

UNIVERSITY OF CAPE TOWN

Department of Chemical Engineering



**Waste-Based Bioenergy: Operationalising
Technology Innovation System Analysis to
Go Beyond Assessments of Potential into
Implementation**

A thesis submitted for the degree of
Doctor of Philosophy
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Declaration

I **Rethabile Bonang Melamu**, declare that this thesis is based is on my own work, save for that which is properly acknowledged. It is being submitted for the degree of Doctor of Philosophy in Engineering in the University of Cape Town. It has not been submitted before for any degree or examination in any other University

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Synopsis

Clean modern energy and improved waste management are two well-recognised challenges in the global transition to sustainable development. There exist synergistic opportunities in simultaneously tackling the two issues via the generation of bioenergy from suitable waste streams. This potential has been successfully exploited elsewhere in the world; however, South Africa, despite having significant potential, lags behind in the implementation of these technologies and the respective conditions to use them. To understand slowly evolving technology trajectories and how to facilitate the pace of implementation, sustainability transition approaches such as the Technology Innovation System (TIS) framework have been found to be useful.

The aim of this thesis is to explore the utility of a TIS approach to investigate how the potential of waste-based bioenergy in South Africa can be unlocked to recover energy from waste using anaerobic digestion technology (*EfWviaAD*). Going beyond previous TIS studies, this thesis also aims to experiment with aspects of the TIS approach, so as to observe steps towards implementation. Key to the TIS approach is the notion of critical activities and processes around an emerging technology called system functions. Seven of these system functions detailed in Chapter 2 are proposed. These include knowledge development and diffusion, market forming activities, mobilisation of resources etc. The thesis sets out to answer two key research questions:

The first question seeks to establish whether the technology innovation system approach be used to locate and describe elements of technological transitions in South Africa's nascent energy-from-waste industry, using the seven functions proposed by Hekkert et al. (2007)? Also whether insights gained from testing the TIS approach on the more mature solar water heater technology are useful in describing the evolution of the anaerobic digestion industry in South Africa?

Results of TIS analyses show that the emergent Biogas Innovation System (BIS) can indeed be identified and its evolution described using the TIS approach. By assessing the applicability of the TIS approach in the context of the solar water heater (SWH) sector in South Africa, insights on how these transitions evolved were gained. Subsequent to the SWH

study, the TIS approach was employed to examine South Africa's BIS. For both of these technologies, the periods of notable inertia are characterised by the occurrence of few critical activities, which do not reinforce one another, and if they do, it is downwards directed reinforcement of so-called vicious cycles. The periods of increased momentum are symbolised by the individual fulfilment of system functions, and their cumulative reinforcement into so-called virtuous cycles. This thesis shows that, for the BIS, six of the seven key system functions suggested by the TIS approach are heavily involved at the end of the period studied play a crucial role in facilitating the evolution of the BIS into a system building mode. The absence of *market formation* activities limits the extent to which the BIS can be propelled into a sustained market dynamic, as observed elsewhere in more mature TIS, as well as in the case of the SWH Innovation System (IS) in South Africa. In addition, this thesis finds that the seven TIS functions described in Chapter 2, adequately described the trajectories of the SWH IS and BIS. Moreover, the results also identify some elements that are unique to transitioning economies. For example, resources are mobilised and knowledge is developed in a unique way. Grants, donor funds and climate change finance have been observed to ignite knowledge development activities, which themselves are dominated by pilot projects and feasibility studies, as opposed to the technical research that is observed in more mature economies.

Locating the status of innovation and technology development and identifying limitations to its growth was the first step in more effectively exploiting the potential in the use of bioenergy in South Africa. The question of how to influence the course of development positively is captured by the second research question:

Which of the seven functions can academic research most influence and strengthen? How would one go about influencing identified functions, consequently contributing to improved operation of an innovation system?

It was hypothesised that of the seven system functions, this project could most likely influence BIS through knowledge-based functions, viz. knowledge development and diffusion. A participatory action-based approach was adopted to plan and participate in three knowledge development and diffusion activities. The former entailed planning and implementing two biogas pilot projects, and the latter entailed organising and hosting a specialist workshop with identified BIS actors. The impact of these interventions on the BIS

was tracked via semi-structured interviews with the pilot projects' visitors on the one hand and the workshop participants on the other hand, at least one year after the visit. The results show that the intervention, through the described activities and events, led to a number of other activities considered critical to the evolution of a TIS. On the one hand, the *knowledge development* activities led to other activities that fulfilled other knowledge-related TIS functions and those that give clarity to the direction of the BIS. The *knowledge diffusion* activity on the other hand contributed to the fulfilment of all the other TIS functions – except for the *resource mobilisation* and *market formation* function.

