WASTE*D* ENERGY

Unlocking the Biogas Potential in Trinidad & Tobago

A Transition Theory Perspective

Keima Gardiner

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LUCSUS
Lund University Centre for
Sustainability Studies

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ABSTRACT

Trinidad and Tobago is heavily dependent on fossil fuels and the attendant challenges from its consumption have sparked a growing interest in the capacity of renewable energies to remedy some of these issues. Biogas has been earmarked as one possible alternative, particularly in light of the problems with waste management however, efforts to initiate its usage have been negligible. This study therefore aims to explore how biogas production can be integrated locally to alleviate these problems. The assessment is empirically illustrated with a qualitative, single case study based on the Beetham Landfill, with input from documents, interviews and observations. The Transition Theory based on the Multi-Level Perspective provided the analytical framework and through it the key driving forces and barriers of this transition process were determined. To overcome the current fossil fuel 'lock-in', the transformation in the energy sector was found to involve a dual transition in both the energy and waste sectors. Further to this Trinidad and Tobago was aligned with a reconfiguration transition pathway, which contrary to the theoretical convention is a regime-based transition. It was recommended that these regime actors facilitate financial inducements, enabling environments and societal changes to activate the process. Strategic niche management was identified be a suitable and useful management tool for steering this process and broader scale linkages with strong sustainability were also established. It is anticipated that collectively, these elements can contribute to the transition to a sustainably oriented energy system.

Keywords: biogas, municipal solid waste**,** renewable energy, transition theory, sustainability, Beetham Landfill, Trinidad and Tobago

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This thesis writing process has certainly been one memorable journey and a mostly self-learning process. The constantly evolving roller-coast of emotions have motivated, stymied, disillusioned and guided me to what I have managed to achieve. However, this was not a solitary process and so I must extend heartfelt thanks to many for their indispensable and unwavering assistance.

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We were told:
"Don't try to save the world when writing your thesis, for now, just write a thesis".
I agreed.
So instead, for now, I set out to 'save' two islands.
The world, well that would be pursued later.
small efforts ♦ for big changes

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Acronyms & Abbreviations

CDM	Clean Development Mechanism
CH_4	Methane
CNG	Compressed Natural Gas
CSO	Civil Society Organisation
GEF	Global Environment Facility
GHG	Greenhouse Gas
IEA	International Energy Agency
ISWM	Integrated Solid Waste Management
LFG	Landfill Gas
LFGTE	Landfill Gas to Energy
LNG	Liquefied Natural Gas
MLP	Multi-Level Perspective
MSW	Municipal Solid Waste
RE	Renewable Energy
TPES	Total Primary Energy Supply
T&T	Trinidad and Tobago
SFC	Sugarcane Feeds Centre
SNM	Strategic Niche Management
SWMCOL	The Trinidad and Tobago Solid Waste Management Company Limited
TTD	Trinidad and Tobago Dollar

1. INTRODUCTION

1.1. RESEARCH CONTEXT

Fossil fuels have been the hallmark of energy usage of modern industrial society and while they have been the basis for economic and social development globally, their use has also resulted in adverse effects. These relate to environmental impacts, most notably climate change (fossil fuels accounts for almost 60% of the global emissions of greenhouse gases), energy security implications and social issues (Jönsson-Belyazid, 2011). Its finite nature also adds to its drawbacks and as a result many countries have initiated efforts to adopt renewable energies as a means of providing long-term, sustainable solutions to these problems.

Trinidad and Tobago (T&T) has endogenous hydrocarbon resources of oil and natural gas which constitute practically 100% of the total primary energy supply (TPES) and 40 % of the GDP (CIA, 2011; IEA, 2011a). This has led to many of these aforementioned fossil fuel problems of high CO_2 emissions, climate change effects and other ecological and social implications. Adding this to a rising demand for these diminishing, exhaustible resources has prompted the government to embark on the renewable energy (RE) trajectory. The Framework for the Development of a RE Policy has been the first step in this regard and aims to assess the potentials of applying a wide range of RE systems.

Biogas, a fuel gas mixture, has come to the forefront globally due to a growing interest in its capacity as a viable fossil fuel substitute. It has an emerging formidable reputation due to the range of environmental, social and economic benefits its usage yields. These advantages have been acknowledged by the government and so the fuel source has been included as a potential alternative within the Framework. However, despite this there have not been any resolute decisions or concerted efforts to employ the use of this particular energy source.

Waste disposal has also become a major issue in the twin island republic as the country's largest landfill (Beetham Landfill) is exceeding its capacity and nearing the end of its operational lifetime. Adding this to the host of environmental and health issues at the site, there is a proposal to either close or rehabilitate the landfill. This decision presents a two-fold opportunity for diversifying the energy sector and providing a more holistic solution to the waste management problem via the initiation of biogas production. The output could be used in refuse collection vehicles or on a larger scale as an alternative fuel within the transport sector, though initially to a smaller degree. The Beetham Landfill could thus be used as a pilot case to explore these possibilities.

To conceptualise this progression towards a biogas integrated energy system, the transition theory will provide a suitable framework. The contemporary versions of the theory focus on transformative change, where the emphasis is on a co-evolutionary, symbiotic developmental relationship between technology and society (Kemp, 2010). This is useful as biogas production will have implications on both the infrastructure and the society.

This study therefore, is geared towards filling the research gaps in the RE field in the country and more specifically, towards providing insights into the prospects of diversifying the energy mix and improving and mitigating waste management problems by incorporating waste-to-energy technology. Additionally, as a small island state, there is limited land space to locate alternative landfills and so this type of study is essential for resolving such issues. On the grander scale and from a sustainability perspective, this topic bears direct relevance with the global sustainability challenges like climate change and has inter-linkages with others like loss of biodiversity and water scarcity as a result of chemical contamination and leachate runoff from the landfill. On the local level within this sustainability context, this research could provide a solution to the burgeoning waste problem and simultaneously offer information on a RE source with an implicit intergenerational focus, as it contributes to energy security to fuel the society on a long-term basis and reduces the country's carbon footprint.

Biogas has been used in both developed and developing countries and even regionally in countries like Jamaica. The specific form of landfill gas to energy (LFGTE) has empirical examples in countries like Brazil and Mexico[1]. Biogas production provides a comprehensive range of benefits for T&T many of which outweigh those of other waste-to-energy technologies like incineration or waste management strategies such as composting. T&T is in an ideal position to develop this RE resource as the country has experience in energy sector developments and an existing energy platform which it can expand from (MEEA, 2011).

[1] In Brazil refer to the Bandeirantes landfill and in Mexico the Bordo Poniente landfill.

1.2. RESEARCH AIM

This thesis explores the possibilities of a synergistic relationship between energy production and waste management in T&T from a transition theory perspective. More specifically the intent is to answer the following questions:

Research Question

How can Trinidad and Tobago transition to waste-to-energy biogas production to contribute to the transformation of its energy and waste sectors?

Sub-research questions:

a) What are the driving forces for LFGTE production at the Beetham Landfill?
b) What are the barriers against LFGTE production at the Beetham Landfill?
c) How can these opposing tensions be resolved to facilitate change?

1.3. DISPOSITION

This sub-section provides guidance on the layout of the thesis. Within Chapter 2 the methodology employed is outlined and from there, Chapter 3 provides introductory material on biogas and LFGTE technology. With this insight Chapter 4 provides a description of the energy and waste sectors of the case. Moving forward with this background, the theoretical framework is explained in Chapter 5 and this is used as the basis for the data analysis and discussion in Chapters 6 & 7. The conclusion in Chapter 8 gives a summary of the arguments presented in the thesis and provides suggestions for further research.

2. METHODOLOGY

2.1. META-THEORETICAL PERSPECTIVE

It can be argued that pre-existing conditions like natural resource endowment may determine the nature of operations within an energy system. This may thereby imply that energy systems exist as independent forces impacting on society. However, pathological dependence on a certain type of energy system may occur due to reinforcement by parallel, generational thinking or lack of technological adaptation. It follows then that actors within this field are capable of influencing and shaping the status quo. Thus, in order to achieve a transition to a different energy system like one with biogas production, definitive steps have to be undertaken to reconstruct this reality (Bryman, 2008). As such this study would be most aptly classed as constructivist. From an epistemological perspective, interpretivism would be the most applicable position as I seek to gain an understanding of the social action (Bryman, 2008) of those affiliated with the waste and energy fields via their perceptions on biogas production.

2.2. STRATEGY

A qualitative research strategy using a single case study design based on the Beetham Landfill in T&T was employed for this exploratory investigation. Case studies allow detailed analysis into the unique features of a specific case (Bryman, 2008). Furthermore, this type of research design favours investigation of contemporary phenomena within a real-life context and is most applicable when 'how' or 'why' research questions are posed (Yin, 2009). These features therefore validate the use of a case study. Although case studies have been criticised for their lack of generalizability, the focus would be on analytical generalizations, where the results from this case could be used as a basis for comparisons and generalisations with theory (Yin, 2009; Silverman, 2005). This improves the external validity of the study by defining the theoretical domain. In so doing it contributes towards formulating assessments of the conditions in similar cases seeking this transition.

Based on this idiographic approach, primary and secondary data collection was accomplished by triangulation. Four sources of evidence for data triangulation: documentation, archival records, interviews and direct observations were incorporated in this study (Yin, 2009). The use of multiple sources ensured completeness and credibility, collection of a stronger array of evidence and increased the construct validity of data (Bryman, 2008; Yin, 2009). The construction of a case study database worked towards increasing the research reliability (Yin, 2009). Obtaining the relevant data was facilitated by the contact made with a former employee of the Solid Waste Management Company (SWMCOL) who acted as a 'gate opener', allowing me to arrange access to interviews, policy documents and other resources from the company including a site visit. Further information was accessed by direct contact with key informants from sectors bearing connections to biogas production. Through such efforts I was able to organise interviews and access publicly available and private literary material.

2.3. METHODS AND TECHNIQUES

A variety of methods were used to garner information for this inductive approach including interviews, email correspondences, literature and document reviews and observations.

2.3.1. Interviews

This assumed the form of semi-structured interviews, using purposive sampling of government, statutory and independent bodies directly affiliated with energy, biogas and waste. The sample varied based on either their sector of occupation or public vs. private (statutory) position. As such the interviewees were from the Ministry of Energy and Energy Affairs, SWMCOL and the Sugarcane Feeds Centre (see Appendix A). Pseudonyms have been used in the report to protect the identity of the interviewees as some preferred to remain anonymous. Snowball sampling was used to an extent as contacts were established based on referrals from interviewees. A combination of face-to-face and telephone interviews were employed. The direct interviews took place at the offices of the interviewees, thereby maintaining the familiarity of the environment and the naturalness of the research (Bryman, 2008). The interviews ranged from 15 to 69 minutes in length. In the initial cases hand notes were made, however, subsequent interviews were accompanied by digital recordings. All interviews were transcribed to an electronic format within twenty-four hours of the discussions.

Semi-structured interviews were useful as they allowed data to be captured on the array of questions on the interview schedule, whilst still allowing freedom in the responses, comparisons amongst different interviewees and the flexibility to include additional questions where further insights were deemed necessary (Bryman, 2008). The sampling method allowed relevant data to be captured within the scope of the research question. Interviews were conducted until the point of empirical saturation (Bryman, 2008).

2.3.2. Documents

Textual material was collected directly from primary sources where they were either published or commissioned for publishing as well as from secondary sources both electronically via internet searches and as published literary material. Many of these were grey literature including official reports on government policy on RE, studies on waste characterisations conducted at the Beetham Landfill and across the country from government bodies and private companies, as well as archival records from state and private sources and peer-reviewed articles on the topic. Information from the mass media, specifically archives from online newspapers was also utilised. Determinations of integrity were based on the independence and purpose surrounding researched and published material and as far as possible Scott's (1990) four criteria of authenticity, credibility, representativeness and meaning (Bryman, 2008). The use of documents helped to increase the validity of the study as such materials can be discredited from the probability of producing a reactive effect as is synonymous with interviews (ibid).

2.3.3. Observation/Site Visit

To gain a better appreciation of the landfill, its dynamics and to gather and validate empirical material a field visit was conducted. This was arranged by one of the interviewees of SWMCOL and took place on 8th February, 2012. The site visit occurred immediately after the interview session and lasted for 50 minutes. As I was not in appropriate protective gear, health and safety restrictions limited the site visit to a narrative-driving tour and so observations were made within the confines of the vehicle. These restrictions compounded with security reasons inhibited interviews with the salvagers. However, discussions with staff familiar with the activities of the salvagers and reference to documents containing one-on-one interviews with these waste interceptors were able to reveal insights that could not be directly captured. Regardless, through the field visit I acquired an understanding of the layout of the facility, the nature of the deposited materials in terms of type and level of decomposition, the variety of activities including landfilling, bottle recovery and sewage ponding, and the interactions among the human elements, the landfill and the natural ecosystem. Photographic documentation was also made of this trip and copies can be viewed in Appendix C.

An abductive approach, based on an inductive orientation was used to analyze the empirical material. Following transcription of the interviews the data analysis consisted of examining and categorizing as the basis of making empirically based conclusions (Yin, 2009). The structuring was conducted according to the divisions in transition theory.

2.4. SCOPE, LIMITATIONS & TRANSFERABILITY

Scope

The thesis is focused primarily on the production segment of biogas and does not provide an in-depth analysis into the methods of diffusion or utilisation of the gas. However, segments on the use of biogas in the transport sector have been included to indicate the manner in which biogas can be integrated into the local context.

Furthermore, this thesis does not investigate the different tiers of waste management starting from production to consumption and eventually disposal, nor does it analyse other strategies for treatment of waste such as recycling or composting. It therefore does not provide a holistic view of an integrated waste management strategy as the focus is on n energy shift, but instead it acknowledges that waste to energy production is but one solution within this larger frame.

Additionally, only one of five main landfill sites in T&T was used as the case study. This was mainly because my preliminary data collection indicated this would have been the best option for biogas research based on its size and the nature of the refuse. As such the potentials at the other sites have not been included as part of this investigation.

Limitations

One of the early limitations identified while conducting the research was that some of the quantitative or technical data was not accessible. This was because in many instances it was never collected by the relevant agency due to lack of expertise, equipment, capability or interest. For example the current gas emissions (particularly methane) from the landfill. As such the focus of the study was restricted by the absence of such data. Additionally, in a number of cases the technical information that was available was actually outdated. This did not severely impede analysis of the data, but it did induce some reservations regarding conclusive statements on future trends or in making calculations to this end.

In terms of the framework chosen, a lot of the empirical evidence used to support the transition theory is based on cases within developed countries. T&T does not fall into this category and it may be argued that the conditions in these examples do not correspond to T&T's context. However, these differences did not restrict the use of this conceptual framework as the theories are being used for analytical generalisations and would require manipulation regardless of the setting.

Transferability

The research is conducted in T&T, which although is still generally classified as a developing country, is fairly affluent due to a prospering hydrocarbon economy. This directly influences the structure of the energy system and even by extension the consumption patterns of the population, which affects the type of waste material deposited. Therefore the results of this case may be difficult to transfer to some similarly developing nation contexts. However, as a small island developing state (SIDS) the country bears a number of similarities that typically make such states vulnerable. Some of these characteristic vulnerabilities include geographical dispersion, vulnerability to natural disasters and climate change, extensive economic openness and small internal markets which result in them sharing similar sustainable development challenges (Briguglio, 2003). Therefore, value would be obtained from the research as the findings could be at least transferred to these other settings, although they would require some adjustments to suit the respective local contexts.

3. BIOGAS- AT THE ENERGY& WASTE CROSSROADS

Biogas is a fuel gas mixture, composed typically of 55-70% methane, 30-45% of carbon dioxide and 200-4000 ppm by volume of hydrogen sulphide as well as other gases in small quantities (RISE-AT, 1998). It is produced under natural conditions during a process called biomethanation, where organic material undergoes anaerobic decomposition. Anaerobic digestion occurs naturally and uncontrolled at landfills and under strict conditions the gas produced is termed landfill gas (LFG) (Johannessen, 1999).

There are multiple sources of input for biogas production such as animal by-products from slaughter houses or agricultural farms, municipal solid waste (MSW) or wastewater. When using MSW there are environmental advantages such as reduced carbon dioxide (CO_2) emissions arising from non-combustion of conventional fossil fuels and a decrease in the quantity of methane gas released into the atmosphere (NSR,2007). The latter is significant as methane tends to be emitted abundantly from landfills and has a twenty times higher global warming potential compared to CO_2 (Verma, 2002). Furthermore, energy production with this feedstock can be expanded with only small risks of conflicts (Borjesson et al., 2009), as for instance it does not create tensions with competition for land use as the case may be when using crop feedstock.

