Wageningen University – Department of Environmental Sciences

Environmental Systems Analysis (ESA) Group

Waste to Energy Islands

Is converting waste to energy more feasible then traditional landfills for small islands, like Curacao?

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Abstract

This study assesses sustainable alternative waste management solutions for Curacao's growing landfill problems. The socio-economic barriers faced by small island developing states (SIDS) is also taken into consideration. These findings are based on research interviews, public questionnaires and supplemented with academic literature reviews. This study explains why most SIDS are delayed in implementing innovative solid waste management solutions equivalent to neighboring larger countries. An assessment of two waste management solutions namely: Anaerobic digestion (AD) and Windrow aerated composting is made. These waste management approaches were selected against conventional approaches based on their scalability and cost-saving potential. These characteristics are important feasibility indicators for financially limited SIDS. Waste projections using Curacao's predominant waste streams: municipal solid waste (MSW) and commercial waste (CW) as input were created to highlight a baseline scenario against a composting and AD intervention scenario over a period of up to two decades. The comparison aims to evaluate the applicability and environmental benefit of these sustainable waste management approaches to Curacao's waste composition. All scenario related input used to project Curacao's waste future were acquired through in field expert interviews and literature. MSW contained a high amount of garden waste (65%) making it ideal for composting while the high organic mix waste content of CW (97%) made it ideal for AD. The projection indicated a overall 40% reduction in total waste with joined technologies. These scenarios' also highlighted the benefits towards reducing anthropogenic methane abundant landfill gas. The results show biogas emissions up to 200.000m^3 in the year 2030 if AD intervention is not applied. Lastly, questionnaire and expert interviews were performed to understand citizen's willingness to participate, awareness and potential institutional barriers of local waste management practices. The results show that a high degree of willingness to be involved in recycling activities (>60%) exists. Moreover, more than 75% of respondents are aware of the waste problem. However, only 20% of the population actually engage in recycling. This highlights top-down institutional gap in communication and facilitation sustainable waste management tools. In conclusion, it is noteworthy that this study demonstrated scalability, environmental and social benefit of applying AD and composting to Curacao within the limited frame of SIDS.

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List of Acronyms

MSW: Municipal Solid Waste
CW: Commercial Waste
SIDS: Small Island Developing States
AD: Anaerobic Digestion
CEM: Circular Economy Method
OFMSW: Organic Fraction Municipal Solid Waste
SDG: Sustainable Development Goals
MDG: Millennium Development Goals
GDP: Gross Domestic Product§
WTE: Waste to Energy
BAT: Best Alternative Technologies
GHG: Green House Gases
AIMS: Atlantic, Indian Ocean, Mediterranean and South China
NGO: Non governmental Organization
NPK: Nitrogen Phosphorus, Potassium
C&D: Construction and Demolition
CO_2: Carbon Dioxide
IPCC: International Panel of Climate Change
NOx: Nitrogen Oxide
LCA: Life Cycle Analysis
WWTP: Waste Water Treatment Plant

1: Introduction

Classical unlined sanitary landfill practices are known to have adverse environmental effects on soil, water and air through leachate ad landfill gas. Moreover, these gasses contain a wide range of potentially dangerous chemicals threatening public health (Li Zhen-shan 2009). Well managed waste processing systems are therefore crucial to provide a healthy environment for the surrounding inhabitants. Even though many governments agree on this issue still over half of solid waste that is generated in developing countries, is being dumped indiscreetly in illegal dumping areas, streets and drains (Mosler, et al. 2005). UN leaders and member states that seek to aid in development policy for developing countries created the Millennium Development Goals (MDGs). These goals can be summarized as improving human conditions by reducing poverty and improving education, gender equality, health and a better environment. Recently the 17 Sustainable Development Goals (SDG) of the 2030 agenda for sustainable development were approved and adopted by 150 national leaders. These 17 SDGs build on the success of MDGs, Agenda 21 and other international treaties to end to all forms of poverty. These goals compromise of strategies for economic development and environmental protection. In relation to better waste management these goals focus on:

- Efficient use of all natural resources
- Significant reductions in waste generation through prevention, reduction, recycling and reuse strategies.
- Promotion of sustainable public procurement practices that are in accordance with national policies.
- Encouragement of companies to adopt sustainable practices
- Increased public awareness as to sustainable development in their daily lifestyles
- Increasing capacity in developing countries and small island developing states (SIDS) to include climate change in national planning and management procedures.

Some (Reddy and Heuty 2008) question the validity and accuracy of the MDGs. They state that the MDG's are to broad and not well defined. However, such agreements do in fact trickle down to national policies being developed through voluntary commitment. For example the European countries transition from 100% incineration to include energy production and recycling in their waste management supply chain.

Currently in Europe, sanitary landfilling is still the predominant means of disposing of solid waste, with about 40% share in waste management options (Saner, et al. 2011). The number of centralized waste incinerators however are gradually being normalized as the means European countries treat their otherwise landfilled waste. With close to 500 plants either in operation or being planned (Saner, et al. 2011), this "sustainable transition" is aiming at reducing waste as described according to the SDG while making efficient use of recourses. International agreements like the MDG could therefore be the cause of innovative policy frameworks like the ladder van Lansink being developed as a means to shape future Dutch/EU waste policies. Lansinks ladder (which is still the EU waste policy framework) is based on a "waste management hierarchy". This model has a starting point of waste avoidance as highest degree of waste management which is subsequently reduced to minimizing, recycling, treating and disposal of waste (Price and Joseph 2000). The Netherlands at the time was incinerating its waste before dumping it in landfills. Although effective in reducing the surface area of waste, it still did not account for valuable resources which would later be deemed important to Lansinks ladder. It was introduced in the waste substance act of 1977 aimed at reducing particular waste streams from reaching landfills. Geographical pressure such as the lack of landfilling space initiated this innovative policy framework that has been adopted from national down to civil society. Collaborative efforts from environmental NGO's, private businesses and civil society promoted and pushed re-use(recycling) activities to where it is today which was and can be construed as an initial step towards Dutch waste legislation contributing to circular economy.

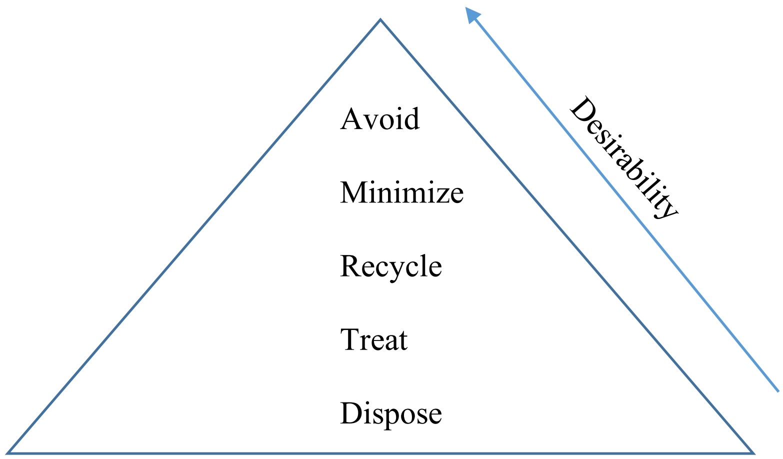

Figure 1.1 Ladder van Lansink

The Circular Economy, which is unlike the traditional linear economy, includes environmental factors in propelling economic development forward (Meyer 2011). This proactive economic model has positively attributed to European policy decisions as it promotes recyclability and the reduction of raw materials throughout the supply chain. The ladder van Lansink partially contributes to circular economy by applying these concepts towards effective integrated solid waste management. Circular economy however goes beyond the reduction of resource use and also looks at the value of otherwise disposable materials. An example of this is by introducing the cradle to cradle approach. Using this framework companies strive to turn waste into resources and food while maximizing economic and ecological benefits (Niero, et al. 2016). By applying the Circular Economy Method (CEM) towards waste management it would mean that otherwise landfilled waste fractions are reused as resources or food for another system. Waste to energy technologies (WTE) encompasses this methodology as a feasible means within the CEM to deal with two of the previously mentioned human impacts namely: landfilling and environmental issues. All this while contributing to the energy sector, improving waste management practices and reducing GHG in the form of landfill gas. In other words, the WTE principle is able to continue a prosperous economy while contributing to a healthy environment (Tukker 2015)

It is estimated according to (Meyer 2011), that by introducing circular economy throughout the value chain in Europe could have a material reduction potential between 17%- 24% by the end of 2030. These saved resources are equated to European industry saving 630 billion Euro per year.

Small Island Developing States

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SIDS according to (Mohee, et al. 2015) are groupings of small developing island economies who share very specific socio-economic and environmental barriers when compared to the surrounding neighboring developed countries. To date there are 52 internationally recognized SIDS grouped together in three regions based on their geographical location, these include Caribbean, Pacific and AIMS (Atlantic, Indian Ocean, Mediterranean and South China) SIDS See *Table 1.1*

All SIDS share several socioeconomic and environmental constrains that hinder them from pursuing sustainable development. A narrow economic base leaves most SIDS to have a high dependence on larger countries in the form of receiving financial aid/ investments but more importantly sea and air transportation. The economies of scale are often obstructed from growing their local economies due to the geographical isolation of these islands and low population/consumers (Mohee, et al. 2015). Local trade market are thus to small to be profitable forcing most SIDS to a near total reliance on larger neighboring countries for the import of consumer goods and resources often leading to higher costs of living (Briguglio 1995). SIDS are also highly susceptible to coastal and land erosions because of their increased susceptibility to natural disasters e.g. tropical cyclones (hurricanes), associated storm surges, tsunamis, droughts and volcanic eruptions, (Wong 2010). Relatively small watersheds and vulnerable water supplies are common in especially low-lying atoll states leaving these islands at risk of fresh water contamination due to their sensitivity to sea-level change. This reduction of freshwater availability combined with limited physical space endemic to SIDS also threaten local biodiversity. Sensitive political relationships when it comes t historical land rights are also among the issues faced by SIDS. The latter relates more to AIMS SIDS then pacific and Caribbean SIDS.

Table 1 List of 52 SIDS UN, 2014b, UNDESA, 2014, UNESCO, 2014 and UN-OHRLLS, 2009)

Caribbean	Anguilla, Antigua and Barbuda, Aruba, The Bahamas, Barbados, Belize, British Virgin Islands, Cuba, Dominica, Dominican Republic, Grenada, Guyana, Haiti, Jamaica, Montserrat, Netherlands Antilles, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, US Virgin Islands
Pacific	American Samoa, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Federated States of Micronesia, Nauru, New Caledonia, Niue, Northern Mariana Islands (Commonwealth of the Northern Marianas), Palau, Papua New Guinea, Samoa, Solomon Islands, Timor-Leste, Tonga, Tuvalu, Vanuatu
AIMS (Atlantic, Indian Ocean, Mediterranean and South China)	Bahrain, Cape Verde (Cabo Verde), Comoros, Guinea-Bissau, Maldives, Mauritius, São Tomé and Principe, Seychelles, Singapore

When Agenda 21 was adopted in 1992 by the world community small island states known subsequently as small island developing states (SIDS) stressed their concerns towards the limitations encompassing SIDS. This led to the 1994 Barbados Program of Action in which 14 problem areas faced by SIDS where identified. This action program has since been peer reviewed in 2005 at Mauritius and out of it came the Mauritius Strategy of implementation, (Wong 2010). Amongst these 14 priority issues ranging from climate change to human resource development there was one which will be the focus of this research namely; Management of Waste.

Chapter - III section 21 of the Barbados Program of action states that the shortage of land area, resources for safe disposal, growing populations and increasing imports of polluting substances without adequate means of disposal makes pollution prevention and waste management a critical issue for SIDS. The limited capacity of monitoring waste streams also leaves the problem to be poorly understood and therefore is considered to be a serious constraint to achieving sustainable development amongst SIDS. Most SIDS often choose short term options e.g. landfilling (as long term options are limited due to socio-economical constrains) as a means of disposing their municipal waste streams which is in direct conflict with sustainable development which advocates long term solutions. Ch. III section 24 therefore recommends that SIDS review options that limit and /or convert waste streams into resources (e.g. fertilizer for agriculture) through a combination of limiting imports of hazardous non-biodegradable products and public awareness leading to change in waste disposal attitudes among local citizens. This proposition is further concretized in (The International Conference For Small Island Developing States 2014)
Ch. A. National Action, policies and measures section (iv) and (v) by emphasizing:

- Public awareness and educational campaigns aimed at the local recognition to point source control of waste and to the added value of reuse, recycling and additional possibilities of integrating the concept of cradle-to cradle converting wastes to valuable resources; and -
- Introduction of sustainable and/or technological systems to treat waste at its source and for solid waste treatment once it leaves the source.

Sustainable cost-effective waste management strategies in SIDS are therefore critical as the socio-economic and geographical constraints hamper the transition to acquire modern technological/institutionalized solutions already implemented in bigger countries.

Research Aim

This study aims to identify and evaluate which organic waste management alternatives best suit Curacao as a replacement for the current landfill by evaluating the degree environmental benefit, social acceptability, scalability and cost-effectiveness.