In summary, this thesis firstly reaffirms that systemic approaches to understanding technology transition, in this case the TIS framework, are useful in locating and explaining technology trajectories. The notions of system functions and cumulative causation describe why the mere presence or absence of certain activities or events (barriers and drivers) does not sufficiently explain technology success or failure. In fact, it is the interaction of specific factors that explains the emergence of technological innovation systems and their development into mature markets. Further, it has been demonstrated that planned interventions by a set of actors (in this case the emergent South African BIS) can steer a TIS towards a more mature structure and functionality.

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LIST OF ACRONYMS

AD	Anaerobic Digestion
BBP	Bronkhorstspruit Biogas Project
BIS	Biogas Innovation System
BMP	Bio-methane Potential
CAE	Cape Advanced Engineering
CDM	Clean Development Mechanism
CEF	Central Energy Fund
CLD	Causal Loop Diagram
CoCT	City of Cape Town
COD	Chemical Oxygen Demand
COSATU	Congress of South African Trade Unions
CSIR	Centre for Scientific and Industrial Research
CSTR	Continuous Stirred Tank Reactor
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DIY	Do-it-Yourself
DME	Department of Minerals and Energy
DoE	Department of Energy
DSM	Demand Side Management
DSW	Durban Solid Waste
Dti	Department of Trade and Industry
E&PSE	Environmental and Process Systems Engineering
EDC	Energy Development Corporation
EIA	Environmental Impact Assessment
EJ	Exajoule
EfWviaAD	Energy from Waste via Anaerobic Digestion
EwB	Engineers Without Borders
GCGC	Global Change Grand Challenge
GCSSRP	Global Change, Society and Sustainability Research Programme
GEF	Global Environmental Facility
GHG	Greenhouse Gas
GIZ	Gesellschaft für Internationale Zusammenarbeit

IDC	Industrial Developmental Corporation
IEA	International Energy Agency
IRP	Integrated Resource Plan
IS	Innovation System
ISWA	International Solid Waste Association
ISWM	Integrated Solid Waste Management
LBP	Lesedi Biogas Project
LCA	Life Cycle Assessment
LMH	Leo Marquard Hall
LTS	Large Technological System
MCEP	Manufacturing Competitiveness Enhancement Programme
MDGs	Millennium Development Goals
MFMA	Municipal Finance Management Act
MSA	Municipal Systems Act
MLP	Multi-Level Perspective
MSA	Municipal Systems Act
MSW	Municipal Solid Waste
NACI	National Advisory Council on Innovation
NEEA	National Energy Efficiency Agency
NEM: WA	National Environmental Management: Waste Act
NERSA	National Energy Regulator of South Africa
NGO	Non-Governmental Organisation
NIC	Newly industrializing country
NIS	National Innovation System (NIS)
NSWHP	National Solar Water Heater Programme
NWMS	National Waste Management Strategy
PAR	Participatory Action Research
PJ	Petajoule
PV	Photovoltaic
R&D	Research and Development
RE	Renewable Energy
REFIT	Renewable Energy Feed-In Tariff
REIPPPP	Renewable Energy Independent Power Producers Procurement Programme
REMT	Renewable Energy Market Transformation

RFI	Request for Information
RFP	Request for Proposal
RIS	Regional Innovation System (RIS)
SA	South Africa
SAB	South African Breweries
SABA	Southern African Bioenergy Association
SABIA	Southern African Biogas Industry Association
SABS	South African Bureau of Standards
SADC	Southern African Development Community
SANEDI	South African National Energy Development Institute
SCAGA	Siyazama Community Allotment Garden Association
SCAGA-BP	SCAGA Biogas Project
SESSA	Sustainable Energy Society of Southern Africa (SESSA)
SIS	Sectoral Innovation System
SNM	Strategic Niche Management
ST	Sustainability Transition
SOP	Standard Offer Programme
SWH	Solar Water Heater
SWH IS	Solar Water Heater Innovation System
T&T	Talbot and Talbot
TIA	Technology Innovation Agency
TIS	Technology Innovation System
TSIS	Technology Specific Innovation System
UCT	University of Cape Town
UASB	Upflow Anaerobic Sludge Blanket
UNIDO	United Nation Industrial Development Organisation
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
WBCSD	World Business Council on Sustainable Development
WESSA	Wildlife and Environment Society of South Africa
WISA	Water Institute of Southern Africa
WSSD	World Summit on Sustainable Development