Biogas can be produced at various scales from household to national and has a range of applications. These include the production of electricity and district heating, as an addition to the natural gas grid, vehicle fuel, or as a bio-fertiliser if the residual matter from the digestion process is utilised (NSR,2007).

Apart from being one solution to energy production, as an alternative, cleaner fuel, biogas production also has a complementary role as a strategy for waste treatment if LFG is used. This is the case as the organic matter segment is removed from the solid waste stream and is used as the feedstock for generation. There are also benefits related to anaerobic digestion (see Appendix F) and improvements with landfilling operations. These will be expanded on below after the discussions firstly on LFGTE production and then on biogas' use in the transport sector.

3.1. PRODUCTION OF BIOGAS: LANDFILL GAS TO ENERGY (LFGTE)

The supply of MSW tends generally to be in a steady flow during the year, thereby ensuring a secure source of input material for digestion. MSW is heterogeneous waste that is classifiable into three broad fractions: readily biodegradable, combustible and inert (IEA, 2001). With regard to LFGTE production the readily biodegradable segment consisting of kitchen and garden waste, food residues, paper and paperboard is the most suitable for energy recovery by anaerobic digestion (Verma, 2002). The digestion of MSW undergoes three key procedures: pre-treatment to homogenise the waste stream, anaerobic digestion when the biogas production occurs and post-treatment where the digestate is purified and refined to meet local standards (IEA, 2001).

There are a number of key determinants of the amount of biogas generated from landfills. These include the quantity and type of refuse, the rainfall activity and ambient temperature at the site, the degree of wetness of the waste stream, the extent of waste compaction, the height of waste deposition mounds, the nature of the cover material, the age of the landfill and finally the barometric pressure (Cenbio, 2008 as cited in Garcilasso et al., 2011). It is estimated that for every tonne of waste deposited in a landfill an average of 200 Nm^3 of biogas is generated (Johannessen, 1999). For any landfill to be eligible for marketable production of LFGTE, the site requires a deposit of at least 200 tonnes of waste daily, have a minimum total capacity of 500,000 tonnes during its lifetime of operation, a mounting height of at least 10 meters and a period of waste deposition not exceeding 5 to 10 years prior to initiation of LFG recovery (ibid).

Bioreactor Landfills as shown in Figure 1, are properly engineered sites designed to capture LFG for bioenergy purposes and to collect the leachate. This creates the ideal operational and environmental conditions particularly regarding the moisture content within the waste. This technology facilitates more rapid and complete degradation of waste (Karthikeyan & Joseph, n.d.) and also optimises the financial returns.

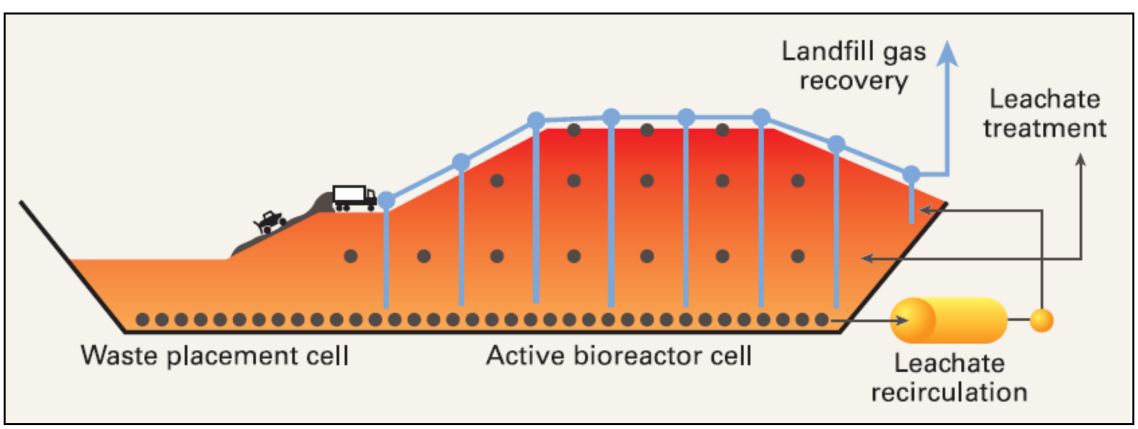


Figure 1: Schematic view of a Bioreactor Landfill

Source: Karthikeyan & Joseph, n.d

3.2. USE OF BIOGAS: TRANSPORT SECTOR

As indicated previously there are multiple uses of biogas but when applied for vehicular use (as is suggested for this case), it is upgraded using a compression and storage technology similar to compressed natural gas (CNG) (Reith et al., 2003). During this procedure the CO_2 is removed to produce biomethane, which has a methane content of 96 - 97 % volume, while impurities like sulphur, water and other particles which can impair engine functioning are also eliminated (ibid). This conversion process is prominent in a number of countries including Sweden, which is the global frontrunner, France, Czech Republic, the USA and New Zealand (Reith et al., 2003; Engdahl, 2010). Studies have shown that biogas and a CNG/ biogas hybrid produce the same level of performance as conventional fuels in vehicles (Addyman, 2010).

3.3. ADVANTAGES &DISADVANTAGES OF BIOGAS PRODUCTION & USE

Advantages

Apart from the enhanced biogas extraction, during a period of 5 to 10 years of bioreactor process implementation there is also a much faster rate of waste stabilisation[2] compared to conventional landfills (Pacey et al., 1999). As a result of this accelerated stabilisation, there is increased capability for recovering landfilling space and by extension a reduced need for finding additional sites as bioreactors can be built on old lots. Additionally, the leachate management that is synonymous with this system procures ecological benefits as it closes the nutrient cycle through the reabsorption of the leachate and the production of bio-fertilisers from the slurry, which returns nutrients to the soil. Reinhart & Al-Yousfi, (1996) also indicate that landfill bioreactor technology aids in minimizing long-term liability of landfill operation.

Notwithstanding these are also the economic and social benefits that are derived as either direct or auxiliary outcomes of the aforementioned advantages. The revenues gained from biogas production and sale, the notable economies of scale emerging from high gas production within a short time frame (Pacey, et al., 1999), alternative fuel source, offsetting of GHG emissions as well as the reduction in the

[2] Waste stabilisation is the ability of the LFG composition and generation rate and leachate constituent concentrations to remain at steady levels and not increase in the event of any partial containment system failures (Pacey et al., 1999).

amount of pollutants emitted, pathogens generated and odour emanating from waste are some of the prime examples.

Disadvantages

One shortcoming of biogas production is the reversal of the positive environmental effect of biomethane compared to petrol which may arise from a methane slip (methane emission during production, upgrading or distribution) (Wellinger, 2009; Linder, 2009). However, there are mitigation measures to avoiding this from transpiring. Additionally, the digestate could contain varying amounts of biological, physical or chemical contaminants from MSW (Lukehurst et al., 2010). This could pose health risks for humans and the ecosystem when used as fertiliser in the agricultural system, but stringent standards and monitoring for quality control can minimise this.

Tensions can also arise if biogas production taps into the same waste stream used by scavengers or alternative waste strategies like recycling or composting. The attendant social conflicts can be reduced by deliberate strategies to integrate the salvagers into the biogas production chain. Unestablished recycling schemes may be more lucrative if alternate materials like plastics are sourced while existing companies may employ legislative interventions or mutual concessions. On the other hand the diverse range of benefits afforded by biogas production will likely outweigh those gained from composting.

4. OVERVIEW OF THE CASE

Trinidad and Tobago is a twin island republic located in the southernmost archipelago of the West Indies. Collectively, there is a land area of 5,128 km^2 and a population of 1.3 million inhabitants (CSO, 2011). Due to its location within the equatorial belt, the islands experience a tropical climate and are subjected to two main seasons, the dry and wet. The geologic history and location has allowed Trinidad to be endowed with a rich supply of petroleum and gas resources. These domestic supplies make the nation the prime producer of crude oil and natural gas in the Caribbean (MEEA, 2011) and procure substantial revenue to qualify the country as the most industrialized economy in the English-speaking Caribbean (Artana et.al, 2007).

4.1. BACKGROUND OF THE ENERGY SECTOR IN TRINIDAD AND TOBAGO

The abundant hydrocarbon deposits located on the south-eastern quadrant of Trinidad were first drilled successfully for oil in 1866 and in 1908 commercial exploits began (Enill, 2009). However, by the early 1970s in the midst of declining domestic revenues from the formerly booming oil sector, the government instituted strategic policy initiatives that catapulted natural gas as the premiere energy resource. Since then, natural gas has been the driver behind the nation's development trajectory and constitutes the primary economic base for the country's GDP, revenue and foreign exchange. In 2010 the energy sector was estimated to account for 35.8% of the GDP (Central Bank of Trinidad and Tobago, 2010).

Energy Demand & Supply

Understandably, these non-renewable resources are also the main source of energy supply in the country. According to the International Energy Agency [IEA] (2009), natural gas accounted for about 92% of the TPES while oil constituted approximately 8% of the total share. Figure 2 illustrates an increasing trend of natural gas production and consumption over the last decade.

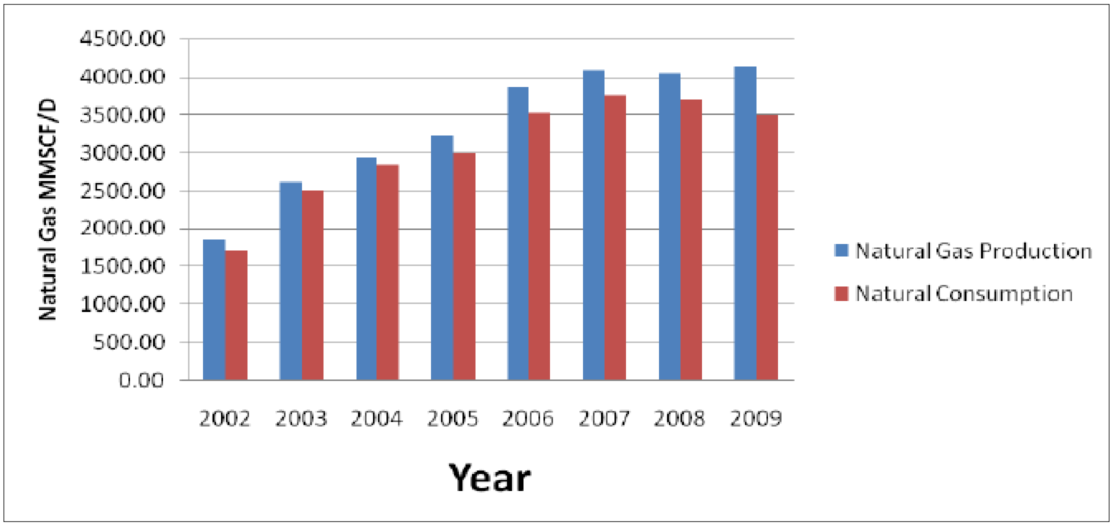


Figure 2: Production and Consumption of Natural Gas in Trinidad & Tobago

Source: MEEA, 2011

The crude oil is used locally for manufacture of petroleum-based products, while the natural gas is used as a fuel source for electricity generation, heavy industry, within the downstream petrochemical industry, commercial ventures or as motor vehicle fuel as CNG (MEEA, 2011). The energy sector accounts for 80% of exports, allowing the nation to position itself as the largest exporter of ammonia and methanol globally (BP, 2008; CIA, 2011).

Impacts of the Energy Sector

Unfortunately, the strides made in the petrochemical industry have had negative outcomes. According to a Ryder Scott Audit, the reserves are declining and as of December 31, 2010, T&T's proven and probable gas reserves were equivalent to roughly 14 years of production (Long, Marajh & Abdul-Haqq, 2011). The booming sector has also resulted in air and water pollution, ecological damage as well as health and safety concerns (Chandool, 2011). One major concern has been the steady increase in CO_2 emissions over the years. Statistics reveal a 253.3% change from 1990 to 2009 and a figure of 40.2 million tonnes of CO_2 as of 2009 (IEA, 2011b). Placed against a global perspective, in 2008 T&T was ranked third with respect to per capita carbon emissions (Thomas, 2009). Figure 3 shows clearly that the petrochemical sector in conjunction with heavy industry represents the largest source of GHG emissions. On closer inspection, when the energy sector is viewed in its totality (i.e. as a combination of direct combustion of fossil fuels, power generation and transportation) it accounts for the predominant portion of CO_2 emissions.

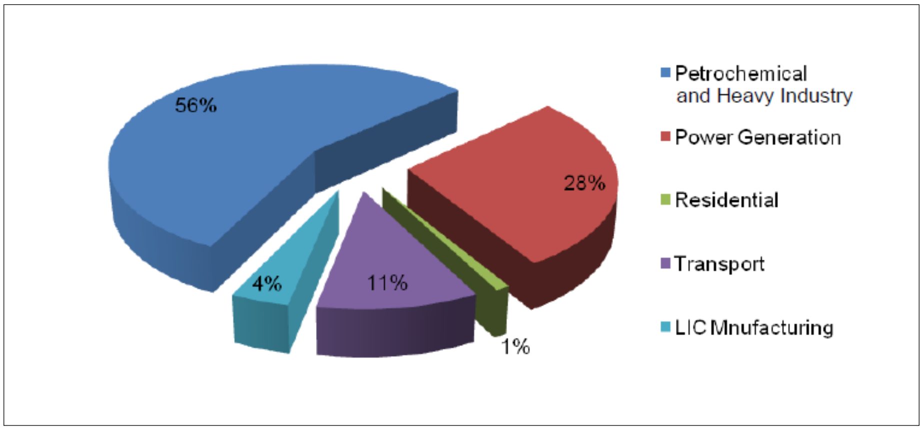


Figure 3: Trinidad & Tobago's CO_2 emissions by sector (2007)

Source: Boodlal, Furlonge & Williams, 2008

Energy Use

R. Khan (personal communication, January 26th, 2012) indicated that Trinidad already receives a substantial supply of energy to the electricity grid and with the new 720 megawatt power generation plant-Trinidad Generation Unlimited-currently there is surplus production until 2016. As such potential use of biogas for power generation would be redundant and possibly unlikely to propagate ample quantities to support local consumption. However, deploying biogas for use in the transport sector will be comparatively easier, fit a better niche market and simply require upgrading to be compatible with recently constructed CNG systems, hence its selection for this sector.

Transport Sector

The transport sector in T&T is profoundly reliant on fossil fuel resources and the Government heavily finances a petroleum fuel subsidy. The National Petroleum Marketing Company Limited reserves the monopoly on gasoline distribution in the country. Over the years there has been a steady increase in vehicle ownership, the result of which has been noticeable contributions to CO_2 emissions as illustrated in Figure 3 above.

The Government's policy position on reducing emissions in the transport sector is to promote the use of CNG. The programme aims at achieving conversion of 20% of the estimated 500,000 vehicular population to CNG use by 2015 through tax allowances and infrastructural investments to increase the quantity of filling stations and fast-fill pumps nationwide (Dookeran, 2011; MEEA, 2011). Currently there are nine CNG stations in operation in the country (Dookeran, 2011). This endorsement of the use of CNG is in line with a viewpoint that it is a cleaner burning fossil fuel with less harmful effects on the environment (ibid). However, there have been interventions moving towards renewable sources and these will be discussed in the upcoming section.

4.1.1. Renewable Energy in Trinidad & Tobago

There have been a number of small scale and uncoordinated initiatives and projects in the past focusing on the development of RE in the country. However, recently the Government of T&T has embarked on measures to incorporate RE policies into the local energy dynamics. The first of these steps has been the formulation of a Framework for Development of a RE Policy[3] in 2011.

The Framework acknowledges that improvements within the RE field will procure several benefits for the country, including increased diversity of the energy supply and entrepreneurial developments, boosting employment opportunities and enhancing the fiscal flow.

The policy framework only underscores the RE options that are profitable and cost effective within the local context. As such, it has highlighted the use of technologies such as wind, solar and waste to energy and biofuels (bio-ethanol and bio-diesel as options where research can be directed as alternatives for electricity generation and for the transport sector.

[3] Framework for Development of a Renewable Energy Policy for Trinidad and Tobago. Accessible at: http://energy.gov.tt/content/266.pdf

4.2. BACKGROUND OF THE WASTE SECTOR IN TRINIDAD AND TOBAGO

Landfilling is the main method of waste disposal in T&T. In 1983 the state enterprise, SWMCOL was established with the directive for responsibility for the three major public landfills in Trinidad: Beetham, Guanapo and Forres Park, while the other two, the Guapo Landfill and Studley Park functioned under private management and the Tobago House of Assembly respectively (Appendix D) (Hilton, 2010). The collection of domestic waste is undertaken by the Regional Corporations within their respective municipality.