Research Questions

This paper relies on consistent literature and stakeholder insights to asses the potential benefits organic composting is able to bring to SIDS. Some of the research questions needed to be answered are:

RQ1: Which OWM option(s) bests suit Curacao and surrounding SIDS given their economic and social limitations?
RQ2: To what degree can these OWM alternatives provide environmental benefit in terms of waste reduction and anthropogenic pollution?
RQ3: What obstacles are currently impeding the integration of OWM technologies in Curacao?

The following sub questions were derived from the main research questions in order to better guide the analysis;

RQ1: Which cost effective sustainable OWM methods are currently successfully operated on a small (island) scale?
RQ2: How much waste is being produced by the commercial sector?
RQ2: How much waste is generated by households or municipal solid waste?
RQ3: How does the municipality see the waste situation 15 years from now?
RQ2: What is the current and projected GDP of Curacao?
RQ2: How much reduction in residential waste can be achieved 15 years from now factoring in population growth?
RQ2: How much organic matter can be created from Curacao's organic fraction of waste?
What are the benefits of integrating composting and/or anaerobic digestion to Curacao's solid waste management plan?
RQ2: How does the waste composition for Curacao look like?
RQ3: Which stakeholders and/or coalition should be involved for the realization of waste management related endeavors?
RQ3: Are citizens aware and willing to participate should there any form of institutional change?
RQ3: How can the institutional/financial/technical obstacles inhibiting Curacao from realizing this project be overcome?

Outline of the Thesis

An introduction into why it is important for SIDS to integrate WTE technologies is given in section 1 with Curacao as case example. A theoretical background of the two chosen WTE technologies is given in section 2 along with the reasoning to why they were chosen and benefit they could potentially provide. Section 3 elaborates on the chosen methodology for the scenario building. The results are presented in section 4 were input data is used to project different scenarios. This section is followed by a discussion (section 5) were the results are discussed and elaborated on what this could mean for Curacao. Last but not least, are the conclusions and proposals for further studies in section 6.

2 Theoretical Background

Case Study Curacao

Curacao (belonging to the Caribbean SIDS) is the biggest Island of the former Netherlands Antilles alongside Aruba and Bonaire. Landfilling is Curacao's preferred means of waste disposal. This is due to landfilling's ability to accommodate all waste types and compositions coupled with its simple and cost-effective implementation (Seng, et al. 2013). This practice however is neither environmentally acceptable nor sanitary as it is done with little to irregular soil coverage facilitating leachate and landfill gas to pollute the surrounding area. This combined with waste scavengers making a living while spreading disease also imposes public health concerns. (Li Zhen-shan 2009) (Manaf, Samah and Zukki 2009). Malpais" (name of the landfill) is where all products on the island end their lifecycle with little to no separation. On the facility itself there are drop-off points for different hazardous waste types (batteries, asbestos) and brown goods (electronics) along with an area encompassing containers to deposit a range of different waste types (e.g. green waste, tires, plastics, metals). The choice in separating waste however is on a voluntary basis. This lack of regulatory presence therefore leads to little public regard for waste separation which is why even today a big portion of MSW and CW makes it to Malpais. Malpais can be considered a "first generation landfill" meaning that it is not operated as a sanitary landfill when compared to more modern landfill management protocols where e.g. capping, layering are implemented (Yidong, et al. 2012). This disregard has the potential of imposing a great deal of environmental damage to the surrounding nature preserve area as well as the local population (Li Zhen-shan 2009)There also seems to be a underground freshwater stream that crosses through the landfill witch is also subject to contamination due to leaching of pollutants and nutrients according to on of our interviewed experts (Mohika 2016). This further threatens Curacao's already limited groundwater availability by adversely effecting its quality which can in term negatively impact agricultural development by forcing farmers to purchase water from the local water board. Curacao's water board acquires its water through reverse osmosis which is the most expensive means of acquiring fresh water. with an average of 7 guilders per m3 compared to 0.90 euros per m^3 for groundwater in the Netherlands. Although the spatial limitations of the landfill have not yet been reached, there is still a great deal to be concerned about. With a life span of about 15 years, Curacao is in a position where alternative waste management practices have to be implemented soon to cope with future waste generation.

SELIKOR B.V. is the local public/private entity responsible for the collection, transportation and disposal of Curacao's Municipal solid waste (MSW). Through interviewing a local expert at Selikor it became evident that in the last 20 years no real policy changes have occurred leaving malpais often to take own initiative in keeping up with global waste management practices. Further more it was also stated that Curacao is one of the few if not the only island in the Caribbean that has not increased its waste collection bill in the last 20 years. The lack of governmental initiative in promoting effective policy and in raising the monthly bill leaves Selikor in the position of only being able to break even most of the time. This leaves little resources/capital available to pursue innovative waste management practices. Currently Selikor owns and operates the local glass recycling company which was previously sourced to 7 private shareholders. Consistent glass recycling is regularly executed and not only when there is added market value as was the previous with previous owners. Options for further recycling other fractions of waste are currently being considered yet no real plans are concrete. Regardless of the situation Selikor believes in recycling all waste fractions. They commit to this by aligning with different NGO's including Greenforce, fundashon korsou bunita and GreenKidz to stimulate bottom –up initiatives like plastic and aluminum recycling. Unfortunately, there seems to be a gap either in bottom or top down level of governance as there is little awareness amongst citizens of Curacao towards waste, this is further elaborated in section 3.

. Key issues and challenges for Malpais can be summarized to include:

- The growing geographical limitations of available space
- Unsustainable landfill management leading to ecosystem & public health damage

For Curacao to comply with Agenda 21 and the CEM criteria on solid waste must focus on bio-waste recycling and reuse in both their municipal and commercial waste streams. In the case of Curacao, like many other Caribbean SIDS it has a relatively high degree of organic biodegradable waste ranging between 46-67% (Mohee, et al. 2015). A range of solutions including Aerobic/Anaerobic digestion, gasification, combustion fit the criteria of WTE technological applications. However, considering Curacao's socio-economical limitations as mentioned by SELIKOR, a low Tech, sustainable, cost-effective option is needed in order to reduce the landfill size.

Organic composting and anaerobic digestion (AD) will be studied to explore their potential for reducing MSW and CW. Their selection is based on their cost-effectiveness, scalability and success in other Caribbean SIDS (Edghill 2012) (Meyer-Kohlstock, et al. 2013). The reuse of organic waste fraction through composting or AD on Curacao unlike the rest of the world is a new concept. Composting and AD, unlike gasification and combustion is energy efficient and thus more cost-effective solution for SIDS. The unique waste composition of Caribbean SIDS also makes these two WTE interesting for Curacao. Composting is an outdoor aerated means of degrading organic waste. According to (*2E Afvalstof Plan Achtergrond Informatie* 11-35) between 50% - 80% of MSW is compromised of yard/grass waste. Current state of affairs however allows citizens to burn this fraction in their backyard. This was not the case prior to Curacao's independence within the kingdom. There where laws and regulation prohibiting dumping or burning of waste on private property. However unfortunately when new Country of Curacao came into existence law/regulation where not transferred to the new country. As a result, it was no longer illegal to dump or burn waste on private property, no permit is required and the police and/or the environmental department can no longer fine or stop the parties conducting these activities. This has led to an increase in environmentally irresponsible waste management. The remainder of waste fractions of which a majority is kitchen waste can be processed through anaerobic fermentations. There is great hidden potential in reusing the Curacao's organic waste fraction with successful composting/AD strategies already proven feasible in other neighboring SIDS including Granada, Sint Vincent and the Grenada (Mohee, et al. 2015).

Curacao like many Caribbean SIDS is heavily reliant on tourism as a main source of income. On average there are more tourists then inhabitants on a yearly basis. This explains the relative high fraction of commercial waste compared to MSW (Annex 3.3). Tourism and population & GDP are also expected to grow according to (Central Bureau of Statistics Curacao 1980) and according to (Seng, et al. 2013) there is a relation between GDP and increased waste production. Curacao is no exception to this phenomenon (Annex 3.1 and 3.2). The amount of biodegradable waste on the island is a parameter to highlight the scale of integrating aerobic and anaerobic digestion to Curacao's waste management plan. This could range from larger centralized institutions to more small scale community propositions. Regardless which method or scale is chosen.

Composting

Aerobic composting is a attractive option for SIDS due to its low operational and technological cost and relatively easy operational procedure (Pendley 2005). There has also been extensive research performed on composting the Organic Fraction of Municipal Solid Waste (OFMSW) with great success (Haug 1993) (Ruggieri, et al. 2008) (Slater 2001).

Organic composting is thermophilic process (best in warm environments) requiring oxygen and optimal moisture conditions to stabilize the OFMSW and promote microorganism development (Haug 1993). Control variables required for optimal organic compost are temperature, moisture, PH, nutrient availability and oxygen. The composting stages highlighted in figure are the same regardless of the different type of composting systems applied. In the early stage (1 and 2) of microbial decomposition there will be high microbial activity and if the conditions listed above are met, heat will be generated. This heat byproduct will rapidly elevate the organic waste temperature in to the thermophilic rage (between 45 and 60˚C) where initial mesophilic microbes begin to die of and thermophilic microbes begin to thrive (Fig1.4) . This steady temperature buffer is maintained for several weeks depending on the system volume capacity, and in which thermophilic microbes will continue to digest carbon and other nutrients as energy source releasing heat as byproduct (Carrol, Caunt and Cunliffe 1993). After the elapsed time, the heat will gradually reduce as there will be less nutrients for thermophilic microbes to digest. Once the temperature is reduced to around 45˚C mesophilic microbes once again become active (figure 1.8) and continuo digestion at a lower temperature. During what is called the maturation or curing stage (3 and 4 figure 1.3) (Kaiser 1996) all ingredients except for woody-substances have been transformed into simple uniform compost with a temperature similar to the surrounding environment. It is indicative that once this occurs can the compost be safely used (Barrena, Canovas and Sanchez 2006). Compost is created when the microbial activity and oxygen demand reaches zero. This can be tested by taking a sample in a container. When there is no visible condensation or swelling of the container is observed it can be concluded that there is no microbial activity due to complete digestion of input nutrients. The C: N ratio (35:1) and dry weight will have also been reduced to half their input value (15:1).

To achieve optimal rates of organic decomposition certain input criteria and material have to be established before hand in order to achieve the desired product. These conditions and materials include:

- 25:1 initial carbon to nitrogen ratio (C:N);

- 40 to 60% water weight (a few drops should be able to be squeezed out from a handful of organic input);
- Minerals (sodium, phosphorus, potassium etc.) must be present;
- Adequate porosity throughout the pile in order to provide oxygen to aerobic micro-organisms responsible for the core process;
- Small particle size are preferable to reduce digestion time of organic matter;
- Temperature should be maintained under 80˚C for thermophilic bacteria;
- PH range should stay between 6-8 for survival of microorganisms;-and
- Large enough initial volume to prevent excessive heat loss through natural insulation

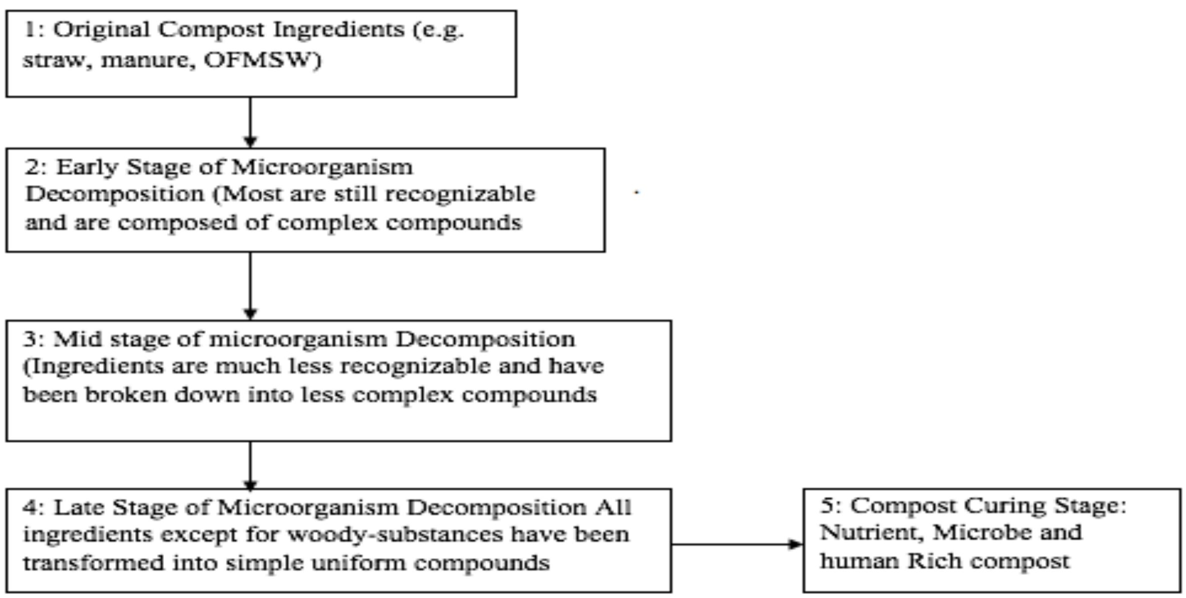


Figure1.2 Organic Composting under Ideal Conditions. (Haug 1993)