SECTION 1: Theoretical Approach and Methods

CHAPTER 1 Introduction

1.1 Background

A lack of access to sufficient and sustainable energy for clean cooking and lighting affects billions of people in developing countries, including several hundred million in Sub-Saharan African countries. Likewise, the provision of adequate waste management services is undoubtedly another key challenge that affects the majority of developing countries. The extent of these challenges is enormous and worth reflecting upon individually, first in the global context, and next in Sub-Saharan Africa, and specifically in South Africa, where the research presented in this thesis was carried out.

1.1.1 Energy

The IEA World Energy Outlook (2010) cautioned that lack of access to basic energy services for the majority of people in developing countries will be a '*serious hindrance to economic and social development and must be overcome if the UN Millennium Development Goals (MDGs) are to be realised*'. The more recent IEA World Energy Outlook (2011) revealed that more people are gaining access to modern energy globally. Yet, in 2009, 2.7 billion people, a significant proportion of which are in rural Sub-Saharan Africa, still relied on traditional biomass for cooking (*ibid*). In these contexts, biomass is typically inefficiently combusted for cooking purposes, leading to air pollution, which has dire health implications for those exposed. In 2005, 80% of people without access to modern energy lived in rural areas, but the urban proportion is set to increase due to rural-urban migration in less developed regions (Flavin & Aeck 2005). Notably, throughout the world, the urban population exceeded the rural population for the first time in 2007. Whilst, in Sub-Saharan Africa, more of the population are still living in rural areas, this region currently experiences the highest rate of urbanisation of any region in the world (Parnell & Walawege 2011; Hove et al. 2013). Consequently, energy poverty will most likely be exacerbated in urban areas, as rural migrants continue to rely on traditional biomass and some fossil fuels such as kerosene to meet their heating and cooking needs, due to a lack of service and the cost of modern energy (Flavin & Aeck 2005).

Improving the provision of energy in transitioning economies in general is thus crucial to address developmental challenges. A few are worth mentioning, namely, eradication of extreme poverty, improvement in environmental and health related conditions, stimulation of economic activities with associated employment creation in the spirit of *energisation* (Nissing & von Blottnitz 2010b). The suitability of a particular technology depends on the need being met as well as the context (Flavin & Aeck 2005; Nissing & von Blottnitz 2010a). Off-grid renewable energy (RE) based systems can make an important contribution in providing energy not only to rural areas, but also to urban areas, which are unlikely to be served by the national grid in the medium-to-long term (Flavin & Aeck 2005). Examples of technologies that are deployable off-grid include small wind-electricity turbines, solar photovoltaic (PV), and small hydro and biogas digesters.

In South Africa, major inroads have been made with regard to providing electricity (largely coal-based) to over 84% of the population (Statistics South Africa 2011). Tait & Winkler (2012) contend that the backlog of unconnected households remains sizeable, but separable from the need to respond to climate change induced by the coal intensive economy, which they describe as a real threat to the country's developmental agenda. Several policies have been proposed to address energy related national challenges, but two are probably the most relevant. These are the White Paper on Renewable Energy (DME 2003) and the National Climate Change Response White Paper (South Africa 2011). Notably, the White Paper on Renewable Energy set a target for 10 000 GWh renewable energy to be added to the national electricity mix by 2013, to address some of the above-mentioned challenges. Although this target was not attained by the end of 2013, plans towards its realisation, perhaps in a few years, are well advanced. These plans are further discussed in Chapters 4 and 5. Moreover, the recently published National Climate Change Response White Paper endeavours to address climate change induced environmental and health impacts. Unclean and inefficient energy systems are largely responsible for the majority of the present environmental problems and, to a lesser extent, health challenges. Another inefficient but critical societal system is waste management, often marred by many limitations and associated environmental and health implications.

