 84). Retrieved 18 January, 2016, from http://www.nzlii.org/nz/legis/hist_act/lga20022002n84209/

New Zealand Legal Information Institute. (2013i, 7 July). Local Government Amendment Act 1979 (1979 No 59). Retrieved 28 January, 2016, from http://www.nzlii.org/nz/legis/hist_act/lgaa19791979n59289/

New Zealand Legal Information Institute. (2013j, 7 July). Local Government Amendment Act 1992 (1992 No 42). Retrieved 20 January, 2016, from http://www.nzlii.org/nz/legis/hist_act/lgaa19921992n42289/

New Zealand Legal Information Institute. (2013k, 7 July). Local Government Amendment Act (No 4) 1996 (1996 No 84). Retrieved 18 January, 2016, from http://www.nzlii.org/nz/legis/hist_act/lgaa419961996n84316/

New Zealand Legal Information Institute. (2013l, 7 July). Ozone Layer Protection Act 1996 (1996 No 40). Retrieved 18 January, 2016, from http://www.nzlii.org/nz/legis/hist_act/olpa19961996n40299/

New Zealand Legal Information Institute. (2013m, 7 July). Resource Management (Energy and Climate Change) Amendment Act 2004 (2004 No 2). Retrieved 17 January, 2014, from http://www.nzlii.org/nz/legis/hist_act/rmaccaa20042004n2479/

New Zealand Legislation. (2008). Waste Minimisation Act 2008. Wellington. Retrieved from http://www.legislation.govt.nz/act/public/2008/0089/latest/DLM999802.html?src=qs

New Zealand Ministry of Foreign Affairs & Trade. (2011, 14 March). Treaties and International Law. Retrieved 20 February, 2014, from http://www.mfat.govt.nz/Treaties-and-International-Law/03-Treaty-making-process/2-National-Interest-Analyses/0-Waigani-Convention.php

New Zealand Parliament. (2008, 30 July). Parliamentary Debates (Hansard) Waste Minimisation Bill — In Committee (48HansD_20080730_00001317). Retrieved 7 March, 2014, from http://www.parliament.nz/en-nz/pb/debates/debates/48HansD_20080730_00001317/waste-minimisation-bill-%E2%80%94-in-committee

Ng, K., & Hase, S. (2008). Grounded Suggestions for Doing a Grounded Theory Business Research. The Electronic Journal of Business Research Methods, 6(2), 155-170.

Niloufer, S., & Swamy, A. V. V. S. (2015). A Brief Assessment of Municipal Solid Waste and its impact on leachate quality at MSW sites in Vijayawada city, India. International Journal of Innovative Science, Engineering & Technology, 2(6), 645-658.

NV Afvalzorg. (2014). Multiphase landfill gas generation and emission model. Retrieved 3 July, 2015, from http://www.afvalzorg.nl/Libraries/Protected_Downloads/NV-Afvalzorg-Multiphase-Model-version-January-2015.sflb.ashx

NZ Parliamentary Library. (2001). The greenhouse effect and climate change: A resource document for New Zealand MPs (background paper No. 24). Wellington. Retrieved from www.parliament.nz/NR/rdonlyres/4B2AB1B5-9D14-4E55-9C7F-037DE689A404/494/greenhouse_effect_complete1.pdf

Oberkampf, W. L., & Trucano, T. G. (2002). Verification and validation in computational fluid dynamics. Progress in Aerospace Sciences, 38(2002), 2009-2272.

Obrst, L., Ceusters, W., Mani, I., Ray, S., & Smith, B. (2007). The evaluation of ontologies. In C. J. O. Baker & K.-H. Cheung (Eds.), Revolutionizing Knowledge Discovery in the Life Science (pp. 139-158). Berlin: Springer.

OECD. (1993). OECD Economic Surveys 1992-1993 New Zealand. Paris: Organisation for Economic Cooperation and Development.

OECD. (1995). OECD Environmental Data Compendium 1995. Paris: Organisation for Economic Cooperation and Development.

OECD. (2001, 14 December). Household food consumption: trends, environmental impacts and policy responses. Retrieved 2 April, 2015, from http://search.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/EPOC/WPNEP(2001)13/FINAL&docLanguage=En

OECD. (2002a). Household energy & water consumption and waste generation: trends, environmental impacts and policy responses. Retrieved 2 April, 2014, from http://search.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/EPOC/WPNEP(2001)15/FINAL&docLanguage=En

OECD. (2002b). Towards Sustainable Household Consumption?: Trends and Policies in OECD Countries. Retrieved from http://www.oecd.org/greengrowth/consumption-innovation/1938984.pdf

OECD. (2002c). Waste generation by country, OECD Environmental Data Compendium: 2002. Retrieved 14 January, 2014, from http://www.nationmaster.com/graph/env_was_gen-environment-waste-generation

OECD. (2003, March 17). Glossary of statistical terms. Retrieved 11 February, 2016, from http://stats.oecd.org/glossary/detail.asp?ID=2896

OECD. (2004). Addressing the economics of waste. Retrieved from http://ewaste.pbworks.com/f/Economics+of+waste.pdf doi:10.1787/9789264106192-2-en

OECD. (2007). Environmental Performance Reviews: New Zealand (2007). Retrieved from http://www.oecd.org/env/country-reviews/37915514.pdf

OECD. (2014). Environmental Strategy for the First Decade of the 21st Century. Retrieved 27 May, 2014, from http://www.oecd.org/environment/ministerial/environmentalstrategyforthefirstdecadeofthe21stcentury.htm

OECD. (n.d). Sustainable Materials Management (SMM). Retrieved 27 May, 2016, from http://www.oecd.org/environment/waste/smm.htm#

Office of the Parliamentary Commissioner for the Environment. (2002:p17). Background Paper: CREATING OUR FUTURE - Sustainable Development for New Zealand Government Strategies. Wellington. Retrieved from http://www.pce.parliament.nz/assets/Uploads/Reports/pdf/creating_bkgrd3.pdf

Ogor, Y., & Guerbois, M. (2005). comparison of landfill methane emission models: A case study Symposium conducted at the meeting of the Tenth International Waste Management and Landfill Symposium, Sardinia, Italy.

Ohrling, U., & Odebjer, K. (2014, 16 April). Sweden shows incineration can play key role in waste management plan. Retrieved 30 May, 2015, from http://www.scmp.com/comment/article/1482809/sweden-shows-incineration-can-play-key-role-waste-management-plan

Oonk, H. (2010). Literature Review: Methane from landfills-Methods to quantify generation, oxidation and emission. Retrieved from http://www.ewp.rpi.edu/hartford/~ernesto/F2014/MMEES/Papers/ENVIRONMENT/4SolidWaste/Oonk2010-FinalReport-LandfillMethane-Review.pdf

Oonk, H., & Boom, T. (1995). Landfill gas formation, recovery and emissions, TNO-report R95-203 (410100035 (1995)). Bilthoven, The Netherland: NRP Programme Office. Retrieved from http://scholar.google.co.nz/scholar_url?url=http://publications.tno.nl/publication/34610172/ZgOfqt/MEP-1995-203.pdf&hl=en&sa=X&scisig=AAGBfm0TkNc8DxYw8qz7s4BzD8j2itU4YA&nossl=1&oi=scholarr&ei=AE78VKfiPIjr8AWhkIGwBA&ved=0CBsQgAMoADAA

Opotiki District Council. (2011). Opotiki District Council Waste Assessment 2011 Retrieved from http://www.odc.govt.nz/media/89481/opotiki%20district%20council%20draft%20waste%20assessment%202011.pdf

Opotiki District Council. (2012). Opotiki District Council Waste Management and Minimisation Plan 2012 Opotiki. Retrieved from http://www.odc.govt.nz/media/91724/opotiki%20district%20council%20waste%20management%20and%20minimisation%20plan%202012%20-%20final.pdf

Özeler, D., Yetiş, Ü., & Demirer. (2006). Life cycle assesment of municipal solid waste management methods: Ankara case study. Environment International, 32(3), 405-411. doi:10.1016/j.envint.2005.10.002

PAC NZ. (2014). About Us. Retrieved 30 January, 2016, from http://www.packaging.org.nz/index.php/about-us/our-history/

Packaging Council of New Zealand. (2012). New Zealand Packaging Accord 2004. Year Five Progress Report. Auckland: Packaging Council of New Zealand. Retrieved from http://www.packaging.org.nz/assets/Uploads/Packaging-Accord-Year5-Report.pdf

Parliamentary Counsel Office. (1991). Resource Management Act 1991. Retrieved from http://www.legislation.govt.nz/act/public/1991/0069/latest/DLM230265.html

Parliamentary Counsel Office. (2004a). Imports and Exports (Restrictions) Prohibition Order (No 2) 2004 (SR 2004/202). Retrieved from http://www.legislation.govt.nz/regulation/public/2004/0202/latest/096be8ed80bf2e00.pdf

Parliamentary Counsel Office. (2004b). Resource Management (National Environmental Standards for Air Quality) Regulations 2004 (SR 2004/309). Wellington. Retrieved from http://www.legislation.govt.nz/regulation/public/2004/0309/latest/096be8ed8072b5a8.pdf

Parliamentary Counsel Office. (2010). Climate Change (Unique Emissions Factors) Amendment Regulations 2010 (Vol. 2014). Wellington. Retrieved from http://www.legislation.govt.nz/regulation/public/2010/0337/latest/096be8ed80610e3b.pdf

Parliamentary Counsel Office. (2012). Climate Change Response (Emissions Trading and Other Matters) Amendment Bill. Retrieved from http://www.legislation.govt.nz/bill/government/2012/0052/latest/096be8ed8098f8fc.pdf

Parliamentary Counsel Office. (2013, 7 July). Maritime Transport Act 1994 (1994 No 104). Retrieved 10 February, 2016 from http://www.nzlii.org/nz/legis/hist_act/mta19941994n104260/

Parliamentry Counsel Office. (2010). Climate Change (Waste) Regulations 2010 (SR 2010/338). Wellington. Retrieved from http://www.legislation.govt.nz/regulation/public/2010/0338/latest/096be8ed80ce2811.pdf

Patel, C., Supekar, K., Lee, Y., & Park, E. K. (2003). OntoKhoj: A Semantic Web Portal for Ontology Searching, Ranking and Classification Symposium conducted at the meeting of the 5th ACM International Workshop on Web Information and Data Management, New Orleans, Louisiana, USA, November 7-8, 2003.

Peccoud, J. (2014). If You Can't Measure It, You Can't Manage It. PLoS Computational Biology, 10(3), e1003462. doi:10.1371/journal.pcbi.1003462

Pernick, M. S. (1978). Politics, parties, and pestilence: epidemic yellow fever in Philadelphia and the rise of the first party system. In J. W. Leavitt, & Numbers, R. L. (Ed.), Sickness and Health in America (pp. 241-256). Madison, WI: University of Wisconsin Press.

Peter, K., & Erling, V. F. (1995). Landfill Gas Migration—Field Investigations At Skellingsted Landfill, Denmark. Waste Management & Research, 13(1995), 467-484. doi:10.1177/0734242X9501300506

Philips, P. S., Pratt, R. M., & Pike, K. (2001). An analysis of UK waste minimization clubs: key requirements for future cost effective developments. Waste Management, 21(4), 389-404. doi:10.1016/S0956-053X(00)00078-7

Pierson, P. (2000). Increasing return, pathdependence and the study of politics. American Political Science Review, 94(2), 251-267.

Pike Research. (2012). Waste to energy technology markets. Renewable power and heat generation from Municipal Solid Waste: market outlook, technology assessment and capacity and revenue forecasts. Boulder, CO USA. Retrieved from http://www.navigantresearch.com/wp-content/uploads/2012/03/WTE-12-Executive-Summary.pdf

Pires, A., Martinho, G., & Ni-Bin, C. (2011). Solid waste management in European countries: A review of systems analysis techniques. Journal of Environmental Management, 92(4), 1033–1050.

Plastics New Zealand Incorporated. (2012). Converting Waste to Energy: Opportunities for New Zealand,. Auckland: Wilkinson Environmental Ltd. Retrieved from http://www.plastics.org.nz/documents/Environmental/Waste%20to%20Energy/Exec%20Summary.pdf

Plinere, D., & Borisov, A. (2014). Evaluation of the Ontological Knowledge Model. Information Technology and Management Science, 17, 81-85. doi:10.1515/itms-2014-0012

Ponder, C. S. (2010, 2 June). Using Life Cycle Analysis to Evaluate the Environmental Benefits of Using Biocidal Medical Garments. presented at the meeting of the Sustainable Textiles and Medical Protections Conference,, Retrieved from http://nsf-muses.ucdavis.edu/pdf/STAMPconference/CPonder%20Biocidal%20Gown%20Infection%20Treatment%20v3-1.pdf

Pongrácz, E., Phillips, P. S., & Keiski, R. L. (2004). Evolving the Theory of Waste Management – Implications to waste minimization. In E. Pongrácz (Ed.), Proceedings of Waste Minimization and Resources Use Optimization Conference, June 10, 2004, University of Oulu, Finland. Oulu: Oulu University Press.

Popa, F., Guillermin, M., & Dedeurwaerdere, T. (2015). A pragmatist approach to transdisciplinarity in sustainability research: From complex systems theory to reflexive science. Advances in transdisciplinarity 2004-2014, 65, 45-56. doi:10.1016/j.futures.2014.02.002

Potter, A. N. (2013, 30 January). Need for the M2M program. Retrieved 28 May, 2014, from http://csanr.wsu.edu/?s=Need+for+the+M2M+program

Poudyal, S. (2013, 9 October). Sweden trashes recycling myths by getting rid of garbage. Retrieved 30 May, 2014, from http://ticker.baruchconnect.com/article/sweden-trashes-recycling-myths-by-getting-rid-of-garbage/

Poulussen, P. (1987). Van burenlast tot milieuhinder Het stedelijk leefmilieu 1500-1800. Kapellen, Belgium: DNB/Uitgeverij Pelckmans.

Puig-Ventosa, I. (2008). Charging systems and PAYT experiences for waste management in Spain. Waste Management, 28(12), 2767-2771. doi:10.1016/j.wasman.2008.03.029

Quast, L. (2012, 26 November). Overcome The 5 Main Reasons People Resist Change. Retrieved 7 June, 2016, from http://www.forbes.com/sites/lisaquast/2012/11/26/overcome-the-5-main-reasons-people-resist-change/#606f544d3393

R. W. Beck Inc. (2001). U.S. Recycling Economic Information Study (prepared for the national recycling coalition). Retrieved from http://www.epa.gov/wastes/conserve/tools/rmd/rei-rw/pdf/n_report.pdf

Ragossnig, A. M., & Hilger, H. (2008). Editorial: Waste Management: Stepping up to the climate change challenge. Waste Management and Research, 26(1), 3-4. doi:10.1177/0734242X080260010601

Rapley, T. (2007). Doing Conversation, Discourse and Document Analysis. London: SAGE. doi:10.4135/9781849208901

Rebitzer, G., Ekvall, T., Frischknecht, R., Hunkeler, D., Norris, G., Rydberg, T., . . . Pennington, D. W. (2004). Life cycle assessment part 1: framework, goal and scope definition, inventory analysis, and applications. Environ Int, 30(5), 701-720. doi:10.1016/j.envint.2003.11.005

Refsgaard, J. C., van der Sluijs, J. P., Brown, J., & van der Keur, P. (2006). A framework for dealing with uncertainty due to model structure error. Advances in Water Resources, 29(2006), 1586-1597. doi:10.1016/j.advwatres.2005.11.013

Reh, F. J. (2014). You Can't Manage What You Don't Measure. Retrieved 28 May, 2014, from http://management.about.com/od/metrics/a/Measure2Manage.htm

Reichenbach, J. (2008). Status and prospects of pay-as-you-throw in Europe – A review of pilot research and implementation studies. Waste Management, 28(12), 2809-2814. doi:10.1016/j.wasman.2008.07.008

Rigamonti, L., Falbo, A., & Grosso, M. (2013). Improvement actions in waste management systems at the provincial scale based on a life cycle assessment evaluation. Waste Management, 33(11), 2568-2578.

Ringstrom, A. (2012, 26 November). Sweden turns trash into cash as EU seeks to curb dumping. Retrieved 30 May, 2014, from http://www.reuters.com/article/2012/11/26/us-sweden-environment-garbage-idUSBRE8AP0MI20121126

Robert Wood Johnson Foundation. (2008). Case Study. Retrieved 23 May, 2016, from http://www.qualres.org/HomeCase-3591.html

Rojo, G., Glaus, M., Hausler, R., Laforest, V., & Bourgeois, J. (2013). Dynamic waste management (DWM): Towards an evolutionary decision-making approach. Waste Management & Research, 31(12), 1285 –1292. doi:10.1177/0734242X13507306

Rotorua Lakes Council. (2015). Draft Waste Strategy 2015. Retrieved from http://www.rdc.govt.nz/our-council/consultation-and-public-notices/ltp2015/Documents/Draft-Waste-Strategy.pdf

Rotter, S. (2011). Incineration: RDF and SRF - Solid waste from fuels. In G. Tchobanoglous & F. Kreith (Eds.), Handbook of Solid Waste Management (2nd ed.): 2012 The McGraw-Hill Companies.

Rotterdam Convention. (2010). History of the negotiations of the Rotterdam Convention. Retrieved 17 February, 2014, from http://www.pic.int/TheConvention/Overview/History/tabid/1045/language/en-US/Default.aspx

Rudden, P. J. (2007). Report: Policy divers and the planning and implementation of integrated waste management in Ireland using the regional approach. . Waste Management & Research, 2007(25), 270-275. doi: 10.1177/0734242X07079151

Rushton, L. (2003). Health hazards and waste management. British Medical Bulletin, 68(1), 183-197. doi:10.1093/bmb/ldg034

Sabou, M., Gracia, J., Angeletou, S., d'Aquin, M., & Motta, E. (2007). Evaluating the Semantic Web: A Task-Based Approach. In Karl Aberer et al. (Ed.), Proceedings of 6th International Semantic Web Conference. 2nd Asian Semantic Web Conference, ISWC 2007 + ASWC 2007, Busan, Korea, November 11-15, 2007 (pp. 449-463). Berlin Heidelberg: Springer-Verlag.

Salhofer, S., Schneider, F., & Obersteiner, G. (2007). The ecological relevance of transport in waste disposal systems in Western Europe. Waste Management, 27(8), S47–S57. doi:10.1016/j.wasman.2007.02.025

Sapota, G., Wik, O., Lundberg, K., & Kleverlaan, E. (2011). Environmental Policy and Legislation on Dredged Material in the Baltic Sea Region (Baltic Sea Region Programme Project No #39). Retrieved from https://www.google.co.nz/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&cad=rja&uact=8&ved=0ahUKEwi1vNTRibrMAhUMH5QKHXgyCzcQFggmMAI&url=http%3A%2F%2Fsmocs.eu%2F%3Fdownload%3DEnvironmental%2520policy&usg=AFQjCNH5KnmmtHkN5Un6sBs2DwfB5FsmXQ&sig2=VbvlNknfsKJIQYTW-wvweg

Sargent, R. G. (2013). Verification and Validation of Simulation Models. Journal of Simulation, 7(2013), 12-24. doi:10.1057/jos.2012.20

Sastry, D. B. S. S. R. (n.d). Composition of municipal solid waste - need for thermal treatment in present Indian context. Retrieved from http://www.seas.columbia.edu/earth/wtert/sofos/DBSSRS_Article_-_WTE_INDIA_BRIEF_Revised.pdf

Šauer, P., Pařízková, L., & Hadrabová, A. (2008). Charging systems for municipal solid waste: Experience from the Czech Republic. Waste Management, 28(12), 2772-2777. doi:10.1016/j.wasman.2008.03.030

Sauro, J. (2015, 13 October). 5 Types of Qualitative Methods. Retrieved 9 December, 2015, from http://www.measuringu.com/blog/qual-methods.php

Scheinberg, A. (2011). Value Added: Modes of Sustainable Recycling in the Modernisation of Waste Management Systems. Wageningen University, Wageningen NL. Retrieved from http://edepot.wur.nl/179408

Scheinberg, A., Simpson, M. h., & Gupt, Y. (2010). Economic Aspects of the Informal Sector in Solid Waste, Final report and annexes. GIZ (German International Co-operation), the CWG (Collaborative Working Groupon Solid Waste Management in Low- and Middle-income Countries, and the German Ministry of Foreign Affairs, Eschborn, Germany. Available at www.GIZ.de.

Scheinberg, A., Wilson, D. C., & Rodic, L. (2010). Solid waste management in the world's cities. UN-Habitat's Third Global Report on the state of water and sanitation in the world's cities. . Newcastle-on-Tyne, UK: Earthscan Publication. Retrieved from http://www.waste.nl/sites/waste.nl/files/product/files/swm_in_world_cities_2010.pdf

Scheutz, C., Kjeldsen, P., Bogner, J. E., Visscher, A. D., Gebert, J., Hilger, H. A., . . . Spokas, K. (2009). Microbial methane oxidation processes and technologies for mitigation of landfill gas emissions. Waste Management and Research, 27(5), 409-455. doi:10.1177/0734242X09339325

Schiermeier, Q. (2011). Extreme Measures. Nature, 477(8 September), 148-149. doi:10.1038/477148a

Scholz, R. W., Lang, D. J., Wiek, A., Walter, A. I., & Stauffacher, M. (2006). Transdisciplinary case studies as a means of sustainability learning - Historical framework and theory. International Journal of Sustainability in Higher Education, 7(3), 226-251. doi:10.1108/14676370610677829

Scholz, R. W., Mieg, H. A., & Oswald, J. E. (2000). Transdisciplinarity in groundwater management – towards mutual learning of science and society. Water, Air and Soil Pollution, 123(1-4), 477-487.

Schübeler, P., Wehrle, K., & Christen, J. (1996). Conceptual Framework for Municipal Solid Waste Management in Low-Income Countries. Urban Management Programme Working Paper No. 9, World Bank, August 1996. Retrieved from http://www.worldbank.org/urban/solid_wm/erm/CWG%20folder/conceptualframework.pdf

Science Communication Unit University of the West of England Bristol. (2013). Science for Environment Policy-Indepth Report: Resource Efficiency Indicators. Report produced for the European Commission DG Environment. Retrieved from http://ec.europa.eu/environment/integration/research/newsalert/pdf/IR4_en.pdf

Sheth, P. A. (1999). Changing Focus on Interoperability in Information Systems:From System, Syntax, Structure to Semantics. In M. Goodchild, M. Egenhofer, R. Fegeas, & C. Kottman (Eds.), Interoperating Geographic Information Systems (Vol. 495, pp. 5-29): Springer US. Retrieved from http://dx.doi.org/10.1007/978-1-4615-5189-8_2. doi:10.1007/978-1-4615-5189-8_2

Skumatz, L. A. (2008). Pay as you throw in the US: Implementation, impacts, and experience. Waste Management, 28(12), 2778-2785. doi:10.1016/j.wasman.2008.03.033

Slagstad, H., & Brattebø, H. (2012). LCA for household waste management when planning a new urban settlement. Waste Management, 32(7), 1482–1490.