There are three commonly known processes used for upscaling from backyard composting to industrial scale (Pendley 2005).These include aeration of static piles, windrow and in vessel forced aeration composting. Each of these exhibit their own advantage and disadvantage listed in table 1.2

Criteria	Aerated Static Pile	Windrow	In-vessel forced aeration
Investment Cost	Low in Smaller systems with increasing price for larger systems	Low	High
Cost of Operation	Medium	Low	High
Land Requirement	Medium	High	Low if no windrow drying and or curing is needed as pretreatment.
Air control measures	Build-in	Limited unless combined with passive aeration	Build-in
Operational Control	Airflow rate	Compost turning frequency	Airflow rate, automatic stirrer, amendment addition
Cold/Wet sensitivity	Efficient in cold/wet climates	Sensitive unless covered (in-house)	Efficient in cold/wet climates
Odor Control	Can pose odor issues in larger facilities but it can be controlled through suction air systems	Depends on feedstock	Good
Potential Operating Problems	Continuous channeling of air supply is crucial for this system to work and its here where disruption of air flow through e.g equipment malfunction may impose operating problems.	Sensitive to wet weather that can hinder waste metabolism to compost.	Can pose to be mechanically complex with the potential of short circuiting and or air flow restriction due to clogged piping. Thoroughly trained personal are required to manage this type of composting
Labor intensity	Medium	High	Low

Table1. 2 Comparison of three main large scale composting options (Rynk, et al. 1992)

Windrow composted in my opinion best suited Curacao's economical constrains as it has a relatively low investment and operational costs. Windrow compositing can be divided into either passively or manual aerated composting. Both passive and manual windrow composting method are fairly similar and In terms of capital cost and operational management. Labor intensity is highest in manual windrow composting due to certain activities (e.g. temperature measurements & turning) occurring daily. In addition; windrows also require transportation, stacking and turning of organic material with the use of front-end or back end loader. Windrows are also more commonly used in farming operations where odor coming from farm material are minimum like the large yard waste fraction of Curacao MSW. Windrows do not require electricity making them ideal for remote areas away from public. The major disadvantage to applying windrow composting on Curacao however is that this method is at the mercy of the weather. During the raining season, mud and rain are more likely to hinder microbial processes in the pile either dispersing the pile or rendering the compost unusable due to its acquired high moisture content leading to incomplete digestion of organic material.

Anaerobic Digestion

Anaerobic digestion (AD) is a biological conversion of organic material through microbial digestion in the absence of oxygen. This process produces biogas and a nutrient rich digestate. This process also known as bio-methanogenisis is naturally occurring in nature by wetlands, intestines of animals, manures and aquatic sediments as part of the earths carbon cycle. Humans have developed a way to harness bio-methanogenisis in a controlled environment as a means to effectively reduce otherwise discarded organic matter. In a general AD scheme, the feedstock is gathered, coarsely shredded and loaded into a reactor with active methanogenic organisms responsible for its digestion. Generally, four main reactions occur during this digestion namely: hydrolysis, acidification, acetogenisis and methanogenisis. Although these reactions are classified in levels (figure 1.6) all reactions actually occur simultaneously and are interdependent on each other. Hydrolysis: is the first stage of digestion where complex organic input like carbohydrates, proteins and fats are hydrolyzed to more simple monomeric components like monosaccharides, amino acids and long chain fatty acids. Acidification is the the follow up digestion level where these monomeric components are further digested by acidifying bacteria to alcohols and volatile fatty acids. This process also releases a small amount of CO_2 and H_2. Acetogenesis: is where acetogenic bacteria take the volatile fatty acids and transform them into acetic and formic acids which in term also releases CO_s and H_2 as byproduct. Lastly methanogenisis: is the final stage where the acetic acids, hydrogen and CO_2 are digested by methanogenic bacteria releasing methane (CH_4) and CO_2 under strictly anaerobic conditions. This mixture of gases otherwise known as biogas is then collected in a separate tank.

Mechanical AD aims to significantly lower the carbon footprint of humans by collecting and reusing this biogas. A large fraction of biogas contains methane (CH_4) which is considered to be a significant greenhouse gas. With 23 times the global warming potential of CO_2 additional methane in the atmosphere can therefore cause long term detrimental impacts on the earths ecosystems. By collecting and reusing this otherwise fugitive significant greenhouse gas a area is able to greatly reduce its carbon footprint. Furthermore, biogas produced through this process can also be reused as for multiple reasons such as energy production and fuel. In Sweden landfill tax and bans on yard and organic waste introduced led to more sustainable waste management strategies being implemented (Swedish environmental protection agency). Command and control policy effectively redirected different organic raw waste streams including carcasses, manure, MSW to a anaerobic co-digestion unit inside a biogas plant. The biogas generated was used as local transportation fuel and effectively reduced NO_x and CO_2 bus emissions with 20 tons per year (Pan, et al. 2015). AD also produces a nutrient rich digestate high in NPK which has beneficial utilizations as nutrient rich organic fertilizer (Karagiannidis 2012).

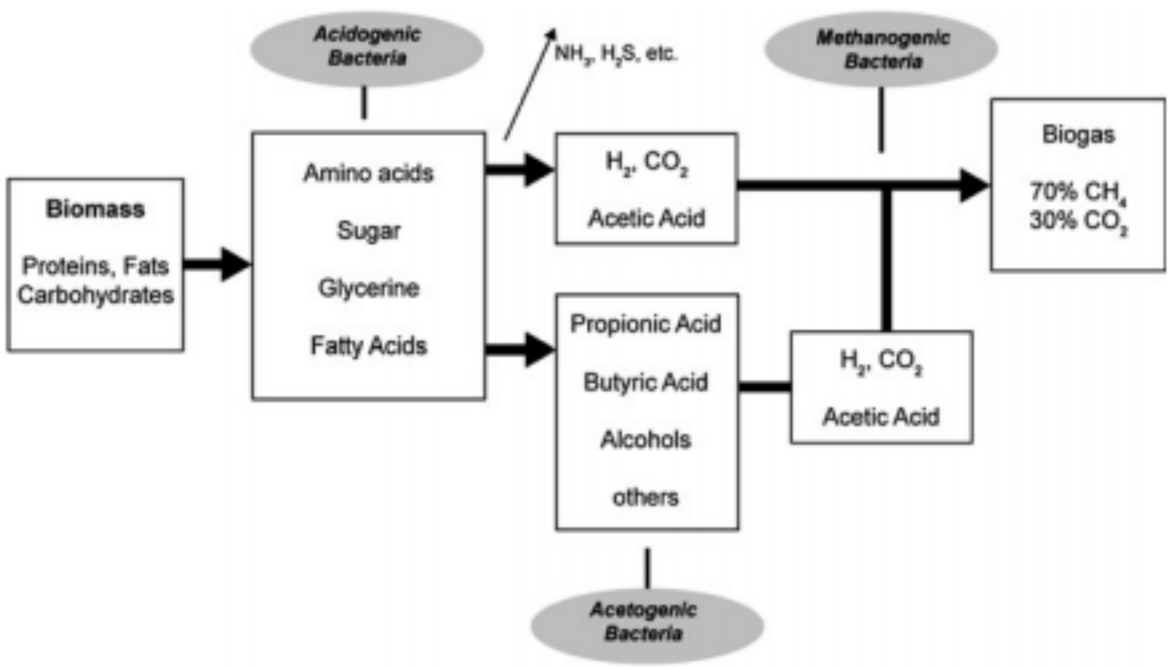


Figure1.3 Reaction chain of anaerobic digestion (Karagiannidis 2012)

AD system similar to compost systems can be subdivided into 3 categories:

- Single Stage reactors that make use of 1 reactor for both the acetogenisis and methanogenic phase.

- Multi Stage reactors are intended to improve digestion by providing a reactor for the different stages of digestion. Typically, there are 2 reactors used were the first is meant for hydrolysis-acetogenisis and the second for methanogenisis. These reactors however require high investment capital and complex to be operate. Furthermore, the reaction rate is limited by the rate of cellulose hydrolysis which is a substantial amount of Curacao’s MSW composition.

- Batch reactors that are periodically loaded with organic feedstock that will be subjected to digestion. Once digestion is completed a new batch is added. There are 3 types of batch systems; single stage, sequential and hybrid batch (USAB)

Potential beneficial impacts of AD and windrow composting for Curacao.

Agricultural Development

Ch.3 Section 22 of the Barbados Program of action also stresses the pressure on forestry areas to provide fuel wood and/or area to expand agricultural development. These agricultural areas are then subjected to heavy use of agro-chemicals that will leach to the soil and can lead to downstream aquatic and or groundwater pollution. Compost or nutrient rich AD residue could therefore in term reduce not only the public health afflictions and environmental damage caused by the OFMSW but also potentially reduce the amount of synthetic fertilizers used as more organic substitutes become more abundant. This could lead to a potential cascading effect culminating in reduced oversees import of fresh produce as local productions economical feasibility becomes more favorable. Composting in Curacao is practically none existent on a large and or commercial scale. According to, (Mohee, et al. 2015) Caribbean SIDS (of which Curacao is included) have 61% of their waste as paper and organic matter (Figure 1.4.) A great deal of this otherwise discarded waste fraction can be reused as cost-effective local fertilizers wile producing its own fuel in order to be distributed throughout Curacao.

Landfill Cover

Compost can be applied directly to landfills as cover material as part of more sanitary landfill management practices (Scheutz, Pedicone, et al. 2011)Covering the landfill layers with compost and dirt regularly will reduce the amount of vectors (e.g. rats, mosquitos, rain etc.) being exposed to waste. This could be a step forward towards effectively managing the disease carrying mosquito epidemic that plagues the island in the raining season. Ground water leaching of nutrients can also be minimized as runoff is much more easily absorbed by the organic material. Curacao is already dealing with a scarcity of groundwater, and with a water vein running under the landfill it seems imperative that this benefit be considered in decision making regarding Curacao's future waste management plans.

Landfill space avoided

As described in 4.2 there is a high degree of organic digestion possible for Curacao MSW & CW waste. With a mass net reduction around 35-40%. Therefore, even if the option was chosen to simply landfill the compost or in combination with AD, t a reduction in landfill size otherwise required could count towards a indirect economic benefit. This benefit is measurable as increased landfill space to continue operations for a longer period of time.

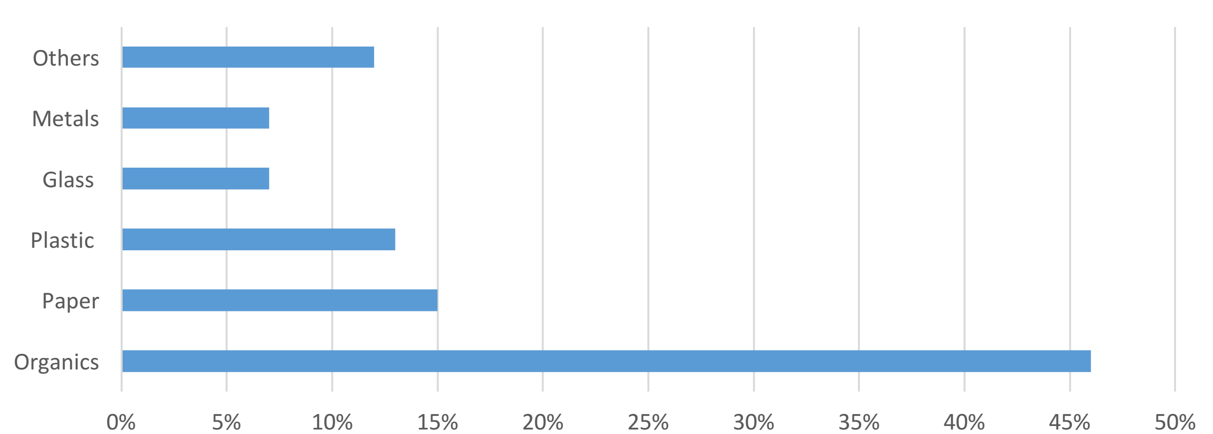
Reduction in Landfill gas emissions

Methane is generated by landfills witch in term leads to global warming (Scheutz, Pedicone, et al. 2011)
These emissions could be mitigated through the reliance on microbial oxidation of methane coming from landfill piles. (Scheutz, Pedersen, et al. 2014) describes a innovative cost effective method of applying a compost bio cover system to treat unlined old landfills as part of their closure. Both the cost-effectiveness and landfill conditions are applicable to Curacao's landfill. Even though climate change impacts are minimum compared to the rest of the world it is still a component of the Mauritius Strategy of implementation and is therefore a valid option for future local waste policies on the island.