Within Trinidad at least 700,000 tonnes of solid waste is generated on an annual basis, equivalent to a waste production rate of 1.50 kilograms per capita per day (CBCL, 2010). This latter figure is synonymous with generation rates found in an average modern, thriving and industrialised society. It is estimated that by the year 2020, the country will be generating 1.4 million tonnes of municipal solid waste (MSW) per year (Singh, Kelly & Sasrty, 2009), a striking figure reflecting the enormity of the situation.

Table 1 displays the composition of waste matter in Trinidad and indicates that organic material represents the highest proportion of the waste stream, constituting a value of 27.15% from food waste (18.98%) and yard waste 8.17% (CBCL, 2010). This organic material figure was considered to be low and was attributed to the unusually high proportions of other materials and dry climatic conditions which reduced the quantity of landscaping vegetation disposed.

Table 1: Waste Composition in Trinidad

Material	Average Proportion	Range of Values at 95% Confidence Limit (plus or minus)
Recyclable		
Organics	27.15%	1.91%
Plastics Excluding Beverage Containers	19.17%	1.31%
Paper, All Classes	18.77%	1.56%
Glass	10.15%	0.97%
Old Corrugated Cardboard	3.83%	0.60%
Metals, Ferrous	2.33%	0.44%
Metals, Non-Ferrous	1.41%	0.21%
Beverage Containers	0.92%	0.15%
Subtotal	83.73%	-
Non-recyclable		
Textiles and Clothing	7.82%	1.21%
Household Hazardous	5.24%	0.90%
Other	2.71%	0.48%
Construction and Demolition	0.50%	0.34%
Subtotal	**16.27%**	-
Grand Total	**100.00%**	-

Source: CBCL, 2010

4.2.1. The Beetham Landfill-Case Study Site

Site Background

The Beetham Landfill, as seen in Figure 4 (Appendix B), is situated in Trinidad to the southeast of the capital city, Port-of-Spain and began as an unplanned, uncontrolled development (J. Smith, personal communication, January 4th, 2012). It is believed to have originated in the 1970s and was inherited from the then County Councils (now Regional Councils) (A. James, personal communication, February 8th, 2012). It was only at the point of SWMCOL'S intervention from 1983 onwards that there was the introduction of a "landfilling principle" (K. Dean, personal communication, January 11th, 2012) with more mechanisation, waste compaction by tractors and local importation of silty soil for use as cover material (Chang, 1998). Beetham currently serves as T&T's largest waste disposal site, comprising 61 hectares and receiving more than 54% of the country's waste (Singh et al., 2009). The landfill services an area spanning the east-west corridor from Chaguaramas to Curepe and areas to the south of Chaguanas (see Figure 4) (CSO, 2007).

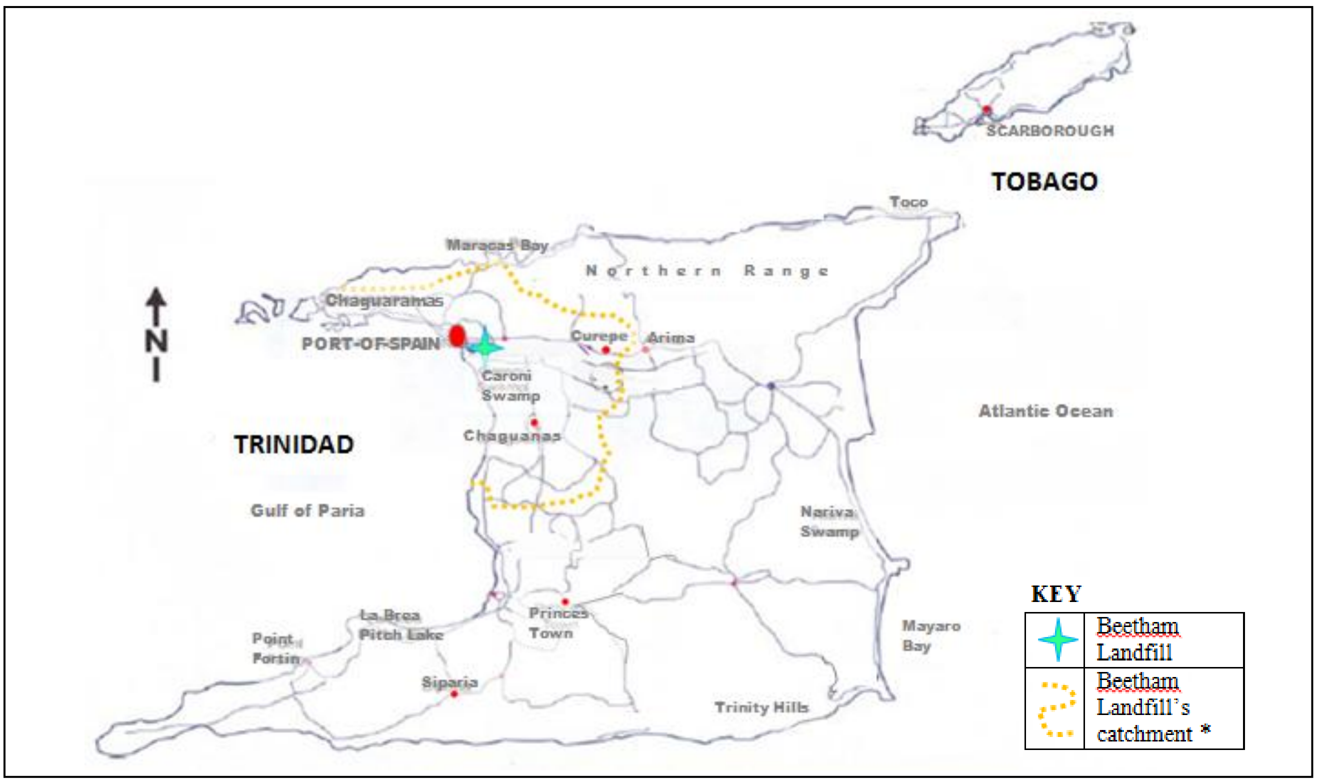


Figure 4: Map of Trinidad and Tobago showing the location of the Beetham Landfill
Source: Adapted from CSO, 2007

*Author's delineation as a visual aid

Apart from landfilling there is also an informal bottle recovery facility, metal recovery by salvagers as well as a faecal waste stabilisation pond system, where dump trucks deliver the waste matter directly to the retention site (Singh et al., 2009). These features were all observed during the field visit and are visible in Appendix C.

This unlined facility rests on wetlands and is also on the northern edge of the Caroni swamp, the largest mangrove swamp in Trinidad (Mohammed, 2010). J. Smith (personal communication, January 4th, 2012) indicated that as the landfill rests on an active tidal swamp, brackish water enters which reduces the speed of waste decomposition. This leads to the occurrence of “wet waste” at lower depths. Its proximity to such fragile ecosystems poses an indisputable environmental threat leading to water pollution from the leachate and physical waste material and also landfill gas migration (Burnside, 2004). There are also health issues arising from compromised air quality due to either the stench emanating or the fires at the site and potential diseases from the plethora of vectors and vermin that inhabit the landfill (ibid). These have effects beyond the community, extending to the capital and on those in transit through the area.

The operating timeframe of the Beetham Landfill has been exceeded, though according to J. Smith (personal communication, January 4th, 2012) “Beetham never should have been opened” and so there was a proposition to close it in 2003 (Hilton, 2010). However, this was never realised and so it remains in operation, mainly because alternatives are lacking.

Waste Composition

Survey findings at the Beetham indicate that organics and paper were in highest proportions amongst the other landfills as well as at that site, a trend well illustrated in Table 2. According to Garcilasso et al. (2011), the quantity of [biogas] production is always affiliated with the type of waste, which consequently is related to the socioeconomic characteristics of the population involved. Organics and paper quantities exhibit a direct proportional relationship with increasing income, as those within the higher income brackets handle more packaging and reading materials and discard more food and perishable organics (CBCL, 2010). The results for Beetham correlate to waste disposal arising from the higher income households situated in the landfill’s catchment.

Table 2: Waste Composition in Trinidad by Income Level and Landfill Site

			'Organics'	'Plastics'	'Paper'	'Glass'	Textiles/ Clothing'	'Household Hazardous'	'Corrugated Cardboard'	'Other'	'Metals - Ferrous'	'Metals - Non Ferrous'	'Beverage Containers'	'Construction & Demolition'
All Samples	Mean (%)		27.15	19.17	18.77	10.15	7.82	5.24	3.83	2.71	2.33	1.41	0.92	0.50
	95% CI (%)		1.91	1.31	1.56	0.97	1.21	0.90	0.60	0.48	0.44	0.21	0.15	0.34
	N		197	197	197	197	197	197	197	197	197	197	197	197
By Income	Mean (%)	'very low'	24.70	21.05	18.24	9.80	7.60	5.84	3.85	3.10	2.77	1.50	1.04	0.52
		'low'	27.26	18.18	19.62	10.90	8.73	4.87	3.71	2.19	2.06	1.38	0.84	0.27
		'high'	39.21	12.30	20.75	6.30	6.13	3.90	4.34	3.02	1.33	0.95	0.86	0.91
By Landfill	Mean (%)	Beetham	32.04	16.04	21.43	8.74	8.18	5.12	2.81	1.79	1.79	1.05	0.81	0.20
		Forres Park	22.37	26.02	13.68	11.56	7.75	4.77	4.87	2.68	2.22	1.75	1.26	1.06
		Guanapo	21.73	19.12	18.00	10.26	6.63	6.42	5.42	5.21	4.16	2.15	0.85	0.05
		Guapo	10.54	17.02	18.69	22.90	8.57	4.70	4.54	5.51	2.86	0.67	0.62	3.40

Source: Reconstructed from CBCL, 2010

The large quantities of organic material deposited at the Beetham in addition to its size were the reasons it emerged as the case site for this analysis. According to Burnside (2004) a site of Beetham's capacity would be an ideal candidate for a LFGTE facility. The empirical information from the Beetham Landfill correlates with the theoretical figures on quantity of waste, climate etc. presented within Section 3, thereby indicating that the technical potential exists for biogas production at the site. Based on some very rough calculations (see Appendix G), it is estimated that approximately 175,000,000Nm^3 of biogas is potentially produced annually at the Beetham Landfill and so figures within this range are potentially recoverable.

4.3. BIOGAS PRODUCTION IN TRINIDAD AND TOBAGO

Biogas production in T&T began in 1989 with the construction of a demonstration plant at the Sugarcane Feeds Centre (SFC), an institution that specializes in applied research, development, demonstration and training in tropical livestock production (Neckles, 1990). This was facilitated through the financial and technical assistance of the formerly GTZ, now known as GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit) and the Caribbean Development Bank. In 1997 two units were simultaneously built; at SFC and at a private enterprise, Ali's Pig Farm (Neckles, 2009). These two units in conjunction with a third constructed at the Golden Grove Prison some years prior, meant a total of three units have been in operation in the country. The feedstock for all these units however, was the effluent from pigs as the biodigester technology was introduced as an integrated on-farm system of production to produce energy, digest waste and reduce environmental concerns of pathogens and [animal waste] disposal (T. Lee, personal communication, February 7th, 2012).

Currently SFC is the foremost producer of biogas in the country. It is a $50m^3$ operation with the gas being used for drying feedstock, heating water for scalding pigs and producing heat for brooding chickens, ducks etc. (T. Lee, personal communication, February 7th, 2012). Funding is received from the Ministry of Agriculture, Land and Marine Affairs, while the outstanding share is obtained from various enterprises at the Centre.

Benefits of Biogas for T&T

In a nation with a relatively small population but high levels of per capita greenhouse gas emissions and heavy reliance on the energy sector, it is evident that alternative measures need to be enacted. Introducing biogas production could provide a number of benefits as: it can work towards reducing the number of GHG and air pollutants, diversify the energy sector, which lessens the effects of shocks from external pricing, reduce the consumption rate of this finite resource, thereby prolonging the availability of the current reserves for use in more favourable ventures as well as encourage the adoption of an inter-generational mind-set. According to some rough calculations (as shown in Appendix G), based on the current biogas emissions from the Beetham Landfill, this could potentially contribute approximately between 8.6%- 11.0% to the energy content in the transport sector annually.

Additionally, LFGTE technology provides irrefutable benefits in waste treatment and for the environment, which directly favours the Beetham Landfill. It also reduces the requirement of finding alternative landfill sites, yet another advantage for a SIDS.

Although for LFGTE, production will be required on a grander scale and using a different waste stream, the existing biogas units indicate the awareness, experience, familiarity and potential for deployment of this type of technology in T&T.

5. THEROETICAL FRAMEWORK~ TRANSITION THEORY

5.1. CHARACTERISATION OF TRANSITIONS: DEFINITION & TYPOLOGY

The theoretical outlook is a key determinant in the manner in which a transition is defined. In terms of societal transitions, it is described by Rotmans et al., (2001) as "a gradual, continuous process of change where the structural character of a society (or complex sub-system of society) transforms". This occurs within at least one generation (25-50) years due to the interaction of several elements including: economic, cultural, technological, institutional and environmental (Rotmans, 2005). For a socio-technical transition, society and technology co-evolve, with technology manifested as both the result and impetus of transformation (Kemp, 2010). In both cases there is a shift in the dynamic equilibrium, with a new system replacing or transforming another.

The transformative change in transitions is comprised of system innovation (as opposed to standard innovations) and this revolves around central characteristics like high uncertainty, lengthy timespans, complexity and based on and influenced from multi-disciplines (Rotmans, 2005). Such features make transition theory useful for charting the incorporation of biogas technology in the T&T context.

Transitions can be classified into two categories: (i) emergent: where there is limited coordination among actors and transitions occur via the principles analogous to evolution via 'survival of the fittest' and (ii) target oriented (teleological): where high levels of coordination occur between decision makers to guide them towards realising a pre-determined (diffuse) objective (Kemp & Rotmans, 2004; Rotmans, 2005). The latter however, does not essentially imply that a preconceived goal must be achieved, but rather it is the orientation towards a transition that minimises conflict and provides collective benefits (Rotmans et al., 2001).

Transitions can be explored using two conceptual frames: multi-level and multi-phase. However, the multi-phase will be excluded from this analysis as its temporal basis negates its applicability since biogas has not yet entered mainstream application and so may be classifiable only in the pre-development phase of this perspective.

5.2 . THE MULTI-LEVEL CONCEPT

The underlying premise behind the multi-level perspective (MLP) is that transitions only arise when trends, developments and events reinforce each other on the three functional scale levels: macro, meso and micro (Rotmans, 2005) as shown in Figure 5. These scale levels correspond with the classification system employed by Rip and Kemp (1998) and include the socio-technical landscape, regime and niche respectively (Rotmans et al., 2001).

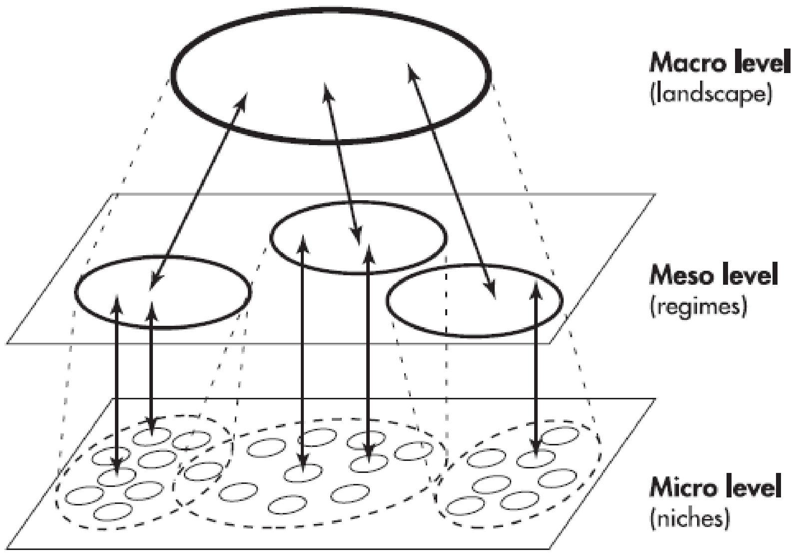


Figure 5: The Different Scale Levels of a Transition
Source: Rotmans, 2005

When the processes at the different phases and scales align, novelties emerge into the established markets where they challenge the structures of the existing regime. These different levels are illustrative of functional relationships between actors, structures and working practices (Rotmans. 2005). Within this nested hierarchy conceptualisation, as one ascends the scale levels from micro to macro, the speed of dynamics between actors, working practices and structures decreases while the level of aggregation of system components increases (Rotmans, 2005).

The socio-technical landscape (macro) level is an exogenous context within which the deep structural trends are embedded (Geels, 2002). These include oil prices, economic growth, globalisation, broad political coalitions, cultural values, paradigms and environmental problems (Geels, 2002; Rotmans, 2005). Changes at this scale lie outside the immediate sphere of control of niche and regime actors and progress relatively slowly (decadal phases) (Geels & Schot, 2007). However, it is these changes that exert pressure on the regime (ibid).