Smith, N. (2015, 26 August). Consultation on steps to ozone recovery and asbestos ban. Retrieved 26 July, 2016, from https://www.beehive.govt.nz/release/consultation-steps-ozone-recovery-and-asbestos-ban-1

Snow, W. (2003). Zero waste does it mean an end to waste? Waste Management World(September-October), 25-31 p. Retrieved from http://www.waste-management-world.com/articles/2003/09/zero-waste.html

Sohn, L. B. (1973). The Stockholm Declaration on the Human Environment. The Harvard International Law Journal, 14(3), 423-515.

Solano, E., Dumas, R. D., & Harrison, K. W. (2002). Life-cycle-based solid waste management. II: Illustrative applications. Journal of Environmental Engineering, 128, 993.

Solano, E., Ranjithan, R., Barlaz, M. A., & Brill, E. D. (2002). Life-cycle-based solid waste management I: model development. . Journal of Environmental Engineering, 981, 992.

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., . . . Miller, H. L. (Eds.). (2007). Climate change 2007: The physical science basis; contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY USA: Cambridge University Press. Retrieved from http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg1_report_the_physical_science_basis.htm

Sound Resource Management Group. (2009). Environmental Life Cycle Assessment of Waste Management Strategies with a Zero Waste Objective - Study of the Solid Waste Management System in Metro Vancouver, British Columbia. Vancouver, BC: Belkorp Environmental Services Inc. Retrieved from http://www.belkorp.ca/Dr_Morris_Report.pdf

Staab, S., Gomez-Perez, A., & Noy, N. F. (2005). Why evaluate ontology technologies? Because it works! Intelligent Systems, IEEE, 19(4), 74-81. doi:10.1109/MIS.2004.37

Stake, R. E. (1995). The Art of Case Study Research. Thousand Oaks, CA: Sage.

Staniskis, J. (2005). Integrated Waste Management: Concept and Implementation. Environmental research, engineering and management, 3(33), 40-46.

Staniskis, J., & Stasiskiene, Z. (2005). Industrial waste minimization – experience from Lithuania. Waste Manage Res, 23(2005), 1-9. doi:10.1177/0734242X05054515

Statistics New Zealand. (2008). Topic 8: Waste. In Measuring New Zealand's Progress Using a Sustainable Development Approach: 2008. Retrieved from http://www.stats.govt.nz/browse_for_stats/snapshots-of-nz/Measuring-NZ-progress-sustainable-dev-%20approach/sustainable-development/waste.aspx

Statistics New Zealand. (2011). New Zealand General Social Survey: 2010. Retrieved 16 January, 2014, from http://www.stats.govt.nz/browse_for_stats/people_and_communities/Households/nzgss_HOTP2008.aspx

Statistics New Zealand. (2014a). 2013 Census meshblock dataset - Excell files (Auckland Region) In 2013 Census meshblock dataset. Retrieved from http://www.stats.govt.nz/Census/2013-census/data-tables/meshblock-dataset.aspx#excelfiles

Statistics New Zealand. (2014b, 13 February). Historical population estimates - tables. Retrieved 13 May, 2016, from http://www.stats.govt.nz/~/media/Statistics/browse-categories/population/estimates-projections/national-pop-estimates/historical-pop-estimates.xls

Statistics New Zealand. (2015a, 18 November). Estimated Resident Population for Territorial Authority Areas, at 30 June(1996+) (Annual-Jun)-Auckland. Retrieved 19 November, 2015, from http://www.stats.govt.nz/infoshare/ViewTable.aspx?pxID=c9c905af-e3a4-4d7c-b442-a1491a452175

Statistics New Zealand. (2015b, 18 November). Group: Population Estimates - DPE - Table: Estimated Resident Population for Territorial Authority Areas, at 30 June(1996+) (Annual-Jun) Retrieved 1 June, 2016, from http://www.stats.govt.nz/infoshare/ViewTable.aspx?pxID=e3a9aa9a-42e4-4b56-8a2f-42108a3cd3c8

Statistics New Zealand. (2015c, 18 November). Group: Population Estimates - DPE - Table: Estimated Resident Population for Territorial Authority Areas, at 30 June(1996+) (Annual-Jun) Retrieved 28 January, 2016, from http://www.stats.govt.nz/infoshare/ViewTable.aspx?pxID=7df0c01f-ae2b-4c90-a9ea-2dc282802686

Statistics New Zealand. (2015d, 18 November). Group: Population Estimates - DPE - Table: Estimated Resident Population for Territorial Authority Areas, at 30 June(1996+) (Annual-Jun) Retrieved 30 January, 2016, from http://www.stats.govt.nz/infoshare/ViewTable.aspx?pxID=ba10bc00-2ddd-493e-80d8-be0ee8b7d0e9

Statistics New Zealand. (2016, 28 February). Subnational population estimates (TA, AU), by age and sex, at 30 June 2006-15 (2015 boundaries) Retrieved 29 February, 2016, from http://nzdotstat.stats.govt.nz/wbos/Index.aspx?DataSetCode=TABLECODE7502#

Stavins, R. N. (2001, November). Experience with Market-Based Environmental Policy Instruments. Discussion Paper 01-58. . Retrieved 1 August, 2014, from http://www.rff.org/documents/RFF-DP-01-58.pdf

Steg, L., & Vlek, C. (2009). Encouraging pro-environmental behaviour: An integrative review and research agenda. Journal of Environmental Psychology, 29, 309-317. doi:0.1016/j.jenvp.2008.10.004

Steketee, J., Cuperus, G., & Jacobs, J. (2011). Validatie van het nationale stortgas emissiemodel. Tauw bv, Devember.

Strasser, S. (1999). Waste and Want. A Social History of Trash. New York: Henry Holt and Company.

Stringfellow, T. (2014, 13 January). An Independent Engineering Evaluation of Waste-to-Energy Technologies. Retrieved 10 August, 2016, from http://www.renewableenergyworld.com/articles/2014/01/an-independent-engineering-evaluation-of-waste-to-energy-technologies.html

Sunar, N., & Plambeck, E. L. (2011, November 2). Greenhouse Gas Emissions Accounting: Allocating Emissions from Processes to Co-Products. Retrieved 25 July, 2014, from http://papers.ssrn.com/sol3/Delivery.cfm/SSRN_ID2152340_code1693610.pdf?abstractid=1956211&mirid=1

Sustainability Roadmap. (n.d.). Waste management plan. Retrieved 28 May, 2014, from http://www.sustainabilityroadmap.org/strategies/planwaste.shtml#.U4WWoLTm7l0

Swedish Environmental Protection Agency. (2005). A Strategy for Sustainable Waste Management: Sweden’s Waste Plan. Retrieved from http://www.naturvardsverket.se/Documents/publikationer/620-1249-5.pdf

Tanaka, M., Matsui, Y., & Nishimura, A. (2004). WLCA (waste LCA) for strategic solid waste management. In: Proceedings of The Sixth International Conference on EcoBalance: Developing and Systematizing of EcoBalance Tools Based on LifeCycle Thinking Tsukuba, Japan

Tchobanoglous, G., Theisen, H., & Vigil, S. (1993). Integrated Solid Waste Management, Engineering Principles and Management Issues. New York: Mc-Gaw-Hill, Inc.

Tchobanoglous, G., Thiesen, H., & Eliassen, R. (1978). Solid Wastes: Engineering Principles and Management Issues. New York, NY: McGraw-Hill.

Technical University of Denmark. (2012). Easewaste User Manual. Copenhagen. Retrieved from http://documents.er.dtu.dk/Projects/Easewaste/Shared%20Files/pdf/120412%20-%20Documanual%20-%20Full.pdf

Teddlie, C., & Tashakkori, A. (2009). Foundations of Mixed Methods Research: Integrating Quantitative and Qualitative Approaches in the Social and Behavioral Sciences. Thousand Oaks, CA: SAGE Publications, Inc.

Thacker, B. H., Doebling, S. W., Hemez, F. M., Anderson, M. C., Pepin, J. E., & Rodriguez, E. A. (2004). Concepts of model verification and validation. Las Alamos National Laboratories, Los Alamos, NM, LA-14167-MS. doi:10.2172/835920

The Chartered Institute of Purchasing & Supply. (2007). How to develop a waste management and disposal strategy. Retrieved from http://www.cips.org/Documents/About%20CIPS/Develop%20Waste%20v3%20-%2020.11.07.pdf

The International Bank for Reconstruction and Development/THE WORLD BANK. (2004). Beyond Economic Growth: An Introduction to Sustainable Development (Second Edition). Washington, D.C.: The World Bank. Retrieved from http://www.worldbank.org/depweb/english/beyond/beyondco/beg_all.pdf

Themelis, N. J., & Ulloa, P. A. (2007). Methane generation in landfills. Renewable Energy, 32(7), 1243-1257. doi:10.1016/j.renene.2006.04.020

Thomas, B., & McDougall, F. (2003.). International expert group on life cycle assessment for integrated waste management. . The International Journal of Life Cycle Assessment, 8(3), 318-320.

Thomeloe, S. A., Weitz, K., & Jambeck, J. (2007). Application of the US decision support tool for materials and waste management. Waste Management, 27(8), 1006–1020. doi:10.1016/j.wasman.2007.02.024

Thompson Klein, J., Grossenbacher-Mansuy, W., Häberli, R., Bill, A., Scholz, R. W., & Welti, M. (Eds.). (2001). Transdisciplinarity: Joint Problem Solving among Science, Technology, and Society: An Effective Way for Managing Complexity. Basel: Birkhauser Verlag.

Thomson, S., Sawyer, J., Bonam, R., & Valdivia, J. E. (2009). Building a better methane generation model: Validating models with methane recovery rates from 35 Canadian landfills. Waste Management, 29, 2085-2091.

Thorneloe, S. A., Weitz, K., & Jambeck, J. (2007). Application of the US decision support tool for materials and waste management. Waste Management, 27, 1006-1020.

Tonglet, M., Philips, P. S., & Bates, M. P. (2004). Determining the drivers for householder pro-environmental behaviour: waste minimisation compared to recycling. Resources, Conservation and Recycling, 42(1), 27-48. doi:10.1016/j.resconrec.2004.02.001

Tonkin & Taylor. (2016). Redvale Landfill, Auckland, NZ. Retrieved 29 February, 2015, from http://www.tonkintaylor.co.nz/projects/all-projects/redvale-landfill-auckland-nz/?sec_id=1205

Tonkin & Taylor Ltd. (2010). Recommendations for methodologies for ETS landfill gas emission reporting (report for the Ministry for the Environment: T&T Ref 27228). Retrieved from www.climatechange.govt.nz/consultation/waste/recommendations-for-methodologies/recommendations.pdf

Trucano, T. G., Swiler, L. P., Igusa, T., Oberkamp, W. L., & Pilch, M. (2006). Calibration, validation, and sensitivity analysis: what's what. Rliab Eng Syst Saf, 91, 1331-1357.

Tulokhonova, A., & Ulanova, O. (2013). Assessment of municipal solid waste management scenarios in Irkutsk (Russia) using a life cycle assessment-integrated waste management mode. Waste Management & Research, 31(5), 475-484. doi:10.1177/0734242X13476745

U.K Environment Agency. (2001). Towards sustainable agricultural waste management. Bristol, UK. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/291600/geho0003bieo-e-e.pdf

UK DEFRA. (2011). Guidance on applying the Waste Hierarchy. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69403/pb13530-waste-hierarchy-guidance.pdf

UK Institute of Mechanical Engineering. (n.d). Energy from waste: A wasted opportunity. Retrieved from http://www.wte.org/userfiles/file/EnergyfromWasteReport.pdf

UN HABITAT. (2010). Solid waste management in the world cities: Water and Sanitation in the world's cities 2010. London, Washington DC. Retrieved from http://books.google.co.nz/books?id=5BuKI8Zeh-wC&pg=PA19&lpg=PA19&dq=Development+drivers+for+waste+management&source=bl&ots=Z4ePsORQtM&sig=bcpIfj_dEp5l5FLlNN_PHmIpGfs&hl=en&sa=X&ei=gPywUr6HJovzkAWk1IHADg&ved=0CGwQ6AEwBg#v=onepage&q&f=false

UNCRD UNEP-RRCAP and IGNES. (2009). National 3R Strategy Development: a progress report on seven countries in Asia from 2005 to 2009. Retrieved from http://www.indiaenvironmentportal.org.in/files/national_3r_strategy_development%28fullversion%29.pdf

UNEP. (2004a). Vital waste graphics. Nairobi, Kenya. Retrieved from file:///C:/Users/mmichael/Downloads/wastereport-full%20(2).pdf

UNEP. (2004b). What is waste - A multitude of approaches and definitions. In Vital Waste Graphics. Retrieved from http://www.grida.no/publications/vg/waste/page/2853.aspx

UNEP. (2005). Integrated waste management scoreboard: A tool to measure performance in municipal solid waste management (92-807-2648-X). Retrieved from http://www.unep.or.jp/ietc/publications/spc/iwm_scoreboard-binder.pdf

UNEP. (2009a). Developing Integrated Solid Waste Management Plan Training Manual, Volume 1: Waste Characterization and Quantification with Projections for Future. Osaka/Shiga, Japan. Retrieved from http://www.unep.or.jp/ietc/Publications/spc/ISWMPlan_Vol1.pdf

UNEP. (2009b). Handbook for the Vienna Convention for the Protection of the Ozone Layer-Eighth Edition (2009) Retrieved from http://ozone.unep.org/Publications/VC_Handbook/VC-Handbook-2009.pdf

UNEP. (2009c). Integrated Solid Waste Management-Training Manual. Retrieved from http://www.unep.or.jp/ietc/SPC/news-oct09/Guidelines_ISWM_Plan.pdf,

UNEP. (2010a). Auditing the Implementation of Multilateral Environmental Agreements (MEAs): A Primer for Auditors. Nairobi. Retrieved from http://www.unep.org/delc/Portals/119/audingmeas.pdf

UNEP. (2010b). Waste and Climate Change: Global Trends and Strategy Framework. Osaka/Shiga, Japan. Retrieved from http://www.unep.or.jp/ietc/Publications/spc/Waste&ClimateChange/Waste&ClimateChange.pdf

UNEP. (2012). Sustainable consumption and production for poverty alleviation. Retrieved from http://www.unep.org/pdf/SCP_Poverty_full_final.pdf

UNEP. (n.d). Training Manual on International Environmental Law. Retrieved from http://www.unep.org/environmentalgovernance/Portals/8/documents/training_Manual.pdf

UNEP (Basel Convention). (2011). Parties to the Basel Convention. Retrieved 20 January, 2014, from http://www.basel.int/Countries/StatusofRatifications/PartiesSignatories/tabid/1290/Default.aspx

UNEP (Ozone Secretariat). (2016). Articl 2: General Obligation. Retrieved 26 July, 2016, from http://ozone.unep.org/en/handbook-vienna-convention-protection-ozone-layer/2208

UNEP (Stockholm Convention). (2008). Status of Ratifications. Retrieved 21 January, 2004, from http://chm.pops.int/Countries/StatusofRatifications/PartiesandSignatories/tabid/252/Default.aspx

UNEP Ozone Secretariat. (2013, 12 November). Status of Ratification. Retrieved 20 January, 2014, from http://ozone.unep.org/new_site/en/treaty_ratification_status.php

UNEP/GRID-Arendal. (2004). Municipal solid waste composition for 7 OECD countries and 7 Asian cities. Retrieved 20 March, 2016, from http://www.grida.no/graphicslib/detail/municipal-solid-waste-composition-for-7-oecd-countries-and-7-asian-cities_f5c4

UNFCCC. (2014a). Article 2: OBJECTIVE. In United Nations framework Convention on Climate Change. Retrieved 10 February, 2016 from http://unfccc.int/essential_background/convention/background/items/1353.php

UNFCCC. (2014b). Kyoto Protocol. Retrieved 4 May, 2016, from https://unfccc.int/kyoto_protocol/items/2830.php

United Nations. (1973). Report of the United Nations Conference on the Human Environment (Stockholm, 5-16 June 1972) (A/CONF.48/14/Rev.1). Retrieved from http://www.un-documents.net/aconf48-14r1.pdf

United Nations. (1977). Convention on the prevention of marine pollution by dumping of wastes and other matter. Retrieved from https://treaties.un.org/doc/Publication/UNTS/Volume%201046/volume-1046-I-15749-English.pdf

United Nations. (1997a, 23 May). Standard-setting. In Earth Summit page 4. Retrieved 23 February, 2014, from http://www.un.org/geninfo/bp/envirp4.html

United Nations. (1997b, 23 May). UNCED Conference. Retrieved 22 February, 2016, from http://www.un.org/geninfo/bp/enviro.html/

United Nations. (2011). Institutional framework for sustainable development. Retrieved 23 February, 2016, from http://www.uncsd2012.org/isfd.html

United Nations. (2012a). The future we want. Rio de Janeiro, Brazil. Retrieved from http://www.unep.fr/scp/pdf/Rio_The_Future_We_Want.pdf

United Nations. (2012b). Report of the United Nations Conference on Sustainable Development - Rio de Janeiro, Brazil 20–22 June 2012 New York. Retrieved from http://www.uncsd2012.org/content/documents/814UNCSD%20REPORT%20final%20revs.pdf

United Nations. (2013). Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, Basel, 22 March 1989. Retrieved 19 February, 2014, from http://legal.un.org/avl/ha/bcctmhwd/bcctmhwd.html

United Nations Framework Convention on Climate Change (UNFCCC). (2008). Kyoto Protocol Reference Manual on Accounting of Emissions and Assigned Amounts. Bonn, Germany. Retrieved from http://unfccc.int/resource/docs/publications/08_unfccc_kp_ref_manual.pdf

United Nations Industrial Development Organisation. (n.d). The Stockholm Convention. Retrieved 20 February, 2014, from http://www.unido.org/en/what-we-do/environment/capacity-building-for-the-implementation-of-multilateral-environmental-agreements/the-stockholm-convention.html

United Nations World Commission on Environment and Development. (2013, 5 June). Chapter 2. Towards Sustainable Development. In Brundtland Report. Retrieved 22 February, 2014, from http://en.wikisource.org/wiki/Brundtland_Report/Chapter_2._Towards_Sustainable_Development

University of Illinois at Urbana-Champaign. (2009). Strategies for Improving the Sustainability of E-Waste Management Systems. Illinois: Sustainable Technology Center. Retrieved from http://www.sustainelectronics.illinois.edu/concept_paper.pdf

US EPA. (1995). AP-42, Fifth Edition, Volume 1 Chapter2: Solid Waste Disposal. Retrieved from www.epa.gov/ttn/chief/ap42/ch02/

US EPA. (2000). Facts about landfill gas. Wasshington, DC. Retrieved from http://www.dem.ri.gov/programs/benviron/waste/central/lfgfact.pdf

US EPA. (2002a). Recycling is working in the United States. Retrieved from http://www.epa.gov/wastes/conserve/tools/rmd/rei-rw/pdf/factsheet_nat.pdf

US EPA. (2002b). Solid Waste Management and Greenhouse Gases. A Life-cycle Assessment of Emissions and Sinks, 2nd ed. Contract EPA530-R-02-006, US Environmental Protection Agency. Washington, DC.

US EPA. (2004). Quantification of Exposure: Development of Emissions Inventory for the Inhalation Risk Assessment. In Air Toxics Risk Assessment Reference Library (Vol. 1). Retrieved from http://www2.epa.gov/sites/production/files/2013-08/documents/volume_1_reflibrary.pdf

US EPA. (2005a). Landfill Gas Emissions Model (LandGEM) Version 3.02 User's Guide (EPA-600/R-05/047). Washington, DC. Retrieved from http://nepis.epa.gov/Adobe/PDF/P1009C8L.pdf

US EPA. (2005b). LandGEM-Landfill Gas Emissions Model, Version 3.02. North Carolina.

US EPA. (2006). Solid waste management and greenhouse gases — A life-cycle assessment of emission and sinks. 3rd Edition. Washington, DC: U.S. Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Exe/ZyPDF.cgi/60000AVO.PDF?Dockey=60000AVO.PDF

US EPA. (2007). August 10, 2007 memoranda: Emissions from large and small MWC units at MACT compliance. Retrieved from http://www.energyrecoverycouncil.org/userfiles/file/2007_EPAemissions_memo.pdf

US EPA. (2008). Background information document for updating AP42 section 2.4 for estimating emissions from municipal solid waste landfills (EPA/600/R-08-116). Retrieved from http://www.epa.gov/ttn/chief/ap42/ch02/draft/db02s04.pdf

US EPA. (2009). Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices: U.S. Environmental Protection Agency Office of Solid Waste and Emergency Response. Retrieved from http://www.epa.gov/oswer/docs/ghg_land_and_materials_management.pdf

US EPA. (2009b, April 24). Proposed Endangerment and Cause or Contribute Findings for Greenhouse Gases Under Section 202(a) of the Clean Air Act. Proposed Rule (Vol. 74). Retrieved from http://www.epa.gov/climatechange/Downloads/endangerment/EPA-HQ-OAR-2009-0171-0001.pdf

US EPA. (2010, 19 August). Amendments to the Montreal Protocol. In Ozone Layer Protection. Retrieved 21 February, 2014, from http://www.epa.gov/ozone/intpol/history.html

US EPA. (2012, 18 September). The Montreal Protocol on Substances that Deplete the Ozone Layer. In Ozone Layer Protection. Retrieved 21 February, 2016, from http://www.epa.gov/ozone/intpol/

US EPA. (2013a, 31 July). Illegal Dumping. Retrieved 23 May, 2014, from http://www.epa.gov/region7/waste/solidwaste/illegal_dumping.htm

US EPA. (2013b, 23 November). Non-Hazardous Waste Management Hierarchy. Retrieved 19 May, 2014, from http://www.epa.gov/waste/nonhaz/municipal/hierarchy.htm

US EPA. (2013c, 27 September). Recent International Developments Under the Montreal Protocol. In Ozone Layer Protection. Retrieved 22 February, 2016, from http://www.epa.gov/ozone/intpol/mpagreement.html

US EPA. (2013, 2 November). History of RCRA Retrieved 7 December, 2013, from http://www.epa.gov/osw/laws-regs/rcrahistory.htm

US EPA. (2014a, 4 April). Emission Factors for Greenhouse Gas Inventories. Retrieved 1 August, 2014, from http://www.epa.gov/climateleadership/documents/emission-factors.pdf

US EPA. (2014b, 20 February). Emissions Factors & AP 42, Compilation of Air Pollutant Emission Factors Retrieved 22 July, 2014, from http://www.epa.gov/ttnchie1/ap42/

US EPA. (2014c). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 - 2012. Washington, D. C. Retrieved from http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Main-Text.pdf

US EPA. (2014d, 10 January). Municipal Solid Waste. In Wastes - Non-Hazardous Waste - Municipal Solid Waste. Retrieved 14 February, 2014, from http://www.epa.gov/epawaste/nonhaz/municipal/index.htm

US EPA. (2014e, 7 February). Sources of Greenhouse Gas Emission: Electricity Sector Emissions. Retrieved 12 September, 2014, from http://www.epa.gov/climatechange/ghgemissions/sources/electricity.html

US EPA. (2016). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 - 2014 (EPA 430-R-16-002). Washington, DC. Retrieved from https://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2016-Main-Text.pdf

US EPA. (n.d). Solid waste management: A local challenge with global impacts. Retrieved from http://www.epa.gov/climatechange/wycd/waste/downloads/folder.pdf

Van Buren, K., Mollineaux, M., Hemez, F., & Atamturktur, S. (2012). Simulating the dynamics of wind turbine blades: Part II, Model validation & uncertainty quantification. Wind Energy, 16(5), 741-758.