1.1.2 Waste management

Provision of adequate waste management services is a major problem in transitioning economies such as South Africa. This is despite municipalities spending between 20-50% of

SECTION 1: THEORETICAL APPROACH AND METHODS

their available budget on solid waste management, according to the World Bank estimates (UNEP 2009b). Moreover, waste management activities are usually uncoordinated (Nahman & Godfrey 2010). Still, the volumes of waste continue to increase globally. For instance, in 2006, it was estimated that the total municipal solid waste (MSW) generated globally was 2 billion tonnes and this value is estimated to have increased by 37% in 2011 (UNEP 2009b). On the other hand, agricultural biomass residues are also increasing, according to the United Nations Environmental Programme's (UNEP) *Converting Waste Agriculture Biomass into a Resource* report (2009a). An estimated 140 billion tonnes of biomass are generated annually from agriculture, which holds an immense bioenergy potential, equivalent to 50 billion tonnes of oil (*ibid*).

Urbanisation relative to economic growth is said to exacerbate the waste management issues in urban Sub-Saharan Africa. An estimated 30-60% of urban solid waste is usually not formally collected, with less than 50% of the population serviced (UNEP 2009b). The weakness in the waste management system, characterised by inadequate waste minimisation strategies and insufficient recycling initiatives in urban areas, leads to illegal dumping, and environmental and health related problems, etc. (Nahman & Godfrey 2010). Remarkably, waste management is also becoming a burgeoning problem in rural areas as a result of population increases, and changing consumption and lifestyle patterns (El-Messery et al. 2009). A study based on solid waste management in rural Egypt confirms that the quantity of waste has increased, while its quality and constituents has changed drastically since the 1980s due to the reasons outlined above (El-Messery et al. 2009). Although not yet quantified, the same could probably be predicted for most of rural Sub-Saharan Africa; this will likely pose a problem in the future and should ideally be incorporated into planning agendas. Still, the issue of waste management in rural areas is not yet widely covered in academic literature, probably because such problems were negligible a few decades ago. Nevertheless, waste management issues in transitioning economies remain pertinent in urban areas.

A note-worthy characteristic of solid waste in developing cities, especially in Sub-Saharan Africa is the high biodegradable content of the MSW stream, at approximately 50% (Couth & Trois 2012). This implies that, even with an efficient recycling system in place, in the absence of treatment technologies over 50% of MSW, largely made up of food waste, could still end up on dumpsites or in landfills. Ironically, Nahman et al. (2012) note that, whilst food waste is increasingly becoming a global issue, so is global hunger. In South Africa, a

SECTION 1: THEORETICAL APPROACH AND METHODS

staggering 1.4 million tonnes of food waste is generated per annum, most of which ends up on dumpsites or in landfills (Nahman et al. 2012). At disposal sites (dumpsites, landfills) biodegradable material is anaerobically decomposed to produce methane rich gas, which is a potent greenhouse gas (GHG). Although it is estimated that the post-consumer waste sector contributes only 3-4% to the total anthropogenic GHG emissions, it is estimated that, unless major inroads are made, developing countries will be responsible for 64% of those emissions by 2030 (ISWA 2009; Friedrich & Trois 2011).

In South Africa, strategies and policies have been proposed to address waste management issues. The National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008) (NEM: WA) (Republic of South Africa 2009) was enacted precisely for that reason. Amongst the various proposed interventions, the act mandates municipalities to find alternative ways of diverting organic waste from landfills. More recently, the National Waste Management Strategy (NWMS), a legislative requirement of the Waste Act, was published by the Department of Environmental Affairs (2012), primarily to achieve the objectives of the Act. NWMS advocates an integrated solid waste management (ISWM) approach. The crux of this approach is the emphasis on avoiding waste altogether, reduction at source, reusing, recycling, and treating the waste, and disposing of it in landfills as the last waste management option.

As noted above, in cases where the waste generated cannot be reused or recycled, its treatment is encouraged, ahead of disposal. The organic fraction of municipal waste streams, whether sewage sludge or solid waste, can be upgraded through appropriate treatment technology instead of disposal. A sustainability analysis conducted by Couth & Trois (2012) on solid waste found that, besides recycling, composting is more beneficial than controlled landfilling in Sub-Saharan African cities. Composting, both aerobic and anaerobic, offers suitable treatment options for organic waste. The former produces fertilizer material, whilst the latter produces energy and, if precautionary measures are taken, such as the removal of pathogens from feedstock, fertiliser rich material.