Effluent Wastewater

(Cordilia 2016) highlighted a unique opportunity for AD in combination with the local waste situation and the waste water treatment plant (WWTP) of Curacao (DOW).There are studies, (Mustafa, et al. 2014) (Razaviarani, et al. 2013) highlighting the feasibility of effective WWTP effluent and MSW through AD. Curacao is currently dumping the solid organic sludge fraction on the landfill and discharges the fluid effluent in the ocean (Cordilia 2016) . This is highly polluting for marine ecosystems as it contributes to coastal eutrophication due to the high amounts of organic minerals in this discharge water. (Mustafa, et al. 2014) highlights a substantial reduction of nutrient rich solid and and wet fraction of WWTP effluent while generating biogas. The potential is therefore present in integrating the local WWTP operation and Selikor towards optimally reducing waste streams while generating energy in the form of biogas that according to (Pan, et al. 2015) could be redirected towards the transport or energy sectors.

Figure 1.4 MSW Composition in Carribbean SIDS (Mohee, et al. 2015)



3 Methodology

Study Area

Research will be conducted on the island of Curacao one of the Caribbean SIDS. Curacao has a total are of 472 square kilometers making it the biggest island of the former Netherlands Antilles. The growing total population of 158.986 people (Central Bureau of Statistics Curacao 1980)increases in tourism makes Curacao a unique case to study as these factor compromise for the main sources of waste being generated.

Data Collection

The data needed to make waste projections will include: population, gross domestic product (GDP) and quantities of MSW & CW. Population and GDP information are acquired through the central bureau of statistics Curacao (CBS) which falls un the ministry of Economic development. This data will be used as a key input parameter to project increases in waste productions. These increases in waste linear to population growth must be corrected for GDP in order to achieve accurate results. (Annex 3.3) highlights a positive waste accumulation to increased GDP on Curacao. MSW & CW are therefore strongly correlated with economic development and not so much with population growth described in (Annex 3.1). GDP therefore cannot be dismissed and will form a key parameter in this analysis alongside population, MSW & CW.

The data on waste generation is collected through SELIKOR and the ministry of environment. The interviews where of a semi structured type:

- The themes and relating questions varied from expert to expert to to make better use of the area of expertise; and-
- Data was recorded by note-taking

Questionnaires provided to local residents in an attempt to gain insight on the local mentality in relation to waste to better formulate an action plan on dealing with the current waste situation. Questions where developed based on (Jeffrey and Seaton 2010) stake holder receptivity principle to asses: awareness, opportunity and motivation towards waste.

Waste Management Scenario’s

Future waste generation will be forecasted depicting the integration of AD and organic composting to Curacao’s two major (CW & MSW) waste supply chains. Hereby illustrating the time and spatial scale of the problem and highlight to what extend it can be reduced through the application of WTE technologies.

There currently are several methods for forecasting future waste generation. (Beigl, Lebersorger and Salhofer 2008) elaborates on this through a review of mostly linear regression models, which concluded that MSW generated are mainly driven by social and economic parameters.

Forecasting future solid waste generations is an important step in creating plans for appropriate MSW strategies. Forecasting inputs therefore serve as the basis on which waste management infrastructures and potential sustainable optimization areas are implemented and identified (Beigl, Lebersorger and Salhofer 2008)

Wherever data is inconsistent and or missing; historical data combined with publications relating to similar geo-political aspects Curacao will be used. The two largest waste fractions containing organic waste (MSW & CM) are used alongside GDP and population/tourist data to create the following 2 scenarios.

- Scenario (S1); where all generated waste in the proposed time frame of 15 years is landfilled
- Scenario (S2); were both municipal and commercial waste is passed through both composting and AD treatment.

The aim of the scenario's is to determine the potential reduction amount of organic waste from these two major waste streams given their unique composition.

Scenario Assumptions & Input Parameters

Curacao possesses a broad range of was classification as described in (Annex 3.3). Next to the generation of waste does the composition play an important role for the development of adequate waste management strategies for the removal of the biological fraction. Through interviews at SELIKOR where the 2 predominantly high waste streams been categorized as following:

- Municipal waste (Household waste) consisting of mostly Bio-waste (vegetables, fruits, garden waste) followed by garden waste, paper/cardboard, plastic, glass, wood, metals, textiles

- Commercial waste: Similar to municipal waste Bio-waste (vegetables, fruits), paper/cardboard, plastic, glass, wood, metals, textiles from small to large industry, commerce, public and private sectors.

Waste Quantity

The inability to access essential equipment at final disposal sites for direct measurements of disposed waste quantities makes current determination of disposed waste impossible. Historical data provided by the (*2E Afvalstof Plan Achtergrond Informatie* 11-35) was used to estimate generation quantities of MSW per person (kg/resident/year). Population growth projection supplied by (Worldometers 1999) then made it possible to project future waste generation increases under the assumption of steady and continuous population growth. It is assumed in this study that household waste is the only source of MSW leaving CW to account for the other sources of waste (restaurants, hotels, businesses etc.). According to (Amarica 2016) there is a relation between GDP and household waste in Curacao (Annex 3.1). GDP was therefore also forecasted to correct yearly waste generation rates. GDP projections where based on the known/historical GDP provided by (Central Bureau of Statistics Curacao 1980) up until 2014. The subsequent years leading to 2030 were laniary plotted based on GDP until 2014 and yearly MSW accumulation rates calculated using (Worldometers 1999) and known values per person/year from the (*2E Afvalstof Plan Achtergrond Informatie* 11-35).

CW will account for restaurant/hotel, business wastes. Apart from these quantities will it also factor in tourism waste. For the estimation of the amount of tourists ,official data of (Berkhout 2007) will be used and linear projections made using yearly CW accumulation
Only known references to account for CW in 2001 is listed in (Annex 3.3). This value (around 100.000 tones) remained stable through to 2013 (Figure 2.3) and will therefore be used as the baseline value for this study. CW has to be corrected for C&D because it composes a large fraction of CW that cannot be organically degraded. According to the "Curacao waste prognosis" report, in 2009; 45.000 tones of C&D waste was included in 93442 tones of CW. This accounts for 42% and will be used as reference value to determine the C&D free fraction of CW in 2001. The amount of C&D free CW waste in 2001 then becomes 42,000T of which 1400T (table 2.2) or 3.3% suitable for composting assuming the values for market and street sweeping grass waste stay the same. The additional 96.7% is assumed to be mixed waste that can be anaerobically digested. According "curacao waste prognosis there is no link between commercial waste and economic development nor population growth (Annex 3.2). This is because CW is a umbrella term for different sectors including schools, hospitals, markets etc (table 2.1). With tourism being a major contributor to curacao's economic developed it is assumed that the strongest relation between CW is tourism. Tourism therefore becomes the benchmark on witch the scenarios are based for CW. Average growth in tourism accounts for 3.9% based on historical data from (Berkhout 2007). I therefore assumed to plot future CW scenarios with an increase of 3.9% until the year 2030 were data on the amount of CW was not available.

Waste Composition

Before the organic fraction of both MSW and CW can be treated through either composting or AD it must go through appropriate pre-treatment to remove impurities.
This includes passing through conventional 70-80mm sorting screens to remove ferrous and non ferrous (plastic) materials from the input and a shredder to create a more homogeneous material that can be better composted or added to the digester. Curacao is already actively removing these materials in separate locations. Plastics and glass are removed through Curacao recycling company while ferrous materials are removed by the Curacao scrap yard. It is difficult to remove other inert objects like stones, rubber and small pieces of plastic from source mixed waste (as in the case of Curacao). This will affect microbial digestion and will interfere with the overall process quality. In order to forecast waste Curacao waste scenarios is being assumed that the organic input is already effectively sorted and pre-treated even though there is currently no pre-treatment facility.

A key parameter for optimal both aerobic and anaerobic digestion is the input feedstock.
With regards to the waste composition it was noted that no actual consensus has been formally agreed upon at SELIKOR. This information was gained through internal interviewing process with the contact person. However by cross-referencing (Mohee, et al. 2015) (Figure 1.4) value of 46% MSW organic fraction and the results of a joint waste management workshop on july 7 2014 where the organic fraction was measured at 52% (28% MSW and 24% CW). It was concluded to agree upon the average of 37% total biological fraction for MSW and 24% for CW. Of this organic fraction the assumption is made that 65% of the MSW is grass waste. This assumption is based on the (*2E Afvalstof Plan Achtergrond Informatie* 11-35) where values between 50 and 80% of MSW compromised of yard waste.
The remaining 35% is assumed as mixed organic waste and therefore input for AD because of its high biogas potential (Tadesse Getahun 2014) .

Commercial waste due to the broad range of interrelating variables was hard to quantify in terms projections. The name commercial waste, although cataloged in Selikors database has not yet received appropriate definition describing its exact composition. CW ranges according to “tweede afvalstoffenplan” (Table 2.1) to include market, hospital, office, industrial C&D, sanitation, wastewater treatment sludge etc.

*Table 2.1 Additional commercial Waste sources and compost suitability *: No biological potential, therefore excluded as data input. tweede afvalstoffenplan 2003*

Source	Amount (tons)	% Organic/paper	Value (T)
Industrial*	-	-	-
Chemical Household*	-	-	-
C&D*	-	-	-
Sanitation*	-	-	-
Street Sweeping	2.000	25	500
Market	1.000	90	900
Hospital*	-	-	-
Slaughterhouse	N/A	100	-
Tires*	-	-	-
Agriculture	N/A	100	-
Private Sector	-	-	-
Total (T/yr)			1400

The biological fraction for both municipal and commercial waste i summarized and calculated below in table 2.2 using data from (*2E Afvalstof Plan Achtergrond Informatie* 11-35) year 2001 and the above mentioned assumptions as example.

Table2.2: example of quantification of the biodegradable component of MSW and CW for 2001

**Correction for 37% Organic fraction*
***Corrected for 42% C&D reduction and 24% organic fraction*

Waste Stream	Waste (T)	Organic fraction and/or C&D correction	Anaerobically Digestible (T)	Compostable (T)
MSW	49130	18178*	6362 (35%)	11815 (65%)
CW	101,000	10180**	9844 (96.7%)	336 (3.3%)

Compost Production

The amount of compost that can be predicted is based on (Seng, et al. 2013) formula of using dry and moisture content reductions. This calculation for final compost and mass reduction is expressed as:

$$Mcomp = Wcomp + DMcomp$$

$$Wcomp = \frac{DMcomp \ x \ MCcomp}{100 - MCcomp}$$

$$DMcomp = \left(1 - \frac{DMreduction}{100}\right) x \ Mraw \ x \ (1 - \frac{MCraw}{100})$$

Equation 1 Compost Production Equation (Seng, et al. 2013)

M_{comp} represents the total mass of compost being generated (kg), W_{comp} (kg) represents the wet fraction of the final compost that needs added to DM_{comp} (kg)or dry mass of the compost to obtain M_{comp}. MC_{comp} and MC_{raw} represents the moisture content of the compost product and raw organic waste (%).M_{raw} is the total weight (kg) of the organic fraction of waste and $DM_{reduction}$ is the reduction in mass after composting has completed its digestion. Standard values for $DM_{reduction}$, MC_{raw} and MC_{comp} where attained through (Seng, et al. 2013) and listed below. For MC_{raw} the value of 73% was chosen by averaging the 59-87%.

- Dm reduction:65%
- MCraw= 59-87% (73%)
- MCcomp= 40%

Landfill Methane Production

Through decomposition can the organic fraction of waste release harmful biogas compromising mostly of methane (CH_4) and carbon dioxide (CO_2) to the environment. This environmental impact can be assessed through IPCC's suggested methane generated equation where:

$$\textit{Methane generated} = (\textit{amount of waste sent to landfill}) \ x \ DOC \ x \ DOC_f \ x \ 16/12 \ x \ 0.5 \ x \ MCF$$

Equation 2 Mehane Generation Equation Source: (Froland and Pipatti 2005

Where:
DOC = the organic degradable fraction of carbon in waste
DOC_f = The organic fraction that is already degraded into biogas witch according to the IPCC 1996 Guidance is between 0.5 and 0.6 of which the average of 0.55 will be chosen for this study.
16/12= The conversion factor of carbon to be converted to methane.
0.5= The default value of methane gas emitted from a landfill
MCF = the percentage of methane in landfill gas relative to landfill gas
IPCC applied the methane correction factor to account for the different type of landfill designs and operations. This according to the IPCC can influence the fraction of organic content converted to methane or carbon dioxide. The MCF therefore should only serve as a relative CH4 generating potential based on "how well the landfill is managed". Well managed landfills (also used as baseline) are given an MCF value of 1 where shallow (less then 5 m deep), unmanaged landfills are given a value of 0.4. Lastly deeper unmanaged landfills are given the value of 0.8. The assumption in accordance with IPCC guidelines uses the default assumption that 50% of the biogas produced by the landfill (biogas) is produced at MCF value of 1. Therefore for the subsequent values of MCF=0.4 and MCF=0.8 it can be said that 20 and 40% of methane is compromised out of the emitted landfill gas.