Van Craen, M., & Van Velthoven, K. (2007, 1 December). Integrated Waste Management Retrieved 27 March, 2014, from http://www.waste-management-world.com/articles/print/volume-8/issue-6/thermal-treatment-and-wte-special/integrated-waste-management.html

van de Klundert, A., & Anschutz, J. (2000). The sustainability of alliances between stakeholders in waste management - using the concept of integrated Sustainable Waste Management: Working paper for UWEP/CWG,. Retrieved from http://www.gdrc.org/uem/waste/ISWM.pdf

van de Klundert, A., & Anschütz, J. (2001). Integrated Sustainable Waste Management-the Concept. Tools for Decision-makers. Experiences from the Urban Waste Expertise Programme (1995-2001). In A. Scheinberg (Ed.), Integrated Sustainable Waste Management. Gouda, the Netherlands: WASTE.

van de Klundert, A., & Anschütz, J. (2001). Integrated Sustainable Waste Management-the Concept. Tools for Decision-makers. Experiences from the Urban Waste Expertise Programme (1995-2001). In A. Scheinberg (Ed.), Integrated Sustainable Waste Management. Gouda, Netherlands: WASTE.

van der Zee, D. J., Achterkamp, M. C., & de Visser, B. J. (2004). Assessing the market opportunities of landfill mining. Waste Management, 24(8), 795-804. doi:10.1016/j.wasman.2004.05.004

vander Werf, H., & Basset-Mens, C. (2012). Life cycle assessment of farming systems. In M. Bertaglia (Ed.), Encyclopedia of Earth. Retrieved from http://www.eoearth.org/view/article/51cbee567896bb431f697206/. Retrieved 21 May 2014

Velis, C. A., Wilson, D. C., & Cheeseman, C. R. (2009). 19th century London dust-yards: A case study in closed-loop resource efficiency. Waste Management, 29(4), 1282-1290.

Vrandecic, D. (2009). Ontology Evaluation. In S. Staab & R. Studer (Eds.), Handbook on Ontologies (Second ed., pp. 293-313). Retrieved from http://hall.org.ua/halls/wizzard/books4/Handbook%20on%20Ontologies%20SE%20-%20S.Staab,%20R.Studer.PDF. doi:10.1007/978-3-540-92673-3

Waikato District Council. (2011a). Waikato District Council Waste Assessment. Retrieved from http://www.waikatodistrict.govt.nz/CMSFiles/43/4369d58a-7e1c-4954-b6ea-73a2fe966258.pdf

Waikato District Council. (2011b). Waste Assessment 2011. Retrieved from https://www.waikatodistrict.govt.nz/Documents-Library/Files/Documents/Plans,-reports,-publications/Waste-assessment-March-2012-web.aspx

Waikato District Council. (2012a). Waste management and minimisation plan. Retrieved from http://www.waikatodistrict.govt.nz/CMSFiles/69/69da4967-1ca9-4d31-b1b8-5f1c24501409.pdf

Waikato District Council. (2012b). Waste Minimisation and Management Plan 2012. Retrieved from https://www.waikatodistrict.govt.nz/Documents-Library/Files/Documents/Plans,-reports,-publications/District-Growth-Strategy/WMMP-2012.aspx

Waikato Regional Council. (2007). Waikato Regional Waste Infrastructure Stocktake and Strategic Assessment Hamilton. Retrieved from http://www.waikatoregion.govt.nz/PageFiles/5481/tr0744.pdf

Waikato Regional Council. (2012). Waste to resource: Waikato waste and resource efficiency strategy 2012-15. Hamilton. Retrieved from http://www.waikatoregion.govt.nz/PageFiles/22384/S3088%20-%20Waste%20Strategy%20WEB.pdf

Wakim, N. (2004). Sustainable solid waste management in New Zealand. Retrieved from http://www.ipenz.org.nz/ipenz/Forms/pdfs/Sustainable_Solid_Waste_%20Management.pdf

Wang, Y., Yan, Y., Chen, G., Zuo, J., & Du, H. (2015). Effective approaches to reduce greenhouse gas emissions from waste to energy process: A China study. Resources, Conservation and Recycling, 104(Part A), 103-108. doi:10.1016/j.resconrec.2015.09.002

Waste-to-Energy Research and Technology Council. (2009). Waste Hierarchy. Retrieved 19 May, 2014, from http://www.wtert.eu/default.asp?Menue=14&ShowDok=25

Waste Management. (2016). Redvale Energy Park Community. Retrieved 29 February, 2016, from https://www.wastemanagement.co.nz/site/redvale-energy-park-community/

Watanabe, R., & Robinson, G. (2005). The European Union Emissions Trading Scheme (EU ETS). Climate Policy, 5(1), 10-14. doi:10.1080/14693062.2005.9685537

WCED. (1987). Our Common Future. Oxford: Oxford University Press.

Weigel, B. A., Southworth, R., & Meyer, M. D. (2009). Calclators for Esimating Greenhouse Gas Emissions from Public Transit Agency Vehicle Fleet Operations. Retrieved from http://cta.ornl.gov/cta/Publications/Reports/Calculators%20for%20Estimating%20Greenhouse%20Gas%20Emissions%20from%20Public%20Transit%20Agency%20Vehicle%20Fleet%20Operations.pdf

Weitz, K. A., Barlaz, M. A., Ranjithan, S., Brill, E. D., Thorneloe, S. A., & Ham, R. (1999). Life cycle management of municipal solid waste. International Journal of Life Cycle Assessment, 4(4), 195-201.

Wetherill, T. D., & Ipenz, T. M. (n.d). Waste management in New Zealand. Retrieved from http://www.seas.columbia.edu/earth/wtert/sofos/nawtec/anacon98/anacon98-25.pdf

White, P. R., Franke, M., & Hindle, P. (1999). Integrated solid waste management: A lifecycle inventory. Gaithersburg, MD: Aspen Publishers, Inc.

Widory, D., Proust, E., Bellenfant, G., & Bour, O. (2012). Assessing methane oxidation under landfill covers and its contribution to the above atmospheric CO2 levels: The added value of the isotope (δ13C and δ18O CO2; δ13C and δD CH4) approach. Waste Management, 32(2012), 1685-1692. doi:10.1016/j.wasman.2012.04.008

Williams, M. (2011). Waste-to-energy success factors in Sweden and the United States: Analyzing the transferability of the Swedish waste-to-energy model to the United States. Retrieved from http://www.acore.org/wp-content/uploads/2012/04/WTE-in-Sweden-and-the-US-Matt-Williams..pdf

Williams, P. T. (2002). Emissions from solid waste management activities. In R. E. Hester, & Harrison, R. M. (Ed.), Environmental and Health Impact of Solid Waste Management Activities. Retrieved from http://pubs.rsc.org/en/content/chapterpdf/2006/9781847550767-00141?isbn=978-0-85404-285-2&sercode=bk. doi:10.1039/9781847550767-00141

Wilson, D., Middleton, B., Purchas, C., & Crowcroft, G. (2009). Auckland Waste Stocktake & Strategic Assessment 2009 (Technical Report No.107 October 2009). Retrieved from http://www.aucklandcity.govt.nz/council/documents/technicalpublications/TR%202009_107%20Auckland%20Waste%20stocktake%20and%20strategic%20assessment%202009.pdf

Wilson, D. C. (2007). Development drivers for waste management. Waste Manag Res, 25(3), 198-207. doi:10.1177/0734242X07079149

Wilson, D. C. (2007). Development drivers for waste management. Waste Management & Research, 25(3), 198-207. doi:10.1177/0734242X07079149

Wilson, D. C., Rodic, L., Scheinberg, A., Velis, C. A., & Alabaster, G. (2012). Comparative analysis of solid waste management in 20 cities. Waste Manag Res, 30(3), 237-254. doi:10.1177/0734242X12437569

Winkler, J., & Bilitewski, B. (2007). Comparative evaluation of life cycle assessment models for solid waste management. Waste Management, 27(8), 1021–1031. doi:10.1016/j.wasman.2007.02.023

Winkler, J., & Bilitewski, B. (2007). Comparative evaluation of life cycle assessment models for solid waste management. Waste Management, 27(8), 1021-1031. doi:10.1016/j.wasman.2007.02.023

Woolridge, A., Morrissey, A., & Phillip, P. S. (2005). The development of strategic and tactical tools, using systems analysis, for waste management in large complex organisations: a case study in UK healthcare waste. Resources, Conservation and Recycling, 44(2), 115-137.

Woolridge, A., Morrissey, A., & Phillip, P.S. (2005). The development of strategic and tactical tools, using systems analysis, for waste management in large complex organisations: a case study in UK healthcare waste. Resources, Conservation and Recycling, 44(2), 115-137.

World Bank. (2011a). Solid waste management strategic planning. Retrieved 31 March, 2014, from http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTURBANDEVELOPMENT/EXTUSWM/0,,contentMDK:20239682~menuPK:497744~pagePK:148956~piPK:216618~theSitePK:463841,00.html

World Bank. (2011b). Urban solid waste management environmental issues. Retrieved 30 March, 2014, from http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTURBANDEVELOPMENT/EXTUWM/0,,contentMDK:20209708~menuPK:404560~pagePK:148956~piPK:216618~theSitePK:341511,00.html

World Bank. (2012). What a waste - A global review of solid waste management. Washington, DC. Retrieved from http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/What_a_Waste2012_Final.pdf

World Energy Council. (2013). World Energy Resources: Waste to Energy Retrieved from https://www.worldenergy.org/wp-content/uploads/2013/10/WER_2013_7b_Waste_to_Energy.pdf

World Resource Institute. (2005). Calculating HFC and PFC Emissions from the Manufacturing, Installation, Operation and Disposal of Refrigeration & Air-conditioning Equipment (Version 1.0) - Guide to calculation worksheets (January 2005) Retrieved from http://www.ghgprotocol.org/files/ghgp/tools/hfc-cfc.pdf

World Resources Institute and World Business Council for Sustainable Development. (2004). The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard (REVISED EDITION). Retrieved from http://www.ghgprotocol.org/files/ghgp/public/ghg-protocol-revised.pdf

World Resources Institute and World Business Council for Sustainable Development. (2007). Greenhouse gas protocol - Measuring to Manage: A Guide to Designing GHG Accounting and Reporting Programs. Retrieved from http://www.wri.org/sites/default/files/pdf/measuring-to-manage.pdf

WRAP UK. (2012). Supply chain: manage and measure waste. Retrieved from http://www.wrap.org.uk/sites/files/wrap/2%20WRAP%20Manage%20and%20Measure%20SC%20Waste%20WEB%20FINAL.pdf

www.guidian.co.uk. (2012, 21 June). Rio+20 summit opens amid protests – video. Retrieved from http://www.theguardian.com/environment/video/2012/jun/21/rio20-summit-opens-protests-video

Yin, R. (2014). Case Study Research: Design and Methods (5th ed.). Los Angeles: Sage.

Yin, R. K. (1994). Case Study Research: Design and Methods. Thousand Oaks, CA: Sage.

Yu-Min, C., Chien-Chung, L., Chao-Yang, H., Hu, A., & Shiao-Shing, C. (2008). Change in MSW characteristics under recent management strategies in Taiwan. Waste Management, 28(12), 2443-2455. doi:10.1016/j.wasman.2007.10.014

Zaman, A. U. (2010). Comparative study of municipal solid waste treatment technologies using life cycle assessment method. Int. Journal Environ. Sc. Tech, 7(2), 225-234.

Zaman, A. U. (2013). Identification of waste management development drivers and potential emerging waste treatment technologies. Int. J. Environ. Sci. Technol., 10(3), 455–464. doi:10.1007/s13762-013-0187-2

Zero Waste America. (n.d). What is waste? Retrieved 11 February, 2015, from http://www.zerowasteamerica.org/WhatIsWaste.htm

Zero Waste International. (2009). Zero Waste Definition. Retrieved 2 April, 2014, from http://zwia.org/standards/zw-definition/

Zero Waste New Zealand. (2012, March). Opotiki District Council. Retrieved 3 February, 2016, from http://www.zerowaste.co.nz/opotiki-district-council/

Zielinska, B., Sagebiel, J., McDonald, J. D., Whitney, K., & Lawson, D. R. (2012). Emission Rates and Comparative Chemical Composition from Selected In-Use Diesel and Gasoline-Fueled Vehicles. J. Air & Water Manage. Assoc., 54(9), 1138-1150. doi:10.1080/10473289.2004.10470973

Zopounidis, C., & Doumpos, M. (2002). Multicriteria classification and sorting methods: a literature review. European Journal of Operational Research, 138(2002), 229-246.

Zotos, G., Karagiannidis, A.,Zampetoglou, S., Malamakis, A., Antonopoulos, I.-S., Kontogianni, S., & Tchobanoglous, G. (2009). Developing a holistic strategy for integrated waste management within municipal planning: Challenges, policies, solutions and perspectives for Hellenic municipalities in the zero-waste, low-cost direction. Waste Management, 29(5), 1686–1692.

Zuma, A. U. (2013). Identification of waste management development drivers and potential emerging waste treatment technologies. Int. J. Environ. Sci. Technol., 10(2013), 455-464. doi:DOI 10.1007/s13762-013-0187-2

Glossary

BREF WI	Blue Ridge Earth First (Ref. Document) Waste Incineration
CAE	Centre for Advanced Engineering
CCRA	Climate Change Response Act
CDM	Clean Development Mechanism
CEQ	Comprehensive Emission Quantification
CEP	Comprehensive Emission Potential
CFCs	Chlorofluorocarbons
CH_4	Methane
CMA	Coastal Marine Area
COP	Conferences of the Parties
CO_2	Carbon Dioxide
CT	Carbon Trading
CWG	Collaborative Working Group (for waste management in middle and low-income countries)
DDT	Dichloro-diphenyl-trichloroethane
DEFRA	Department of Environment Food and Rural Affairs
EC	European Commission
EEA	European Environment Agency
EPA	Environmental Protection Agency
ER	Emission Ratio
ERMA	Environmental Risk Management Authority
ESM	Environmentally Sound Management
ETC/SCP	European Topic Centre on Sustainable Consumption and Production
ETS	Emission Trading Scheme
EU	European Union
FOA	Food and Agricultural Organization
FOD	First Order Decay
GDP	Gross Domestic Product
Gg	Gigagrams
GHG	Greenhouse Gas
GNI	Gross National Income
HCB	Hexachlorobenzene
HCFCs	Hydro chlorofluorocarbons
HFCs	Hydrofluorocarbons
HSNO	Hazardous Substances and New Organisms

HWD	Hazardous Waste Directive
IED	Industrial Emissions Directive
IGES	Institute for Environmental Strategies
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
ISWA	International Solid Waste Association
ISWM	Integrated Solid Waste Management
LAs	Local Authorities
LCA	Life Cycle Assessment
LCT	Life Cycle Thinking
LCDs	Less Developed Countries
MoE	Ministry for the Environment (New Zealand)
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
MTA	Maritime Transport Act
MWC	Municipal Waste Combustors
NES	National Environmental Standard
NGO	Non-Governmental Organization
NIMBY	Not In My Back Yard
NLC	National Landfill Census
NPEC	National Physical Environment Conference
NZETS	New Zealand Emission Trading Scheme
NZWS	New Zealand Waste Strategy
NZ	New Zealand
N_2O	Nitrous Oxide
ODSs	Ozone-depleting substances
OECD	Organisation for Economic Cooperation and Development
PCB	Polychlorinated Biphenyls
PIC	Prior Informed Consent
POPs	Persistent Organic Pollutants
PWA	Public Works Act
RCRA	Resource Conservation and Recovery Act
RMA	Resource Management Act
R1 Formula	Recovery One Formula

SCP	Sustainable Consumption and Production
SWDA	Solid Waste Disposal Act
TAS	Tasmania
TEQ	Toxic Equivalent Quantity
UK	United Kingdom
UN	United Nations
UNCED	United Nation Conference on Environment and Development
UNCRD	United Nations Centre for Regional Development
UNCSD	United Nations Conference on Sustainable Development
UNDP	United Nations Development Programme
UNECE	United Nation Economic Commission for Europe
UNEP	United Nation Environment Programme
UNEP-RRCAP	United Nation Environment Programme Regional Resource Centre for Asia and the Pacific
UNFCCC	United Nations Framework Convention on Climate Change
UNSD	United Nations Statistics Division
USA (US)	United States of America
US EPA	U.S. Environmental Protection Agency
UV	Ultraviolet
WAP	Waste Assessment Protocol
WBCSD	World Business Council for Sustainable Development
WCED	World Commission on Environment and Development
WFD	Waste Framework Directive
WMA	Waste Minimization Act
WMH	Waste Management Hierarchy
WMMP	Waste Management and Minimisation Plan
WRAP UK	Waste and Resources Action Programme – United
KingdomWSR	Waste Shipment Regulation

APPENDICES

APPENDIX I: LandGEM MODEL OUTPUT ON AUCKLAND MSWM EMISSIONS QUANTIFICATION, 1996-2015

Summary Report

Landfill Name or Identifier: Auckland MSW Comprehensive Emission 1996-2015

Date: Thursday, 2 June 2016

Description/Comments:

About LandGEM:

First-Order Decomposition Rate Equation:

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k L_o \left(\frac{M_i}{10} \right) e^{-kt_{ij}}$$

Where,
Q_{CH4} = annual methane generation in the year of the calculation *(m^3/year)*
i = 1-year time increment
n = (year of the calculation) - (initial year of waste acceptance)
j = 0.1-year time increment
k = methane generation rate (*$year^{-1}$*)
L_o = potential methane generation capacity (*m^3/Mg*)

M_i = mass of waste accepted in the i^{th} year (*Mg*)
t_{ij} = age of the j^{th} section of waste mass M_i accepted in the i^{th} year (*decimal years*, e.g., 3.2 years)

LandGEM is based on a first-order decomposition rate equation for quantifying emissions from the decomposition of landfilled waste in municipal solid waste (MSW) landfills. The software provides a relatively simple approach to estimating landfill gas emissions. Model defaults are based on empirical data from U.S. landfills. Field test data can also be used in place of model defaults when available. Further guidance on EPA test methods, Clean Air Act (CAA) regulations, and other guidance regarding landfill gas emissions and control technology requirements can be found at http://www.epa.gov/ttnatw01/landfill/landflpg.html.

LandGEM is considered a screening tool — the better the input data, the better the estimates. Often, there are limitations with the available data regarding waste quantity and composition, variation in design and operating practices over time, and changes occurring over time that impact the emissions potential. Changes to landfill operation, such as operating under wet conditions through leachate recirculation or other liquid additions, will result in generating more gas at a faster rate. Defaults for estimating emissions for this type of operation are being developed to include in LandGEM along with defaults for convential landfills (no leachate or liquid additions) for developing emission inventories and determining CAA applicability. Refer to the Web site identified above for future updates.

Input Review

LANDFILL CHARACTERISTICS		
Landfill Open Year	**1996**	
Landfill Closure Year (with 80-year limit)	**2015**	
Actual Closure Year (without limit)	***2015***	
Have Model Calculate Closure Year?	**No**	
Waste Design Capacity		*megagrams*
MODEL PARAMETERS		
Methane Generation Rate, k	**0.040**	*$year^{-1}$*
Potential Methane Generation Capacity, L_o	**100**	*m^3/Mg*
NMOC Concentration	**600**	*ppmv as hexane*
Methane Content	**50**	*% by volume*

GASES / POLLUTANTS SELECTED

Gas / Pollutant #1:	Methane
Gas / Pollutant #2:	Carbon dioxide
Gas / Pollutant #3:	NMOC
Gas / Pollutant #4:	Total landfill gas

WASTE ACCEPTANCE RATES

Year	Waste Accepted		Waste-In-Place	
	(Mg/year)	*(short tons/year)*	*(Mg)*	*(short tons)*
1996	909,405	1,000,345	0	0
1997	880,456	968,501	909,405	1,000,345
1998	847,263	931,989	1,789,861	1,968,847
1999	870,972	958,069	2,637,124	2,900,836
2000	901,948	992,143	3,508,096	3,858,905
2001	928,600	1,021,460	4,410,044	4,851,049
2002	961,132	1,057,245	5,338,644	5,872,509
2003	990,740	1,089,814	6,299,776	6,929,753
2004	1,033,549	1,136,903	7,290,516	8,019,567
2005	1,034,703	1,138,173	8,324,064	9,156,471
2006	1,035,508	1,139,059	9,358,768	10,294,644
2007	987,465	1,086,211	10,394,276	11,433,703
2008	938,199	1,032,019	11,381,740	12,519,914
2009	887,943	976,737	12,319,939	13,551,933
2010	826,924	909,617	13,207,882	14,528,670
2011	849,857	934,842	14,034,806	15,438,287
2012	819,531	901,485	14,884,663	16,373,129
2013	872,592	959,852	15,704,194	17,274,614
2014	947,373	1,042,111	16,576,787	18,234,465
2015	1,054,485	1,159,934	17,524,160	19,276,576
2016	0	0	18,578,645	20,436,510
2017	0	0	18,578,645	20,436,510
2018	0	0	18,578,645	20,436,510
2019	0	0	18,578,645	20,436,510
2020	0	0	18,578,645	20,436,510
2021	0	0	18,578,645	20,436,510
2022	0	0	18,578,645	20,436,510
2023	0	0	18,578,645	20,436,510
2024	0	0	18,578,645	20,436,510
2025	0	0	18,578,645	20,436,510
2026	0	0	18,578,645	20,436,510
2027	0	0	18,578,645	20,436,510
2028	0	0	18,578,645	20,436,510
2029	0	0	18,578,645	20,436,510
2030	0	0	18,578,645	20,436,510
2031	0	0	18,578,645	20,436,510
2032	0	0	18,578,645	20,436,510
2033	0	0	18,578,645	20,436,510
2034	0	0	18,578,645	20,436,510
2035	0	0	18,578,645	20,436,510

WASTE ACCEPTANCE RATES (Continued)