Since the provision of sustainable energy remains a challenge in developing cities, especially those in Sub-Saharan Africa, technologies that generate energy from waste are attractive, as they simultaneously address energy and waste management problems. Such clean technologies are key to securing environmental sustainability in specific sectors of the

economy or indeed the whole economy, whilst improving economic competitiveness (Coenen & López 2010). Waste to energy technologies have been adopted extensively elsewhere in the world, but to a far lesser extent in Sub-Saharan Africa, despite the magnitude of both energy provision and waste management challenges. In particular, bio-wastes are potential feedstock for modern bioenergy technologies. Moreover, their diversion from their disposal sites including landfills and dumpsites can help to ease the environmental impacts on landfills (UNEP 2009a) and improve the highly burdened waste management systems. Anaerobic digestion (AD) is one such technology that it is able to convert bio-wastes into energy; in this thesis, it will thus be used as an example for understanding how bioenergy from waste can be unlocked in South Africa. It is therefore useful to give a brief overview of the AD technology and its application in the following section. Those familiar with the basics of the AD technology can proceed to the next section 1.1.3.

Notes on biogas generation via anaerobic digestion (AD)

Anaerobic digestion (AD) is a process in which organic materials (biomass, sewage sludge, etc.) are biodegraded under the action of fermentation microorganisms in the absence of oxygen to produce biogas. There are three types of AD processes, classified on the basis of the operating temperature. At temperatures between 10 and 25 °C, the process is usually referred to as psychrophilic AD. Mesophilic AD takes place between 25 and 45 °C, whilst thermophilic AD takes place between 45 and 65 °C. Thermophilic AD exhibits faster reaction rates, higher gas production, and higher rates of the destruction of pathogens and weed seeds than at psychrophilic and mesophilic operating temperatures. However, typical AD systems in European countries (~62%) operate at mesophilic conditions, mainly due to the lower energy requirements, but also for better stability of the process (temperature control, etc.) (Forster-Carneiro et al. 2008; Karagiannidis & Perkoulidis 2009).

Organic materials that are the feedstock to the AD process can also be broadly classified into agricultural (manure, energy crops, grasses etc.) and waste streams (food waste, MSW, sewage sludge etc.). Material left over at the end of the AD process is rich in nutrients (digestate) and can be used as a fertilizer, if the feedstock was free of toxic material and pathogens. AD produced biogas has various applications, including thermal applications, electricity generation and transport fuel.

The AD process itself is complex, consisting of four stages with different microbial activity. These four main groups of bacteria, viz. hydrolytic, acidogenic, acetogenic and methanogenic bacteria operate in a synergetic way in AD. Hydrolysis is the first step; here insoluble complex organic compounds (e.g., cellulose, carbohydrates) are broken down into smaller soluble monomers (glucose, fatty acids and amino acids). Monomers from hydrolysis are synthesised into organic acids in acidogenesis. Organic acids are used as substrates to produce H₂, CO₂ and mainly acetate in acetogenesis. Finally, CH₄ and CO₂ are produced from acetate by different types of methanogenic bacteria, as illustrated in Figure 1.