Potential AD Methane Generation

Biological methane production for this study is calculated using the Buswell Equation (Westlake 1995) This equation is based on the elemental composition ($C_nH_aO_b$) in which theoretically methane and carbon dioxide can be derived from the feedstock's organic composition. Its composition is described in Eq. 3

$$C_nH_aO_b + \left[n - \frac{a}{4} - \frac{b}{2}\right]H_2O \rightarrow \left[\frac{n}{2} - \frac{a}{8} + \frac{b}{4}\right]CO_2 + \left[\frac{n}{2} + \frac{a}{8} - \frac{b}{4}\right]CH_4$$

Equation 3 AD theoretical biogas production for reuse. (Westlake 1995)

Since no measurements of the protein, carbohydrates and fats were made, typical values sought after in the literature where used. Values prescribed by (Westlake 1995) for MSW C-H-O compositions were used and listed in table 2.3 to account for the organic composition of both MSW and CW. Theoretical methane generation was then calculated using these values as input for Eq 3.

Composition of Organic Fraction	C	H	O
	99	149	59

Table 2.3 Organic fraction composition (Westlake 1995)

Stakeholder assessment

The other perspective of this study focuses on stakeholder's assessments and the critical realism that knowledge and science are processes involving groups of people creating their own picture of reality and influencing others in a process of social interaction. Stakeholder receptivity as defined by (Jeffrey and Seaton 2010) will also assessed to determine the citizens level of acceptability of potentially introducing these technologies.
Receptivity is "*the extent to which there exists not only a willingness (or disposition) but also an ability (or capability) in different constituencies (individuals, communities, organizations, agencies, etc.) to absorb, accept and utilize innovation options*". In the case of integrating organic composting and AD prescribe four different attributes that must be aligned to the receptivity framework before they become institutionalized. These elements in the case of Curacao's waste dilemma include:

- Awareness: Raising social awareness on the current waste problem on Curacao while emphasizing the availability of alternative options.
- Association: Correlate Curacao's waste problem to the stakeholders own agendas and objectives.
- Acquisition: Providing evidence that these practices and/or technological applications are acquirable, easily implemented and operationally feasible.
- Application: Acquisition of enough legal and financial incentives in order to implement the alternative practice and/or technological application.

In this study a questionnaire was used addressing these elements enclosed in (Annex). Receptivity therefore serves to open up stakeholders to the new concepts when introduced by change agents. In the past, waste management on Curacao has received little priority in its transition to include CEM. This research aims therefore to explore the potential in introducing an alternative that is not only in line with the Barbados plan of action, but also with circular economy improving the socio-economical status of curacao, promotion of environmental remediation and alignment with sustainable development as defined in the Brundland report (Simon 1987).

3: Results

3.1 Review of current waste situation on Curacao

Both MSW and CW in Curacao will increase rapidly in the last decade. From 91,550 tones accumulated in 2001 to 1,659,583 tones in 2017. This rapid waste increase is attributed to rapid population growth in combination with economic development in the form of local GDP and tourism (Annex 2) (Berkhout 2007). In terms of waste generation per capita and thus MSW, the gross rate of generation was found to be around 384 kg/yr. According to "Curacao waste prognosis paper" waste on Curacao is classified as; Municipal (including garden waste), Bulky, Commercial (including car tires) and Sanitation (including diabase). The largest portion of waste is Commercial waste (66%) "Curacao waste prognosis paper" followed by Municipal waste (32%), bulky (2%) and sanitation waste (1%). The high degree of CW has to do with the inclusion of C&D waste as CW, once removed MSW becomes the largest fraction of waste for Curacao. C&D correction will be applied throughout the scenario's. Industrial and hospital waste were not included in this study due to lack of data. MSW mostly compromised of kitchen waste followed by plastics and cardboard. The remaining waste includes: paper, glass, metals, textiles and others. Private Recycling companies are active in recycling of most of the remaining non-organic waste types (Table 3.1). The reason for not choosing to recycle organic wastes according to (Amarica 2016) has to do with the low cost recovery of end-products (for composting), enough landfill availability, non-existing operational procedures, lack of technology and human capital.

Company	Waste Type	Uses
CRC	Glas & Plastic	Gridblasting/ Export
SSS	Metals	Export
Milieustraat	Chemicals	Export to Ned for treatment

Table 3.1: Private Companies and the waste stream being recycled. Source: (Amarica 2016)

3.2 CW & MSW generation and forecast

Municipal Solid Waste

The forecasted total amount of waste generated from 2001 to 2030 for MSW is highlighted in fig 3.1. The amount of waste is predicted to substantially increase from 49130 T/yr. in 2001 to 1,823,962T/yr. in 2030 on the landfill. The amount of waste generated was predicted using the " tweede afvalstoffenplan pag 10" highlighted in Table 3.2. The forecasted projections were made using the relation between the amount of waste produced per capita and population growth through the years (Central Bureau of Statistics Curacao 1980). GDP was also included in the scenario predictions because of the correlation between GDP and MSW (Annex 3.1) (Amarica 2016). I was therefore more accurately determine the amount of MSW produced on Curacao.

From 2015 to 2030 there was a lack on GDP estimations data and it was therefore decided to forecast GDP estimations based on the actual amount of waste generated and the actual GDP (up until 2015) though statistical linear extrapolation.

Year	Amount (Tons)	Population	Amount/inhabitant (kg)
2002	49.922	130.000	348
2003	50.546	132.000	383
2004	51.055	135.000	378

Table 3.2 Yearly household waste from 2002 to 2004 "Source: tweede afvalstoffenplan pag 10"

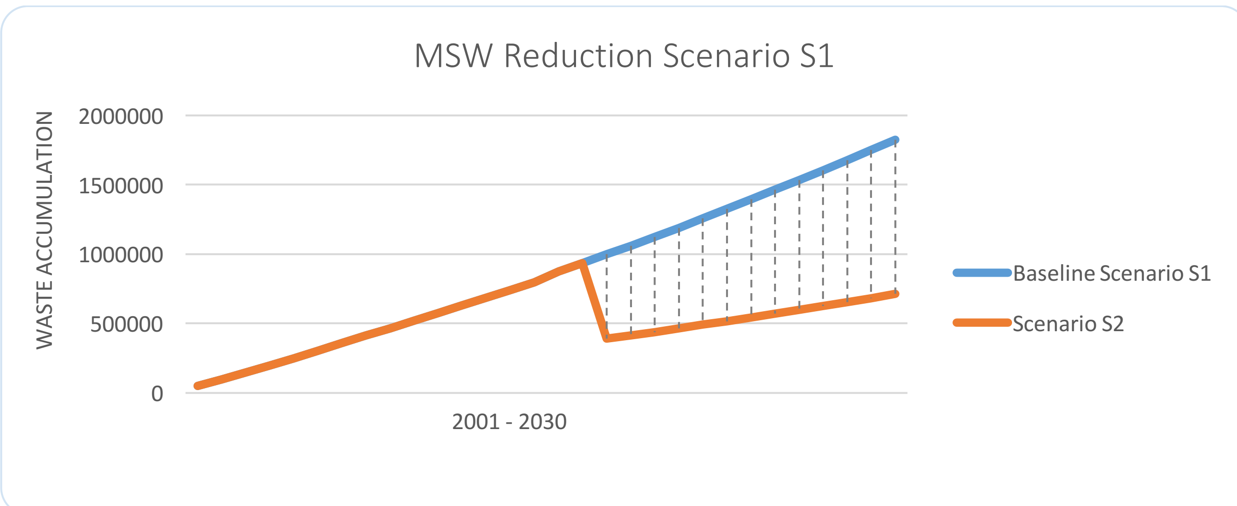


Figure 4 Figure 3.1 Curacao MSW scenario depicting the baseline scenario started at 2001 up until 2030 with the intervention of WTE technologies at 2018

2 scenarios were set up to evaluate the potential of AD and composting systems as WTE solutions for Curacao's growing waste situation. The first scenario depicted in figure 3.1 highlighted the total reduction achievable by integrating both technologies while the second scenario depicted in figure 3.3 would highlight the the percentage each individual WTE could potential contribute. For municipal waste it was found that organic composting would be better suited to significantly reduce the amount of waste making it to malpais. This due to the high organic fraction and "garden waste" content of MSW (50%-80%) "tweede afvalstoffenplan pag 11". High lignin containing garden waste would impede accurate digestion through AD meaning that composting would be the primary treatment choice. Additional organic fraction presumed to be kitchen waste is then left as input for AD. Collectively both AD and composting then are responsible for 40% recyclability (fig 3.3).

The accumulated total amount reaching the landfill therefore is also greatly reduced from 1,823,862 T to 711,345 T in 2030. In addition, about 392,727 tons of compost can be made from

2018 on reaching up to 718,010 by 2030 if the practice is integrated and sustained. Using IPCC methane generation equation between 624729 and 114229 T of methane is generated from the left over “un-compostable” waste fraction. This fraction of methane can be effectively captured by redirecting this un-compostable fraction to a AD. The combined reduction of these two waste management applications are highlighted in fig 3.3 and have a collective reduction of around 40%.

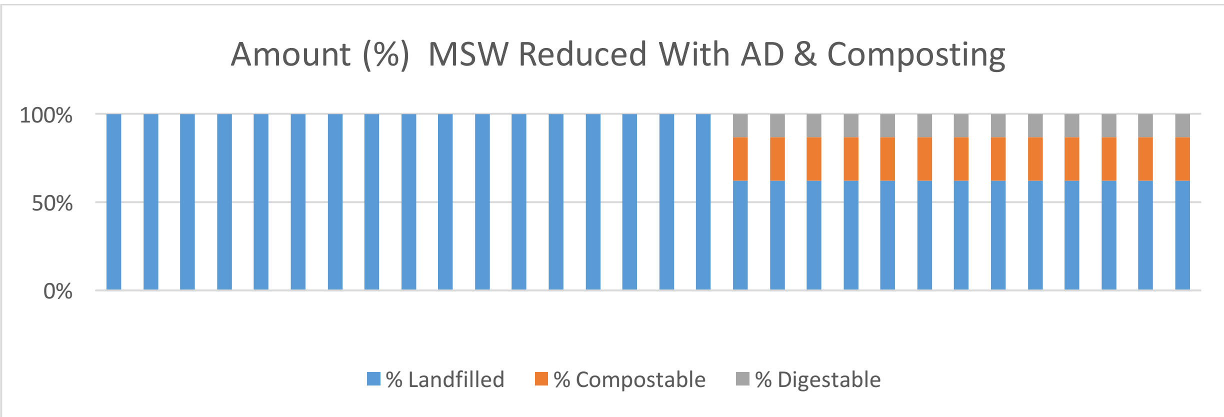


figure 3.3: percentage (%) MSW reduction forecasted from 2001 to 2030

Commercial Waste

The forecasted total amount of CW generated from 2001 to 2030 is highlighted in fig 3.2. The amount of waste is predicted to substantially increase from 48,480 T/yr. in 2001 to 800,778 T/yr. in 2030 on the landfill. A large fraction of commercial waste coming from the tourism sector could not be accounted for in this study yet it could be the major contributor to CW. Estimated values as described in Annex 3.3 corrected for the organic content to exclude C&D waste. The organic content of commercial waste according to the “curacao waste prognosis report” is measured at 24% and this value used as indicator to plot the organic reuse potential of commercial waste. The forecast based on C&D correction is deemed acceptable as it is comparable to C&D corrected CW values in the “ curacao waste prognosis report”.
Tourism is important for curacao economical development with linear increases in international visitors each year (Berkhout 2007). And since economical development is a driver for MSW, tourism was also included in building scenario’s for CW.

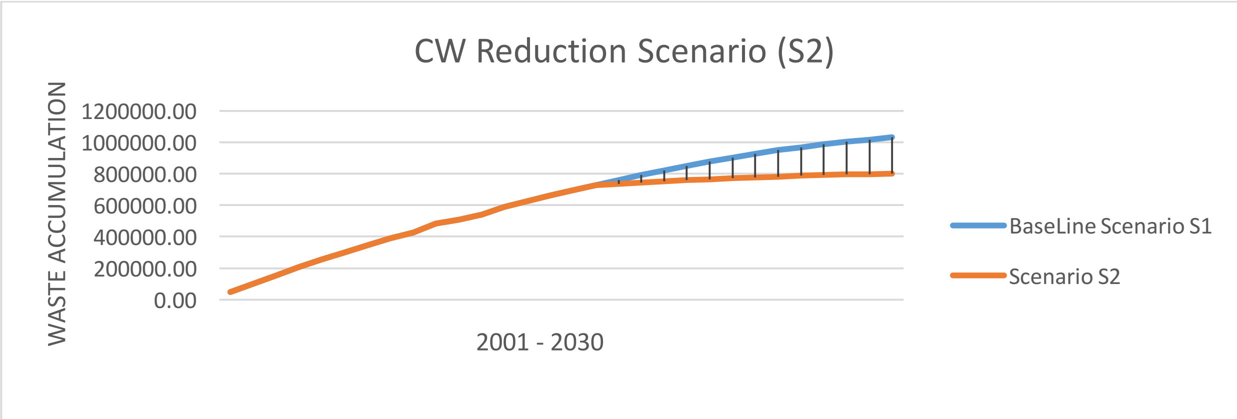


Fig 3.2 Curacao CW scenario depicting the baseline scenario started at 2001 up until 2030 with the intervention of WTE technologies at 2018

If no change is brought forth, Curacao's landfill will have around 1,594,521 T of CW on its grounds in 2030. This value could be reduced to 1,211,836 if governments choose to separately treat the organic fraction (24%) using AD and composting. Composting could also be applied for CW however in smaller scale (3.3%) then for MSW (65%) (Table 2.2). This small value is a combination of lacking data enclosed in table 2.1. This coupled with the lack of data on on tourism and private sector waste leaving only a few including market waste as quantifiable waste for this study. It was opted therefore to process majority of CW waste through AD (fig 3.4) until further analysis is completed to better highlight the composition of CW organic fraction and different streams.