Year	Waste Accepted		Waste-In-Place	
	(Mg/year)	*(short tons/year)*	*(Mg)*	*(short tons)*
2036	0	0	18,578,645	20,436,510
2037	0	0	18,578,645	20,436,510
2038	0	0	18,578,645	20,436,510
2039	0	0	18,578,645	20,436,510
2040	0	0	18,578,645	20,436,510
2041	0	0	18,578,645	20,436,510
2042	0	0	18,578,645	20,436,510
2043	0	0	18,578,645	20,436,510
2044	0	0	18,578,645	20,436,510
2045	0	0	18,578,645	20,436,510
2046	0	0	18,578,645	20,436,510
2047	0	0	18,578,645	20,436,510
2048	0	0	18,578,645	20,436,510
2049	0	0	18,578,645	20,436,510
2050	0	0	18,578,645	20,436,510
2051	0	0	18,578,645	20,436,510
2052	0	0	18,578,645	20,436,510
2053	0	0	18,578,645	20,436,510
2054	0	0	18,578,645	20,436,510
2055	0	0	18,578,645	20,436,510
2056	0	0	18,578,645	20,436,510
2057	0	0	18,578,645	20,436,510

2058	0	0	18,578,645	20,436,510
2059	0	0	18,578,645	20,436,510
2060	0	0	18,578,645	20,436,510
2061	0	0	18,578,645	20,436,510
2062	0	0	18,578,645	20,436,510
2063	0	0	18,578,645	20,436,510
2064	0	0	18,578,645	20,436,510
2065	0	0	18,578,645	20,436,510
2066	0	0	18,578,645	20,436,510
2067	0	0	18,578,645	20,436,510
2068	0	0	18,578,645	20,436,510
2069	0	0	18,578,645	20,436,510
2070	0	0	18,578,645	20,436,510
2071	0	0	18,578,645	20,436,510
2072	0	0	18,578,645	20,436,510
2073	0	0	18,578,645	20,436,510
2074	0	0	18,578,645	20,436,510
2075	0	0	18,578,645	20,436,510

Pollutant Parameters

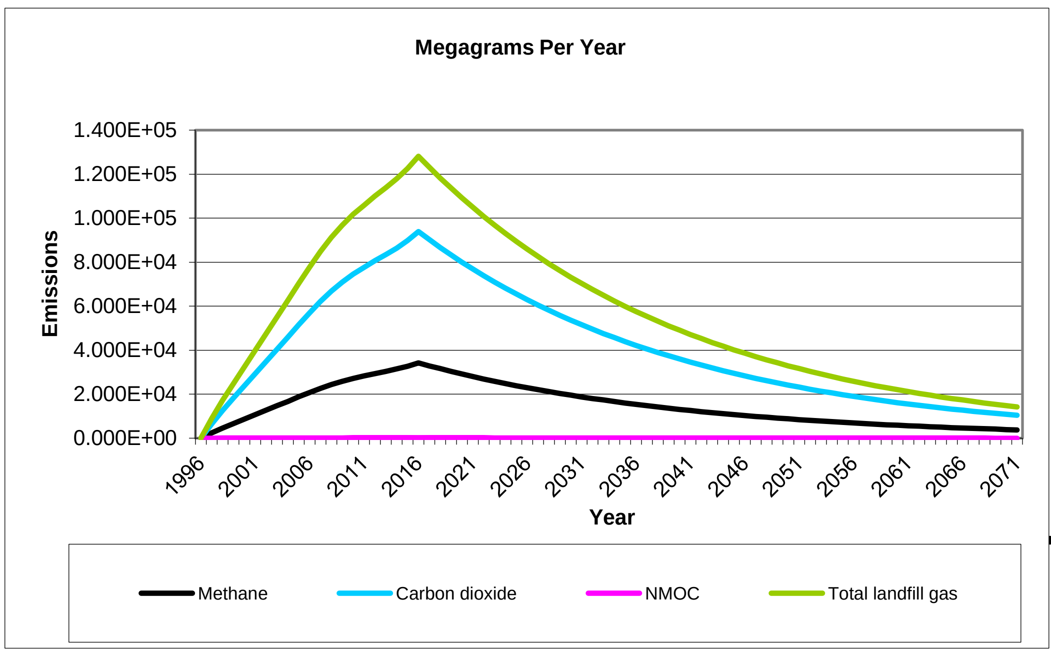
		Gas / Pollutant Default Parameters:		***User-specified Pollutant Parameters:***	
	Compound	Concentration (*ppmv*)	Molecular Weight	Concentration (*ppmv*)	Molecular Weight
Gases	Total landfill gas		0.00		
	Methane		16.04		
	Carbon dioxide		44.01		
	NMOC	4,000	86.18		
Pollutants	1,1,1-Trichloroethane (methyl chloroform) - HAP	0.48	133.41		
	1,1,2,2-Tetrachloroethane - HAP/VOC	1.1	167.85		
	1,1-Dichloroethane (ethylidene dichloride) - HAP/VOC	2.4	98.97		
	1,1-Dichloroethene (vinylidene chloride) - HAP/VOC	0.20	96.94		
	1,2-Dichloroethane (ethylene dichloride) - HAP/VOC	0.41	98.96		
	1,2-Dichloropropane (propylene dichloride) - HAP/VOC	0.18	112.99		
	2-Propanol (isopropyl alcohol) - VOC	50	60.11		
	Acetone	7.0	58.08		
	Acrylonitrile - HAP/VOC	6.3	53.06		
	Benzene - No or Unknown Co-disposal - HAP/VOC	1.9	78.11		
	Benzene - Co-disposal - HAP/VOC	11	78.11		
	Bromodichloromethane - VOC	3.1	163.83		
	Butane - VOC	5.0	58.12		
	Carbon disulfide - HAP/VOC	0.58	76.13		
	Carbon monoxide	140	28.01		
	Carbon tetrachloride - HAP/VOC	4.0E-03	153.84		
	Carbonyl sulfide - HAP/VOC	0.49	60.07		
	Chlorobenzene - HAP/VOC	0.25	112.56		
	Chlorodifluoromethane	1.3	86.47		
	Chloroethane (ethyl chloride) - HAP/VOC	1.3	64.52		
	Chloroform - HAP/VOC	0.03	119.39		
	Chloromethane - VOC	1.2	50.49		

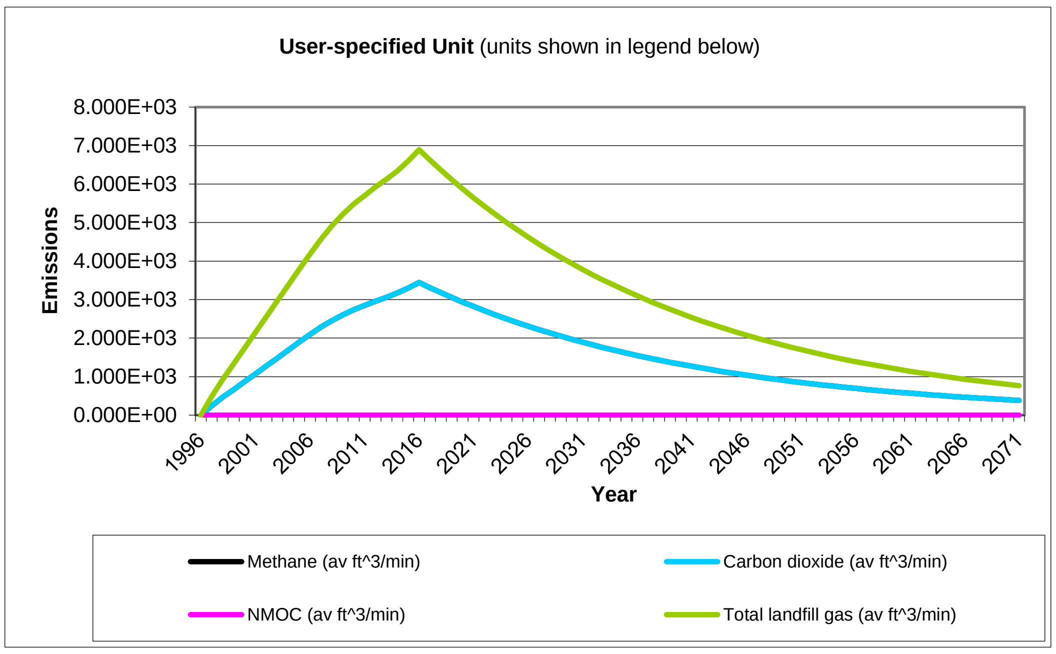
	Dichlorobenzene - (HAP for para isomer/VOC)	0.21	147		
	Dichlorodifluoromethane	16	120.91		
	Dichlorofluoromethane - VOC	2.6	102.92		
	Dichloromethane (methylene chloride) - HAP	14	84.94		
	Dimethyl sulfide (methyl sulfide) - VOC	7.8	62.13		
	Ethane	890	30.07		
	Ethanol - VOC	27	46.08		

Pollutant Parameters (Continued)

		Gas / Pollutant Default Parameters:		***User-specified Pollutant Parameters:***	
	Compound	Concentration (*ppmv*)	Molecular Weight	Concentration (*ppmv*)	Molecular Weight
Pollutants	Ethyl mercaptan (ethanethiol) - VOC	2.3	62.13		
	Ethylbenzene - HAP/VOC	4.6	106.16		
	Ethylene dibromide - HAP/VOC	1.0E-03	187.88		
	Fluorotrichloromethane - VOC	0.76	137.38		
	Hexane - HAP/VOC	6.6	86.18		
	Hydrogen sulfide	36	34.08		
	Mercury (total) - HAP	2.9E-04	200.61		
	Methyl ethyl ketone - HAP/VOC	7.1	72.11		
	Methyl isobutyl ketone - HAP/VOC	1.9	100.16		
	Methyl mercaptan - VOC	2.5	48.11		
	Pentane - VOC	3.3	72.15		
	Perchloroethylene (tetrachloroethylene) - HAP	3.7	165.83		
	Propane - VOC	11	44.09		
	t-1,2-Dichloroethene - VOC	2.8	96.94		
	Toluene - No or Unknown Co-disposal - HAP/VOC	39	92.13		
	Toluene - Co-disposal - HAP/VOC	170	92.13		
	Trichloroethylene (trichloroethene) - HAP/VOC	2.8	131.40		
	Vinyl chloride - HAP/VOC	7.3	62.50		
	Xylenes - HAP/VOC	12	106.16		

Graphs





Results

Year	Methane			Carbon dioxide		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
1996	0	0	0	0	0	0
1997	2.384E+03	3.573E+06	2.401E+02	6.540E+03	3.573E+06	2.401E+02
1998	4.598E+03	6.892E+06	4.631E+02	1.262E+04	6.892E+06	4.631E+02
1999	6.639E+03	9.951E+06	6.686E+02	1.821E+04	9.951E+06	6.686E+02
2000	8.661E+03	1.298E+07	8.723E+02	2.376E+04	1.298E+07	8.723E+02
2001	1.069E+04	1.602E+07	1.076E+03	2.932E+04	1.602E+07	1.076E+03
2002	1.270E+04	1.904E+07	1.279E+03	3.485E+04	1.904E+07	1.279E+03
2003	1.472E+04	2.207E+07	1.483E+03	4.039E+04	2.207E+07	1.483E+03
2004	1.674E+04	2.509E+07	1.686E+03	4.594E+04	2.509E+07	1.686E+03
2005	1.879E+04	2.817E+07	1.893E+03	5.157E+04	2.817E+07	1.893E+03
2006	2.077E+04	3.113E+07	2.092E+03	5.699E+04	3.113E+07	2.092E+03
2007	2.267E+04	3.398E+07	2.283E+03	6.220E+04	3.398E+07	2.283E+03
2008	2.437E+04	3.653E+07	2.454E+03	6.686E+04	3.653E+07	2.454E+03
2009	2.587E+04	3.878E+07	2.606E+03	7.099E+04	3.878E+07	2.606E+03
2010	2.719E+04	4.075E+07	2.738E+03	7.459E+04	4.075E+07	2.738E+03
2011	2.829E+04	4.240E+07	2.849E+03	7.761E+04	4.240E+07	2.849E+03
2012	2.941E+04	4.408E+07	2.961E+03	8.068E+04	4.408E+07	2.961E+03
2013	3.040E+04	4.557E+07	3.062E+03	8.341E+04	4.557E+07	3.062E+03
2014	3.150E+04	4.721E+07	3.172E+03	8.642E+04	4.721E+07	3.172E+03
2015	3.274E+04	4.908E+07	3.298E+03	8.984E+04	4.908E+07	3.298E+03
2016	3.422E+04	5.130E+07	3.447E+03	9.390E+04	5.130E+07	3.447E+03
2017	3.288E+04	4.929E+07	3.312E+03	9.022E+04	4.929E+07	3.312E+03
2018	3.159E+04	4.735E+07	3.182E+03	8.668E+04	4.735E+07	3.182E+03
2019	3.035E+04	4.550E+07	3.057E+03	8.328E+04	4.550E+07	3.057E+03
2020	2.916E+04	4.371E+07	2.937E+03	8.002E+04	4.371E+07	2.937E+03
2021	2.802E+04	4.200E+07	2.822E+03	7.688E+04	4.200E+07	2.822E+03
2022	2.692E+04	4.035E+07	2.711E+03	7.387E+04	4.035E+07	2.711E+03
2023	2.587E+04	3.877E+07	2.605E+03	7.097E+04	3.877E+07	2.605E+03
2024	2.485E+04	3.725E+07	2.503E+03	6.819E+04	3.725E+07	2.503E+03
2025	2.388E+04	3.579E+07	2.405E+03	6.551E+04	3.579E+07	2.405E+03
2026	2.294E+04	3.439E+07	2.310E+03	6.294E+04	3.439E+07	2.310E+03
2027	2.204E+04	3.304E+07	2.220E+03	6.048E+04	3.304E+07	2.220E+03
2028	2.118E+04	3.174E+07	2.133E+03	5.811E+04	3.174E+07	2.133E+03
2029	2.035E+04	3.050E+07	2.049E+03	5.583E+04	3.050E+07	2.049E+03
2030	1.955E+04	2.930E+07	1.969E+03	5.364E+04	2.930E+07	1.969E+03
2031	1.878E+04	2.815E+07	1.892E+03	5.153E+04	2.815E+07	1.892E+03
2032	1.805E+04	2.705E+07	1.817E+03	4.951E+04	2.705E+07	1.817E+03
2033	1.734E+04	2.599E+07	1.746E+03	4.757E+04	2.599E+07	1.746E+03
2034	1.666E+04	2.497E+07	1.678E+03	4.571E+04	2.497E+07	1.678E+03
2035	1.601E+04	2.399E+07	1.612E+03	4.392E+04	2.399E+07	1.612E+03
2036	1.538E+04	2.305E+07	1.549E+03	4.219E+04	2.305E+07	1.549E+03
2037	1.477E+04	2.215E+07	1.488E+03	4.054E+04	2.215E+07	1.488E+03

2038	1.420E+04	2.128E+07	1.430E+03	3.895E+04	2.128E+07	1.430E+03
2039	1.364E+04	2.044E+07	1.374E+03	3.742E+04	2.044E+07	1.374E+03
2040	1.310E+04	1.964E+07	1.320E+03	3.595E+04	1.964E+07	1.320E+03
2041	1.259E+04	1.887E+07	1.268E+03	3.454E+04	1.887E+07	1.268E+03
2042	1.210E+04	1.813E+07	1.218E+03	3.319E+04	1.813E+07	1.218E+03
2043	1.162E+04	1.742E+07	1.171E+03	3.189E+04	1.742E+07	1.171E+03
2044	1.117E+04	1.674E+07	1.125E+03	3.064E+04	1.674E+07	1.125E+03
2045	1.073E+04	1.608E+07	1.081E+03	2.944E+04	1.608E+07	1.081E+03

Results (Continued)

Year	Methane			Carbon dioxide		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2046	1.031E+04	1.545E+07	1.038E+03	2.828E+04	1.545E+07	1.038E+03
2047	9.904E+03	1.485E+07	9.974E+02	2.717E+04	1.485E+07	9.974E+02
2048	9.516E+03	1.426E+07	9.583E+02	2.611E+04	1.426E+07	9.583E+02
2049	9.142E+03	1.370E+07	9.208E+02	2.508E+04	1.370E+07	9.208E+02
2050	8.784E+03	1.317E+07	8.847E+02	2.410E+04	1.317E+07	8.847E+02
2051	8.440E+03	1.265E+07	8.500E+02	2.316E+04	1.265E+07	8.500E+02
2052	8.109E+03	1.215E+07	8.166E+02	2.225E+04	1.215E+07	8.166E+02
2053	7.791E+03	1.168E+07	7.846E+02	2.138E+04	1.168E+07	7.846E+02
2054	7.485E+03	1.122E+07	7.539E+02	2.054E+04	1.122E+07	7.539E+02
2055	7.192E+03	1.078E+07	7.243E+02	1.973E+04	1.078E+07	7.243E+02
2056	6.910E+03	1.036E+07	6.959E+02	1.896E+04	1.036E+07	6.959E+02
2057	6.639E+03	9.951E+06	6.686E+02	1.822E+04	9.951E+06	6.686E+02
2058	6.378E+03	9.561E+06	6.424E+02	1.750E+04	9.561E+06	6.424E+02
2059	6.128E+03	9.186E+06	6.172E+02	1.681E+04	9.186E+06	6.172E+02
2060	5.888E+03	8.826E+06	5.930E+02	1.616E+04	8.826E+06	5.930E+02
2061	5.657E+03	8.480E+06	5.697E+02	1.552E+04	8.480E+06	5.697E+02
2062	5.435E+03	8.147E+06	5.474E+02	1.491E+04	8.147E+06	5.474E+02
2063	5.222E+03	7.828E+06	5.259E+02	1.433E+04	7.828E+06	5.259E+02
2064	5.017E+03	7.521E+06	5.053E+02	1.377E+04	7.521E+06	5.053E+02
2065	4.821E+03	7.226E+06	4.855E+02	1.323E+04	7.226E+06	4.855E+02
2066	4.632E+03	6.943E+06	4.665E+02	1.271E+04	6.943E+06	4.665E+02
2067	4.450E+03	6.670E+06	4.482E+02	1.221E+04	6.670E+06	4.482E+02
2068	4.276E+03	6.409E+06	4.306E+02	1.173E+04	6.409E+06	4.306E+02
2069	4.108E+03	6.158E+06	4.137E+02	1.127E+04	6.158E+06	4.137E+02
2070	3.947E+03	5.916E+06	3.975E+02	1.083E+04	5.916E+06	3.975E+02
2071	3.792E+03	5.684E+06	3.819E+02	1.040E+04	5.684E+06	3.819E+02
2072	3.643E+03	5.461E+06	3.669E+02	9.997E+03	5.461E+06	3.669E+02
2073	3.501E+03	5.247E+06	3.526E+02	9.605E+03	5.247E+06	3.526E+02
2074	3.363E+03	5.041E+06	3.387E+02	9.228E+03	5.041E+06	3.387E+02
2075	3.231E+03	4.844E+06	3.254E+02	8.866E+03	4.844E+06	3.254E+02
2076	3.105E+03	4.654E+06	3.127E+02	8.519E+03	4.654E+06	3.127E+02
2077	2.983E+03	4.471E+06	3.004E+02	8.185E+03	4.471E+06	3.004E+02
2078	2.866E+03	4.296E+06	2.886E+02	7.864E+03	4.296E+06	2.886E+02
2079	2.754E+03	4.127E+06	2.773E+02	7.555E+03	4.127E+06	2.773E+02
2080	2.646E+03	3.966E+06	2.665E+02	7.259E+03	3.966E+06	2.665E+02
2081	2.542E+03	3.810E+06	2.560E+02	6.974E+03	3.810E+06	2.560E+02
2082	2.442E+03	3.661E+06	2.460E+02	6.701E+03	3.661E+06	2.460E+02
2083	2.347E+03	3.517E+06	2.363E+02	6.438E+03	3.517E+06	2.363E+02
2084	2.255E+03	3.379E+06	2.271E+02	6.186E+03	3.379E+06	2.271E+02
2085	2.166E+03	3.247E+06	2.182E+02	5.943E+03	3.247E+06	2.182E+02
2086	2.081E+03	3.119E+06	2.096E+02	5.710E+03	3.119E+06	2.096E+02
2087	2.000E+03	2.997E+06	2.014E+02	5.486E+03	2.997E+06	2.014E+02
2088	1.921E+03	2.880E+06	1.935E+02	5.271E+03	2.880E+06	1.935E+02
2089	1.846E+03	2.767E+06	1.859E+02	5.065E+03	2.767E+06	1.859E+02
2090	1.773E+03	2.658E+06	1.786E+02	4.866E+03	2.658E+06	1.786E+02
2091	1.704E+03	2.554E+06	1.716E+02	4.675E+03	2.554E+06	1.716E+02
2092	1.637E+03	2.454E+06	1.649E+02	4.492E+03	2.454E+06	1.649E+02
2093	1.573E+03	2.358E+06	1.584E+02	4.316E+03	2.358E+06	1.584E+02
2094	1.511E+03	2.265E+06	1.522E+02	4.146E+03	2.265E+06	1.522E+02
2095	1.452E+03	2.176E+06	1.462E+02	3.984E+03	2.176E+06	1.462E+02
2096	1.395E+03	2.091E+06	1.405E+02	3.828E+03	2.091E+06	1.405E+02

Results (Continued)

Year	Methane			Carbon dioxide		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2097	1.340E+03	2.009E+06	1.350E+02	3.678E+03	2.009E+06	1.350E+02
2098	1.288E+03	1.930E+06	1.297E+02	3.533E+03	1.930E+06	1.297E+02
2099	1.237E+03	1.855E+06	1.246E+02	3.395E+03	1.855E+06	1.246E+02
2100	1.189E+03	1.782E+06	1.197E+02	3.262E+03	1.782E+06	1.197E+02
2101	1.142E+03	1.712E+06	1.150E+02	3.134E+03	1.712E+06	1.150E+02
2102	1.097E+03	1.645E+06	1.105E+02	3.011E+03	1.645E+06	1.105E+02