At the socio-technical regime (meso) level there are three interconnected dimensions (Geels, 2005; Verbong & Geels, 2007): a socio-technical system, a network of human actors and social groups and a set of formal, cognitive and normative rules. The prevailing practices, beliefs, rules and interests are used as the basis for steering the activity of actor groups, who work towards resisting changes to the configuration of the status quo (Rotmans et al., 2001; Rotmans, 2005). This opposition may be the outcome of a lock-in situation arising out of increasing path dependence. Consequently, interferences that may be caused by the introduction of new innovations, or pressure from the surrounding levels are counteracted by system improvements to existing structures so as to maintain the stability of the regime. When the regime is destabilised however, windows of opportunity are created for niche innovations (Geels & Schot, 2007).

Within the niche (micro) level, which relates to individual actors or technologies, greater flexibility exists to digress from the norm (Rotmans et al., 2001). It is at this level that radical innovations, techniques and deviant social practices tend to build up momentum. These are enabled by learning processes, price/performance improvements, and support from powerful groups (Geels & Schot, 2007). Niches provide 'safe' spaces where novelties are shielded from the market forces found at the regime scale and they also facilitate the formation of innovation support networks (Geels, 2002). Novelties arise as mechanisms to deal with the deficiencies within the existing regimes (ibid).

5.3 . CRITICISMS OF TRANSITION THEORY & RESPONSES

The transitions concept has gone under criticisms for three main aspects. Firstly, there is a view that a disconnect exists in reconciling empirical cases with the conceptual levels in the MLP. Proponents of this argument advance that it is difficult to ascertain the boundaries of the socio-technical regime in empirical cases and therefore by extension to make accurate assessments on whether an actual transition has taken place (Berkhout, Smith & Stirling, 2004). The second point of contention is the seemingly insignificant esteem to which agency is embodied in the framework (Geels & Schot, 2007). The framework is also admonished for making representations that are functionalistic and depict a uniform, rational process with minimal acknowledgements of variations in contexts (Smith, et. al., 2005).

Lastly, there is a position that changes to the regime are not necessarily the outcome of thrusts from the technological niche and conventional discourses should reduce this emphasis (Berkhout et al., 2004).

In light of these shortfalls Geels & Schot (2007) have advanced some responses which seek to address the matter and make improvements to the concept. With respect to the first critique these authors assert a distinction exists between analytical levels and empirical levels and it should be within the user's cognition to discern the appropriate empirical scale before applying the MLP. In so doing, the more befitting scale would be one where system changes occur, that is, one where there is an impact on policies, behaviour and cultural meaning. Regarding the oversight of agency in the MLP, in their estimation Geels and Schot (2007) see the three levels as structures that vary in their impact on the action and interaction of actors as they interpret, replicate, modify and reconstruct rules. So while there are no explicit references to actors in the figure, their actions have an influence on the processes. Geels and Schot (2007) also contend that this cognitive nature of actors along with other elements like market or power rivalries can be used to refute the claims that the MLP is functionalistic and action is rational.

On the third point of criticism there is a proposition that greater attention needs to be paid to the continual processes at the landscape and regime levels, instead of the explicit niche driven bias (Geels & Schot, 2007). As such four different transition pathways; transformation, technological substitution, reconfiguration and de-alignment and re-alignment were devised where different multi-level interactions can take place to lead to transitions (ibid).

5.4. ANALYTICAL APPROACH

The use of transition theory as an analytical and theoretical framework is suited for this case as it neatly maps the multiplicity of changes and synergistic evolution of society and technology involved in integrating a sustainable innovation system in T&T. According to Rotmans and Loorbach (2009) the process of social learning and acceleration, which are critical elements of the transition process, can be stimulated by monitoring the rate of progress (along with the driving forces), the barriers, and the points to be improved. The MLP conceptualises these dynamics and from multiple hierarchical levels which is useful as the transformations in the energy and waste sectors are not only complex and uncertain, but are also influenced from different scales. These multi-scalar, multi-faceted and interconnected features are similar to the characteristics of sustainability challenges and so likewise require integrated solutions across scales and domains (Kates et al., 2001), which the MLP effectively frames.

However, there are practical limitations in applying the theory and framework as there are contextually specific features that it cannot capture. As such the author's discretion had to be applied at certain occasions.

This analysis is classified as a target oriented approach as the actors work towards achieving a pre-determined goal of incorporating biogas production within the T&T context. Within the proceeding data analysis the landscape level would include activities and developments stemming from an international scale. The regime level would involve the decisions, rules and actions originating from actors like the government and organisations or networks at and beyond the national scale. The niche level makes reference to specific features at the scale of the Beetham Landfill, individual actors like households or scavengers and to the biogas technology.

Bearing this in mind the succeeding section opens with a description of the status quo and then an exploration of what are considered the key driving forces and barriers of this transition process. These findings will then be used to inform the subsequent discussion and recommendations on resolving these tensions so as to facilitate the transition.

6. DATA ANALYSIS & DISCUSSION

As fossil fuel energy production has been the dominant energy system since its commercial exploitation in 1906, its preeminent role in the nation's economy has led to a fossil fuel lock-in. Foxon (2002) argues that the current state of carbon lock-in energy systems is driven by technological and institutional factors mutually reinforcing each other to create a techno-institutional complex. This according to Unruh (2002) has driven industrial economies to a path dependency, which is what has occurred in T&T.

Innovation is very important for overcoming lock-in to existing technological systems and/or lock out of emerging, more resource efficient technologies (Foxon, 2002). This stands as it provides a range of positive externalities like creating options for substitution, mitigating against uncertainties and enabling shorter resolution timeframes for environmental problems (ibid). Thus the introduction of a technological system like LFGTE will deliver these benefits for propelling the transition to break the fossil fuel carbon lock-in in T&T. Further, as experimental projects such as pilots are means to create technological niches[4] (Raven et. al, 2011) a pilot study at Beetham Landfill will provide an ideal foundation for developing this technology. The driving forces and barriers of this LFGTE transition process will be elucidated below.

6.1. DRIVING FORCES FOR LFGTE PRODUCTION

6.1.1. Socio-Technical Landscape (Macro Level)

i. Worldviews

The paradigm of sustainable development became a popularised dogma since the report of the Bruntland Commission 'Our Common Future'. By encouraging a balance among the three pillars economy, society and the environment with regard to development, the report aimed to shift the inter-generational thinking and understanding of these interlinkages. This approach has transcended into local political and societal arenas and T&T has similarly expressed intentions to embark on a course of sustainable development. In terms of the energy sector, the government's ambition is to encourage RE, clean energy production, the maximization of energy efficiency and the provision of a sufficient and

[4] Technological niches are protected spaces that allow nurturing and experimentation with the co-evolution of technology, user practices, and regulatory structures (Geels & Schot, 2008).

affordable energy supply for societal needs, as they recognise these as critical elements in the pursuit of sustainable development (MEEA, 2011).

ii. Natural Environment

Since the period of Industrialisation, anthropogenic activity such as fossil fuel combustion and land use change (deforestation and agriculture) has significantly increased the amount of GHG emissions in the atmosphere. The escalating pace of these emissions has intensified the global threat of climate change thereby engaging the international community on a course of action and sensitising leaders on the issue at hand. These international scale developments led to the United Nations Framework Convention on Climate Change, which encouraged industrialised countries to curb their GHG emissions. Although T&T is not an industrialised country as a ratified signatory to the Convention it has a directive to fulfil its ultimate objectives, i.e. of pursuing development pathways that follow low carbon trajectories. As such the government has formulated climate change mitigation and adaptation measures which include diversification away from limited non-renewables towards increased usage of renewable resources. This is a particularly significant step in line with the threat the country faces due to its vulnerabilities as a SIDS. According to the Alliance for Small Island States, climate change poses the most serious risk to these countries' survival and viability and undermines their strides in attaining sustainable development goals (AOSIS, 2009).

iii. Macro-Political Developments

The threat of climate change has led to the establishment of international treaties where member countries commit themselves to stabilize the amount of GHG in the atmosphere. The Kyoto Protocol which came into force in 2005 is the most prominent global emissions reduction system and obligates parties to reduce their GHG emissions. It was signed and ratified by T&T in 1998 and 1999 respectively (UNFCCC, 2012a). The developments from these exogenous forces have meant that as a non-annex 1 country, T&T can benefit from the flexible mechanisms adopted by the Protocol. The Clean Development Mechanism (CDM) is one of these three instruments that bear most relevance to T&T.

The CDM gives Annex 1 countries the flexibility to achieve their GHG emission reductions by assisting non-Annex 1 countries with achieving sustainable development through investments, technology transfer and livelihood improvements in (UNFCCC, 2012b). The institution of biogas technology can provide emission reductions that would not have otherwise occurred, which falls in line with one of the stipulations of the CDM under the methodology for Landfill Methane Recovery ('AMS-III.G.'). The CDM therefore gives rise to the earning of carbon credits and provides a potential source of funding to initiate or support a LFGTE project.

iv. International Oil Prices

As an energy based economy the international oil and gas prices lie at the heart of the country's development. While LNG prices tend to be more stable than those of the fluctuating oil market, at some point, after 15 years or so, the tax and monetised revenues from oil and gas will start to decline (Dawe, 2008). This anticipated decadal occurrence is a major thrust for T&T to begin early adoption of alternative fuels to contribute to its future energy and economic security.

6.1.2. Socio-Technical Regime (Meso Level)

These changes at the landscape level have exerted pressure on the energy regime to transition to cleaner, less polluting alternatives. Such developments have created a small window of opportunity for the introduction of newer technologies. Although these are yet to replace the incumbents there are a number of features that can work towards destabilizing the regime. As the regime consists of the interplay of the socio-technical system, a network of human actors and social groups and institutions, the analysis will revolve around these elements.

i. Financial

The Global Environment Facility (GEF) is an independent financial organization that addresses global environmental issues by supplying developing countries and countries with economies in transition with grants for projects in spheres such as biodiversity, climate change, persistent organic pollutants and the ozone layer (GEF, 2010). The assistance is extended on the premise that beneficial national projects could be scaled up to produce global level environmental benefits. A LFGTE plant should essentially qualify for funding as the combination of energy and environmental advantages would transpire to the international stage.

GEF financing has been used to support the upgrading of medium to large scale biomass plants in China and the GEF Small Grants Programme has made contributions towards the construction of biogas demonstration plants in Namibia and Vietnam. Although the feedstock for these plants is animal manure, it nonetheless indicates the potential of accessing funding for biogas based ventures. T&T has previously accessed GEF funding for six projects in the areas of climate change, biodiversity, multi-focal points and POPs and so there would be a level of familiarity with the application procedure and other technicalities.

There are also domestic provisions for funding of environmental projects in T&T within the regime. The Green Fund established in 2000 is the National Environmental Fund that provides finances for eligible community groups and organizations engaged in activities focusing on remediation, reforestation or conservation of the environment (MHE, 2011). A Green Fund Levy of 0.1% on the gross sales or receipts of companies carrying on business in T&T is the source of the input (ibid). This financing can be useful for contributing towards the operations at the LFGTE facility. A. James (personal communication, February 8th, 2012) envisioned a scenario where civil society organisations (CSO) and/or scavengers mobilised and accessed the Funds to introduce some variant of the technology, if even initially on a small scale.

The Green Fund system has an inherent network of actors and includes the private sector who are the financial contributors, the Ministry of Housing and the Environment and the Ministry of Finance who are respectively responsible for certification, disbursement and acting as custodians to the funds and finally the community groups and CSOs that use the finances to create tangible environmental features. This actor network could provide a useful platform to launch a transition.

ii. Infrastructure

Purified biomethane uses a compression and storage technology similar to that used for CNG. This means that the existing infrastructure for CNG filling stations and the modified vehicles will be compatible with a biogas or biogas/CNG hybrid fuel. This can therefore provide a smoother transition to integrate the use of this new vehicular fuel into the local context.

iii. Institutional

Foxon (2002) defines institutions as any form of constraint that human beings devise to shape human interaction and may include formal constraints, such as legislation, [policies], economic rules and contracts, and informal constraints, such as social conventions and codes of behaviour.

The government has recognized the escalating problem with waste management in the country and so in 2008 embarked on an Integrated Waste Management project. By February 2012, this culminated with the completion of the final draft of the 10 year scope ISWM Policy. This is to be accompanied by the complementary ISWM legislation. As part of the vision of this Policy the waste hierarchy prioritises prevention over disposal. However, as part of the inevitable treatment and disposal process there is the intention to employ the use of technologies and systems that can recover value from waste where economically and environmentally feasible, to manage residual wastes in ways that are protective of community health and the environment (MOLG, 2012). It was also articulated in this Policy that biogas recovery will be part of the methods used in the initial phases. The development of this Policy therefore provides an exceptional opportunity to propel LFGTE into future waste management plans.

The draft Climate Change Policy and Strategy of T&T was prepared in 2008 pursuant to the obligations of the UNFCCC and the Kyoto Protocol, the exogenous landscape features, and it outlines the measures the country will adopt to embark on a low-carbon development path. In so doing it provides broad policy statements on the commitment to deliver strategies for mitigation such as maximizing renewable energy resources, clean energy and clean production technology as well as methods to adapt to the adverse impacts of climate change. One of the methods proposed within the Climate Change Policy for implementing the mitigating strategies is the development of RE policy and standards.

The development of the RE Policy was facilitated by the establishment of a Renewable Energy Committee. Within the RE Policy, the considerations on viable options as alternative vehicular fuels highlighted the value of using waste as a raw material as opposed to crops. These are promising signals of the possible role biogas technology could play in the energy system if such declarations are translated into real action. Furthermore, the policy position assumed by the government to promote the use of CNG can easily accommodate the addition of biogas on the RE agenda for use in the transport sector since the relevant infrastructure is already in place. Additionally, the CNG measures such as tax allowances and infrastructural investments can also be applied to support the inclusion of biogas. Thus it would be feasible to readjust the 2015 target of 20% CNG vehicular conversion to include an incremental percentage of vehicles running on biogas. Alternatively in the short term a similar policy could be adopted whereby it would not only be mandatory for state-owned and public vehicles to be converted to CNG use, but biogas could be a replacement or supplement in waste disposal vehicles.

6.1.3. Niche (Micro Level)

Despite the relatively slow pace of research into biogas technology, in comparison with other alternative vehicle fuels it has exhibited promising and competitive performance results (Svensen & Rydehell, 2009). As a relatively new form of technology this works towards increasing the efficiency of the process as well as its marketability, which increases its prospects for local uptake.

Along with this, the imminent closure or improvement of the Beetham Landfill is a great impetus and window of opportunity for incorporation of a biogas plant, especially as the country is committed to treating the waste already deposited at the site. Biogas technology is not a foreign innovation to T&T and 15 years of experience at SFC with operating these units means there has also been a parallel learning process. As these operators will be familiar with the local conditions, their contextually based learning experiences will be invaluable. These can be extrapolated and adjusted to suit the conditions at the Beetham Landfill and used for initiating the adoption process and during plant operations.

However, as a new and unestablished technology, support from powerful actors will be required to secure biogas' space in the market. This role may have to be assumed by the government as the Beetham landfill is under the management of a state entity and any plans to have biogas properly integrated into the local context would require government endorsement. For instance past proposals from foreign parties interested in possible construction of a LFGTE facility have been disregarded as the Memoranda of Understanding were not found to be in the best interest of the country. Thus, the government has heavy leverage and fortunately the ambition and preliminary steps to incorporate renewable energy and biogas into the domestic energy mix, based on its feasibility are positive and reassuring signs for this technological development. Figure 6 below conceptualises all the driving forces presented.