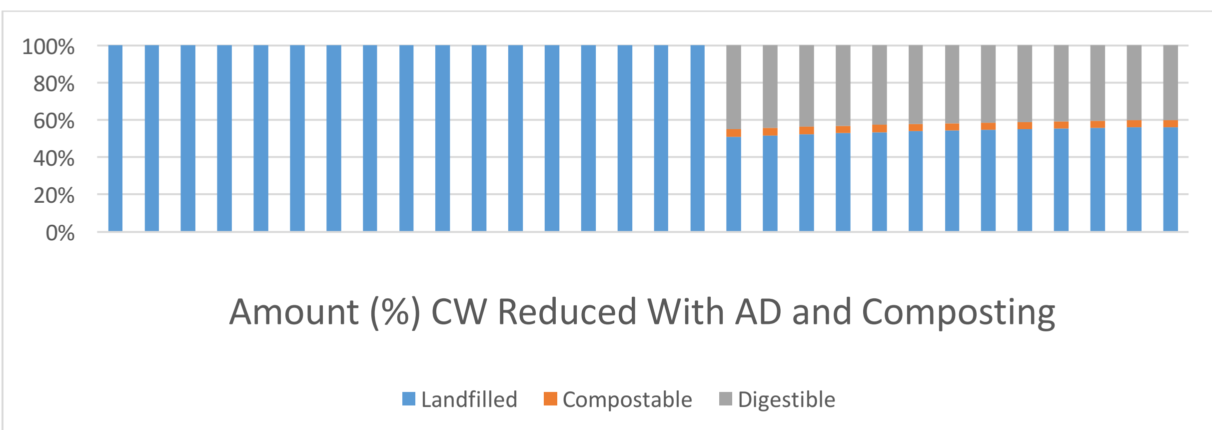


Figure 3.4: percentage (%) CW Reduction Forecasted from 2001 to 2030

Compost created out of CW is projected to remain about the same with values between 6064.06T in 2018 to 12628.61 T in 2030. This amount is assumed to be the correlated to the range of missing variables otherwise required to make a more accurate estimate. Values for AD of CW organic waste fraction therefore account for 96.7% of waste treatment ranging from 208,722 T of methane in 2018 to 227,144 T in 2030.

When both the largest waste streams (CW and MSW) are combined a reduction closer to 40% can be expected when both AD and composting are implemented (Figure 3.5).

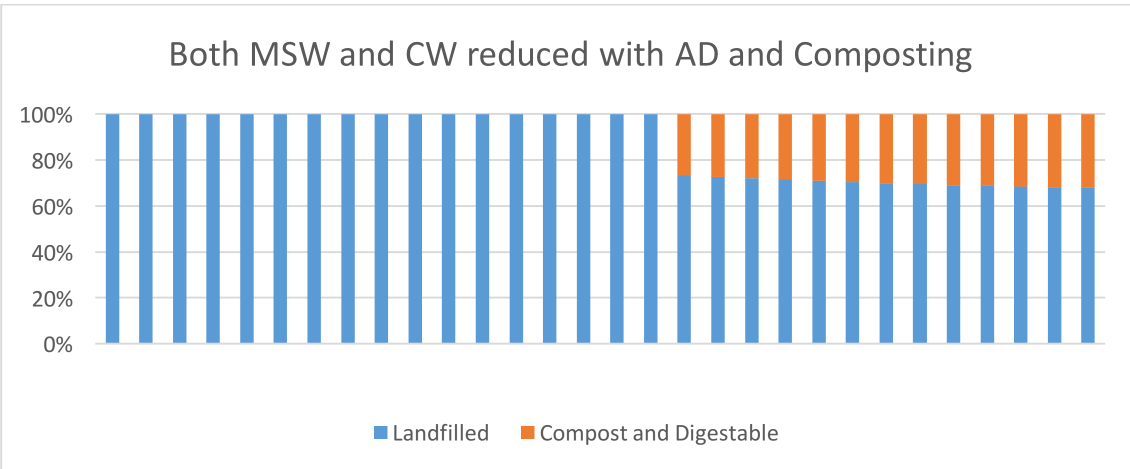


Figure 3.5: Percentage (%) Total Reduction Forecasted from 2001 to 2030 For both MSW and CW.

Theoretical Methane Production

Assuming 35% water content (eq.2) and 60% methane estimates based on (Tadesse Getahun 2014) research on biogas generation in tropical climates, could the total theoretical methane production and residual digestate be calculated. Figure 3.6 illustrates potential methane and digestate yields for Curacao based on the amount of mixed waste that could otherwise not be processed using windrow composting for both MSW and CW. This is because of the high food/mixed waste content that would offset the C: N ratio of 25:1 required for optimal aerobic composting. Methane containing landfill gas values where derived from the anaerobically digestible fraction of both CW (96.7%) and MSW (35%) that could not be composted. Methane fraction of landfill gas where calculated by adding these values together in combination with eq 2 to project estimates until 2030 listed in figure 3.6.

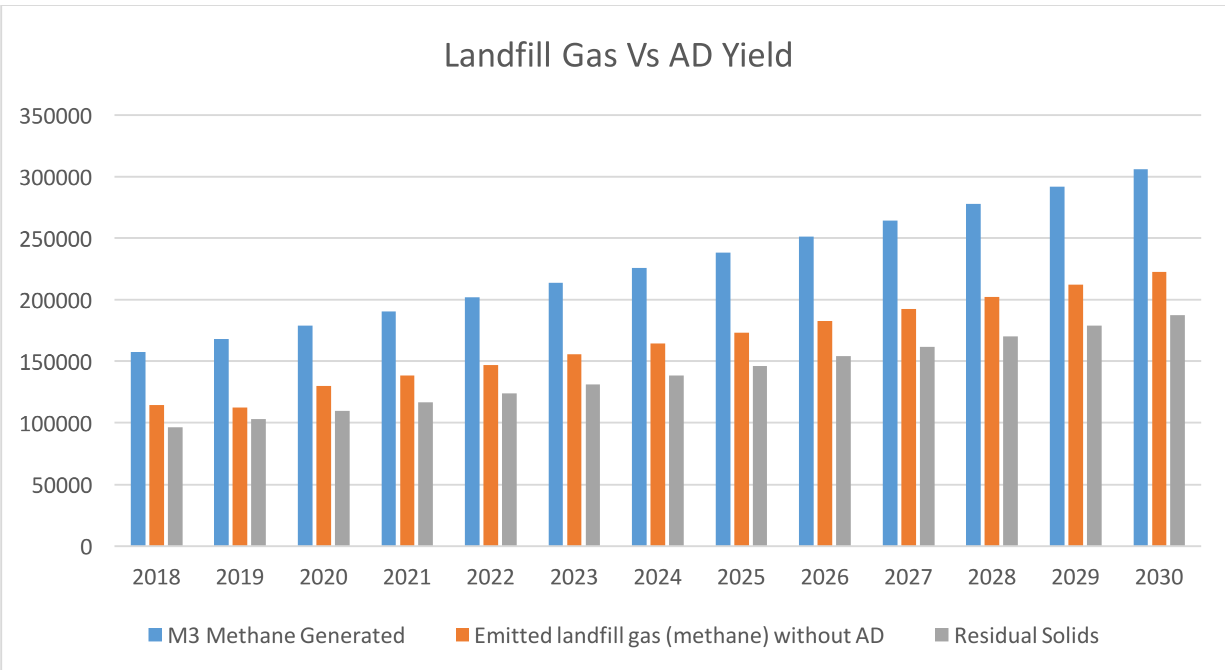


Figure 3.6 Landfill gas amounts vs potentially recaptured methane and residual solids.

3.4 Questionnaire and interview Results

A small field study assessing local knowledge based (Jeffrey and Seaton 2010) receptivity principles was carried out. The questionnaire examined the relationship between local residents divided over different criteria e.g. age, gender, social status etc.) (Annex 1). The study was designed based on (Jeffrey and Seaton 2010) receptivity principles enclosed in section 2. The questionnaire includes 4 sections divided amongst open and multiple choice questions (Annex 1). The study compromises of general questions relating to age and gender followed by the subsequent sections including integral motivation knowledge and willingness to participate if the opportunity was provided. A statistical analysis then followed to interpret the results derived from this study.

One of the main issues that differs Curacao from other SIDS and countries is that it is the only island to our knowledge that has not changed its MSW bill in the last 20 years. When interviewing the expert at Selikor why this was the case he responded that a proposition of increasing this service costs is a purely political manner. Raising the utility service price is seen as taboo in the political arena and thus not a favorable option for candidates seeking re-election. Residents of Curacao like many other SIDS and developing countries are limited in financial recourses, and thus it is believed that such a proposition would therefore only be met with great opposition. However, this inability to act puts Selikor is a difficult position. It limits Selikor's ability to invest in potential sustainable application and struggling to break even. The case of simply raising the monthly service cost is therefore a very delicate yet important subject mater according to our interviewees as it is needed yet public acceptability is questioned. The questionnaire results however (table 3.3) highlight that more then 50% of the participants in this study, contrary to the expert's belief are willing to pay in this case in an additional 25% to their current service bill. This will add to an additional 5 guilders per household. This could be traced to the fact that more and more citizens are becoming waste conscious due to more active NGO's and public campaigns (Cleanup 2016).When asked if they "think that Curacao has a waste problem most (80%) responded with: yes, highlighting inappropriate storage of waste and recognizing landfilling as an unsustainable practice.
Small scale composting and/or AD feasibility projects could potentially be funded by by opting to increase the service fee. This additional revenue stream without concern in the political arena as a great portion of the questioned individuals showed a willingness to grant an additional 25% if the funds would go towards improvement local waste management. (Cleanup 2016) (Cleanup 2016)

Motivation/willingness to participate was tested trough the following questions "are you doing any recycling?" and "if the option was provided would you recycle?". 79% of responds where not currently engaged in recycling of any kind while 87% is willing to recycle if the option was provided. For AD and composting to be done in a cost effective matter, source separation is of up most importance as an effective means to facilitate integrated WTE (Zhan, et al. 2012). Local citizens have to be incentivized to separate waste in order to make composting and AD a reality. This has to be done through national policy. The lack of this top down initiative highlights one of the gaps that need to be filled in order to transition to a more waste conscious society. Although it is generally recognized that there are recycling stations present (with 61% of responders answered with yes) the fact that they are not actively used highlights the lack of intrinsic motivation to actually engage even though there is a high degree of willingness.

The high degree of willingness to participate coupled with the low number of actual ongoing household recycling could be interpreted as need for policy aimed at compelling citizens to do what (according to my findings) they are already willing to do.

In addition to being willing to pay, it was noted when asked regarding the knowledge on NGO's that 80 % of the responders where not aware of any NGO's concerned with waste management yet the majority voted that effective waste management strategies should be both bottom as top down initiatives (table 3.3). NGO's and municipality therefore both serve a crucial role in incentivizing societal change and this survey provided evidence that both are prerequisites as a foundation on which to build a strategic waste management plan.

Known waste Related NGO's		
	Frequency	Percent
Yes	13	19%
No	57	81%
Willingness to recycle if option was provided		
Yes	61	87%
No	9	12%
Willingness to pay Additional service fee on top of current price.		
0%	18	26%
25	38	54%
50	9	13%
More then 50%	5	7%
Top down and/or Bottom up incentive		
Government	20	28%
Household	21	30%
Both	29	42%
Does Curacao Have a waste problem		
Yes	56	80%
No	14	20%
Awareness of recycling stations		
Yes	43	62%
No	27	38%
Currently Recycling		
Yes	15	22%
no	55	78%

Total Respondents	70	100%

Table 3.3 Frequency table of questionnaire results

The traditional approach applied to environmental problems has been one of ‘‘command and control’’ by the responsible authorities, which largely apply ‘‘end-of-pipe’’ solutions to existing problems. In the past, all waste management elements were often only evaluated from a purely engineering and technical viewpoint instead of being embedded in a local, institutional, socio-cultural and economic context, which is also influenced by national, political and regulatory aspects as well as national, global and economic factors. In the last decade, focus has shifted towards finding approaches which could possibly avoid or tackle the problem as close to its source as possible. Central to this strategy is the need to minimize waste generation and enhance recycling. This is achieved by closer collaboration and exchange with the individual municipal residents. Household involvement is paramount to the success of recycling initiatives,
From the questionnaires it is evident that there is a willingness towards recycling. It is the lack of municipal drive that is impeding the institutionalization of a waste conscious Curacao. Potential strategies include command and control, information platforms, economic incentives, public-private partnerships, environmental education, international collaborations, research and development and Technical assistance as stated in section one of this thesis. Effective command and control coupled with environmental education could facility national policy development, similarly can command and control, information platforms and economic incentives around waste further facilitate and increase social acceptability and in corporation with the right public-private partnership aim to achieve a certain goal. Especially with NGO’s like green force could greatly aid in this aspect as it was mostly known on the island as a waste concerning NGO.