2103	1.054E+03	1.580E+06	1.062E+02	2.893E+03	1.580E+06	1.062E+02
2104	1.013E+03	1.518E+06	1.020E+02	2.779E+03	1.518E+06	1.020E+02
2105	9.733E+02	1.459E+06	9.802E+01	2.670E+03	1.459E+06	9.802E+01
2106	9.351E+02	1.402E+06	9.418E+01	2.566E+03	1.402E+06	9.418E+01
2107	8.985E+02	1.347E+06	9.049E+01	2.465E+03	1.347E+06	9.049E+01
2108	8.632E+02	1.294E+06	8.694E+01	2.369E+03	1.294E+06	8.694E+01
2109	8.294E+02	1.243E+06	8.353E+01	2.276E+03	1.243E+06	8.353E+01
2110	7.969E+02	1.194E+06	8.025E+01	2.186E+03	1.194E+06	8.025E+01
2111	7.656E+02	1.148E+06	7.711E+01	2.101E+03	1.148E+06	7.711E+01
2112	7.356E+02	1.103E+06	7.408E+01	2.018E+03	1.103E+06	7.408E+01
2113	7.068E+02	1.059E+06	7.118E+01	1.939E+03	1.059E+06	7.118E+01
2114	6.790E+02	1.018E+06	6.839E+01	1.863E+03	1.018E+06	6.839E+01
2115	6.524E+02	9.779E+05	6.571E+01	1.790E+03	9.779E+05	6.571E+01
2116	6.268E+02	9.396E+05	6.313E+01	1.720E+03	9.396E+05	6.313E+01
2117	6.023E+02	9.027E+05	6.065E+01	1.652E+03	9.027E+05	6.065E+01
2118	5.786E+02	8.673E+05	5.828E+01	1.588E+03	8.673E+05	5.828E+01
2119	5.560E+02	8.333E+05	5.599E+01	1.525E+03	8.333E+05	5.599E+01
2120	5.342E+02	8.007E+05	5.380E+01	1.466E+03	8.007E+05	5.380E+01
2121	5.132E+02	7.693E+05	5.169E+01	1.408E+03	7.693E+05	5.169E+01
2122	4.931E+02	7.391E+05	4.966E+01	1.353E+03	7.391E+05	4.966E+01
2123	4.738E+02	7.101E+05	4.771E+01	1.300E+03	7.101E+05	4.771E+01
2124	4.552E+02	6.823E+05	4.584E+01	1.249E+03	6.823E+05	4.584E+01
2125	4.373E+02	6.555E+05	4.404E+01	1.200E+03	6.555E+05	4.404E+01
2126	4.202E+02	6.298E+05	4.232E+01	1.153E+03	6.298E+05	4.232E+01
2127	4.037E+02	6.051E+05	4.066E+01	1.108E+03	6.051E+05	4.066E+01
2128	3.879E+02	5.814E+05	3.906E+01	1.064E+03	5.814E+05	3.906E+01
2129	3.727E+02	5.586E+05	3.753E+01	1.023E+03	5.586E+05	3.753E+01
2130	3.581E+02	5.367E+05	3.606E+01	9.824E+02	5.367E+05	3.606E+01
2131	3.440E+02	5.156E+05	3.465E+01	9.439E+02	5.156E+05	3.465E+01
2132	3.305E+02	4.954E+05	3.329E+01	9.069E+02	4.954E+05	3.329E+01
2133	3.176E+02	4.760E+05	3.198E+01	8.713E+02	4.760E+05	3.198E+01
2134	3.051E+02	4.573E+05	3.073E+01	8.372E+02	4.573E+05	3.073E+01
2135	2.931E+02	4.394E+05	2.952E+01	8.043E+02	4.394E+05	2.952E+01
2136	2.817E+02	4.222E+05	2.837E+01	7.728E+02	4.222E+05	2.837E+01

Results (Continued)

Year	NMOC			Total landfill gas		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
1996	0	0	0	0	0	0
1997	1.537E+01	4.288E+03	2.881E-01	8.924E+03	7.146E+06	4.801E+02
1998	2.965E+01	8.271E+03	5.557E-01	1.721E+04	1.378E+07	9.262E+02
1999	4.280E+01	1.194E+04	8.023E-01	2.485E+04	1.990E+07	1.337E+03
2000	5.584E+01	1.558E+04	1.047E+00	3.243E+04	2.596E+07	1.745E+03
2001	6.890E+01	1.922E+04	1.291E+00	4.001E+04	3.203E+07	2.152E+03
2002	8.189E+01	2.284E+04	1.535E+00	4.755E+04	3.807E+07	2.558E+03
2003	9.492E+01	2.648E+04	1.779E+00	5.512E+04	4.413E+07	2.965E+03
2004	1.079E+02	3.011E+04	2.023E+00	6.268E+04	5.019E+07	3.372E+03
2005	1.212E+02	3.381E+04	2.271E+00	7.036E+04	5.634E+07	3.786E+03
2006	1.339E+02	3.736E+04	2.510E+00	7.776E+04	6.226E+07	4.183E+03
2007	1.462E+02	4.078E+04	2.740E+00	8.487E+04	6.796E+07	4.566E+03
2008	1.571E+02	4.383E+04	2.945E+00	9.123E+04	7.305E+07	4.908E+03
2009	1.668E+02	4.654E+04	3.127E+00	9.686E+04	7.756E+07	5.211E+03
2010	1.753E+02	4.890E+04	3.285E+00	1.018E+05	8.150E+07	5.476E+03
2011	1.824E+02	5.088E+04	3.419E+00	1.059E+05	8.480E+07	5.698E+03
2012	1.896E+02	5.289E+04	3.554E+00	1.101E+05	8.815E+07	5.923E+03
2013	1.960E+02	5.468E+04	3.674E+00	1.138E+05	9.114E+07	6.123E+03
2014	2.031E+02	5.665E+04	3.806E+00	1.179E+05	9.442E+07	6.344E+03
2015	2.111E+02	5.890E+04	3.957E+00	1.226E+05	9.816E+07	6.595E+03
2016	2.207E+02	6.156E+04	4.136E+00	1.281E+05	1.026E+08	6.894E+03
2017	2.120E+02	5.915E+04	3.974E+00	1.231E+05	9.858E+07	6.623E+03
2018	2.037E+02	5.683E+04	3.818E+00	1.183E+05	9.471E+07	6.364E+03
2019	1.957E+02	5.460E+04	3.668E+00	1.136E+05	9.100E+07	6.114E+03
2020	1.880E+02	5.246E+04	3.525E+00	1.092E+05	8.743E+07	5.874E+03
2021	1.807E+02	5.040E+04	3.386E+00	1.049E+05	8.400E+07	5.644E+03
2022	1.736E+02	4.842E+04	3.254E+00	1.008E+05	8.071E+07	5.423E+03
2023	1.668E+02	4.653E+04	3.126E+00	9.684E+04	7.754E+07	5.210E+03
2024	1.602E+02	4.470E+04	3.003E+00	9.304E+04	7.450E+07	5.006E+03
2025	1.539E+02	4.295E+04	2.886E+00	8.939E+04	7.158E+07	4.809E+03
2026	1.479E+02	4.126E+04	2.773E+00	8.589E+04	6.877E+07	4.621E+03
2027	1.421E+02	3.965E+04	2.664E+00	8.252E+04	6.608E+07	4.440E+03
2028	1.365E+02	3.809E+04	2.559E+00	7.928E+04	6.349E+07	4.266E+03
2029	1.312E+02	3.660E+04	2.459E+00	7.617E+04	6.100E+07	4.098E+03
2030	1.260E+02	3.516E+04	2.363E+00	7.319E+04	5.860E+07	3.938E+03
2031	1.211E+02	3.378E+04	2.270E+00	7.032E+04	5.631E+07	3.783E+03
2032	1.163E+02	3.246E+04	2.181E+00	6.756E+04	5.410E+07	3.635E+03
2033	1.118E+02	3.119E+04	2.095E+00	6.491E+04	5.198E+07	3.492E+03

2034	1.074E+02	2.996E+04	2.013E+00	6.237E+04	4.994E+07	3.355E+03
2035	1.032E+02	2.879E+04	1.934E+00	5.992E+04	4.798E+07	3.224E+03
2036	9.915E+01	2.766E+04	1.858E+00	5.757E+04	4.610E+07	3.097E+03
2037	9.526E+01	2.658E+04	1.786E+00	5.531E+04	4.429E+07	2.976E+03
2038	9.152E+01	2.553E+04	1.716E+00	5.314E+04	4.256E+07	2.859E+03
2039	8.794E+01	2.453E+04	1.648E+00	5.106E+04	4.089E+07	2.747E+03
2040	8.449E+01	2.357E+04	1.584E+00	4.906E+04	3.928E+07	2.639E+03
2041	8.117E+01	2.265E+04	1.522E+00	4.714E+04	3.774E+07	2.536E+03
2042	7.799E+01	2.176E+04	1.462E+00	4.529E+04	3.626E+07	2.437E+03
2043	7.493E+01	2.091E+04	1.405E+00	4.351E+04	3.484E+07	2.341E+03
2044	7.200E+01	2.009E+04	1.350E+00	4.181E+04	3.348E+07	2.249E+03
2045	6.917E+01	1.930E+04	1.297E+00	4.017E+04	3.216E+07	2.161E+03

Results (Continued)

Year	NMOC			Total landfill gas		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2046	6.646E+01	1.854E+04	1.246E+00	3.859E+04	3.090E+07	2.076E+03
2047	6.385E+01	1.781E+04	1.197E+00	3.708E+04	2.969E+07	1.995E+03
2048	6.135E+01	1.712E+04	1.150E+00	3.562E+04	2.853E+07	1.917E+03
2049	5.894E+01	1.644E+04	1.105E+00	3.423E+04	2.741E+07	1.842E+03
2050	5.663E+01	1.580E+04	1.062E+00	3.289E+04	2.633E+07	1.769E+03
2051	5.441E+01	1.518E+04	1.020E+00	3.160E+04	2.530E+07	1.700E+03
2052	5.228E+01	1.458E+04	9.800E-01	3.036E+04	2.431E+07	1.633E+03
2053	5.023E+01	1.401E+04	9.415E-01	2.917E+04	2.336E+07	1.569E+03
2054	4.826E+01	1.346E+04	9.046E-01	2.802E+04	2.244E+07	1.508E+03
2055	4.637E+01	1.294E+04	8.692E-01	2.692E+04	2.156E+07	1.449E+03
2056	4.455E+01	1.243E+04	8.351E-01	2.587E+04	2.071E+07	1.392E+03
2057	4.280E+01	1.194E+04	8.023E-01	2.485E+04	1.990E+07	1.337E+03
2058	4.112E+01	1.147E+04	7.709E-01	2.388E+04	1.912E+07	1.285E+03
2059	3.951E+01	1.102E+04	7.406E-01	2.294E+04	1.837E+07	1.234E+03
2060	3.796E+01	1.059E+04	7.116E-01	2.204E+04	1.765E+07	1.186E+03
2061	3.647E+01	1.018E+04	6.837E-01	2.118E+04	1.696E+07	1.139E+03
2062	3.504E+01	9.777E+03	6.569E-01	2.035E+04	1.629E+07	1.095E+03
2063	3.367E+01	9.393E+03	6.311E-01	1.955E+04	1.566E+07	1.052E+03
2064	3.235E+01	9.025E+03	6.064E-01	1.878E+04	1.504E+07	1.011E+03
2065	3.108E+01	8.671E+03	5.826E-01	1.805E+04	1.445E+07	9.710E+02
2066	2.986E+01	8.331E+03	5.598E-01	1.734E+04	1.389E+07	9.329E+02
2067	2.869E+01	8.004E+03	5.378E-01	1.666E+04	1.334E+07	8.964E+02
2068	2.757E+01	7.691E+03	5.167E-01	1.601E+04	1.282E+07	8.612E+02
2069	2.649E+01	7.389E+03	4.965E-01	1.538E+04	1.232E+07	8.274E+02
2070	2.545E+01	7.099E+03	4.770E-01	1.478E+04	1.183E+07	7.950E+02
2071	2.445E+01	6.821E+03	4.583E-01	1.420E+04	1.137E+07	7.638E+02
2072	2.349E+01	6.553E+03	4.403E-01	1.364E+04	1.092E+07	7.339E+02
2073	2.257E+01	6.296E+03	4.231E-01	1.311E+04	1.049E+07	7.051E+02
2074	2.168E+01	6.050E+03	4.065E-01	1.259E+04	1.008E+07	6.775E+02
2075	2.083E+01	5.812E+03	3.905E-01	1.210E+04	9.687E+06	6.509E+02
2076	2.002E+01	5.584E+03	3.752E-01	1.162E+04	9.307E+06	6.254E+02
2077	1.923E+01	5.366E+03	3.605E-01	1.117E+04	8.943E+06	6.008E+02
2078	1.848E+01	5.155E+03	3.464E-01	1.073E+04	8.592E+06	5.773E+02
2079	1.775E+01	4.953E+03	3.328E-01	1.031E+04	8.255E+06	5.547E+02
2080	1.706E+01	4.759E+03	3.197E-01	9.905E+03	7.931E+06	5.329E+02
2081	1.639E+01	4.572E+03	3.072E-01	9.516E+03	7.620E+06	5.120E+02
2082	1.575E+01	4.393E+03	2.952E-01	9.143E+03	7.322E+06	4.919E+02
2083	1.513E+01	4.221E+03	2.836E-01	8.785E+03	7.034E+06	4.726E+02
2084	1.454E+01	4.055E+03	2.725E-01	8.440E+03	6.759E+06	4.541E+02
2085	1.397E+01	3.896E+03	2.618E-01	8.109E+03	6.494E+06	4.363E+02
2086	1.342E+01	3.743E+03	2.515E-01	7.791E+03	6.239E+06	4.192E+02
2087	1.289E+01	3.597E+03	2.417E-01	7.486E+03	5.994E+06	4.028E+02
2088	1.239E+01	3.456E+03	2.322E-01	7.192E+03	5.759E+06	3.870E+02
2089	1.190E+01	3.320E+03	2.231E-01	6.910E+03	5.533E+06	3.718E+02
2090	1.143E+01	3.190E+03	2.143E-01	6.639E+03	5.317E+06	3.572E+02
2091	1.099E+01	3.065E+03	2.059E-01	6.379E+03	5.108E+06	3.432E+02
2092	1.056E+01	2.945E+03	1.979E-01	6.129E+03	4.908E+06	3.298E+02
2093	1.014E+01	2.829E+03	1.901E-01	5.889E+03	4.715E+06	3.168E+02
2094	9.744E+00	2.718E+03	1.826E-01	5.658E+03	4.530E+06	3.044E+02
2095	9.361E+00	2.612E+03	1.755E-01	5.436E+03	4.353E+06	2.925E+02
2096	8.994E+00	2.509E+03	1.686E-01	5.223E+03	4.182E+06	2.810E+02

Results (Continued)

Year	NMOC			Total landfill gas		
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(Mg/year)*	*(m^3/year)*	*(av ft^3/min)*
2097	8.642E+00	2.411E+03	1.620E-01	5.018E+03	4.018E+06	2.700E+02
2098	8.303E+00	2.316E+03	1.556E-01	4.821E+03	3.861E+06	2.594E+02

2099	7.977E+00	2.226E+03	1.495E-01	4.632E+03	3.709E+06	2.492E+02
2100	7.665E+00	2.138E+03	1.437E-01	4.451E+03	3.564E+06	2.394E+02
2101	7.364E+00	2.054E+03	1.380E-01	4.276E+03	3.424E+06	2.301E+02
2102	7.075E+00	1.974E+03	1.326E-01	4.108E+03	3.290E+06	2.210E+02
2103	6.798E+00	1.896E+03	1.274E-01	3.947E+03	3.161E+06	2.124E+02
2104	6.531E+00	1.822E+03	1.224E-01	3.792E+03	3.037E+06	2.040E+02
2105	6.275E+00	1.751E+03	1.176E-01	3.644E+03	2.918E+06	1.960E+02
2106	6.029E+00	1.682E+03	1.130E-01	3.501E+03	2.803E+06	1.884E+02
2107	5.793E+00	1.616E+03	1.086E-01	3.364E+03	2.693E+06	1.810E+02
2108	5.566E+00	1.553E+03	1.043E-01	3.232E+03	2.588E+06	1.739E+02
2109	5.347E+00	1.492E+03	1.002E-01	3.105E+03	2.486E+06	1.671E+02
2110	5.138E+00	1.433E+03	9.630E-02	2.983E+03	2.389E+06	1.605E+02
2111	4.936E+00	1.377E+03	9.253E-02	2.866E+03	2.295E+06	1.542E+02
2112	4.743E+00	1.323E+03	8.890E-02	2.754E+03	2.205E+06	1.482E+02
2113	4.557E+00	1.271E+03	8.541E-02	2.646E+03	2.119E+06	1.424E+02
2114	4.378E+00	1.221E+03	8.207E-02	2.542E+03	2.036E+06	1.368E+02
2115	4.206E+00	1.174E+03	7.885E-02	2.442E+03	1.956E+06	1.314E+02
2116	4.041E+00	1.127E+03	7.576E-02	2.347E+03	1.879E+06	1.263E+02
2117	3.883E+00	1.083E+03	7.279E-02	2.255E+03	1.805E+06	1.213E+02
2118	3.731E+00	1.041E+03	6.993E-02	2.166E+03	1.735E+06	1.166E+02
2119	3.584E+00	1.000E+03	6.719E-02	2.081E+03	1.667E+06	1.120E+02
2120	3.444E+00	9.608E+02	6.455E-02	2.000E+03	1.601E+06	1.076E+02
2121	3.309E+00	9.231E+02	6.202E-02	1.921E+03	1.539E+06	1.034E+02
2122	3.179E+00	8.869E+02	5.959E-02	1.846E+03	1.478E+06	9.932E+01
2123	3.054E+00	8.521E+02	5.726E-02	1.774E+03	1.420E+06	9.543E+01
2124	2.935E+00	8.187E+02	5.501E-02	1.704E+03	1.365E+06	9.168E+01
2125	2.820E+00	7.866E+02	5.285E-02	1.637E+03	1.311E+06	8.809E+01
2126	2.709E+00	7.558E+02	5.078E-02	1.573E+03	1.260E+06	8.463E+01
2127	2.603E+00	7.261E+02	4.879E-02	1.511E+03	1.210E+06	8.132E+01
2128	2.501E+00	6.977E+02	4.688E-02	1.452E+03	1.163E+06	7.813E+01
2129	2.403E+00	6.703E+02	4.504E-02	1.395E+03	1.117E+06	7.506E+01
2130	2.309E+00	6.440E+02	4.327E-02	1.340E+03	1.073E+06	7.212E+01
2131	2.218E+00	6.188E+02	4.158E-02	1.288E+03	1.031E+06	6.929E+01
2132	2.131E+00	5.945E+02	3.995E-02	1.237E+03	9.909E+05	6.658E+01
2133	2.047E+00	5.712E+02	3.838E-02	1.189E+03	9.520E+05	6.397E+01
2134	1.967E+00	5.488E+02	3.687E-02	1.142E+03	9.147E+05	6.146E+01
2135	1.890E+00	5.273E+02	3.543E-02	1.097E+03	8.788E+05	5.905E+01
2136	1.816E+00	5.066E+02	3.404E-02	1.054E+03	8.444E+05	5.673E+01