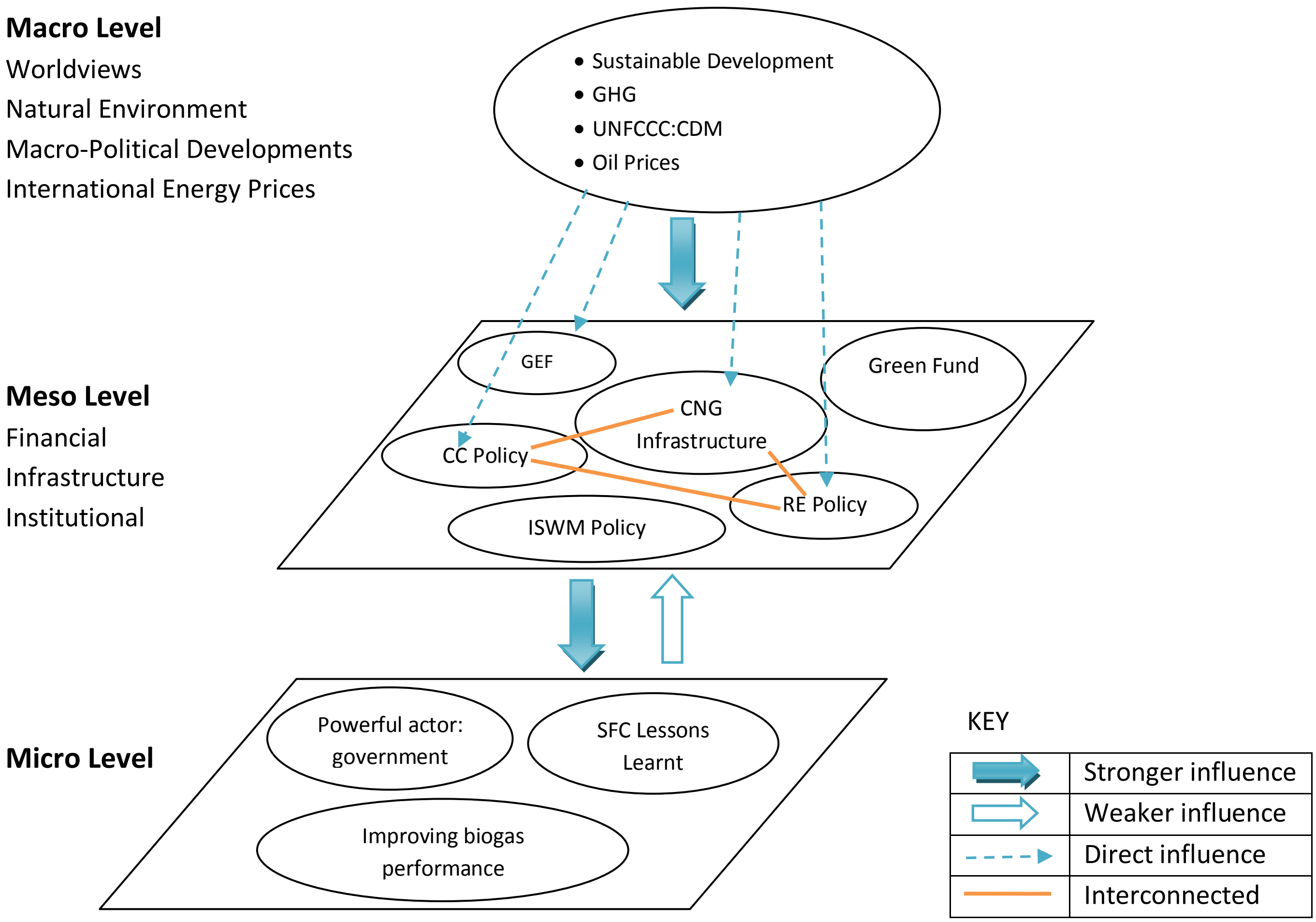


Figure 6: Driving Forces for a Biogas Transition in Trinidad & Tobago based on a MLP

Author's construction

6.2. BARRIERS AGAINST LFGTE PRODUCTION

6.2.1. Socio-Technical Landscape (Macro Level)

i. Macro-political Developments/Natural Environment/Social Value

The conditions within the Kyoto Protocol expire in 2012 and in anticipation of this happening zealous attempts were being made at preceding sessions of the Conference of the Parties (COP) to set out a framework that would see the reinstatement of a new global climate treaty. Unfortunately, the difficulty of getting all countries and their economies to resolve to a carbon-neutral status has been highlighted in the current protocol and will require forthright attention in a Post-Kyoto agreement. The divergences in the stance of countries like the United States, India, Brazil and China have also aided in progress at a less than favourable rate. The last COP (17) did ebb on the side of optimism, with a roadmap being set out from both developed and developing countries on how negotiations are to proceed until 2015, when a new agreement is to be signed and then ratified and enforced by 2020. However, until then countries will not be legally bound and as a result changes in these external factors could diminish pressure and reduce the stimulus for action on the T&T stage.

ii. Macro-Economic

Global energy systems revolve around fossil fuel use and there have been sizeable investments in infrastructure to support this fuel source. Added to this are powerful oil and gas coalitions with deep-seated economic interests and influence. Collectively this has created a carbon lock-in, which constrains the development and competitiveness of alternative renewable energy systems. The repercussions of this of course transcends to the national scale and with no exogenous pressure, T&T is not compelled to modify its status as an oil and gas economy, but rather is encouraged to maintain or enhance its status quo.

6.2.2. Socio-Technical Regime (Meso Level)

i. Institutional

- Formal Constraints

When approached from an institutional perspective there are a lot of factors that work towards reinforcing the current socio-technical configuration. The formal or regulative rules are one of the largest barriers. As oil and natural gas have assumed such an illustrious standing in the national economy and society, the mass majority of policies and legislation are in its favour. One of the greatest obstacles inhibiting the integration of renewable energy and biogas technology in particular is the petroleum fuel subsidy. The provision of such subsidies can amount to TTD[5]$3.5 billion per annum (Dookeran, 2011), contingent on oil prices, though other reports suggested figures in excess of TTD $4 billion in 2011 (Bagoo, 2011). Based on rough calculations this accounts for 7.4%-8.5% of the estimated total budget revenue for the period 2011-2012. The result of such subsidisation is that the diesel fuel prices in the country are amongst the lowest in most of the Latin American and Caribbean region (see Appendix E) (MEEA,2011). Such polices therefore reduces the financial incentive to invest in alternative, cleaner technologies and according to R. Khan (personal communication, January 26th, 2012) this competition with existing prices creates a challenge for any new project. This he stated "will take some years before there is a levelling out of the playing field".

This prediction on the heavy subsidization ties closely with the cognitive rules ingrained in the state and transferred to the energy sector. These rules are the shared beliefs and expectations of future perceptions or user preferences which guide the present actions of actors (Geels, 2004). Within these domains there is a common belief that fossil fuels will meet the energy demands both locally and internationally in the future and so efforts should be geared towards sustaining production to meet this anticipated demand. In keeping within this mindset exploration of undiscovered oil reserves has been a policy focus and this perseverance has led to the recent discovery of a reservoir of 48 million barrels of crude oil by the state-owned oil company Petrotrin (Ramdass, 2012). Such a finding will only reinforce the policies for fuel subsidization, its perverse incentives and the current line of thinking.

[5] TTD (Trinidad & Tobago Dollar): 1TTD = ~1.05SEK (Swedish Kronor)

Added to this is the problem of 'cognitive capital' which refers to the competencies and skills acquired from years of experience (Geels, 2004) within the conventional energy system. The familiarity with executing procedures designed for the provision of crude oil and natural gas to the society formed part of the cognitive routine and so would lead to great reluctance if attempting to introduce new technologies. A similar situation occurs in the waste sector as the established routines for landfilling would have to be reformulated and new techniques thought, which would be sure to generate resistance.

- Informal constraints: Socio-cultural conventions/ Codes of behaviour

Waste in T&T is held in very low esteem and this cultural mindset is reflected in the indiscriminate dumping of waste by the local citizenry in the streets or at other inappropriate sites. This lack of acknowledgement of the value of waste perpetuates the indifferent behaviour, general lack of awareness and reinforces the negative attitudes towards its handling and disposal. So although there have been outcries to close the Beetham Landfill, when there are propositions of possible relocation the 'not in my backyard' mantra is quick to surface. As A. James (personal correspondence, 8th February, 2012) stated:

> No one is willing to have a sanitary landfill built in their area. Everyone says no, not in my backyard, but they want everything closed!
> So what, put it in a rocket and ship it to the moon?

Such ambivalent attitudes, based mainly on ignorance, clearly have implications for the introduction of biogas technology as this may prejudice the willingness to understand its benefits or its eventual application.

ii. ***Limited Technical Capacity & Regulations***

Although biogas production is not a new feature in Trinidad, the use of a different raw material towards the production of LFGTE would require technical knowledge that is not very prevalent on the domestic stage. This inhibits speedy uptake of LFGTE technology locally due to the limited number of advocates and qualified practitioners in the field. Without such proponents there is a lack of pressure on the government to create polices and legislation that would incentivize potential investors and guarantee a secure market for biogas operation. This lack of a facilitative environment makes it difficult for potential RE businesses and investors to make plans for long term investments (MEEA, 2011) or to reduce the market barriers. According to A. James (personal communication, February 8th, 2012) past proposals to construct waste to energy facilities in the country included stipulations for a guaranteed quantity and price for waste treatment or a form of exclusive rights for accessing the required waste. These proposals never came to fruition because they were in contradiction with Multilateral Environmental Agreements ratified by the country. The absence of a well formulated legislative framework essentially propagates these technical barriers.

iii. ***Administration***

At the meso level, the variation in responsibility for solid waste management poses a problem for coordinating activity in the future. While SWMCOL is the national authority for management of solid waste, the regional authorities are responsible for the actual waste collection and as a result at times there is duplication, negligence (UNCCD, 2007) or just general of lack of harmonization of activities between the two. Furthermore, the constant reshuffling and shifting of Ministries either because of elections or cabinet shifts means that SWMCOL keeps falling victim to this restructuring and ends up under the purview of a different Ministry ever so often. The result is a lack of continuity with policies and plans or amplified lethargy of already slow bureaucratic processes. These are noteworthy obstacles for a new technology like biogas which would already be receiving resistance from the incumbent actors and would require optimal use of timing to take advantage of the windows of opportunity.

iv. ***Politics***

The decisions made by the respective governments are in many instances politically motivated and act as a further barrier to the adoption of cleaner technologies. The half-hearted attempts to remove or reduce the fuel subsidy are one such example. The fear of losing popularity or support for one's political party severely impedes the capabilities of politicians. A similar situation arose with respect to the Beetham Landfill. In the past SWMCOL made an attempt to clean and properly manage the site, which also included eliminating salvaging as these waste interceptors did not follow proper health and safety protocol. However, this was met with heavy protests from the salvagers who felt they were losing a segment of their earnings. After petitioning the then Prime Minister, SWMCOL received instructions that a compromise had to be sought and this essentially meant that salvaging was continued. In effect, appeasing the complaints of the protesters took precedence for maintaining a secure electoral base.

v. Infrastructure

The oil and gas infrastructure represent a certain material 'hardness' (Geels 2004) which has become embedded in society and benefits from an extensive period of increasing returns (Foxon, 2002), thereby making them difficult to change. Attempting to integrate biogas production for use in the transport sector on a national scale would make the existing infrastructure obsolete for that purpose. Such a realisation could therefore work towards locking out the development of this new technology.

6.2.3 Niche (Micro Level)

Bioreactor landfills typically have higher initial capital costs (EPA, 2012) and this could be one of the main drawbacks of establishing LFGTE technology. There are also higher transaction costs for RE systems like LFGTE as additional time, finances and planning would need to be devoted towards the unknown performances of these unfamiliar systems (MEEA, 2011).

Added to this are site-specific characteristics at the Beetham Landfill that could pose as challenges. For one A. James (personal communication, February 8th, 2012) stated the history of the site being an open burning dump could potentially decrease the leveraging power for LFGTE project approval under the CDM. This would be due to the reduction in the amount of potentially extractable gas. Additionally, the previously highlighted ecological sensitivity of the site may form part of the arsenal of arguments used by environmentalist opposing construction of a LFGTE facility. Introducing this new technology with clear environmental benefits or forgoing such action will certainly be a livid point of contention and the divergent arguments will undoubtedly weigh heavily on the final decision.

The inclusion of LFGTE technology would also certainly garner resistance from the salvagers as well, who may view the new technology as a threat to their livelihood. Although the metal waste stream which the salvagers depend on to earn an income would be unaffected directly by biogas production, the engineering requirements at the facility will surely upset their daily routine. Based on the past experience where the waste interceptors were able to muster political support when they felt their livelihood was being threatened, a negative perception of biogas production may severely impede its prospects of establishment. Figure 7 below illustrates the multi-level barriers presented.

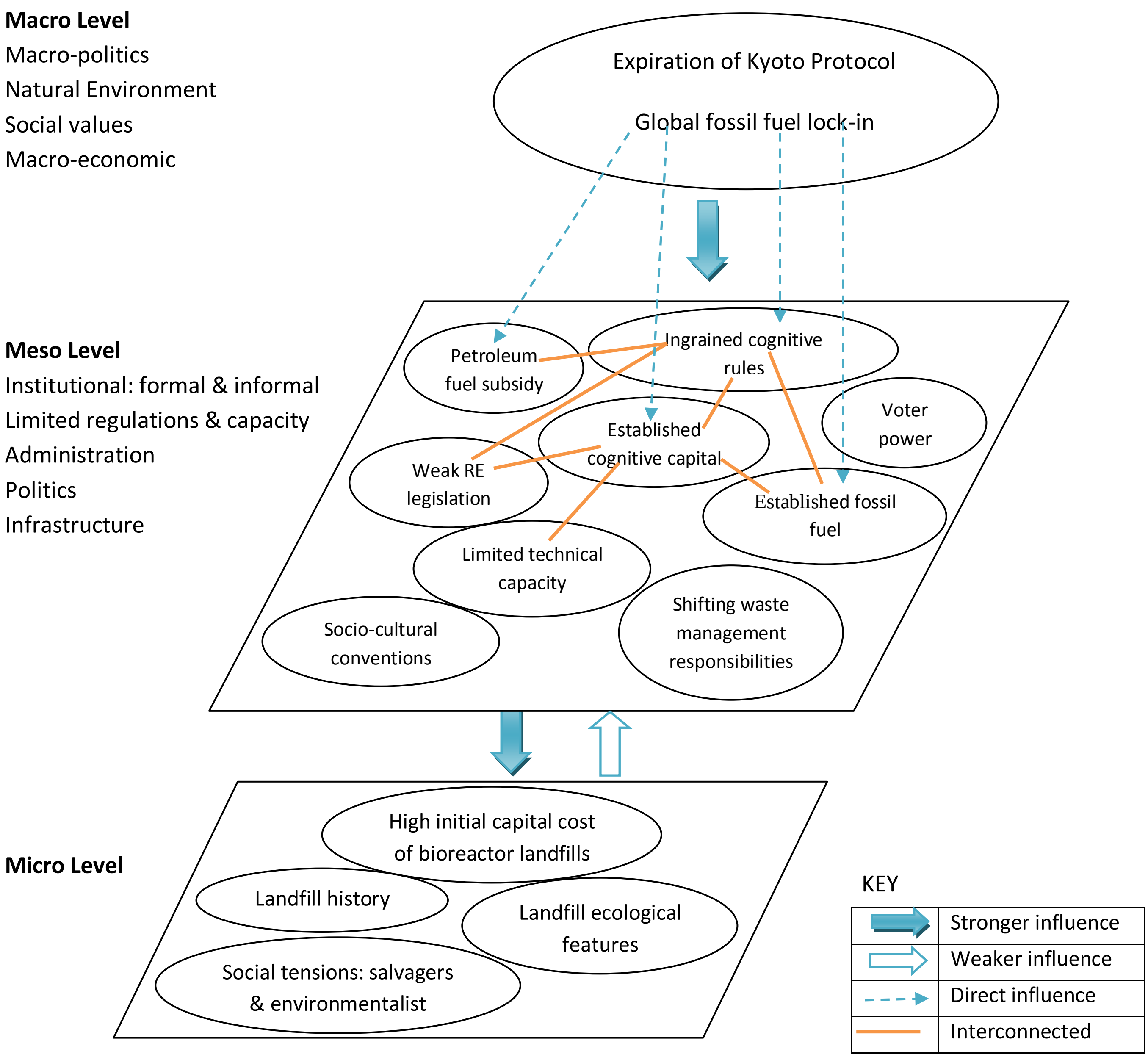


Figure 7: Barriers against the Transition to Biogas Production in Trinidad & Tobago based on a MLP
Author's construction

6.3. RESOLVING THE TENSIONS TO FACILITATE A TRANSITION

The analysis of the driving forces and barriers has shown that although the transition is geared towards the energy sector, as depicted by the landscape components, the process is unique as it actually involves a dual transition of two systems; energy and waste. The discussion however, has thus far failed to address one key question, that is, from where is the catalyst for change going to emerge? In this case for T&T, unlike the traditional scenario where transitions are driven by niche actors, regime actors will likely be the ones stimulating the process. This is anticipated as in retrospect it is evident that the majority of the barriers lie at the regime level (Figure 7), indicating there is great need for meso-scalar changes. Additionally, based on the current situation it is unlikely that there will be any specific niche level proponents or market pull encouraging deployment of such a technology.

Based on this presumption, the features of this transition process correlate with those of the reconfiguration pathway as postulated by Geels & Schot (2007). Within the reconfiguration pathway symbiotic niche innovations are adopted by the main agents, regime actors, to solve local problems, with the new regime emerging from the old (ibid). These innovations correspond with those arising from the interdependent energy and waste sectors, to be adopted by regime actors for alleviating the issues in these respective sectors. According to the authors, as a result of multiple component innovations within the socio-technical system and the influence of landscape pressures, the basic architecture of the regime undergoes changes and reconfiguration (ibid). These effects of the multiple component innovations will be explored later in this section, but first the focus will be on the impact of the landscape pressures and reconciling the conflicting driving forces and barriers.