5: Discussion

The findings from this study assessed the feasibility of applying sustainable waste management alternatives in order to cope with future waste demands for the island of Curacao. The methodology on achieving this goal led to a literature study concluding anaerobic digestion (AD) and windrow composting as feasible technologies for island scale applicability. The lifespan of the local landfill (Malpais) is nearing its end of life with an average of 10 more operating years and in dire need to upgrade. This study was therefore designed to highlight alternative means of managing waste as a substitute to the planned expansion of the landfill area. The two major waste streams namely MSW and CW where projected over a 15-year period against the intervention of both AD and windrow composting to highlight potential waste reductions. Following current projections; increasing population and tourism activities will lead to waste accumulations from 1.6 million tones in 2017 to almost doubling to 2.8 million tons in 2030. However, this amount could be significantly reduced by integrating AD and/or windrow composting as a means of dealing with the abundant organic waste stream on the island. Both commercial (CW) and municipal solid waste (MSW) streams on Curacao contain sufficient amounts of organic input to run these technologies effectively and reuse a great deal of otherwise disposable organic waste. Fundamental to the creation of the scenarios were the waste composition and quantity amounts. Historical data gained through the municipality was used instead of more traditional in-field sampling strategies. Further research should include testing different waste samples collected at different time intervals for more accurate results on Curacao's current waste composition and quantity. However, organic waste composition data acquired through the municipality of Curacao coincides with other Caribbean SIDS suggested by (Mohee, et al. 2015) at around to 40% (Curacao's composition being 46) . The results therefore still reflect relevant waste compositions based on the independent studies used for this paper.

Treating of the organic fraction in AD and windrow composting facilities showed successes in multiple other islands and countries. However, there are still a few challenges that need to be discussed prior to its application on Curacao. There is a need to uniform the feedstock in order to make it suitable for digestion. This can only be achieved through institutionalizing source separation as part of Curacao's waste management policy. As is the case for composting, impurities must be effectively removed prior to composting in order to avoid contamination when the compost is reapplied to the land. This issue also applies for AD as impurities can hinder the biogas and fertilizer creation process. This can be achieved if SELIKOR and NGO's continuo working and expand their efforts to educate the waste generators to include organics in their recycling practices. It is crucial that businesses and citizens are made aware of the significance of AD and windrow composting including information on proper source separation. Likewise, cleaner feedstock should be prioritized and collection points established for commercial sectors e.g. market places, restaurants. These instances have higher concentration of organic waste with minimum impurities.

Somewhat Surprisingly, the organic municipal solid waste (MSW) fraction contained substantially higher degrees of yard waste compared to commercial waste (CW). Manual aerated composting is optimal at ratios of 25:1 (C-N) which coincides with grass/yard waste C:N ratios. Of the total amount of MSW 65% could potentially be composted while only smaller fraction of 3.3% could be composted for CW. The reduction of organic commercial waste therefore favors anaerobic digestion because of the ability of AD to handle a broader range of mixed organic waste. In addition to waste reduction AD also provides the additional benefit of reusing its outputs (biogas) as a sustainable energy source. CW has significantly more organic waste (96.7%) that is not suitable for composting compared to MSW (35%).According to the results, these AD input estimates collectively could provide Curacao with up to 300.000m^3 of biogas by 2030. I argue based on the results that windrow composting therefore will best suit Curacao's high grass waste containing MSW while applying AD for the organic fraction (compromised mostly of food & mixed waste) which is is otherwise not suitable for composting.

In addition to the efficacy and scalability of these two waste management options, did this study also focus on cost effectiveness. Manual windrow composting according to (Pendley 2005) is the most cost effective means of composting. In addition, it has also been implemented with success on the island of Jamaica which further proves its high potential for success on Curacao. Windrow composting however comes with high surface area requirements, potential for odor pollution and limited to the recycling of grass/yard waste. Initial high investment costs for AD may initially not be the best option for Curacao's financial limitations. However, the increased capital required for AD can be compensated for through biogas creation which can lower curacao's dependence on expensive imported petrochemical electrical power generation. Furthermore, there are factors that cannot directly be expressed in monetary equivalent but provide great benefit. These benefits include the ability to treat higher waste inputs from both MSW and CW as feedstock, job creation, reduced odor pollution and smaller surface area requirements then windrow composting. In addition, landfill gas reductions were also assed assed due to its high environmental footprint. Landfill gas holds a large fraction of methane (CH_4) with a GWP of 21. Offsetting this CH_4 therefore through AD could significantly reduce Curacao carbon food print. The results highlighted in figure 3.6 depict ever increasing values that would otherwise be mitigated with the implementation of AD. Further research comparing initial cost to long term returns on investment are required to accurately compare long term implementation of these two waste management alternatives in order to determine their feasibility considering the financial strains of Curacao.

The citizens of Curacao do recognize that there is a growing waste problem on Curacao. An infield survey highlighted that 80% of the population is aware of the current waste situation and limited time frame. Furthermore, the survey also emphasized that inhabitants are willing to be included in mitigation measures. One of these measures highlighted by the interviewed expert at SELIKOR indicated that Curacao has not increased its waste collection service fee since being introduced in Curacao's waste policy. This according to him is a important factor as to why SELIKOR is often left with insufficient funding to invest in innovation e.g. the exploration of windrow composting and AD. In contrast to his statement did the survey highlight that a majority of responders are willing to pay additional fees up to 50% more if it would go to more efficient and effective waste management. Willingness to recycle was also noted to be substantial with 87% of respondents expressing a willingness to be involved in recycling if the option was provided. I argue that source separation therefore can be implemented due to already high degree of commitment to recycling. Even though most respondents (62%) are aware of the recycling stations, few are actually involved in recycling (22%). These stations are limited to certain supermarkets and the landfill area. Recycling must therefore be made easily accessible to citizens as current stations do not provide sufficient stimulation to recycle.

Conclusions

This study was carried out to establish whether sustainable OWM applications could be applied to small island developing states in order to replace traditional landfilling. The study area focused on the island of Curacao as a case study were AD and windrow composting proved feasible in managing a great deal of municipal solid and commercial waste. Literature on both Windrow composting and AD determined that these applications best suite the socio-economic and scalability limitations of Curacao and other SIDS. The main activities reviewed in this study assessed the scalability, degree of organic waste reductions, anthropogenic landfill gas emissions and public acceptability for Curacao's main waste streams. Both waste streams contain a high fraction of organic waste that could achieve reduced to up to 40%. Windrow composting alone is able to account for 65-68% of MSW reductions as it is mostly compromised of organically degradable yard waste. This fraction is currently burned in back yards due to lack of regulatory presence. In addition, and if combined with AD, the generated biogas through a digestion of the leftover mixed organic waste will further benefit Curacao by generating clean energy and offsetting a great deal of landfill gas (up to 80%) that is currently passively emitted to the surrounding environment.

For both AD and composting to become truly feasible household waste policies and collection strategies need to be implemented. An on site stakeholder analysis revealed that Curacao has a relatively high waste conscious society. The majority of the population expressed commitment to recycling if the option becomes available. The gap in transitioning towards either composting and/or AD therefore lies with national government. There appears to be a lack of governmental support towards SELIKOR as they seldom have additional capital to go towards pursuing innovation.

This was confirmed through interviews with local waste management representatives. Additionally, citizens need to be provided with the tools (separate collection bins) as well as education in order to facilitate the integration of waste separation practices as part of their modern day routines. Economic incentives and policy (e.g. increasing waste collection price and backyard burning fines) could greatly increase the current limited governmental budget and waste homogeneity of waste streams while reducing the national environmental footprint. Fund acquired through this proposition could then be allocated towards pilot scale investments feasibility and education projects.

Source separation of waste is a relatively new concept for Curacao. For this to be effectively implemented societal waste awareness strategies are needed to make citizens (especially the older generations) more waste conscious. Communication, therefore, should always be at the core of policy. These approaches could include:

- Development and implementation of multiannual communication plan in the field of communication, education and information should be put forward. Besides action campaigns aimed at the separate collection of waste and the prevention of litter, it should serve as a umbrella campaign to raise awareness. In a attempt to make sustainable waste management on Curacao a reality it is of importance to work together with as many stakeholders as possible in the public and private sectors to join forces and to ensure continuity of top as well as bottom up incentives. This applies to communication on the theme of waste, but also for the broad field of environmental and natural communication. By applying a theme in campaigns and other forms of communication prevents a fragmented picture of the target groups and different messages will reinforce each other.

- Marketing Selikor: Selikor should use the next few years in the marketing and commercial aspects of waste management. In this way Selikor will eventually generate revenue from the sale of secondary raw materials or energy. This can be done in collaboration with Aqualectra, the local water and energy provider. This could not only reduce the amount of fossil fuels used in electrical generation which in term could reduce the citizen's monthly energy bill. If marketed this way Selikor could overcome the "what's in it for me mentality" as described by (Brink 2016) that is hindering local citizens towards recycling.

- Education and enforcement are important in preventing illegal dumping, backyard waste burning and litter. Waste management NGO in conjunction with Selikor and the government should organize a framework for reintegration of previous regulations as was the case before Curacao's independence, banning backyard dumping and burning. This will not only reduce residential environmental footprint, but will also provide more nutrient rich input for digestion and biogas formation

- Similar to public education and enforcement, so should commercial waste generators also be engaged in waste separation. Currently they don't have to pay landfilling fee if they opt for recycling. However, with the high degree of CW it appears that most business still see landfilling as the most cost-effective option. It is therefore recommended to increase this dumping fee to a degree where it starts to passively push business towards choosing recycling as the most cost effective option.

- Multiple drop-off points further familiarize residents with the concept of recycling in daily life and through the creation of homogenous waste. Selikor is better able to collect and process this waste. Neighborhood drop-off areas could potentially reduce the waste pickup time and will facilitate recyclability of all products.

Whether windrow composting, AD or a combination of technologies will be implemented in the future is a political manner. Both have roved scalable, environmentally sound and for the most part publically acceptable. Political, ethical and environmental questions will arise, however I strongly believe that the long-term economic and environmental savings will outweigh these issues through the economies of scale that will be initiated by these sustainable waste applications. Both AD and windrow composting are able to provide Curacao with a sustainable approach towards dealing with its organic waste. Future research is needed in the planning and cost-estimations areas in order to accurately determine to what extend these benefits will exceed the current future cost. In order to achieve this goal; a structured, systematic and long-term approach to waste education and investments with local, regional and (inter) national stakeholders is essential for Curacao's waste future.

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Annex

Annex 1 : Questionnaire Setup: Municipal Waste Management Survey Questionnaire

About You

1. Your Age / Bo aña

(Select only one.)

☐ 17 or less
☐ 18-25
☐ 26-35
☐ 36-45
☐ 46-55
☐ 56-65
☐ 66-75
☐ 76 or more

2. Your Gender / Bo Sexo

(Select only one.)

☐ Female
☐ Male

3. What is your role/ work / Okupashon/Trabou

(Select all that apply.)

☐ Unemployed
☐ Sales (shops)
☐ Finance
☐ Marketing
☐ Executive
☐ Student
☐ Other

4. How many people live in your Household? / Kuantu hende ta biba den bo kas

(Select one.

☐ 1
☐ 2
☐ 3
☐ 4
☐ More then 4

Motivation

5. Are you doing any recycling (plastic, organic, metal, garden waste)?/ Bo ta inbolbi den un forma di resiklahe (plastic, sushi organiko, metal, sushi di kura)?

(Select only one.)

☐ Yes, which:……………..
☐ No

6**. Do you think Curacao has a problem with managing waste accordingly? / Bo ta haña ku na Korsou tin ku problema ku manehamentu di sushi efiktivamente?**
(Select only one.)

☐ Yes: how so:………………………………………………..
………………………………………………………………………
☐ No

7. How much more would you be willing to pay over your current 20 ANG a month in order to better manage Curacao's waste management practices? Kuantu mas lo ke paga si e extra gastunan lo bai na mio manehamentu di un gran parti di bo sushi di kas?

(Select one.

☐ 0%
☐ 25%
☐ 50%
☐ More then 50%

Opportunity
8. Are you aware that Selikor has recycling stations placed around Curacao? Bo ta konsiente ku tin station nan ront Korsou kaminda por resikla?
(Select only one.)