APPENDIX II: INTEGRATED WASTE MANAGEMENT MODEL OUTPUT ON AUCKLAND MSWM EMISSIONS QUANTIFICATION, 1996-2015

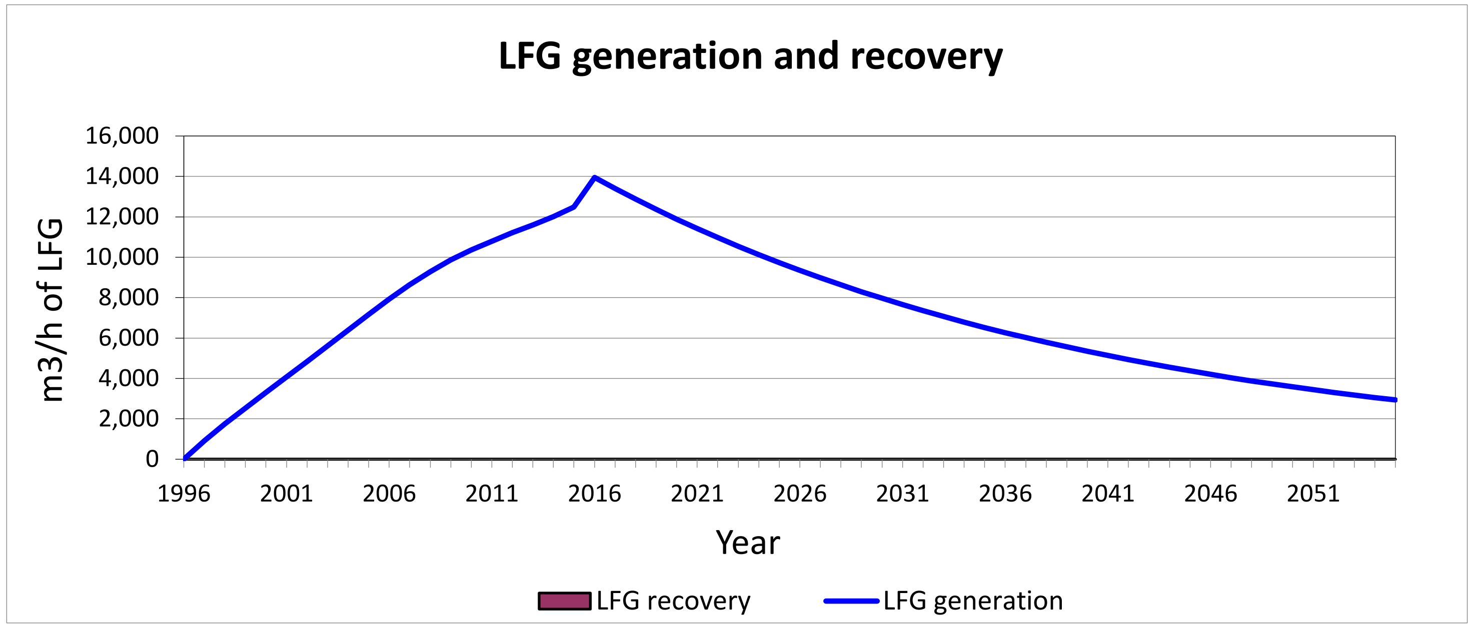
Auckland MSWM Emission - IWM Model

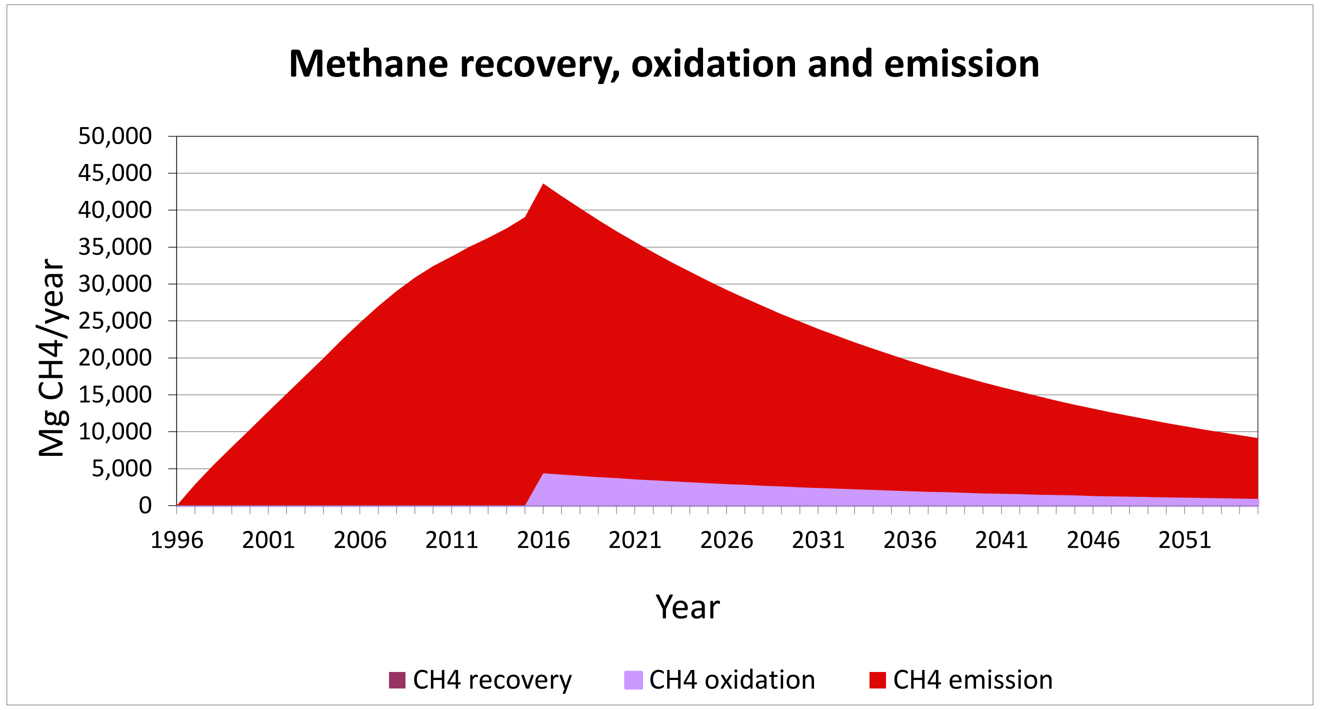
	RECYCLING						**COMPOSTING**				**ENERGY FROM WASTE**			**LANDFILL**		
	Collection & Transp.	MRF	Reprocessing	Total Recycling	Virgin Material Displacement Credit	**Net Energy/ Emissions**	Collection	Composting	Land Application	**Net Energy/ Emissions**	Collection	EFW	**Net Energy/ Emissions**	Collection	Landfilling	**Net Energy/ Emissions**
Energy Consumed (GJ)	0	0	0	0	0	**0**	0	0	0	**0**	0	0	**0**	775,956	266,215	**1,042,171**
Greenhouse Gas Emissions																
- CO2 (tonnes)	0	0	0	0	0	**0**	0.00	0	0.0	**0**	0.0	0	**0**	54,453	3,879,283	**3,933,736**
- CH4 (tonnes)	0.00	0.00	0.0	0.0	0.0	**0.0**	0.00	0.00	0.0	**0.00**	0.00	0.0	**0**	69.079	1,406,248	**1,406,317**
CO2 Equivalents (tonnes)*	0	0	0	0	0	**0**	0	0	0.0	**0**	0.0	0	**0**	55,904	33,410,486	**33,466,390**
Acid Gas Emissions																
- NOx (tonnes)	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.00	0.00	**0.0**	0.0	0.0	**0.0**	476.4	139.81	**616.16**
- SOx (tonnes)	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.00	**0.0**	0.0	0.0	**0.0**	109.5	45.38	**154.89**
- HCl (tonnes)	0.000	0.00	0.0	0.0	0.0	**0.0**	0.000	0.000	0.000	**0.00**	0.0	0.0	**0.0**	0.277	254.88	**255.16**
Smog Precursors																
- NOx (tonnes)	0.0	0.0	0	0.0	0.0	**0.0**	0.0	0.00	0.00	**0.0**	0.0	0.0	**0.0**	476.4	139.81	**616.16**
- PM (tonnes)	0.0	0.0	0	0.0	0.0	**0.0**	0.0	0.0	0.00	**0.0**	0.0	0.0	**0.0**	84.6	5045.7	**5,130.25**
- VOCs (tonnes)	0.0	0.00	0	0.0	0.0	**0.0**	0.0	0.00	0.000	**0.0**	0.0	0.0	**0.0**	208.3	8647.2	**8,855.54**
Toxic emissions																
- Air																
Pb (kg)	0.00	0.000	0.00	0.00	0.0	**0.0**	0.000	0.0000	0.0000	**0.000**	0.00	0.0	**0.0**	2.39	21.194	**23.58**
Hg (kg)	0.000	0.000	0.0	0.0	0.00	**0.0**	0.0000	0.0000	0.0000	**0.0000**	0.0000	0.0	**0.0**	0.0792	0.3024	**0.382**
Cd (kg)	0.00	0.0000	0.00	0.00	0.00	**0.0**	0.000	0.0000	0.0000	**0.000**	0.000	0.0	**0.0**	0.568	22.036	**22.60**
Dioxins (TEQ) (g)	0.0000	0.0	0.0000	0.00000	n/a	**0.00000**	0.00000	0.000000	0.0000000	**0.00000**	0.000000	0.00	**0.00**	0.00936	1.328	**1.338**
- Water																
Pb (kg)	0.0	0.0	0	0	0.00	**0.0**	0.00	0.0	0.00	**0.0**	0	0	**0**	8.81	18.19	**27.0**
Hg (kg)	0.0000	0.0000	0.00	0.00	0.00	**0.00**	0.00000	0.00000	0.00000	**0.00000**	0	0	**0**	0.01	0.01	**0.02**
Cd (kg)	0.00	0.000	0.0	0.0	0.00	**0.0**	0.000	0.0000	0.0000	**0.000**	0	0	**0**	0.96	0.39	**1.3**
BOD (kg)	0.00	0.00	0	0	0	**0**	0.0	0.000	0.000	**0.0**	0	0	**0**	75	18	**93**
Dioxins TEQ (mg)	n/a	n/a	n/a	n/a	n/a	**0.00000**	n/a	n/a	n/a	**n/a**	-	-	**-**	n/a	0.00000	**0.00000**

ENVIRONMENTAL INVENTORY - MSW MANAGEMENT SYSTEM
Auckland MSWM Emission – IWM Model

	Recycling	Composting	EFW	Landfill	Total Waste Management System	Virgin Material Displacement Credit	Reprocessing of Recycled Materials	Net Life Cycle Inventory	Collection
Tonnes Managed	0	0	0	18,578,650	18,578,650				
Energy Consumed (GJ)	0	0	0	1,042,171	1,042,171	0	0	1,042,171	775,956
Greenhouse Gases									
- CO2 (tonnes)	0	0	0	3,933,736	3,933,736	0	0	3,933,736	54,453
- CH4 (tonnes)	0.0	0.00	0.0	1,406,317	1,406,317	0.0	0.0	1,406,317	69.08
- CO2 Equivalents (tonnes)	0	0	0	33,466,390	33,466,390	0	0	33,466,390	
Acid Gases									
- NOx (tonnes)	0.00	0.000	0.0	616.16	616.16	0.0	0.0	616.2	476.4
- SOx (tonnes)	0.00	0.000	0.0	154.89	154.89	0	0.0	154.9	109.52
- HCl (tonnes)	0.000	0.000	0.00	255.160	255.16	0.0	0.00	255.2	0.28
Smog Precursors									
- NOx (tonnes)	0.00	0.000	0.0	616.16	616.2	0.0	0.0	616.2	476.4
- PM (tonnes)	0.00	0.0	0.00	5130.2	5130.2	0.0	0.0	5130.2	84.57
- VOCs (tonnes)	0.00	0.00	0.00	8855.5	8855.5	0.0	0.0	8855.5	208.34
Heavy Metals & Organics									
- Air									
Pb (kg)	0.000	0.000	0.0	23.58	23.6	0.00	0.00	23.6	2.39
Hg (kg)	0.000	0.000	0.00	0.382	0.38	0.00	0.00	0.38	0.08
Cd (kg)	0.000	0.000	0.00	22.603	22.60	0.00	0.00	22.60	0.57
Dioxins (TEQ) (g)	0.0000	0.00000	0.000	1.338	1.338	n/a	0.0000	1.338	0.00936
- Water									
Pb (kg)	0.000	0.000	0.000	27.00	27.00	0.0	0.0	27.00	8.81E+00
Hg (kg)	0.0000	0.00000	0.000	0.016	0.016	0.00	0.00	0.016	9.11E-03
Cd (kg)	0.000	0.000	0.000	1.35	1.35	0.0	0.00	1.346	9.56E-01
BOD (kg)	0.00	0.000	0.000	93	93	0	0	93	7.47E+01
Dioxins (TEQ) (g)	n/a	n/a	n/a	0.00000	0.0000	n/a	n/a	0.00000	n/a
Residual Waste (tonnes)	0	0	0	18,578,645	18,578,645	0	0	18,578,645	

APPENDIX III: AUCKLAND EMISSION QUANTIFICATION USING AFVALZORG MODEL





Parameters to be adapted for modelling (see tab 'manual' for more information)

Step 1: Enter year of start of disposal in cell A47

Step 2: Enter waste mass deposited in column B for each year of operation
Step 3: Enter landfill cell number where waste is placed for each year in column C (default value = 1)
Step 4: Enter Methane Correction Factor (MCF) in column D until the last year of disposal
Step 5: Estimate general waste composition of the landfill in percentages in table 1 (column O)
Step 6: Enter amount of Degradable Organic Carbon (DOC) in MSW in table 1 (cell P32)
Step 7: Enter the reaction rate constant (k) of Municipal Solid Waste in cell D41

Step 8: Enter the percentage of methane oxidised (OX) in the cover layer in cell D42
Step 9: Enter LFG recovery efficiency in column J for each year
Step 10: Please check that moving/editting cells has not impacted the calculations or the graphs

Table 1: Waste composition

Waste category	percentage	DOC (by weight wet basis)
Municipal solid waste (MSW)	45%	0.220
timber	14%	0.430
Paper	10%	0.400
textiles	3%	0.240
Food waste	19%	0.150
Construction and demolition waste	9%	0.043
Soil	0%	0.003
Total	100%	**0.239**

Reaction rate constant (k):	0.040
Oxidation factor (OX):	10%

year [a]	waste mass [Mg]	cell number [-]	MCF [-]	DDOCm [Mg]	DDOCma [Mg]	DDOCm decomp [Mg]	CH_4 gen [Mg]	LFG gen [m^{3}STP/h]	Recovery efficiency [-]	CH_4 rec [Mg]	LFG rec [m^{3}STP/h]	CH_4 oxid [Mg]	LFG oxid [m^{3}STP/h]	CH_4 emit [Mg]	LFG emit [m^{3}STP/h]
1996	909,405	1	1.0	108,736	108,736	0	0	0		0	0	0	0	0	0
1997	880,456	1	1.0	105,274	209,746	4,264	2,842	909	0.00	0	0	0	0	2,842	909
1998	847,263	1	1.0	101,305	302,827	8,224	5,483	1,753	0.00	0	0	0	0	5,483	1,753
1999	870,972	1	1.0	104,140	395,094	11,874	7,916	2,531	0.00	0	0	0	0	7,916	2,531
2000	901,948	1	1.0	107,844	487,446	15,492	10,328	3,302	0.00	0	0	0	0	10,328	3,302

2001	928,600	1	1.0	111,031	579,364	19,113	12,742	4,074	0.00	0	0	0	0	12,742	4,074
2002	961,132	1	1.0	114,920	671,567	22,717	15,145	4,843	0.00	0	0	0	0	15,145	4,843
2003	990,740	1	1.0	118,461	763,695	26,333	17,555	5,613	0.00	0	0	0	0	17,555	5,613
2004	1,033,549	1	1.0	123,579	857,330	29,945	19,963	6,384	0.00	0	0	0	0	19,963	6,384
2005	1,034,703	1	1.0	123,717	947,430	33,616	22,411	7,166	0.00	0	0	0	0	22,411	7,166
2006	1,035,508	1	1.0	123,814	1,034,095	37,149	24,766	7,919	0.00	0	0	0	0	24,766	7,919
2007	987,465	1	1.0	118,069	1,111,616	40,547	27,032	8,644	0.00	0	0	0	0	27,032	8,644
2008	938,199	1	1.0	112,178	1,180,208	43,587	29,058	9,292	0.00	0	0	0	0	29,058	9,292
2009	887,943	1	1.0	106,169	1,240,101	46,277	30,851	9,865	0.00	0	0	0	0	30,851	9,865
2010	826,924	1	1.0	98,874	1,290,349	48,625	32,417	10,366	0.00	0	0	0	0	32,417	10,366
2011	849,857	1	1.0	101,616	1,341,369	50,595	33,730	10,786	0.00	0	0	0	0	33,730	10,786
2012	819,531	1	1.0	97,990	1,386,763	52,596	35,064	11,212	0.00	0	0	0	0	35,064	11,212
2013	872,592	1	1.0	104,334	1,436,721	54,376	36,251	11,592	0.00	0	0	0	0	36,251	11,592
2014	947,373	1	1.0	113,275	1,493,662	56,335	37,556	12,009	0.00	0	0	0	0	37,556	12,009
2015	1,954,485	1	1.0	233,694	1,668,789	58,567	39,045	12,485	0.00	0	0	0	0	39,045	12,485
2016	0	0	0.0	-	1,603,354	65,434	43,623	13,949	0.00	0	0	4,362	1,395	39,260	12,554
2017	0	0	0.0	-	1,540,486	62,868	41,912	13,402	0.00	0	0	4,191	1,340	37,721	12,062
2018	0	0	0.0	-	1,480,083	60,403	40,269	12,876	0.00	0	0	4,027	1,288	36,242	11,589
2019	0	0	0.0	-	1,422,048	58,035	38,690	12,372	0.00	0	0	3,869	1,237	34,821	11,134
2020	0	0	0.0	-	1,366,289	55,759	37,173	11,886	0.00	0	0	3,717	1,189	33,456	10,698
2021	0	0	0.0	-	1,312,716	53,573	35,715	11,420	0.00	0	0	3,572	1,142	32,144	10,278
2022	0	0	0.0	-	1,261,243	51,472	34,315	10,973	0.00	0	0	3,431	1,097	30,883	9,875
2023	0	0	0.0	-	1,211,789	49,454	32,969	10,542	0.00	0	0	3,297	1,054	29,672	9,488
2024	0	0	0.0	-	1,164,274	47,515	31,677	10,129	0.00	0	0	3,168	1,013	28,509	9,116
2025	0	0	0.0	-	1,118,622	45,652	30,435	9,732	0.00	0	0	3,043	973	27,391	8,759
2026	0	0	0.0	-	1,074,761	43,862	29,241	9,350	0.00	0	0	2,924	935	26,317	8,415
2027	0	0	0.0	-	1,032,619	42,142	28,095	8,984	0.00	0	0	2,809	898	25,285	8,085
2028	0	0	0.0	-	992,129	40,490	26,993	8,631	0.00	0	0	2,699	863	24,294	7,768
2029	0	0	0.0	-	953,227	38,902	25,935	8,293	0.00	0	0	2,593	829	23,341	7,464
2030	0	0	0.0	-	915,851	37,377	24,918	7,968	0.00	0	0	2,492	797	22,426	7,171
2031	0	0	0.0	-	879,940	35,911	23,941	7,655	0.00	0	0	2,394	766	21,547	6,890
2032	0	0	0.0	-	845,437	34,503	23,002	7,355	0.00	0	0	2,300	736	20,702	6,620
2033	0	0	0.0	-	812,287	33,150	22,100	7,067	0.00	0	0	2,210	707	19,890	6,360
2034	0	0	0.0	-	780,436	31,850	21,233	6,790	0.00	0	0	2,123	679	19,110	6,111
2035	0	0	0.0	-	749,835	30,601	20,401	6,523	0.00	0	0	2,040	652	18,361	5,871
2036	0	0	0.0	-	720,434	29,401	19,601	6,268	0.00	0	0	1,960	627	17,641	5,641
2037	0	0	0.0	-	692,185	28,249	18,832	6,022	0.00	0	0	1,883	602	16,949	5,420
2038	0	0	0.0	-	665,044	27,141	18,094	5,786	0.00	0	0	1,809	579	16,285	5,207
2039	0	0	0.0	-	638,967	26,077	17,384	5,559	0.00	0	0	1,738	556	15,646	5,003
2040	0	0	0.0	-	613,913	25,054	16,703	5,341	0.00	0	0	1,670	534	15,033	4,807
2041	0	0	0.0	-	589,841	24,072	16,048	5,132	0.00	0	0	1,605	513	14,443	4,618
2042	0	0	0.0	-	566,713	23,128	15,419	4,930	0.00	0	0	1,542	493	13,877	4,437
2043	0	0	0.0	-	544,492	22,221	14,814	4,737	0.00	0	0	1,481	474	13,333	4,263
2044	0	0	0.0	-	523,142	21,350	14,233	4,551	0.00	0	0	1,423	455	12,810	4,096

2045	0	0	0.0	-	502,629	20,513	13,675	4,373	0.00	0	0	1,368	437	12,308	3,936
2046	0	0	0.0	-	482,921	19,708	13,139	4,201	0.00	0	0	1,314	420	11,825	3,781
2047	0	0	0.0	-	463,985	18,936	12,624	4,037	0.00	0	0	1,262	404	11,361	3,633
2048	0	0	0.0	-	445,792	18,193	12,129	3,878	0.00	0	0	1,213	388	10,916	3,490
2049	0	0	0.0	-	428,313	17,480	11,653	3,726	0.00	0	0	1,165	373	10,488	3,354
2050	0	0	0.0	-	411,518	16,794	11,196	3,580	0.00	0	0	1,120	358	10,077	3,222
2051	0	0	0.0	-	395,382	16,136	10,757	3,440	0.00	0	0	1,076	344	9,682	3,096
2052	0	0	0.0	-	379,879	15,503	10,335	3,305	0.00	0	0	1,034	330	9,302	2,974
2053	0	0	0.0	-	364,984	14,895	9,930	3,175	0.00	0	0	993	318	8,937	2,858
2054	0	0	0.0	-	350,673	14,311	9,541	3,051	0.00	0	0	954	305	8,587	2,746
2055	0	0	0.0	-	336,923	13,750	9,167	2,931	0.00	0	0	917	293	8,250	2,638

APPENDIX IV: IPCC MODEL OUTPUT AUCKLAND MSW EMISSION QUANTIFICATION, 1996-2015

Results

Auckland Emission Using IPCC Model: 1996-2015

Enter starting year, industrial waste disposal data and methane recovery into the yellow cells.
MSW activity data is entered on MSW sheet

	Methane generated											
Year	**Food**	**Garden**	**Paper**	**Wood**	**Textile**	**Nappies**	**Sludge**	**MSW**	**Industrial**	**Total**	**Methane recovery**	**Methane emission**
	A	B	C	D	E	F	G	H	J	K	L	M = (K-L)*(1-OX)
	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg
1996	0	0	0	0	0	0	0		0	0	0	0
1997	1,467	0	734	528	127	208	0		0	3,064	0	2,757
1998	2,639	0	1,403	1,023	243	389	0		0	5,697	0	5,127
1999	3,560	0	2,005	1,485	347	546	0		0	7,943	0	7,149
2000	4,364	0	2,592	1,946	449	693	0		0	10,043	0	9,039
2001	5,082	0	3,169	2,412	549	833	0		0	12,045	0	10,840
2002	5,721	0	3,735	2,880	646	966	0		0	13,948	0	12,553
2003	6,305	0	4,293	3,353	743	1,093	0		0	15,787	0	14,209
2004	6,838	0	4,843	3,828	838	1,215	0		0	17,564	0	15,807
2005	7,350	0	5,396	4,315	934	1,336	0		0	19,331	0	17,398
2006	7,778	0	5,917	4,788	1,024	1,445	0		0	20,952	0	18,857
2007	8,134	0	6,409	5,248	1,109	1,544	0		0	22,444	0	20,200
2008	8,353	0	6,833	5,666	1,183	1,623	0		0	23,657	0	21,291
2009	8,456	0	7,193	6,043	1,245	1,682	0		0	24,618	0	22,157
2010	8,460	0	7,491	6,379	1,296	1,725	0		0	25,352	0	22,816
2011	8,365	0	7,722	6,671	1,337	1,750	0		0	25,844	0	23,260
2012	8,323	0	7,959	6,967	1,378	1,777	0		0	26,403	0	23,763
2013	8,227	0	8,151	7,232	1,411	1,794	0		0	26,815	0	24,133
2014	8,245	0	8,381	7,525	1,451	1,822	0		0	27,424	0	24,681
2015	8,380	0	8,658	7,852	1,499	1,865	0		0	28,255	0	25,429
2016	8,666	0	9,005	8,232	1,559	1,929	0		0	29,391	0	26,452
2017	7,202	0	8,481	7,989	1,468	1,745	0		0	26,885	0	24,197
2018	5,986	0	7,987	7,753	1,382	1,579	0		0	24,687	0	22,218
2019	4,975	0	7,522	7,524	1,302	1,429	0		0	22,751	0	20,476
2020	4,135	0	7,084	7,301	1,226	1,293	0		0	21,039	0	18,935
2021	3,436	0	6,671	7,085	1,155	1,170	0		0	19,518	0	17,566
2022	2,856	0	6,283	6,876	1,087	1,058	0		0	18,161	0	16,345
2023	2,374	0	5,917	6,673	1,024	958	0		0	16,945	0	15,251

2024	1,973	0	5,572	6,476	964	867	0		0	15,852	0	14,267
2025	1,639	0	5,248	6,284	908	784	0		0	14,864	0	13,378
2026	1,363	0	4,942	6,099	855	709	0		0	13,968	0	12,571
2027	1,132	0	4,654	5,918	806	642	0		0	13,153	0	11,838
2028	941	0	4,383	5,743	759	581	0		0	12,408	0	11,167
2029	782	0	4,128	5,574	714	526	0		0	11,724	0	10,552
2030	650	0	3,888	5,409	673	476	0		0	11,095	0	9,986
2031	540	0	3,661	5,249	634	430	0		0	10,515	0	9,463
2032	449	0	3,448	5,094	597	389	0		0	9,977	0	8,980
2033	373	0	3,247	4,943	562	352	0		0	9,478	0	8,530
2034	310	0	3,058	4,797	529	319	0		0	9,014	0	8,112
2035	258	0	2,880	4,655	498	288	0		0	8,580	0	7,722
2036	214	0	2,712	4,518	469	261	0		0	8,175	0	7,358
2037	178	0	2,554	4,384	442	236	0		0	7,795	0	7,016
2038	148	0	2,406	4,255	416	214	0		0	7,439	0	6,695
2039	123	0	2,266	4,129	392	193	0		0	7,103	0	6,393
2040	102	0	2,134	4,007	369	175	0		0	6,787	0	6,108
2041	85	0	2,009	3,889	348	158	0		0	6,489	0	5,840
2042	71	0	1,892	3,774	328	143	0		0	6,207	0	5,587
2043	59	0	1,782	3,662	308	130	0		0	5,941	0	5,347
2044	49	0	1,678	3,554	290	117	0		0	5,689	0	5,120
2045	41	0	1,581	3,449	274	106	0		0	5,450	0	4,905
2046	34	0	1,489	3,347	258	96	0		0	5,223	10	4,692
2047	28	0	1,402	3,248	243	87	0		0	5,007	10	4,498
2048	23	0	1,320	3,152	229	79	0		0	4,803	10	4,313
2049	19	0	1,243	3,059	215	71	0		0	4,608	10	4,138
2050	16	0	1,171	2,968	203	64	0		0	4,423	10	3,971
2051	13	0	1,103	2,881	191	58	0		0	4,246	10	3,812
2052	11	0	1,039	2,796	180	53	0		0	4,078	10	3,661
2053	9	0	978	2,713	169	48	0		0	3,917	10	3,517
2054	8	0	921	2,633	159	43	0		0	3,764	10	3,379
2055	6	0	867	2,555	150	39	0		0	3,618	10	3,247
2056	5	0	817	2,479	141	35	0		0	3,478	10	3,122
2057	4	0	769	2,406	133	32	0		0	3,345	10	3,002
2058	4	0	725	2,335	125	29	0		0	3,218	10	2,887
2059	3	0	682	2,266	118	26	0		0	3,096	10	2,777
2060	3	0	643	2,199	111	24	0		0	2,979	10	2,672
2061	2	0	605	2,134	105	21	0		0	2,868	10	2,572
2062	2	0	570	2,071	99	19	0		0	2,761	10	2,476
2063	1	0	537	2,010	93	18	0		0	2,658	10	2,384
2064	1	0	506	1,950	87	16	0		0	2,561	10	2,295
2065	1	0	476	1,893	82	14	0		0	2,467	10	2,211
2066	1	0	448	1,837	78	13	0		0	2,377	10	2,130
2067	1	0	422	1,783	73	12	0		0	2,290	10	2,052
2068	1	0	398	1,730	69	11	0		0	2,208	10	1,978
2069	0	0	374	1,679	65	10	0		0	2,128	10	1,906
2070	0	0	353	1,629	61	9	0		0	2,052	10	1,838
2071	0	0	332	1,581	57	8	0		0	1,979	10	1,772
2072	0	0	313	1,534	54	7	0		0	1,909	10	1,709
2073	0	0	295	1,489	51	6	0		0	1,841	10	1,648
2074	0	0	277	1,445	48	6	0		0	1,776	10	1,590
2075	0	0	261	1,402	45	5	0		0	1,714	10	1,534

	2076	0	0	246	1,361	43	5	0		0	1,654	10	1,480

Site	Auckland Emission Using IPCC Model: 1996-2015

Long-term stored C in SWDS

In this sheet carbon long-term stored C in SWDS is calculated.