Recommendations

To trigger the transition in T&T naturally the aim should be to sustain the driving forces and minimise the barriers. In line with the assumptions of the reconfiguration pathway, the landscape pressures illustrated in Figure 6 will be critical for influencing this process. However, while the influence of these are indispensable, particularly as many of the regime changes have direct correlations with activities at this scale, there also needs to be greater influence from the underlying levels. This stands particularly for the niche scale which is currently very weak. Based on the insights derived from the MLP, it appears one of the main ways to strengthen niche dynamics and speed up the process of regime reconfiguration is to remove the regime barriers. This is so as the majority of micro level blocking mechanisms stem from this scale.

As highlighted, the regime level possesses the greatest number of restrictions and one of the more prominent barriers is a lack of financial incentives. The absence of bottom-up action and clamour from local actors is partially linked to a lack of tangible signals on the effects of climate change, as these are masked locally by the low energy prices. To stimulate niche level activity and to make biogas production more economically feasible, a subsidy shift from fossil fuels towards renewable energy takes uppermost precedence for operationalizing change. This would reveal the true effects of fossil fuel use. Similarly a reformed tax system with tax exemptions on renewable fuels and the importation or purchase of hybrid vehicles and tax increases in the hydrocarbon sector, will also help with reducing the path dependency on the conventional fuels especially as its true costs, particularly on the environment, will be mediated to some degree. The liberated funds could also be used to assist with reducing the capital costs of biogas technology.

In Sweden, the world leader in production of biogas as vehicle fuel (Engdahl, 2010), there are state subsidies for investment in projects that aim to reduce greenhouse gas emissions (Börjesson & Berglund, 2006). This of course has a favorable impact on biogas production. Similarly, tax breaks have shown positive results in cases like Germany which is the top ranked manufacturer and project developer in the biogas industry (REN 21, 2011).

Enhancing the economic viability can also be achieved by the continuance and improvement of gate fees at the Beetham landfill and the sale of other products from the biogas production process such as fertilizers.

Tied strongly with improving this financial capacity is the necessity to amend the policies and regulations to create an enabling environment and also for institutional strengthening. This is also important to safeguard investor confidence in the short term in light of the longer pay-back period for biogas investments, as well as to make production profitable and favourable for the country's interest. Policies that set national targets and standards for incorporating biogas into the mainstream market would also encourage momentum on the national scale. Collectively, this could work towards helping to reshape the cognitive rules by altering the mindsets of the actors in the incumbent system and realigning the broader societal goals. Supplementary to this would be the necessity to strengthen the technical capacity by facilitating training for citizens in LFGTE technology. Thus a strong political will supported by resolute action is crucial for expediting this transition process.

Equally as important is the endorsement from the rest of society in order to raise awareness of the benefits of biogas production, to improve its productivity, change the perceptions, attitudes and social conventions regarding waste and circumvent the possible fallout from scavengers and households. Through educational and promotional campaigns the subject must be translated in a form that is direct, clear and inclusive to inculcate social learning and to avoid a backlash. Inclusivity is integral as studies have shown that source separation of waste provides the best quality feedstock for anaerobic digestion (IEA, 2001) and hands-on experience is a more effective strategy for creation and maintenance of public support (Kemp & Rotmans, 2004). Therefore cooperation at the household level will be essential. However, as new practices and behaviour require time to be properly instilled, in the short term centralised or community-based (J. Smith, personal communication, January 4th, 2012) separation can be established. This could be either mechanical processing or manual labour, but in both instances it provides invaluable, formal employment and opportunities for integrating the salvagers and the wider public.

Combining the subsidy shifts with these informational campaigns can have supplementary roles for solidify biogas or renewable energy for that matter, as part of the local discourse, which by extension would directly target niche strengthening. As the perverse effects of ‘king oil’ will be manifested through these combined mechanisms, with the heightened awareness of alternative fuel solutions local actors will be more motivated to rally for their integration. Through the formation of innovation support networks among household, scavenger, CSO, business sector and state representatives, the coordinated action and strong force necessary to drive this process will be established. This shift in local level perception will also contribute to changing the cognitive rules, which based on Figure 7, seem to be at the focal point for many of the meso-scale barriers.

It is very evident then that the activities at the different hierarchal scales are highly interrelated, as are the technical, social and economic factors, government support and institutional arrangements for the installation of biogas technology (Reith, Wijffels, & Barten, 2003). Thus coordinated improvements in each scale and sector are fundamental for producing measurable results and the government plays a significant role initially, in activating the process. Understanding how these coordinated developments can be effected and their broader scale implications will be the focus of the proceeding section.

Scaling Up Action

The socio-technical regime for energy production in T&T, shown below in Figure 8, shows the multiple technological components within the reconfiguration pathway. As mentioned previously, multiple component innovations are required in the different parts of the regime system to enable the niche to assume regime status. Thus, technological and infrastructural transformations in the production and distribution sectors will be necessary. However, based on the data analysis and recommendations, the transition will also require systematic adjustments of encompassing structures like the local guiding principles, markets, knowledge base, policy and regulations and the cultural meanings and underpinning practices (Geels, 2002) with regard to energy use and waste in the country. Essentially, these changes in practices and perceptions indicate that introducing biogas technology goes beyond acting as a techno-fix, but rather underscores that by integrating biogas in the country broader societal changes are virtually obligatory.

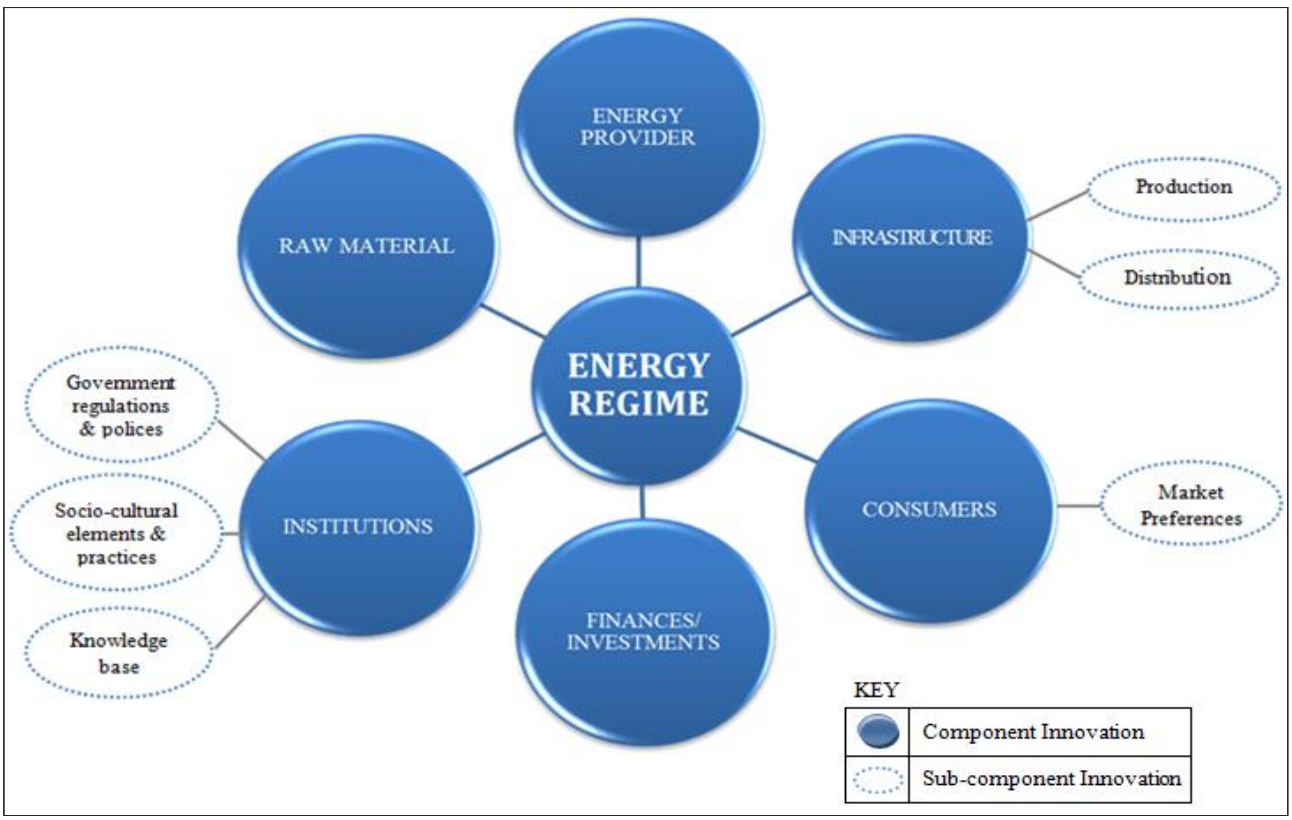


Figure 8: Component Innovations of the Socio-technical Regime for Energy Production in T&T
Author's construction

These societal implications of the technological innovations are similar to positions expressed in the Strategic Niche Management (SNM) concept. SNM was developed for the management of socially desirable innovations serving long term goals like sustainability or innovations that were incompatible with existing infrastructure, regulations etc. (Schot & Geels, 2008). It has been used to explain biogas development in the Netherlands for example as found in Geels & Raven (2006). Its adherents assert that to facilitate sustainable innovation journeys, there needs to be moderating of technological niches, which take the form of pilot projects, as well as social and technological changes (ibid). SNM is therefore regarded as more than just a technology push approach.

This clearly bears direct relevance for use in a pilot study on biogas production in T&T, as the discussions have indicated the current socio-technical configuration is mismatched for successful biogas adoption. Regime interventions such as governmental proposed subsidies or support networks (Raven & Geels, 2010) are the typical market buffers for technological niches and this regime stimulus has been anticipated for the Beetham landfill, which makes SNM even more applicable. Modulating of the technological niche can be conducted by the innovation support network. The later work on SNM has also emphasized that niche innovations can incorporate and transform the regime from within and not necessarily compete with and substitute for the prevailing regime, contrary to earlier arguments (Schot & Geels, 2008). This bears distinct connections with the reconfiguration pathway presumed for T&T. SNM therefore proves to be a useful management tool to assist with regulating and realigning the multiple component innovations and reconciling the tensions between the driving forces and barriers.

Building on the arguments presented thus far, to a certain degree this transition to biogas production in T&T may actually be linked to pursuing a path of strong sustainability. The theoretical foundations of strong sustainability according to Daly (2005), state that subsystems like the economy are ecologically bound since the biosphere is finite, non-growing, and constrained by the laws of thermodynamics. To sustain the natural capital, economic subsystems must adjust to these biophysical limits and approach a steady state (ibid). As the energy sector is the primary driver of the economy in T&T, renewable energy in the form of biogas production can be one alternative method to sustain the natural capital (climate regulating ecosystem services). This is imperative as it has been conveyed these regulating services are rapidly approaching their limits. Another premise of strong sustainability is the non-substitutability of natural capital by manmade capital, as the two are considered to be complementary. Similarly, these ecosystem services will need to be maintained for their own sake as technological advances will be unable to replace them once exhausted.

Daly (2005) further argues that for strong sustainability establishing and maintaining a sustainable economy entails an enormous change of mind and heart by economists, politicians and voters. This, as well as the instruments needed for this change which are based on top down mechanisms of political choice, have both been specified as adjustments required in the T&T context to effectively facilitate biogas production.

Drawing further on this strong sustainability approach, remaining within the biophysical limits is achieved through a steady state economy (SSE). This is a system that promotes qualitative development over aggregate quantitative growth, where a constant population and capital stock are sustained by a low rate of throughput falling within the regenerative and assimilative capacities of the ecosystem (Daly, 2010). How then does biogas production correspond with such a system, as it may be plausible to assume continuous consumption to guarantee constant waste production (or high throughput) would be advocated to ensure the project's viability? While biogas production has been proposed for dealing with the existing waste and energy issues, this study has shed light on an underlying problem of excessive consumption and waste production in T&T which needs to be addressed. Limiting throughput can contribute towards tackling this deeper problem and according to Daly (2005) this can be accomplished by several methods. For instance a "demographic transition" in populations of products with higher durability would reduce their frequency of replacement, thereby lowering rates of resource use and throughput. Additionally, Daly (2010) recommended directing taxes towards the point of resource extraction to aid with reducing throughput and so contribute towards the sustainable SSE. This corresponds with the recommendations presented for improving the economic leverage of biogas in T&T. Therefore moving towards a SSE may actually have less conflict with LFGTE production than anticipated. The linkages between strong sustainability and the biogas transition indicate a possible long-term symbiosis by pursuing these parallel paths.

Biogas production therefore moves beyond just providing separate benefits for the waste and energy sectors towards more holistic, developmental advantages. The opportunities for and barriers against LFGTE production have been presented along with recommendations to resolve these conflicting forces.

Through the implementation of these and SNM, it is anticipated that T&T's transition towards a sustainably oriented energy system and society may be more achievable.

6.4. FINAL CONSIDERATIONS

In operationalizing the biogas transition process, the following are some critical points that must be taken into account:

- There is the potential for a lock-in once the LFGTE infrastructure has been constructed, with a perception that T&T's high rate of consumption and waste production must be sustained for the project's success. This scenario resembles a wicked problem where finding the solution to one problem may reveal or create contradictory or even more complex issues due to interdependencies (Jerneck et al., 2010). However, LFGTE is proposed for dealing with the existing problem and so measures should be implemented that promote reflectivity and flexibility in the system to accommodate changes for a better method that has been feasibly demonstrated and dispels this convoluted problem.

- Following from this point is the potential lock-out of alternative waste treatment systems, as numerous years may be required to reap the benefits from the investments in LFGTE technology. Biogas production is but one waste management strategy and its introduction should be part of a larger Integrated Solid Waste/Resource Management (ISWM) strategy and so should not negate implementation of alternative waste systems.

- A system should also be implemented to ensure the phasing out of protective mechanisms associated with technological niches and SNM to safeguard the long-term autonomy of the project.

- This final point will certainly be easier said than done, but there will be differences in power relations throughout the transition process especially based on the anticipated regime stimulus. This must be acknowledged and counterbalanced through open dialogues and transparent processes. While this may need to be addressed progressively, it is hoped that highlighting it will at least keep it prevalent in the minds of the agents of change.

7. CONCLUSION

This study has explored the prospective potential of integrating biogas production in T&T based on the Beetham Landfill as a pilot case. Using the MLP of the transition theory the key driving forces and barriers were identified and then analysed to determine how these conflicting forces could be reconciled to bring about the LFGTE transition. The analytical framework revealed that in order to break the current fossil fuel lock-in, the diffusion of biogas technology requires dual transitions in the energy and waste sectors and system-wide changes of both technology and society. Based on the MLP, the majority of the driving forces of the transition were found to be at the landscape and regime levels, while the barriers dominated the regime scale. These necessary meso-scale changes tied into the reconfiguration transition pathway the country was found to be aligned with. This pathway asserts a regime driven transformation which departs from the typical, theoretical niche-based transition.

To embark on this journey it was recommended that there be increased financial incentives especially a subsidy shift towards the renewable energy sector, policy and legislative amendments to make renewables more competitive and educational and awareness raising campaigns on the merits of biogas production. Applying SNM as a management tool was found to have potential for feasibly expediting this process. A linkage was also established between biogas production and strong sustainability, reflecting the broader scale elements emerging within the transition process.

Further Research

This empirical research provides useful material to add to the fertile body of concepts on transition theory, particularly as it is based on a developing country. This study can also assist with bridging the research gap identified by Schot & Geels (2007) as it explicitly incorporates the idea of transition pathways into a prescriptive application of SNM work. For sustainability science it attempts to combine a problem solving facet with a critical approach.

However, for further research on the local scale it is suggested that more quantitative studies be conducted at the Beetham landfill to determine the potential of LFGTE and to improve the repository of current data. Further, the potential from the other landfills in the country should be assessed along with the possibilities of using other feedstock, for example sewage. In addition the social implications for the salvagers of such construction should be profoundly analysed along with further studies to determine how the necessary changes on the societal level can be accomplished. More extensive studies on the distribution and utilisation of the gas whether in the transport sector or otherwise should also be included on the research agenda.

On the theoretical level, there should be more prescriptive studies like this using the MLP in transition theory and SNM. Additionally, more empirical cases linking transition pathways and SNM should be done to strengthen the theoretical framework.