☐ Yes
☐ No

8. If the option was provided (additional bin) would you be willing to start separating you kitchen from other waste? Si e opta pa ofrese un kliko mas, bo lo ta mas inbolbi den separamentu di sushi?

☐ Yes
☐ No

Capacity

9. Do you believe that waste is a governmental endeavor or something that should be addressed on a household level? Bo ta hanja ku manehamentu di sushi ta algu reserve pa gobiernu of ta algu ku ta keda na kada individual?
(Select all that apply.)

☐ Government

☐ Household

10. What is the best means of communicating waste reduction programs to you? Kua medio di kuminikashon lo ta mas efektivo pa informabu tokante medionan pa anda mio ku sushi di kas? **(Select all that apply.)**

☐ Articles and local newspapers /artikulo di revista anto korant
☐ information package at home / pakete di informashon na kas
☐ Radio Community bulletin board / Radio
☐ Social Media
☐ info with utility bills / informashon huntu ku resibu di selikor
☐ Email

11. Do you know of any NGO's that have waste reduction on their agenda? Bo konose inisiativanan ku tin redukshon di sushi na korsou?

☐ Yes, which: …………………………………………….
☐ No

Annex 2 GDP Growth estimates used to generate scenarios. Source (Central Bureau of Statistics Curacao 1980)

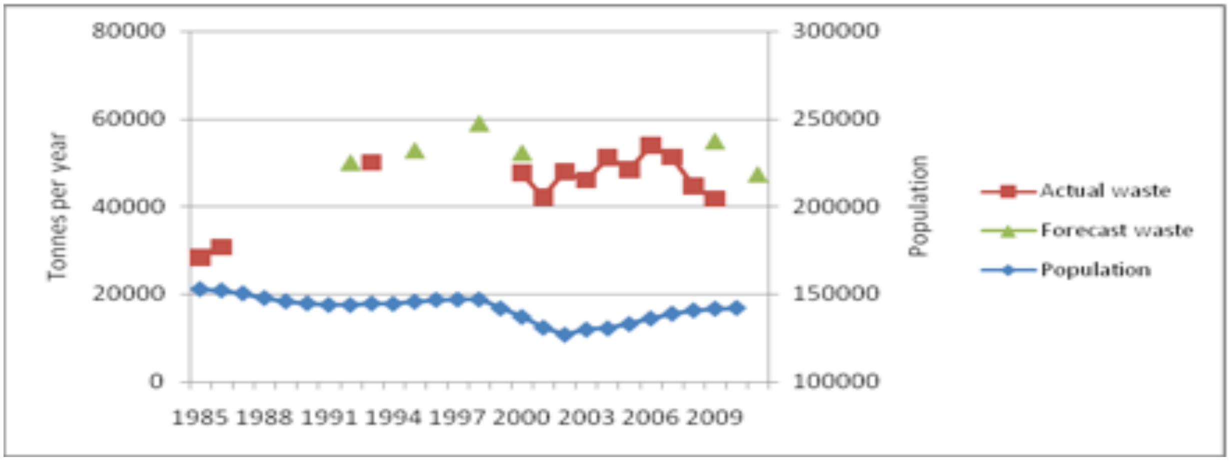
TABLE
Domestic product by sector and industry, Curaçao (mln ANG)

		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	*2013	*2014	*2015
	Non-financial corporations																
A+B+C	Agriculture, fishing and mining	19,5	31,1	22,7	21,5	20,5	23,2	22,7	26,8	30,1	22,0	21,5	22,5	14,3	19,0	18,5	19,2
D	Manufacturing	291,2	307,3	289,2	273,6	292,0	252,3	339,2	346,8	336,9	395,2	327,0	384,0	372,5	631,0	634,5	605,9
E	Electricity, gas and water	125,0	179,1	155,4	162,1	142,0	171,2	161,7	170,7	147,8	216,8	185,6	148,4	133,9	109,2	108,2	102,1
F	Construction	143,8	181,7	192,5	173,2	166,1	221,3	205,0	241,9	284,3	252,0	268,6	320,9	300,9	283,7	280,0	303,7
G	Trade	452,4	461,5	429,2	406,3	412,6	445,3	439,4	442,7	556,9	555,5	550,8	604,4	663,8	567,5	557,8	544,2
H	Hotels and restaurants	92,2	106,0	89,8	100,5	100,7	119,3	128,6	144,6	201,5	157,0	182,3	255,8	235,2	260,4	278,3	269,4
I	Transport, storage and communications	254,9	326,8	364,3	366,9	283,5	284,2	334,4	331,3	449,8	417,0	525,9	618,6	609,4	632,8	624,2	574,9
K	Real estate, renting and business activities	243,0	294,4	279,3	295,0	412,0	300,7	299,9	333,2	340,8	332,0	368,0	401,5	392,2	390,7	387,7	404,8
M	Education private	10,9	8,7	10,7	13,8	19,7	16,3	21,1	21,2	21,6	22,7	23,7	25,5	24,9	24,8	25,7	26,1
N	Health and social work	129,4	165,6	163,2	157,7	160,2	167,7	175,5	177,7	218,2	211,4	242,2	267,8	267,5	253,7	261,3	259,6
O	Other community, social and personal service activities	97,1	106,3	114,6	113,2	148,1	141,1	151,1	142,4	152,4	142,1	136,3	171,8	146,1	163,8	165,3	174,9
	Value added, gross, marketprices	**1859,2**	**2168,5**	**2110,9**	**2083,8**	**2157,5**	**2142,7**	**2278,5**	**2379,3**	**2740,3**	**2723,7**	**2831,9**	**3221,2**	**3160,8**	**3336,5**	**3341,5**	**3284,7**
	Financial corporations																
J	Financial intermediation	640,2	647,5	718,3	797,1	775,1	900,8	834,3	885,0	848,9	904,5	897,2	609,0	792,9	639,7	635,8	637,5
	Value added, gross, marketprices	**640,2**	**647,5**	**718,3**	**797,1**	**775,1**	**900,8**	**834,3**	**885,0**	**848,9**	**904,5**	**897,2**	**609,0**	**792,9**	**639,7**	**635,8**	**637,5**
	Government																
A+B	Agriculture	0,7	0,6	0,6	0,8	0,6	0,8	0,9	1,7	1,1	1,1	1,9	1,5	2,1	3,0	3,0	3,0
I	Transport,storage and communications	14,6	11,3	9,4	10,6	10,1	10,3	9,5	6,5	6,7	8,4	7,7	16,4	14,6	13,6	17,6	18,3
K	Real estate, renting and business activities	3,0	1,9	3,2	4,5	3,5	4,4	4,4	3,9	3,3	3,1	3,4	3,7	4,1	3,7	3,7	3,7
L	Public administration and defence;compulsory social security	442,8	243,0	244,5	268,6	268,2	299,3	310,1	322,9	334,9	353,9	383,1	355,3	372,9	366,9	350,8	364,7
M	Education	57,3	48,3	51,8	63,3	63,0	66,4	74,1	78,5	79,5	91,2	92,0	105,8	97,2	99,8	100,2	103,9
N	Health and social work	83,2	62,6	60,9	65,0	53,2	58,9	59,2	63,0	60,2	66,7	70,3	86,9	84,0	86,8	85,1	86,3
O	Other community, social and personal service activities	50,4	39,8	35,8	38,0	40,3	42,7	43,9	43,9	53,6	46,3	49,9	61,7	54,3	49,7	48,8	50,1
	Value added, gross, marketprices	**652,0**	**407,5**	**406,2**	**450,8**	**438,9**	**482,8**	**502,1**	**520,3**	**539,3**	**570,7**	**608,3**	**631,4**	**629,3**	**623,5**	**609,2**	**630,0**
	Households & Non-profit institutions serving households																
A+B	Agriculture and fishing	0,6	1,1	0,6	0,9	1,3	0,7	0,9	1,1	1,4	0,2	0,3	0,2	1,8			
D	Manufacturing	0,6	0,7	0,5	0,4	0,7	0,6	0,5	0,7	1,0	0,1	1,0	1,9	1,7			
F	Construction	0,9	1,3	0,7	1,0	1,0	1,4	1,6	1,3	1,6	1,0	1,4	6,7	4,4			
G	Trade	6,0	8,9	5,9	5,3	8,0	12,7	11,9	12,1	13,0	6,2	5,4	5,5	3,1			
H	Hotels and restaurants	4,5	8,4	3,1	5,1	4,2	4,1	4,7	4,9	1,2	0,1	1,9	1,0	0,3			
I	Transport,storage and communications	16,1	15,5	15,6	16,0	16,1	16,8	17,8	15,5	15,5	14,6	15,4	15,1	14,9			
K	Real estate, renting and business activities	288,1	270,4	270,3	256,2	296,6	334,4	379,4	403,4	442,1	443,9	463,4	480,9	507,8			
N	Health and social work	0,9	1,2	1,2	1,8	2,3	1,4	1,7	1,4	2,0	0,1	2,2	0,9	1,4			
O	Other community, social and personal service activities	15,7	16,8	13,6	16,5	15,5	15,9	12,6	14,1	14,5	11,7	15,1	14,2	16,1			
P	Private households	8,9	20,3	20,8	25,4	30,1	30,8	32,5	34,1	41,3	42,1	42,9	45,1	46,9			
	Value added, gross, marketprices	**342,5**	**344,7**	**332,2**	**328,5**	**375,8**	**418,6**	**463,5**	**488,5**	**533,6**	**520,0**	**548,9**	**571,4**	**598,3**	**567,8**	**588,7**	**596,8**
	Total Value Added gross, market prices	**3493,9**	**3568,2**	**3567,7**	**3660,3**	**3747,2**	**3944,9**	**4078,5**	**4273,0**	**4662,1**	**4718,9**	**4886,2**	**5033,0**	**5181,3**	**5167,4**	**5175,3**	**5149,0**
	plus Taxes less subsidies on products	398,2	368,0	387,9	367,3	348,2	348,8	426,2	478,0	535,2	548,7	540,8	554,9	576,0	626,0	622,1	628,3
	minus Fisim	**96,4**	**99,4**	**87,8**	**85,8**	**90,9**	**96,8**	**105,6**	**108,1**	**125,4**	**131,8**	**144,1**	**148,6**	**152,6**	**159,2**	**143,9**	**135,4**
	Domestic Product gross, market prices	3795,7	3836,8	3867,8	3941,8	4004,5	4196,9	4399,1	4643,0	5071,9	5135,8	5282,9	5439,3	5604,7	5634,2	5653,5	5641,9
	Nominal GDP growth	**3,5**	**1,1**	**0,8**	**1,9**	**1,6**	**4,8**	**4,8**	**5,5**	**9,2**	**1,3**	**2,9**	**3,0**	**3,0**	**0,5**	**0,3**	**-0,2**
	Inflation	**5,8**	**1,8**	**0,4**	**1,6**	**1,4**	**4,1**	**3,1**	**3,0**	**6,9**	**1,8**	**2,8**	**2,3**	**3,2**	**1,3**	**1,5**	**-0,5**
	Real GDP growth	**-2,2**	**-0,7**	**0,4**	**0,3**	**0,2**	**0,7**	**1,6**	**2,5**	**2,2**	**-0,5**	**0,1**	**0,6**	**-0,1**	**-0,8**	**-1,1**	**0,3**

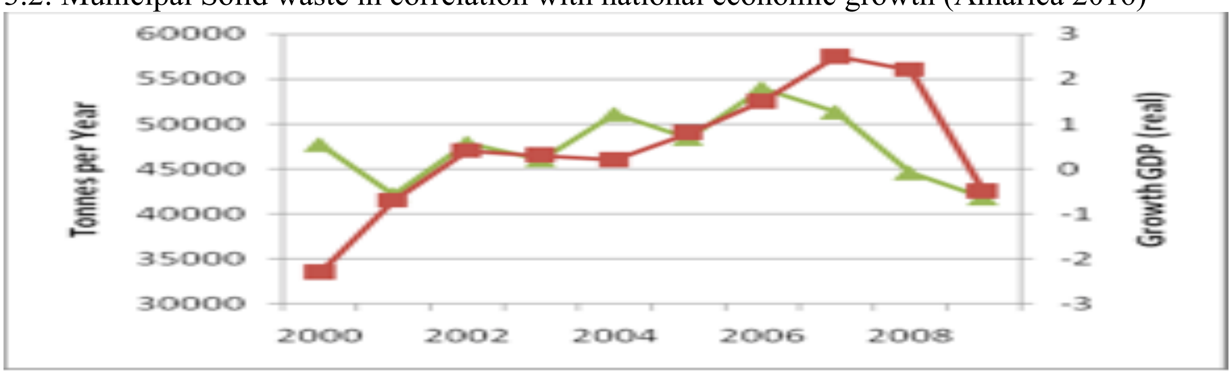
* Estimated Values

Annex 3

3.1: forecasted Municipal solid waste in relation to population growth on Curacao (Amarica 2016)



3.2: Municipal Solid waste in correlation with national economic growth (Amarica 2016)



3.3: Major Categories of waste (and total amount) landfilled at "Malpais (Amarica 2016)