DOC:					
MSW	0	Food waste	0.15	Nappies	0.24
Paper	0.4	Garden	0.2	Sludge	0.05
Wood	0.43	Textiles	0.24	Industry	0.15

Year	MSW	Food	Garden	Paper	Wood	Textiles	Nappies	Sludge	C, Industry	Paper, industry subtotal	Wood, industry subtotal	Long-term stored C	Long-term stored C accumulated
	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg	Gg
1996	0	13,027	0	18,916	26,787	3,274	3,274	0	0	0	0	65,277	65,277
1997	0	12,613	0	18,314	25,934	3,170	3,170	0	0	0	0	63,199	128,477
1998	0	12,141	0	17,629	24,964	3,051	3,051	0	0	0	0	60,835	189,312
1999	0	12,477	0	18,116	25,654	3,135	3,135	0	0	0	0	62,518	251,830
2000	0	12,920	0	18,761	26,567	3,247	3,247	0	0	0	0	64,742	316,572
2001	0	13,302	0	19,315	27,352	3,343	3,343	0	0	0	0	66,655	383,227
2002	0	13,768	0	19,991	28,310	3,460	3,460	0	0	0	0	68,990	452,217
2003	0	14,192	0	20,607	29,182	3,567	3,567	0	0	0	0	71,116	523,332
2004	0	14,806	0	21,498	30,443	3,721	3,721	0	0	0	0	74,188	597,521
2005	0	14,822	0	21,522	30,477	3,725	3,725	0	0	0	0	74,271	671,791
2006	0	14,834	0	21,538	30,501	3,728	3,728	0	0	0	0	74,328	746,120
2007	0	14,145	0	20,539	29,086	3,555	3,555	0	0	0	0	70,880	817,000
2008	0	13,440	0	19,515	27,635	3,378	3,378	0	0	0	0	67,344	884,344
2009	0	12,720	0	18,469	26,154	3,197	3,197	0	0	0	0	63,736	948,080
2010	0	11,846	0	17,200	24,357	2,977	2,977	0	0	0	0	59,356	1,007,436
2011	0	12,174	0	17,677	25,032	3,059	3,059	0	0	0	0	61,002	1,068,439
2012	0	11,740	0	17,046	24,139	2,950	2,950	0	0	0	0	58,826	1,127,265
2013	0	12,500	0	18,150	25,702	3,141	3,141	0	0	0	0	62,635	1,189,900
2014	0	13,571	0	19,706	27,905	3,411	3,411	0	0	0	0	68,003	1,257,903
2015	0	15,106	0	21,933	31,060	3,796	3,796	0	0	0	0	75,691	1,333,594
2016	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2017	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2018	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2019	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2020	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2021	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2022	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2023	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2024	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2025	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2026	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2027	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594

2028	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2029	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2030	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2031	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2032	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2033	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2034	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2035	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2036	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2037	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2038	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2039	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2040	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2041	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2042	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2043	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2044	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2045	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2046	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2047	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2048	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2049	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2050	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2051	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2052	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2053	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2054	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2055	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2056	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2057	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2058	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2059	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2060	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2061	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2062	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2063	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2064	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2065	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2066	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2067	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2068	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2069	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2070	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2071	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2072	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2073	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2074	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2075	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594
2076	0	0	0	0	0	0	0	0	0	0	0	0	1,333,594

APPENDIX V: EASEWASTE MODEL OUTPUT ON AUCKLAND MSWM EMISSIONS QUANTIFICATION, 1996-2015

Substance Name	Category	Emission	Unit	Total Amount	Auckland 1996-2015 waste collection	Auckland Waste Transportation 1996-2015 [Landfill Mixed Waste]	Auckland Waste disposal 1996-2015
Mercury (Hg)	Emission	Air	kg	6.310474582	0.251988894	0.830081063	5.228404625
Zinc (Zn)	Emission	Air	kg	167.0225347	28.88866638	95.16266572	42.97120262
Chromium (Cr)	Emission	Air	kg	12.1927172	2.007965037	6.614473062	3.570279102
Nickel (Ni)	Emission	Air	kg	1302.845165	55.78368639	183.7580258	1063.303453
Carbon Monoxide (CO)	Emission	Air	kg	1179847.971	164927.5111	543290.6247	471629.8356
Nitrogen Oxides (NOx)	Emission	Air	kg	6459376.114	1077044.349	3547910.796	1834420.969
Particles - PM 10	Emission	Air	kg	121383.574	28267.40763	93116.16632	0
Sulphur Dioxide (SO2)	Emission	Air	kg	739019.8388	98479.8836	324404.3224	316135.6327
Lead (Pb)	Emission	Air	kg	28.36786536	5.343126394	17.60088694	5.423852018
Selenium (Se)	Emission	Air	kg	8.286203744	1.135629132	3.740895963	3.409678649
Carbon Dioxide (CO2 - Fossil)	Emission	Air	kg	847763797.2	101025034	332788347.2	413950416
Copper (Cu)	Emission	Air	kg	79.00412129	5.059645035	16.667066	57.27741026
Cadmium (Cd)	Emission	Air	kg	111.2389818	1.663195881	5.478762902	104.097023
VOC, Diesel Engine, Pre EURO	Emission	Air	kg	386827.8154	61272.36962	201838.394	123717.0517
Iron (Fe)	Resource	Raw Material	kg	688564.3885	104132.4579	343024.5671	241407.3635
Manganese (Mn)	Resource	Raw Material	kg	5314.965756	672.2174152	2214.36325	2428.38509
Energy Unspecified (APME)	Resource	Raw Material	MJ	-2254508.829	-421384.8393	-1388091.235	-445032.7544
Calcium Carbonate (CaCO3)	Resource	Raw Material	kg	3416342.723	167636.8382	552215.467	2696490.418
Sodium Chloride (NaCl)	Resource	Raw Material	kg	178935.3716	22083.40367	72745.32975	84106.63822
Clay	Resource	Raw Material	kg	209.6066115	23.4940583	77.39219205	108.7203612
Water (Unspecified)	Resource	Raw Material	kg	817308211	146354472	482108848.9	188844890.1
Water (Groundwater)	Resource	Raw Material	kg	47991079.91	42397.529	139662.4485	47809019.93
Water (Surface Water)	Resource	Raw Material	kg	975249.4297	98.28011441	323.7462592	974827.4033
Air	Resource	Raw Material	kg	480.5930074	91.13813731	300.2197464	89.23512364
Barium Sulphate	Resource	Raw Material	kg	811443.754	181197.9807	596887.4657	33358.30756
Quartz (Danish) (SiO2)	Resource	Raw Material	kg	118463.76	9722.733178	32027.82694	76713.19993
Water (Cooling)	Resource	Raw Material	kg	3.67548E+11	69711533106	2.29638E+11	68198161312
Bentonite Imported to Denmark	Resource	Raw Material	kg	63004.35261	11944.95371	39348.0828	11711.3161
Uranium Natural	Resource	Raw Material	kg	309.0197341	53.71921414	176.9574113	78.34310863
Hard Coal, Pure, Fuel	Resource	Raw Material	kg	865239.9918	69711.53311	229637.9914	565890.4673
Crude Oil	Resource	Raw Material	kg	238593989.3	42510151.31	140033439.6	56050398.38
Biomass, Dry Matter (Fuel)	Resource	Raw Material	kg	262094.3012	48805.03073	160769.513	52519.75748
Natural Gas, Fuel	Resource	Raw Material	kg	37973082.4	2349611.432	7739896.482	27883574.48
Brown Coal (Lignite)	Resource	Raw Material	kg	3135419.388	581133.7369	1914322.898	639962.7531
Hard Coal, Raw, Fuel	Resource	Raw Material	kg	4975580.578	776914.0832	2559246.392	1639420.103
Unspecified Minerals	Resource	Raw Material	kg	63284.46629	11930.7638	39301.33957	12052.36292

Biomass, Dry Matter (Raw Material)	Resource	Raw Material	kg	635.8256912	120.5045293	396.9560965	118.3650654
Wood, Soft, Dry Matter (Fuel)	Resource	Raw Material	kg	27.46602596	0.846554205	2.788649147	23.83082261
Natural Gas, Raw Material	Resource	Raw Material	kg	1122.456899	250.6482089	825.6646882	46.14400233
Unspecified Resources	Resource	Raw Material	kg	14399.97777	581.1313407	1914.315005	11904.53143
Lead (Pb)	Emission	Water	kg	75.08578221	1.797942907	5.922635457	67.36520385
Chromium (Cr)	Emission	Water	kg	949.6152654	8.067739225	26.57608215	914.971444
Iron (Fe)	Emission	Water	kg	7083.752021	1304.9686	4298.720094	1480.063327
Magnesium (Mg)	Emission	Water	kg	1268529.365	3403.554545	11211.70909	1253914.101
Copper (Cu)	Emission	Water	kg	1212.900406	4.086924912	13.46281148	1195.35067
Mercury (Hg)	Emission	Water	kg	1.004617451	0.016984858	0.05595012	0.931682473
Zinc (Zn)	Emission	Water	kg	10411.81075	19.95304303	65.72767117	10326.13003
N-total (N)	Emission	Water	kg	7810.896977	865.5823205	2851.329997	4093.984659
P-total (P)	Emission	Water	kg	101.0077004	18.98099682	62.52563658	19.50106702
Methane (CH4)	Emission	Air	kg	122213858.9	168169.2827	553969.4017	121491720.2
Nitrous Oxide (Laughing Gas) (N2O)	Emission	Air	kg	7311.766466	456.1631487	1502.655078	5352.94824
NMVOC (Unspecified)	Emission	Air	kg	1740495.78	329328.1119	1084845.545	326322.1232
Hydrogen Chloride (HCl)	Emission	Air	kg	12971.72188	180.3233873	594.0064522	12197.39204
Hydrogen Fluoride (HF)	Emission	Air	kg	2751.69659	8.040576028	26.48660339	2717.16941
Antimony (Sb)	Emission	Air	kg	0.146390902	0.027752638	0.091420453	0.027217811
Arsenic (As)	Emission	Air	kg	42.07479611	0.630551772	2.077111721	39.36713262
Chromium +III (Cr3+)	Emission	Air	kg	0.674141774	0.127803295	0.42099909	0.125339389
Cobalt (Co)	Emission	Air	kg	7.44614053	1.411544944	4.649795111	1.384800475
Manganese (Mn)	Emission	Air	kg	121.8292248	15.4149232	50.77857055	55.63573106
Thallium (Tl)	Emission	Air	kg	0.003254349	0.000616933	0.002032249	0.000605167
Tin (Sn)	Emission	Air	kg	0.026384567	0.005003943	0.016483576	0.004897049
Ammonia (NH3)	Emission	Air	kg	354.6331695	4.745911037	15.6335893	334.2536691
Cyanide (CN-)	Emission	Air	kg	6.223724548	0.031110646	0.102482129	6.090131772
Fluoride (F-)	Emission	Air	kg	11.02210031	0.63680278	2.097703275	8.287594255
Hydrogen Sulphide (H2S)	Emission	Air	kg	153.317392	14.7427742	48.56443265	90.01018511
Benzene	Emission	Air	kg	709.8216803	3.616806543	11.91418626	694.2906875
AOX (Adsorbable Organic Halogen Compounds)	Emission	Water	kg	45.78779073	8.67957446	28.5915394	8.516676872
BOD (Biological Oxygen Demand)	Emission	Water	kg	1752477.318	190.3495745	627.0338924	1751659.935
COD (Chemical Oxygen Demand)	Emission	Water	kg	35384.87037	6431.400984	21185.79148	7767.677911
Unspecified Organic Compounds	Emission	Water	kg	425.8420319	80.73015852	265.9346398	79.17723353
TOC (Total Organic Carbon)	Emission	Water	kg	101371.6066	19216.42598	63301.16794	18854.01267
Arsenic (As)	Emission	Water	kg	184.2690384	1.711479055	5.637813356	176.919746
Chromium +III (Cr3+)	Emission	Water	kg	0.497115088	0.094119551	0.310040873	0.092954665
Unspecified Metals	Emission	Air	kg	7.021418392	0.783135277	2.579739735	3.65854338
Manganese (Mn)	Emission	Water	kg	661.1316491	125.1933912	412.4017591	123.5364988
Aluminum (Al)	Emission	Water	kg	54.5683151	10.20972608	33.63203887	10.72655015
Hydrogen Ions (H+)	Emission	Water	kg	544.4323132	53.88729947	177.5111041	313.0339096
Chloride (Cl-)	Emission	Water	kg	12286216.91	1210368.652	3987096.737	7088751.516
Cyanide (CN-)	Emission	Water	kg	45.89201454	8.69954947	28.65733943	8.535125636
Sodium (Na)	Emission	Water	kg	3264060.361	728859.466	2400948.829	134252.066
Phosphate (PO4(3-))	Emission	Water	kg	303485.3579	0.315044521	1.037793716	303484.0051
Calcium (Ca)	Emission	Water	kg	4583026.405	78248.11326	257758.4907	4247019.801
Sulphate (SO4(2-))	Emission	Water	kg	238844.1061	40211.22714	132460.5129	66172.36602

Phenol	Emission	Water	kg	163684.3648	31.05687964	102.3050153	163551.0029
Acetaldehyde	Emission	Air	kg	0.085257963	0.019038375	0.062714648	0.00350494
Hazardous Waste (Unspecified)	Emission	Solid Waste	kg	924.1499551	167.1614085	550.6493458	206.3392008
Radioactive Waste	Emission	Solid Waste	kg	17353.75499	152.7387523	503.1394194	16697.87681
Medium and Low Radioactive Wastes	Emission	Solid Waste	kg	92795.61649	20721.5574	68259.2479	3814.811193
Unspecified Solids (Dissolved)	Emission	Water	kg	3448.386964	472.9447985	1557.935807	1417.506359
Sludge	Emission	Solid Waste	kg	120404.6516	58.59980551	193.0346534	120153.0171
Oil Sludge	Emission	Solid Waste	kg	3562282.81	794241.512	2616324.981	151716.3171
Unspecified Heavy Metals	Emission	Air	kg	0.00211963	1.40E-05	4.62E-05	0.002059434
Unspecified Solids (Suspended)	Emission	Water	kg	68720.48057	251.486365	828.4256728	67640.56854
Hydrocarbons (HC)	Emission	Water	kg	24092.17858	4551.787268	14994.12276	4546.268546
Unspecified Oil	Emission	Water	kg	186989.4548	35417.36479	116668.9664	34903.12362
PAH (Benzo{a}pyrene TEQ)	Emission	Water	kg	155.7917021	29.50129173	97.18072571	29.1096847
Unspecified Metal Ions	Emission	Water	kg	74.88826535	7.714831529	25.41356269	41.75987113
Inert Chemical Waste	Emission	Solid Waste	kg	1459.384473	191.2171131	629.8916668	638.2756931
Boron (B)	Emission	Water	kg	349.9160644	66.33019156	218.4994545	65.0864183
Chlorate	Emission	Water	kg	33.61780803	6.372800276	20.99275385	6.252253904
Dioxin (2,3,7,8-TCDD TEQ)	Emission	Air	kg	0.00030605	1.75E-06	5.78E-06	0.000298519
Boron Compounds (Unspecified)	Emission	Air	kg	97.89972677	21.86132152	72.013765	4.024640254
PAH (Benzo{a}pyrene TEQ)	Emission	Air	kg	13.60627006	1.348855325	4.44328813	7.81412661
Strontium (Sr)	Emission	Water	kg	72161.59417	13682.00022	45070.11836	13409.4756
Ammonia (NH3)	Emission	Water	kg	270814.8703	0.008285285	0.027292704	270814.8348
Mineral Waste	Emission	Solid Waste	kg	284739.8066	53332.67096	175684.0926	55723.04302
VOC, Heating with Natural Gas	Emission	Air	kg	1751.464868	11.21469164	36.94251362	1703.307662
VOC, Heating with Coal	Emission	Air	kg	124.3193769	0.761535012	2.508585923	121.0492559
VOC, Diesel Powered Car, Exhaust	Emission	Air	kg	4316.32411	691.8365937	2278.991132	1345.496383
NMVOC, Power Plants	Emission	Air	kg	117.2801364	4.004222764	13.19038087	100.0855327
NMVOC, Diesel Engines	Emission	Air	kg	40681.61441	6050.960703	19932.57643	14698.07727
NMVOC, Petrol Engines without Catalytic Converter	Emission	Air	kg	1477.574691	0.435951889	1.436076811	1475.702663
Hydrocarbones (HC)	Emission	Air	kg	38099.28492	3266.302057	10759.58325	24073.39961
Unspecified Particles	Emission	Air	kg	70277.35144	10082.27928	33212.21409	26982.85807
Unspecified Organic Compounds	Emission	Air	kg	8.868520214	0.038076751	0.125429296	8.705014168
Nitrate-N (NO3-N)	Emission	Water	kg	7447.396783	1410.929431	4647.767538	1388.699813
Ammonium (NH4+)	Emission	Water	kg	18453.66226	3497.32579	11520.6026	3435.733867
Unspecified Salt	Emission	Water	kg	11226.41379	2072.329401	6826.496849	2327.587539
Unspecified Substance	Emission	Water	kg	2213.941005	413.3615657	1361.661628	438.9178105
Slag and Ashes from Waste Incineration	Emission	Solid Waste	kg	6569.438712	708.1015662	2332.569865	3528.767281
Slag and Ashes from Energy Production	Emission	Solid Waste	kg	354379.1523	57570.76049	189644.8581	107163.5337
Bulky Waste	Emission	Solid Waste	kg	5135567.213	249895.0753	823183.7775	4062488.36
Rubber	Emission	Solid Waste	kg	15138.23332	3219.347496	10604.9094	1313.976425
Unspecified Radioactive Emission	Emission	Air	Bq	2.35609E+13	4.46467E+12	1.47072E+13	4.38904E+12
NMVOC, EU Base Load Electricity	Emission	Air	kg	238.9511294	45.2935343	149.2022306	44.45536444
P-total (P)	Emission	Air	kg	0.768394301	0.145664006	0.479834374	0.142895921
Ammonium (NH4)	Emission	Air	kg	3.61834488	0.686017046	2.259820858	0.672506976
Magnesium (Mg)	Emission	Air	kg	88.53661033	6.46950894	21.31132357	60.75577783
Uranium (Mass) (U)	Emission	Air	kg	0.018102279	0.003431612	0.011304135	0.003366532

Thorium (Th)	Emission	Air	kg	0.018846906	0.003572998	0.011769875	0.003504033
VOC, Heating with Oil	Emission	Air	kg	95.75019526	13.74396661	45.27424296	36.73198569
NMVOC, Heating with Natural Gas	Emission	Air	kg	36.39374268	6.898832415	22.7255656	6.769344661
NMVOC, Heating with Oil	Emission	Air	kg	5631.890428	1067.589565	3516.765627	1047.535235
Unspecified C9-C10 Aromates	Emission	Air	kg	0.004493201	0.000851505	0.002804957	0.000836739
Calcium (Ca)	Emission	Air	kg	75.28047891	4.41525535	14.54437056	56.320853
Unspecified Oxides	Emission	Water	kg	469.7036401	72.03178985	237.2811901	160.3906601
VOC (Unspecified)	Emission	Water	kg	4173.64656	790.9337992	2605.428986	777.2837755
Unspecified Iron Oxides	Emission	Water	kg	565.2812535	86.64693561	285.4251997	193.2091182
Unspecified C9-C10 Aromates	Emission	Water	kg	0.001192741	0.000266343	0.000877364	4.90E-05
Catalysts Material	Emission	Solid Waste	kg	15079.12219	2858.589103	9416.52881	2804.004275
Quartz (Silica) (SiO2)	Emission	Solid Waste	kg	22195.46638	27.6977891	91.23977587	22076.52881
Slags Containing Manganese	Emission	Solid Waste	kg	3630.401186	459.1243649	1512.409672	1658.867148
Ferriferous Furnace Slags	Emission	Solid Waste	kg	102311.5668	15659.08475	51582.86741	35069.61466
Unspecified Slag and Ashes	Emission	Solid Waste	kg	18679.82403	3536.126231	11648.41582	3495.281978
Bulky Waste from Steel Production	Emission	Solid Waste	kg	82643.58737	14301.96407	47112.35223	21229.27106
Unspecified Radioactive Emission	Emission	Water	Bq	6155372164	1167080723	3844501204	1143790237
Unspecified Industrial Waste	Emission	Solid Waste	kg	104778.0855	19862.6136	65429.78598	19485.68591
Iron (Fe)	Emission	Air	kg	36.71982677	6.96086149	22.92989667	6.829068607
Molybdenum (Mo)	Emission	Air	kg	3.926103939	0.70662543	2.327707298	0.891771211
Strontium (Sr)	Emission	Air	kg	1.191112665	0.225795237	0.743796074	0.221521354
Vanadium (V)	Emission	Air	kg	616.9354371	115.1550065	379.3341391	122.4462915
Cadmium (Cd)	Emission	Water	kg	43.23424214	2.384244736	7.853982661	32.99601474
Fluoride (F-)	Emission	Water	kg	145.665024	25.31355774	83.38583725	36.96562897
Molybdenum (Mo)	Emission	Water	kg	10.71179066	1.698483468	5.595004365	3.418302826
Nickel (Ni)	Emission	Water	kg	1079.959224	8.235378586	27.12830593	1044.59554
Selenium (Se)	Emission	Water	kg	35.69410913	1.698483468	5.595004365	28.4006213
Vanadium (V)	Emission	Water	kg	9.618950044	1.698483468	5.595004365	2.32546221
Water (Hydro Power)	Resource	Raw Material	kg	1925103038	301952764.2	994667929.1	628482344.9
N-unspecified (N)	Emission	Water	kg	7.069086475	0.783135277	2.579739735	3.706211463
DOC (Dissolved Organic Carbon)	Emission	Water	kg	172.413601	15.19662058	50.05945604	107.1575244
Unspecified Water	Emission	Water	kg	2356.510521	446.7277927	1471.573906	438.2088222
Aluminum (Al)	Resource	Raw Material	kg	9112.502335	0	0	9112.502335
Chromium (Cr)	Resource	Raw Material	kg	7131.627634	0	0	7131.627634
Copper (Cu)	Resource	Raw Material	kg	19026.24215	0	0	19026.24215
Nickel (Ni)	Resource	Raw Material	kg	3072.413436	0	0	3072.413436
Zinc (Zn)	Resource	Raw Material	kg	680.7176444	0	0	680.7176444
Hard Coal	Resource	Raw Material	kg	97046342.18	0	0	97046342.18
Straw, Dry Matter, Fuel	Resource	Raw Material	kg	122.5042193	0	0	122.5042193
Wood Soft, Dry Matter (Raw Material)	Resource	Raw Material	kg	98961.68311	0	0	98961.68311
Natural Aggregates from Land (Danish)	Resource	Raw Material	kg	2148.170441	0	0	2148.170441
Wood Hard, Dry Matter (Raw Material)	Resource	Raw Material	kg	1.463224912	0	0	1.463224912
Natural Gas, Raw Material	Resource	Raw Material	kg	707077.9009	0	0	707077.9009
Unspecified Iron Oxides	Emission	Air	kg	7.24017112	0	0	7.24017112
Acetic Acid	Emission	Air	kg	516.2649963	0	0	516.2649963
Formaldehyde (Methanal)	Emission	Air	kg	10.17765727	0	0	10.17765727
Nitrobenzene	Emission	Air	kg	0.024950502	0	0	0.024950502