Trinidad and Tobago is a country teeming with untapped potential and integrating biogas production as a sustainable technology, can contribute towards unharnessing some benefits in the energy and waste sectors. Its production however, is but one of other solutions for charting T&T's energy system along a more sustainable tract. This transition process will admittedly take time, but the sooner the country begins integrating an alternative system the better. It is hoped the ideas presented in this research will have contributed towards mobilising this process.

Not everything that is faced can be changed, but nothing can be changed until it is faced.

James Baldwin

REFERENCES

Addyman, S. (2010). *Biogas is just as good as CNG. Theme: Alternative Fuels, Featured article.* Retrieved April 2, 2012, from: http://www.mindsinmotion.net/index.php/mimv34/themes/alternative_fuels/featured/biogas_austria

AOSIS [Alliance of Small Island States]. (2009). *Alliance of Small Island States (AOSIS) Declaration on Climate Change.* Retrieved March 31, 2012 from: http://www.aosis.info/documents/AOSISSummitDeclarationSept21FINAL.pdf

Artana, D., Auguste, S., Moya, R., Sookram, S., & Watson, P. (2007*). Trinidad & Tobago: Economic Growth in a Dual Economy*. An IDB Research Project.

Bagoo, A. (2011, October 9). Dookeran: We are ready. *The Trinidad and Tobago Newsday*. Retrieved April 9, 2012, from: http://www.newsday.co.tt/news/0,148603.html

Berkhout, F., Smith, A., & Stirling, A. (2004). Socio-Technical Regimes and Transition Contexts. In Elzen, B., Geels, F. W. & Green, K, (Eds.). *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy* (pp. 48-72). Cheltenham: Edward Elgar Publishing Ltd.

Bethel, C. (2011, September 13). Unlimited Power. *The Trinidad Express Newspapers*. Retrieved April 9, 2012, from: http://www.trinidadexpress.com/business-magazine/Unlimited_power-129769308.html

Boodlal,D., Furlonge, H., & Williams, R. (2008, October). *Trinidad and Tobago's CO_2 Inventory and Techno-Economic Evaluation of Carbon Capture Options for Emission Mitigation*. Paper presented at the 3rd Tobago Gas Technology Conference, Lowlands , Tobago.

Börjesson, P. & Berglund, M. (2006). Environmental systems analysis of biogas systems-Part I: Fuel-cycle emissions. *Biomass and Bioenergy, 30* (5), 469-485.

Börjesson, P, Ericsson, K, Di Lucia, L, Nilsson, L, and Åhman, M. (2009) *Sustainable vehicle fuels – Do they exist?* EESS Report 67. Lund University-Bil Sweden Report.

Boyle, G., Everett, R., & Ramage, J. (Eds). (2003). *Energy Systems and Sustainability*. Oxford: Oxford University Press.

Briguglio, L. (2003, September). *Vulnerability and Small Island States a Review of Conceptual and Methodological Issues.* Presentation for the AIMS Regional Preparatory Meeting 1 on the BPoA+10 Review, Praia, Cape Verde.

Bryman, A. (2008). *Social Research Methods* (3rd ed.). Oxford: Oxford University Press.

Burnside, R.J. International Limited (2004*). Baseline Study for the Beetham Landfill Disposal Site, Trinidad.* Canadian CDM and JI Office- Department of Foreign Affairs and International Trade. Unpublished Report.

Central Bank of Trinidad and Tobago (2010*). 2010 Annual Economic Survey. Review of the National Economy.* Table 2 Economic Contribution of the Energy Sector, 2006-2010. Retrieved January 16, 2010, from: http://www.centralbank.org.tt/sites/default/files/2010%20Annual%20Economic%20Survey.pdf

CBCL. (2010). *Trinidad Solid Waste Management Program Waste Characterization and Centroid Study, Final Report*. Prepared for the Government of the Republic of Trinidad and Tobago Ministry of Local Government. CBCL Limited Consulting Engineers. Unpublished Report.

Chandool, C. (2011, May- June). *Oil and Gas and the Environment in Trinidad and Tobago: Experience and Challenges.* Paper presented at the IAIA11 Conference Proceedings, Impact Assessment and Responsible Development for Infrastructure, Business and Industr y. 31st Annual Meeting of the International Association for Impact Assessment, Puebla, Mexico.

Chang, T. (1998). *A Visual Assessment of the Existing Solid Waste Disposal Sites in Trinidad and Tobago.* Submitted to PAHO/WHO, Trinidad. Unpublished Report.

CIA. (2011). *The World Factbook*. *Trinidad and Tobago, Economy Overview*. Retrieved January, 4, 2012, from: https://www.cia.gov/library/publications/the-world-factbook/geos/td.html

CSO [Central Statistical Office]. (2007). *Chapter 14 Solid Waste*. First Compendium of Environmental Statistics Trinidad and Tobago. Republic of Trinidad and Tobago. Ministry of Planning and Development. Port of Spain: Retrieved January 12, 2012, from: http://www.cso.gov.tt/files/statistics/Chapter%2014.pdf

CSO. (2011). Ministry of Planning & Development. *Key Indicators Government of the Republic of Trinidad and Tobago*. Retrieved March 5, 2012, from: http://www.cso.gov.tt/Pages/default.aspx

Daly, H. E. (2005). Economics in a Full World. *Scientific American*, 293(3), 100-107.

Dookeran, W. (2011). *Government of the Republic of Trinidad and Tobago. Budget Statement 2012. From Steady foundation to Economic Transformations; Safety, Jobs, Investment.* Presented by the Minister of Finance, Mr. Winston Dookeran, 10th, October 2011. Retrieved March 29, 2012 from: http://www.finance.gov.tt/content/Budget-Statement-2012.pdf

Enill, C. (2009). *Introduction.* In Trinidad and Tobago, Celebrating a Century of Commercial Oil Production. Official Centenary Publication of the Ministry of Energy and Energy Affairs.

Engdhal, E. (2010). *Biogas policies, incentives and barriers. A survey of the strategies of three European countries*. (Master's Dissertation, Lund University, 2010). Retrieved January 5, 2012, from: http://www.miljo.lth.se/svenska/internt/publikationer_internt/pdffiler/exjobb%20imes%20Kristina%20Engdahl.pdf

EPA. (2012). *Bioreactor Landfills. Special Considerations of Bioreactor Landfills*. Retrieved April 9, 2012, from: http://www.epa.gov/osw/nonhaz/municipal/landfill/bioreactors.htm

Garcilasso, V. P., Velázquez, S., Coelho, S. T., & Silva, L. S. (2011*). Electric Energy Generation from Landfill Biogas –Case Study and Barriers.* Paper presented at International Conference on Electrical and Control Engineering (ICECE). Yichang, China: IEEE.

Geels, F.W. (2002). Technological Transitions as Evolutionary Reconfiguration Processes: A Multi-Level Perspective and A Case-Study. *Research Policy,31,* 1257–1274.

Geels, F.W. (2005). *Technological Transitions and System Innovations. A Co-evolutionary and Socio-Technical Analysis*. Cheltenham: Edward Elgar Publishing Ltd.

Geels, F. & Raven, R. (2006). Non-linearity and Expectations in Niche-Development Trajectories: Ups and Downs in Dutch Biogas Development (1973–2003). *Technology Analysis & Strategic Management, 18 (*3/4), 375–392.

Geels, F.W. & Schot, J. (2007). Typology of Sociotechnical Transition Pathways. *Research Policy*, *36,* 399–417.

GEF [Global Environmental Facility]. (2010). *What is the GEF*. Retrieved March 24, 2012, from: http://www.thegef.org/gef/whatisgef

Hilton, A. (2010, April 22). Beetham Landfill well past its expiration date. *The Trinidad and Tobago Newsday.* Retrieved February 1, 2012, from: http://www.newsday.co.tt/features/0,126454.html

IEA [International Energy Agency]. (2001). *Biogas and More! Systems and Markets Overview of Anaerobic digestion.* Retrieved January 25, 2012, from*: http://w eb.sdu.dk/bio/pdf/biogas.pdf*

IEA. (2011a). *Trinidad and Tobago Share of total primary energy supply in 2008*. IEA Energy Statistics. Retrieved January, 10, 2012, from: http://www.iea.org/stats/pdf_graphs/TTTPESPI.pdf

IEA. (2011b). *CO2 Emissions from Fuel Combustion Highlights (2011 Edition).* IEA statistics. International Energy Agency. Retrieved from: February 2, 2012, from: http://www.iea.org/co2highlights/co2highlights.pdf

IEA. (2011c). *2009 Energy Balance for Trinidad and Tobago*. Retrieved January, 10, 2012, from: http://www.iea.org/stats/balancetable.asp?COUNTRY_CODE=TT

IEA. (2012). *Oil in Trinidad and Tobago 2009*. Retrieved June 4, 2012, from: http://www.iea.org/stats/oildata.asp?COUNTRY_CODE=TT

Jerneck, A., Olsson, L., Ness, B., Anderberg, S. Baier, M., Clark, E., et al. (2010). Structuring Sustainability Science. *Sustainability Science, 6*(1), 69-82.

Johannessen, L. M. (1999). Guidance Note on Recuperation of Landfill Gas from Municipal Solid Waste Landfills. Working Paper Series. Washington.

Jönsson-Belyazid, U. (2011). *Energy for Sustainable Development*. Retrieved January 3, 2012, from http://www.cec.lu.se/o.o.i.s/16379

Kates, R.W., Clark, W.C., Correll R, Hall, J.M., Jaeger, C.C., Lowe I., et al. (2001). Sustainability Science. *Science, 292*(5517), 641-642.

Kemp, R. &. J. Rotmans, (2004). *Managing the Transition to Sustainable Mobility*. In Elzen, B., Geels, F. W. & Green, K, (Eds.). *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy* (pp. 137-164). Cheltenham: Edward Elgar Publishing Ltd.

Kemp, R. (2010). The Dutch Energy Transition Approach. *International Economics and Economic Policy, 7*, 291–316.

Linder, J.P. (2009, September). *Life Cycle Assessment of Biomethane Provision*. Plenary Session 2 / Results of the Biogasmax Project. Presentation at the European Conference on Biomethane Fuel, Göteborg, Sweden.

Long, S., Marajh, P. & Abdul-Haqq, N. (2011). *2011 The Year in Energy*. Energy Chamber of Trinidad and Tobago: Retrieved January 25, 2012, from: http://www.energy.tt/index.php?categoryid=1&p2001_articleid=1179

Lukehurst, C.T. ,Frost, P & T. Al Seadi. (2010). Utilisation of Digestate from Biogas Plants as Biofertiliser. IEA Bioenergy. Task 37 – Utilisation of digestate from biogas plants as biofertiliser. Retrieved April 10, 2012, from: http://www.iea-biogas.net/_download/publi-task37/Task37_Digestate_brochure9-2010.pdf

Mohammed, A. (2010, September 16). Deadly toxins in garbage soup at the Beetham Dump. *The Trinidad & Tobago Guardian Online.* Retrieved January 5, 2012, from: http://test.guardian.co.tt/?q=news/general/2010/09/16/deadly-toxins-garbage-soup-beetham-dump

MEEA [Ministry of Energy and Energy Affairs, Trinidad and Tobago]. (2011). *Framework for Development of a Renewable Energy Policy for Trinidad and Tobago*. A Report of the Renewable Energy Committee. Retrieved January 3, 2012, from: http://energy.gov.tt/content/266.pdf

MOLG [Ministry of Local Government]. (2012). An Integrated Solid Waste/Resource Management Policy for Trinidad and Tobago (Final Draft). Submitted by: EGARR & Associates. Retrieved March 24, 2012, from: http://localgov.gov.tt/docs/TT%20MOLG%20SWM%20Policy%20-%20Final%20Draft%20Integrated%20Policy%2014%2011%2011.pdf

Neckles, F.A. (1990). *Proposals for a Biodigester Programme for Trinidad and Tobago*. Unpublished paper.

Neckles, F. A. (2009). *Biogas Digesters*. Report submitted on the request of the Agricultural Development Bank (ADB). Unpublished paper.

NSR [Nordvästra Skånes Renhållnings AB]. (2007). *Biogas-The Fuel at the Centre of the Cycle.* [Brochure]. Helsingborg:Author.

Pacey, J.G., Augenstein, D., Morck, R., Reinhart, D.R., & Yazdani, R. (1999). *The Bioreactor Landfill - An Innovation in Solid Waste Management.* Paper presented at the Seventh International Waste Management and Landfill Symposium, *S*ardinia.

Physics Hypertextbook. (1998*). Chemical Potential Energy, Discussion*. Retrieved July 2, 2012, from: http://physics.info/energy-chemical/

Ramdass, A. (2012, March 29). 'God is a Trini'. *The Trinidad Express Newspaper*. Retrieved April 3, 2012, from: http://www.trinidadexpress.com/news/_GOD__IS_A_TRINI_-145020805.html

Raven, R.V. & Geels, F.W. (2010). Socio-Cognitive Evolution in Niche Development: Comparative Analysis of Biogas Development in Denmark and the Netherlands (1973–2004). *Technovation*, *30,* 87-99.

Raven, R., Verbong, G., Schilpzand, W.F. & Witkamp, M.J. (2011). Translation Mechanisms in Socio-Technical Niches: case study of Dutch river management. *Technology Analysis & Strategic Management*, *23*(10), 1063-1078.

Reinhart, D.R., & Al-Yousfi, A.B. (1996). The Impact of Leachate Recirculation on Municipal Solid Waste Landfill Operating Characteristics [Abstract]. *Waste Management & Research, 14*(4), 337 – 346.

Reith, J.H., Wijffels, R.H. & Barten, H. (Eds.) (2003). *Bio-methane and Bio-hydrogen. Status and Perspectives of Biological Methane and Hydrogen Production.* The Hague*:* Dutch Biological Hydrogen Foundation.

REN21 [Renewable Energy Policy Network]. (2011). *Renewables 2011 Global Status Report*. Retrieved April 11, 2012, from: http://www.ren21.net/Portals/97/documents/GSR/REN21_GSR2011.pdf

Rip, A., & Kemp, R., (1998). Technological Change. In: Rayner, S., & Malone, E.L. (Eds), *Human Choice and Climate Change*, *2,* 327–399.

RISE-AT (1998). Review of Current Status of Anaerobic Digestion Technology for Treatment of Municipal Solid Waste. Chiang Mai University Institute of Science and Technology Research and Development. Retrieved February 23, 2012, from: http://www.faculty.ait.ac.th/visu/Data/AIT-Thesis/Master%20Thesis%20final/chea%20combined.pdf

Rotmans, J., Kemp, R., & van Asselt, M. (2001). More evolution than revolution: Transition Management In Public Policy. *Foresight-Journal of Future Studies, Strategic Thinking and Policy, 3*(1),15-31.

Rotmans, J. (2005, June*). Societal Innovation: Between dream and reality lies complexity.* Inaugural Addresses, Research in Management Series, Rotterdam, The Netherlands.

Rotmans, J., & Loorbach, D. (2009). Complexity and Transition Management. *Journal of Industrial Ecology, 13(*2), 184-196.

Schot, J. & Geels, F.W. (2008). Strategic Niche Management and Sustainable Innovation Journeys: Theory, Findings, Research Agenda, and Policy. *Technology Analysis & Strategic Management, 20*(5), 537–554.

SGS [SGS United Kingdom Ltd]. (2005). CDM Verification and Certification Report for the Biogas Management Project, Battre, 12th March 2004 to 31st December 2004. Retrieved June 4, 2012 from: http://cdm.unfccc.int/filestorage/V/e/r/VerificationReport.370/Verification%20Report.pdf?t=eFh8bTVwcmtlfDBJoolAKSUBNa8_h9FJmSdD

Silverman, D. (2005). *Doing Qualitative Research (*2nd ed.). Los Angeles: Sage.

Singh, K., Kelly S., & Sastry, M.K.S. (2009). Municipal Solid Waste to Energy: Potential for Application in Trinidad and Tobago. *The Journal of the Association of Professional Engineers of Trinidad and Tobago, 38*(1), 42-49.

Smith, A, Stirling, A & Berkhout, F. (2005). The Governance of Sustainable Socio-Technical Transitions. *Research Policy, 34,* 1491–1510.

Smith, A. (2007). Translating Sustainabilities between Green Niches and Socio-Technical Regimes. *Technology Analysis & Strategic Management, 19(4),* 427–450.

Thomas, S. (2009, October). *Impacts of Economic Growth on CO_2 Emissions*. Paper presented at the 45th ISOCARP Congress, Porto, Portugal.

UNCCD [United Nations Convention to Combat Desertification]. (2007). *The 2005 Report on the State of Land Resources of Trinidad and Tobago.* Third National Reporting to the UNCCD.