Phenol	Emission	Air	kg	12.02307613	0	0	12.02307613
HFC 134a (Tetrafluoroethane)	Emission	Air	kg	0.073231567	0	0	0.073231567
Styrene	Emission	Air	kg	403.8980719	0	0	403.8980719
Toluene	Emission	Air	kg	86870.32963	0	0	86870.32963
1,1,1-Trichloroethane	Emission	Air	kg	168.6049197	0	0	168.6049197
Unspecified Waste Water	Emission	Water	kg	4644735.531	0	0	4644735.531
Chromium +VI (Cr6+)	Emission	Water	kg	1.661451315	0	0	1.661451315
Hydrogen Cyanide (Prussic Acid) (HCN)	Emission	Water	kg	0.074106419	0	0	0.074106419
Butylene Glycol (Butane Diol)	Emission	Water	kg	19.9212251	0	0	19.9212251
Methanol	Emission	Water	kg	0.014903826	0	0	0.014903826
Slags Containing Chromium	Emission	Solid Waste	kg	14785.38004	0	0	14785.38004
Tailings	Emission	Solid Waste	kg	8938.547302	0	0	8938.547302
Industrial Waste for Municipal Disposal	Emission	Solid Waste	kg	20727.39727	0	0	20727.39727
Waste (Unspecified)	Emission	Solid Waste	kg	20144767.57	0	0	20144767.57
Unspecified Organic Chlorine Compounds	Emission	Air	kg	10.354088	0	0	10.354088
Unspecified Organic Chlorine Compounds	Emission	Water	kg	0.056046338	0	0	0.056046338
Hydrogen (H2)	Emission	Air	kg	0.023374701	0	0	0.023374701
Lead Dross	Emission	Solid Waste	kg	293.1179101	0	0	293.1179101
Steam (H2O)	Emission	Air	kg	25190.67768	0	0	25190.67768
Wood	Emission	Solid Waste	kg	69079.64247	0	0	69079.64247
VOC (Unspecified)	Emission	Air	kg	2780.554095	0	0	2780.554095
Acetic Acid	Emission	Water	kg	105.402145	0	0	105.402145
Hydrogen Chloride (HCl)	Emission	Water	kg	434.2444246	0	0	434.2444246
Glass (Unspecified)	Emission	Solid Waste	kg	854.1175053	0	0	854.1175053
Paper	Emission	Solid Waste	kg	17.57339879	0	0	17.57339879
HCL in Slag and Ashes	Emission	Solid Waste	kg	1114.776732	0	0	1114.776732
Unspecified Oxides	Emission	Air	kg	9.712424673	0	0	9.712424673
Chlorine (Cl2)	Emission	Air	kg	0.011209268	0	0	0.011209268
Dust Containing Heavy Metals	Emission	Solid Waste	kg	2543.009332	0	0	2543.009332
Dust Containing Zinc	Emission	Solid Waste	kg	333.9913629	0	0	333.9913629
Soil and Sand Containing Heavy Metals	Emission	Solid Waste	kg	157.6465776	0	0	157.6465776
Heavy Metal Sludge	Emission	Solid Waste	kg	241.0014429	0	0	241.0014429
Hazardous Waste from Steel Production	Emission	Solid Waste	kg	216.2534005	0	0	216.2534005
Scrap Waste	Emission	Solid Waste	kg	499955.7824	0	0	499955.7824
Silicon (Si)	Emission	Water	kg	0.004501905	0	0	0.004501905
Unspecified Plastic, Pure	Emission	Solid Waste	kg	4733.547436	0	0	4733.547436
Naphthalene	Emission	Air	kg	0.003846396	0	0	0.003846396
Propylene Oxide	Emission	Air	kg	0.081382174	0	0	0.081382174
Dichloropropane	Emission	Air	kg	0.398035861	0	0	0.398035861
Epichlorhydrin	Emission	Air	kg	0.073511882	0	0	0.073511882
Nitrogen Oxides (NOx)	Emission	Water	kg	0.732925876	0	0	0.732925876
NMVOC, Jet Engines	Emission	Air	kg	0.027240576	0	0	0.027240576
Potassium Hydroxide (KOH)	Emission	Water	kg	6.566546979	0	0	6.566546979
Unspecified Anionic Detergent	Emission	Water	kg	5.059043192	0	0	5.059043192
Unspecified Nonionic Detergent	Emission	Water	kg	0.207231194	0	0	0.207231194
Cardboard	Emission	Solid Waste	kg	38.96817335	0	0	38.96817335
Unspecified Biomass	Emission	Solid Waste	kg	14.44135483	0	0	14.44135483

Silicate Ion (SiO3(2-))	Emission	Water	kg	33.55823388	0	0	33.55823388
Unspecified Oil	Emission	Air	kg	8.884476025	0	0	8.884476025
Sand (Silica) (SiO2)	Emission	Air	kg	51.34266507	0	0	51.34266507
TOC	Emission	Air	kg	140.5712226	0	0	140.5712226
NMVOC, Painting Processes	Emission	Air	kg	0.772170263	0	0	0.772170263
Unspecified Substance	Emission	Air	kg	0.037533066	0	0	0.037533066
Stainless Steel Cuttings	Emission	Solid Waste	kg	731.1430605	0	0	731.1430605
Iron Chips	Emission	Solid Waste	kg	700.0746585	0	0	700.0746585
Glass Containing Heavy Metals	Emission	Solid Waste	kg	6835.048441	0	0	6835.048441
Unspecified Dust (Harmless)	Emission	Solid Waste	kg	3.450595235	0	0	3.450595235
Unspecified Aldehydes	Emission	Air	kg	3.04670377	0	0	3.04670377
1,1,1-Trichloropropane	Emission	Air	kg	0.0049901	0	0	0.0049901
Boron (B)	Emission	Air	kg	19.51124614	0	0	19.51124614
Unspecified Furnace Slag	Emission	Solid Waste	kg	14143.45528	0	0	14143.45528
Unspecified Grease Lubricant	Emission	Water	kg	223.8582152	0	0	223.8582152
Unspecified Bulky Waste	Emission	Solid Waste	kg	199163.0692	0	0	199163.0692
Unspecified Slag and Ashes, Energy	Emission	Solid Waste	kg	45703.46551	0	0	45703.46551
Unspecified Biomass, Dry Matter, Fuel	Resource	Raw Material	kg	38903.68162	0	0	38903.68162
Unspecified Fuel	Resource	Raw Material	MJ	-401298.7216	0	0	-401298.7216
Wood	Resource	Raw Material	kg	0.67626266	0	0	0.67626266
Uranium (U238)	Resource	Raw Material	kg	42.73088239	0	0	42.73088239
Unspecified Metals	Emission	Water	kg	6.130952691	0	0	6.130952691
Sodium Ion (Na+)	Emission	Water	kg	580853.8894	0	0	580853.8894
NMVOC, Gasoline Engine without Catalysator	Emission	Air	kg	0.347420652	0	0	0.347420652
Particles TSP from Diesel Engine, Pre EURO	Emission	Air	kg	25336.44067	0	0	25336.44067
Unspecified Rubber	Emission	Solid Waste	kg	2563.852943	0	0	2563.852943
Unspecified Slag and Ashes, Incineration	Emission	Solid Waste	kg	564.7907933	0	0	564.7907933
Unspecified Chemical Waste	Emission	Solid Waste	kg	152.344885	0	0	152.344885
Unspecified Waste from Steelproduction (Internal)	Emission	Solid Waste	kg	11407.28773	0	0	11407.28773
Unspecified Oil	Emission	Solid Waste	kg	631673.9136	0	0	631673.9136
Unspecified Sludge	Emission	Solid Waste	kg	46.81818419	0	0	46.81818419
CFC 11 (Trichlorofluoromethane)	Emission	Air	kg	1276.712713	0	0	1276.712713
Lead (Pb)	Emission	Groundwater	kg	46.60143333	0	0	46.60143333
Lead (Pb)	Emission	Marine Water	kg	0	0	0	0
Lead (Pb)	Emission	Soil	kg	370.9768255	0	0	370.9768255
Lead (Pb)	Emission	Stored Water	kg	12943479.21	0	0	12943479.21
Lead (Pb)	Emission	Stored Soil	kg	12943479.21	0	0	12943479.21
Chromium (Cr)	Emission	Groundwater	kg	203.2813354	0	0	203.2813354
Chromium (Cr)	Emission	Marine Water	kg	0	0	0	0
Chromium (Cr)	Emission	Soil	kg	387.6898645	0	0	387.6898645
Chromium (Cr)	Emission	Stored Water	kg	535296.7613	0	0	535296.7613
Chromium (Cr)	Emission	Stored Soil	kg	535296.7613	0	0	535296.7613
HCFC 21 (Dichlorofluoromethane)	Emission	Air	kg	2257.765639	0	0	2257.765639
VOC, Controlled Landfilling of Houshold Waste	Emission	Air	kg	68001.7508	0	0	68001.7508
CFC 113 (Trichlorotrifluoroethane)	Emission	Air	kg	1276.712713	0	0	1276.712713
HCFC 22 (Chlorodifluoromethane)	Emission	Air	kg	4367.701385	0	0	4367.701385

Naphthalene	Emission	Water	kg	322.0298383	0	0	322.0298383
Naphthalene	Emission	Marine Water	kg	0	0	0	0
Calcium (Ca)	Emission	Groundwater	kg	4722072.148	0	0	4722072.148
Calcium (Ca)	Emission	Stored Water	kg	145601980	0	0	145601980
Calcium (Ca)	Emission	Stored Soil	kg	145601980	0	0	145601980
Vinylchloride	Emission	Air	kg	1599.250661	0	0	1599.250661
Selenium (Se)	Emission	Groundwater	kg	28.88979223	0	0	28.88979223
Selenium (Se)	Emission	Marine Water	kg	0	0	0	0
Selenium (Se)	Emission	Soil	kg	150.7331876	0	0	150.7331876
Chloroform	Emission	Air	kg	6383.563563	0	0	6383.563563
Sodium (Na)	Emission	Stored Water	kg	71232630.21	0	0	71232630.21
Sodium (Na)	Emission	Stored Soil	kg	71232630.21	0	0	71232630.21
Magnesium	Emission	Groundwater	kg	1416621.644	0	0	1416621.644
Chloride (Cl-)	Emission	Groundwater	kg	5370776.486	0	0	5370776.486
Chloride (Cl-)	Emission	Stored Water	kg	49801681.95	0	0	49801681.95
Chloride (Cl-)	Emission	Stored Soil	kg	49801681.95	0	0	49801681.95
Phenol	Emission	Marine Water	kg	0	0	0	0
Cadmium (Cd)	Emission	Groundwater	kg	31.21212279	0	0	31.21212279
Cadmium (Cd)	Emission	Marine Water	kg	0	0	0	0
Cadmium (Cd)	Emission	Soil	kg	172.4469784	0	0	172.4469784
Cadmium (Cd)	Emission	Stored Water	kg	8387.753077	0	0	8387.753077
Cadmium (Cd)	Emission	Stored Soil	kg	8387.753077	0	0	8387.753077
Tetrachloroethylene (Tetrachlorethene)	Emission	Air	kg	21771.31152	0	0	21771.31152
Ethylene dichloride	Emission	Groundwater	kg	74.46940011	0	0	74.46940011
1,2-Dichloroethane	Emission	Water	kg	164.3745574	0	0	164.3745574
1,2-Dichloroethane	Emission	Marine Water	kg	0	0	0	0
Ethyl Benzene	Emission	Air	kg	63835.63563	0	0	63835.63563
CFC 12 (Dichlorodifluoromethane)	Emission	Air	kg	11423.21901	0	0	11423.21901
Carbon Tetrachloride	Emission	Air	kg	38.30138138	0	0	38.30138138
Trichloro ethylene	Emission	Groundwater	kg	32.59003893	0	0	32.59003893
Trichloroethylene	Emission	Water	kg	55.71271025	0	0	55.71271025
Trichloroethylene	Emission	Marine Water	kg	0	0	0	0
1,4-Dichlorobenzene	Emission	Water	kg	54.38898183	0	0	54.38898183
1,4-Dichlorobenzene	Emission	Marine Water	kg	0	0	0	0
Tetrachloroethylene (Tetrachlorethene)	Emission	Groundwater	kg	47.22072148	0	0	47.22072148
Tetrachloroethylene (Tetrachlorethene)	Emission	Water	kg	83.37166727	0	0	83.37166727
Tetrachloroethylene (Tetrachlorethene)	Emission	Marine Water	kg	0	0	0	0
Trichloroethylene	Emission	Air	kg	12901.51794	0	0	12901.51794
1,2-Dichlorobenzene	Emission	Water	kg	16.67433345	0	0	16.67433345
1,2-Dichlorobenzene	Emission	Marine Water	kg	0	0	0	0
dichloromethane (methylene chloride)	Emission	Groundwater	kg	25.85528029	0	0	25.85528029
Dichloromethane (Methylene Chloride)	Emission	Water	kg	61.91333286	0	0	61.91333286
Ethyl Benzene	Emission	Groundwater	kg	94.44144297	0	0	94.44144297
Polychlorinated Biphenyls (PCB Unspecified)	Emission	Air	kg	0	0	0	0
Particles - PM (Combustion)	Emission	Air	kg	0	0	0	0
Vinyl Chloride	Emission	Groundwater	kg	191.2052165	0	0	191.2052165
Vinyl Chloride	Emission	Water	kg	346.7239533	0	0	346.7239533

Vinylchloride	Emission	Marine Water	kg	0	0	0	0
Benzene	Emission	Groundwater	kg	30.69346896	0	0	30.69346896
Benzene	Emission	Water	kg	1.806386124	0	0	1.806386124
Benzene	Emission	Marine Water	kg	0	0	0	0
Xylenes, Mixed	Emission	Air	kg	55436.20989	0	0	55436.20989
Propylbenzene	Emission	Air	kg	40317.24356	0	0	40317.24356
Chloroform	Emission	Groundwater	kg	1.416621644	0	0	1.416621644
Chloroform	Emission	Water	kg	0.083371667	0	0	0.083371667
Chloroform	Emission	Marine Water	kg	0	0	0	0
Nickel (Ni)	Emission	Groundwater	kg	203.2813354	0	0	203.2813354
Nickel (Ni)	Emission	Marine Water	kg	0	0	0	0
Nickel (Ni)	Emission	Soil	kg	258.4599097	0	0	258.4599097
Nickel (Ni)	Emission	Stored Water	kg	317332.7361	0	0	317332.7361
Nickel (Ni)	Emission	Stored Soil	kg	317332.7361	0	0	317332.7361
Phosphate (PO4(3-))	Emission	Groundwater	kg	66109.01008	0	0	66109.01008
Phosphate (PO4(3-))	Emission	Marine Water	kg	0	0	0	0
Chlorobenzene	Emission	Water	kg	25.01150018	0	0	25.01150018
Chlorobenzene	Emission	Marine Water	kg	0	0	0	0
Dichloromethane (Methylene Chloride)	Emission	Air	kg	40317.24356	0	0	40317.24356
Xylenes	Emission	Groundwater	kg	236.1036074	0	0	236.1036074
Xylenes, Mixed	Emission	Water	kg	555.8111152	0	0	555.8111152
Xylenes, Mixed	Emission	Marine Water	kg	0	0	0	0
Zinc (Zn)	Emission	Groundwater	kg	4480.54977	0	0	4480.54977
Zinc (Zn)	Emission	Marine Water	kg	0	0	0	0
Zinc (Zn)	Emission	Soil	kg	24044.17209	0	0	24044.17209
Zinc (Zn)	Emission	Stored Water	kg	1689261.768	0	0	1689261.768
Zinc (Zn)	Emission	Stored Soil	kg	1689261.768	0	0	1689261.768
Copper (Cu)	Emission	Groundwater	kg	366.3089411	0	0	366.3089411
Copper (Cu)	Emission	Marine Water	kg	0	0	0	0
Copper (Cu)	Emission	Soil	kg	1173.086579	0	0	1173.086579
Copper (Cu)	Emission	Stored Water	kg	1337898.852	0	0	1337898.852
Copper (Cu)	Emission	Stored Soil	kg	1337898.852	0	0	1337898.852
Ammonia	Emission	Groundwater	kg	1032662.991	0	0	1032662.991
Ammonia (NH3)	Emission	Marine Water	kg	0	0	0	0
Arsenic (As)	Emission	Groundwater	kg	95.8348413	0	0	95.8348413
Arsenic (As)	Emission	Marine Water	kg	0	0	0	0
Arsenic (As)	Emission	Soil	kg	407.5999785	0	0	407.5999785
Arsenic (As)	Emission	Stored Water	kg	78159.37064	0	0	78159.37064
Arsenic (As)	Emission	Stored Soil	kg	78159.37064	0	0	78159.37064

Toluene	Emission	Groundwater	kg	126.9540709	0	0	126.9540709
Toluene	Emission	Water	kg	234.7102091	0	0	234.7102091
Toluene	Emission	Marine Water	kg	0	0	0	0
	Emission	Groundwater	kg	3672378.733	0	0	3672378.733
Mercury (Hg)	Emission	Groundwater	kg	0.972282396	0	0	0.972282396
Mercury (Hg)	Emission	Marine Water	kg	0	0	0	0
Mercury (Hg)	Emission	Soil	kg	5.174462142	0	0	5.174462142
Mercury (Hg)	Emission	Stored Water	kg	1035.4932	0	0	1035.4932
Mercury (Hg)	Emission	Stored Soil	kg	1035.4932	0	0	1035.4932
Chlorobenzene	Emission	Air	kg	2553.425425	0	0	2553.425425
Carbon Dioxide (CO2 - Biological)	Emission	Air	kg	1970205539	0	0	1970205539
Carbon Sequestered	Emission	Air	kg	2125710628	0	0	2125710628

APPENDIX VI: *CEQ-MODEL* OUTPUT OF AUCKLAND EMISSION, 1996-2015

The quantification is based on the emission factor for CH_4 and CO_2 as computed in 6.3.2.1 and Section 6.3.2.2.

The emission factor for CH4 is 1.0767 Gg and the total waste disposed is 18,578,645.1.

Therefore the volume of CH_4 is:

$1.0767 \times 18578645.1 = 2000362.3$ Tonnes CO_2-e

Similarly;

The volume of CO_2 emission is:

$0.1316 \times 18578645.1 = 2444887.8$ Tonnes CO_2-e

Emission Resulting from Transportation

Landfill (1)	**Distance (km) (2)**	**Total Waste Volume (tonnes) (3)**	**Volume Per Run (tonnes) (4)**	**No of Runs (5)= [(3)/(4)]**	**Total Distance (6)= [2x(2)x(5)]**	**EF (7)**	**Emission (kg) (8)**
						CO_2 kg/unit	CO_2
						CH_4 (CO_2-e)	CH_4
						N2O (CO_2-e)	N_2O
Auckland	40	18578645.1	25	743,145.8	59,451,664.3	0.227	13,495,527.8
						0.00134	79665.2
						0.00152	90366.5
	Total emission (kg) CO_2-e						**13,665,559.5**

APPENDIX VII: QUESTIONNAIRE FOR ONTOLOGY EVALUATION

S/No	Question	Very Poor ⟷ Excellent									
		1	2	3	4	5	6	7	8	9	10
1	Does the ontology capture and represent correctly aspects of the real world?										
	Comment:										
2	Does the axioms comply with the expertise of one or more users within the domains?										
	Comment:										
3	Is the ontology anticipatory in its applications?										
	Comment:										
4	How will the ontology react to changes in the axioms?										
	Comment:										
5	Does the ontology comply with procedures for extensions, integration and adaption?										
	Comment:										
6	Is the ontology expandable to include more domain area?										
	Comment:										
7	Is the ontology looking flexible to adapt to different scenarios?										
	Comment:										
8	Does the ontology communicate effectively the intended application?										
	Comment:										
9	Is the domain of interest appropriately covered?										
	Comment:										
10	Does the ontology include all relevant concepts and their lexical representation?										
	Comment:										
11	How easy can the usual reasoning services (instance classification, querying, etc.) be applied to the ontology?										
	Comment:										
12	Does the ontology include irrelevant axioms with regards to the domain to be covered?										
	Comment:										
13	Does the ontology impose a minimal ontological commitment?										
	Comment:										
14	How weak are the assumptions regarding the ontology's underlying philosophical theory about the reality?										

	Comment:										
15	Are the formal and informal description of the ontology consistent, i.e. does the documentary description match the architecture?										
	Comment:										
16	Is the ontology easily deployable within real life scenarios?										
	Comment:										
General Comment:											