UNFCCC [United Nations Framework Convention on Climate Change] (2012a*). Status of Ratification of the Kyoto Protocol*. Retrieved April 10, 2012, from: http://unfccc.int/kyoto_protocol/status_of_ratification/items/2613.php

UNFCCC. (2012b). *CDM Benefits*. Retrieved April 9, 2012, from: http://cdm.unfccc.int/about/dev_ben/index.html

Unruh, G. C. (2000). Understanding Carbon Lock-in. *Energy Policy, 28*, 817-830.

Verbong, G & Geels, F.W. (2007). The Ongoing Energy Transition: Lessons from a Socio- Technical, Multi-level Analysis of the Dutch Electricity System (1960–2004). *Energy Policy, 35*(2)*,* 1025–1037.

Verma, S. (2002*). Anaerobic Digestion of Biodegradable Organics in Municipal Solid Wastes.* (Masters Dissertation, Columbia University, 2002). Retrieved February 1, 2012, from: http://www.seas.columbia.edu/earth/vermathesis.pdf

Wellinger, A. (2009, September). *Gas Upgrading Issues*. Training Session 3. Presentation at the European Conference on Biomethane Fuel, Göteborg, Sweden.

WRA [Water Resources Agency]. (2001). *National Report on Integrating the Management of Watersheds and Coastal Areas in Trinidad and Tobago.* Prepared for the Ministry of the Environment. Retrieved March 14, 2012, from: http://www.oas.org/reia/iwcam/pdf/trinidad%20and%20tobago/trinidad%20and%20tobago%20national%20report.pdf

Yin, R. (2009). *Case Study Research: Design and Methods* (4th ed.). Applied Social Research Methods Series, Volume 5. London: Sage.

APPENDICES

APPENDIX A

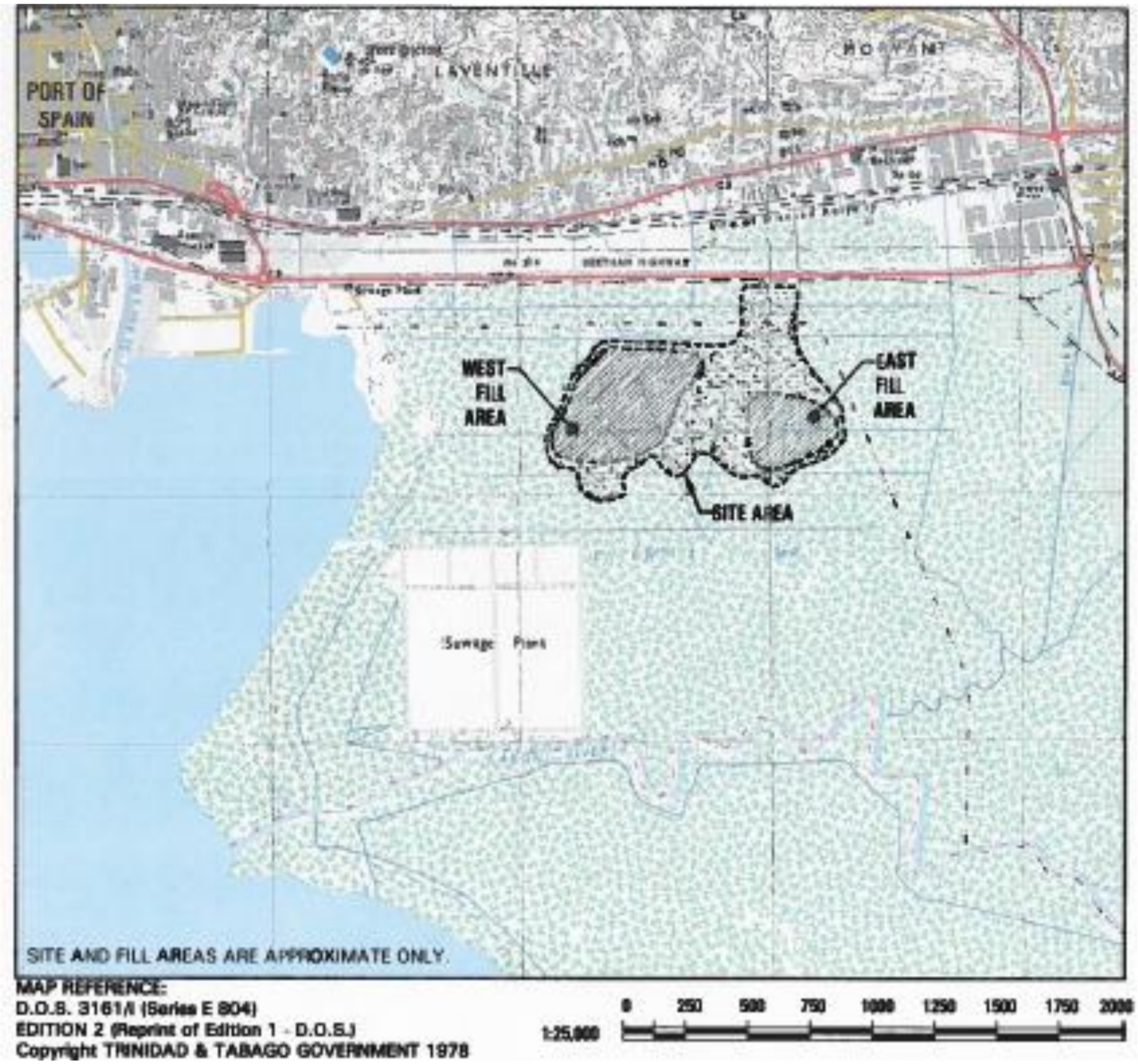
Table showing Interview Respondents

Name *	Organisation	Type of Interview	Location of Interview	Date of Interview	Length of Interview (mins.)
J. Smith	SWMCOL	Direct	Port of Spain	4 January, 2012	35
K. Dean	SWMCOL	Telephone	Telephone	11 January, 2012	15
R. Khan	Ministry of Energy & Energy Affairs	Telephone	Telephone	26 January, 2012	15
T. Lee	Sugarcane Feeds Centre (SFC)	Direct	Longdenville	7 February, 2012	30
A. James	SWMCOL	Direct	Port of Spain	8 February, 2012	64
A. James	SWMCOL	Site visit	Beetham Landfill, Port of Spain	8 February, 2012	50

* *Pseudonyms have been used to protect the identity of the interviewees as some preferred to remain anonymous*

APPENDIX B

Map of the Beetham Landfill



Source: Burnside, 2004

APPENDIX C

Pictures of the Beetham Landfill

Picture A- Waste mound at the Beetham Landfill

Picture B- A selection of waste material discarded at the site

Picture C- Salvaging activity at the Beetham landfill

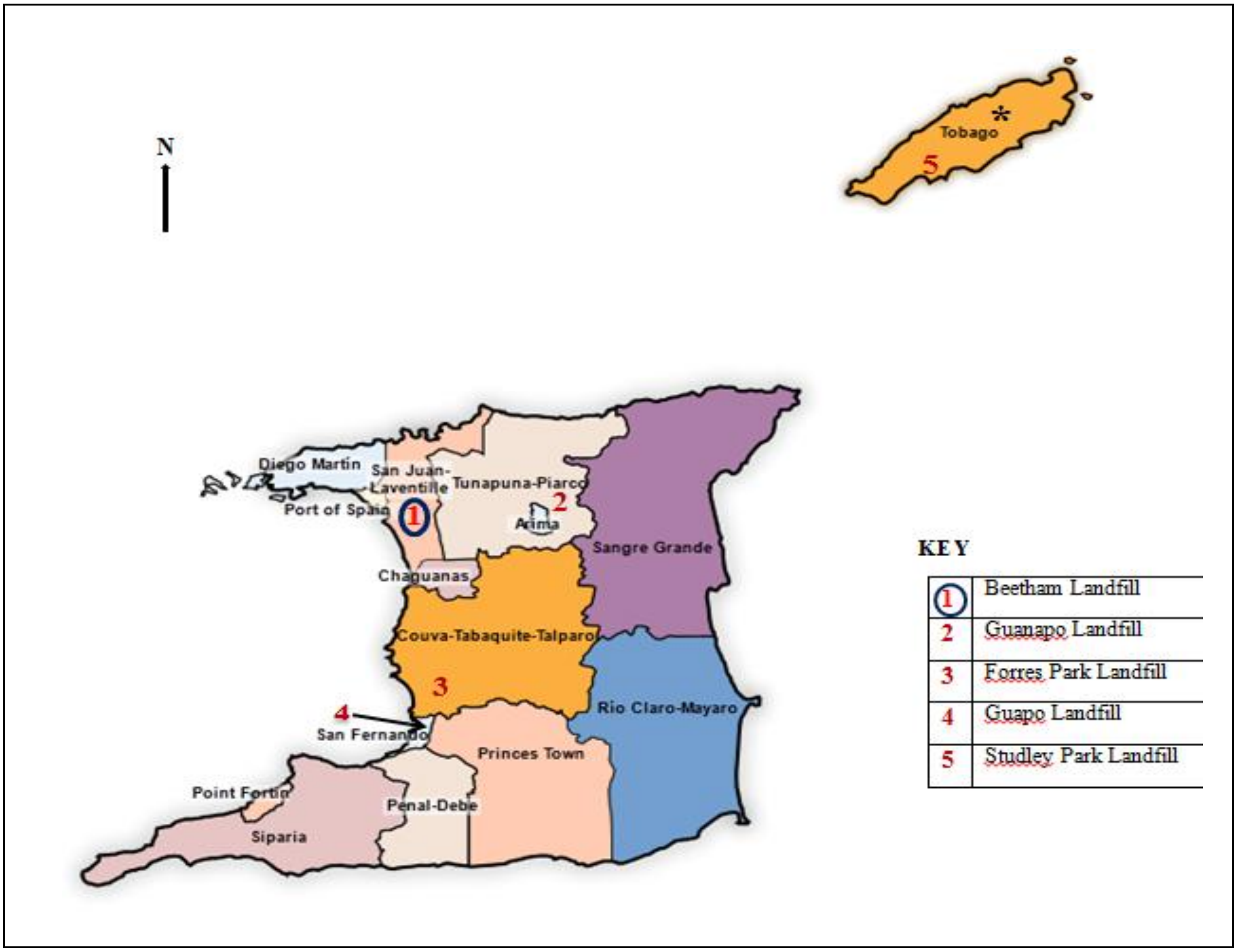
Picture D-Panoramic view of the Beetham Landfill with mangrove visible in the background

Picture E- Faecal pond located at the site

Picture F- Activity at the site with incoming refuse collection vehicle and informal bottle recovery (indicated by arrow)

APPENDIX D

Location of landfills in Trinidad and Tobago shown within the Regional Corporations and Municipalities



** Tobago is governed locally by the Tobago House of Assembly*

Source: Adapted from:
http://en.wikipedia.org/wiki/Regional_corporations_and_municipalities_of_Trinidad_and_Tobago

APPENDIX E

Regional (Latin America and the Caribbean) 2009 Domestic Fuel Prices

COUNTRY	DOMESTIC FUEL (USD/ GALLON)	
	GASOLINE TRANSPORT	DIESEL OIL
ARGENTINA	3.57	2.70
BARBADOS	2.57	2.02
BOLIVIA	2.00	1.99
BRASIL	4.77	3.87
CHILE	3.64	2.86
COLOMBIA	3.64	2.70
COSTA RICA	3.37	2.93
CUBA	1.70	1.21
ECUADOR	1.28	0.92
EL SALVADOR	3.24	2.60
GRENADA	3.48	3.46
GUATEMALA	2.93	2.47
GUYANA	2.58	2.38
HAITI	4.93	3.26
HONDURAS	3.55	3.03
JAMAICA	1.86	1.55
MEXICO	2.51	2.13
NICARAGUA	3.35	2.85
PANAMA	2.64	2.23
PARAGUAY	3.58	3.26
PERU	3.82	3.23
REP. DOM	3.82	2.80
SURINAME	2.11	1.55
TRINIDAD & TOBAGO	1.93	0.89
URUGUAY	4.88	n/d
1 Barrel = 42 US gallons = 158.98 liters		

Source: MEEA, 2011

APPENDIX F

Waste Treatment: Aerobic vs. Anaerobic Digestion

Within the aerobic and anaerobic categories of waste treatment, biogas production occurs under anaerobic conditions. The application of anaerobic digestion has several advantages compared to its aerobic counterpart. Although there may be issues with sludge disposal, space requirements, energy needs and burdens with management and upkeep of equipment when it comes to aerobic treatment, the converse is true for anaerobic digestion. Using this method the output is predominantly gaseous and has higher commercial benefits, there is greater potential processing capacity of feedstock, thereby making the process more space efficient and it is also comparatively easier to operate and maintain the unit as it boasts a lower energy budget (IEA, 2001).

Many of the aerobic methods of waste treatment which may either have similar outcomes or use the same type of substrates as found within biogas production do not provide the holistic benefits as can be derived from using the anaerobic process. For instance thermal aerobic processes like incineration (combustion in presence of oxygen), which although like anaerobic digestion works towards reducing the quantity of refuse, does not have as its primary aim energy recovery. As such this limits the benefits gained from energy generation by biogas production. Similarly, biological aerobic methods like composting, which like anaerobic digestion aims to treat the organic waste segment, is actually very energy intensive (approximately 30-35 kWh is consumed per tonne of input waste), compared to anaerobic digestion which is a net energy generating activity (approximately 100-150 kWh per tonne of input waste) (Reith, Wijffels & Barten, 2003).

Although the anaerobic process does have its disadvantages as the decomposition of organic material is not as complete as with aerobic processes, increasing the efficiency of this process by use of hybrid methods creates a trade-off. This occurs as the quantity of gas produced is lower compared with using the independent anaerobic process (IEA, 2001). Thus, in terms of energy production, the benefits derived from usage of the end-product and based on the other previously referenced insights, it is apparent that anaerobic digestion proffers more advantages than aerobic methods for waste treatment.

APPENDIX G

Biogas Calculations for the Beetham Landfill*

A) According to Johannessen (1999):

1tonne of waste=200Nm^3 of biogas production

At the Beetham Landfill, according to CBCL (2010) using 2005 as a baseline year:

Annual tonnage=875,000 tonnes

Therefore, annually at the Beetham Landfill:

If 1t = 200Nm^3

875,000t = 875,000t × 200 Nm^3

= 175, 000,000 Nm^3

So potential **annual 'natural' biogas production** at the Beetham Landfill: **175 million Nm^3**

B) In Trinidad and Tobago for 2009 the final consumption in Transport sector (IEA, 2012):

- Gas/Diesel: 418,000 tonnes
- Motor gasoline: 475,000 tonnes

C) Converting to the respective energy contents:

According to the Physics Hypertext book (1998):

- Diesel: 45.3MJ/kg (or alternatively 45,400MJ/t)
- Gasoline: 45.8MJ/kg (or alternatively 46,000MJ/t)

Thus, the energy content per fuel for T&T's transport sector:

Gas/Diesel: 418,000t × 45, 300MJ/t=18,935,400,000MJ

Motor gasoline: 475,000t × 45,800MJ/t= 21,755,000,000MJ

Therefore, T&T's **total energy content** in the transport sector:

18,935,400,000MJ **+** 21,755,000,000MJ **=40,690,400,000MJ**

D) Assuming a methane range of 55%-70% (based on RISE-AT, 1998):

If the total annual biogas production at the Beetham Landfill is 175, 000,000 Nm^3

- Lower range of methane (55%): 175, 000,000 Nm^3 × 0.55=96,250,000 Nm^3 of CH_4
- Higher range of methane (70%): 175, 000,000 Nm^3 ×0.70=122,500,000 Nm^3 of CH_4

E) Converting Nm^3 to tonnes (SGS, 2005):

1 $Nm^{3=}$ 0.000662 t/Nm^3

- Lower range (55%): 96,250,000 Nm^3 × 0.000662 t/Nm^3 = 63,717.5 tonnes CH_4
- Higher range (70%): 122,500,000 Nm^3 × 0.000662 t/Nm^3 = 81,095 tonnes CH_4

Where the volume of gas corresponds with temperature and pressure at which density of 0.662 kg/m3 (SGS, 2005)

F) According to Boyle, Everett & Ramage (2003):

Energy content of methane= 55 MJ/kg (or alternatively 55,000 MJ/t)

Therefore for Trinidad and Tobago:

- Energy content at 55% methane = 63,717.5 8t × 55,000=3,504,466,900 MJ
- Energy content at 70% methane = 81,095t × 55,000=4,460,225,000MJ

So, for the transport sector in Trinidad and Tobago in terms of the energy content, annually biogas could potentially contribute:

- Lower range of methane (55%): 3,504,466,900 MJ/40,690,400,000MJ × 100= **8.6%**
- Upper range of methane (70%): 4,460,225,000MJ/40,690,400,000MJ × 100= **11.0%**

i.e**. between 8.6%-11% of the total energy content annually**

**Calculations are merely for illustrative purposes as the figures used require verification and updating*