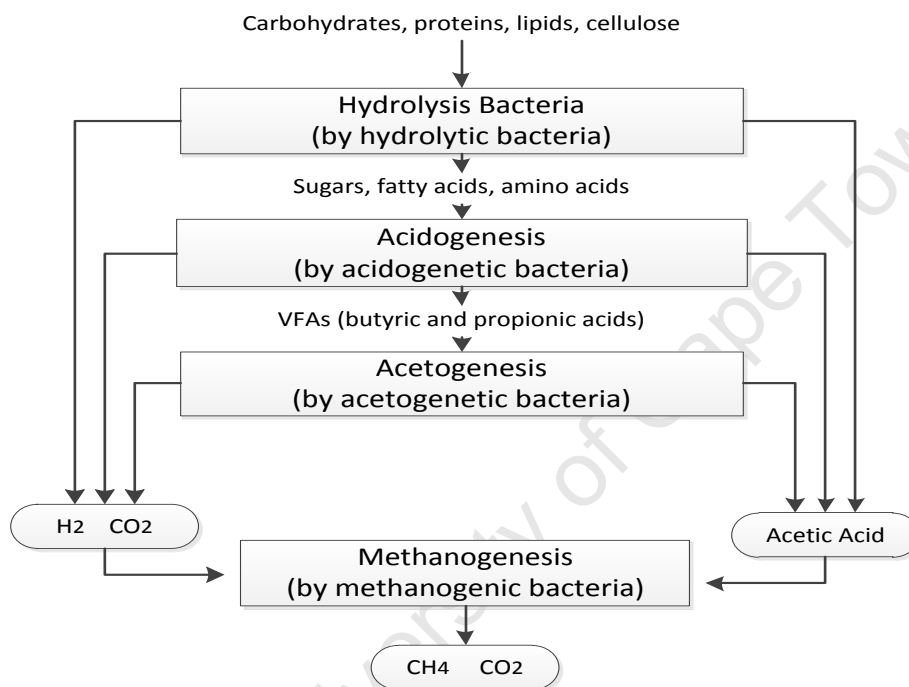


Figure 1.1: The anaerobic digestion process (Cheng 2010 pp. 517)

Since the AD technology is highly versatile, and can be adopted at different scales, viz. at household, medium and industrial scales, it lends itself to a variety of designs. As a result, AD systems vary widely, based on the scale of application. On the smaller scale, common designs include; fixed domes, floating drums and bladder digesters. At the larger scale, plug flow, up-flow anaerobic sludge blanket and Continuous Stirred Tank Reactor (CSTR) types of digesters are commonly found. In the following section, the bioenergy potential in South Africa, and to a limited extent in Africa, will be quantified.

1.1.3 Bioenergy Potential in South Africa

Over the past 18 years, a number of studies have made estimates of the bioenergy potential in Africa in general and in South Africa in particular, considering both the crop-based and the

waste-based resources. Marrison and Larson (1996) carried out a preliminary analysis of crop-based biomass energy production potential in Africa. Their base case scenario, which assumed that only 10% of the land that was not forest, cropland or wilderness was planted with some biomass energy crops, found that 18 Exajoule (EJ) of primary energy could be produced by 2025, 1.35 EJ of which could be produced in South Africa.

Elaborating on this approximation, Lynd et al. (2004) estimated the energy potential from biomass in South Africa at 1470 Petajoule (PJ) (= 1.47 EJ) from cellulosic residues (agriculture and forestry), energy crops and invasive species. This corresponds to approximately 25% of the current total energy consumption in South Africa (Department of Energy 2009); moreover, if converted at 50% efficiency, it could provide approximately 85% of the current use in the transport sector. Potential energy from residues alone at 300 PJ/annum could provide 5% of the current primary energy consumption.

Austin et al. (2006) examined the potential energy that could be recovered from the MSW generated by six South African metropolitan areas. According to their study, a total of 8.9 million tonnes of MSW with net energy content of 71 000 TJ/annum (= 71 PJ) was disposed in the landfill sites of the South African metros. This is equivalent to 20 100 GWh/annum of net energy being discarded, double the amount of the renewable energy target for South Africa of 10 000 GWh/annum by the year 2013, or about 2400 MW_{th}.

In another study, the potential energy that could be recovered from four types of wastewaters, viz. wastewater from treatment plants, formal and informal animal husbandry, fruit factories and breweries, was investigated (Burton et al. 2008). It was found that total of 3 000 - 10 000 MW_{th} could be recovered from wastewater in the whole of South Africa (approximately 5% of Eskom's current electricity supply), largely via established biogas technology. Formal and informal animal husbandry had the greatest energy recovery potential, optimistically set at 7500 MW_{th}.

1.1.4 Bioenergy success in Asia and Germany

Several Asian states, and more recently Germany, are good examples of countries that are increasingly fostering the conversion of various wastes into heating, lighting and/or electricity, utilising AD technology. Although various energy conversion technologies could be utilised for waste- and crop-based biomass conversion, biogas digesters are preferred,

mostly at small (household) and medium (farm) scale, due to the relatively low cost of installation, the ability to operate successfully at ambient temperatures and low pressures, and low operational and maintenance costs (Austin et al. 2006). In addition, there are claims that better energy yields can be gained from biogas compared to other organic waste energy recovery technologies (Shilton & Guieysse 2010).

Successful biogas implementation and dissemination in Asia

The success behind the implementation of biogas plants in Asia rests largely with those countries' policy initiatives to provide cleaner cooking and lighting energy for their rural population, although in some countries, such as India and China, biogas plants are increasingly found in urban areas (Vogeli & Zurbrugg 2008). Most digesters in Asia utilise manure (e.g., cow dung, pig and poultry wastes) as feedstock. Food waste and sewage are however being increasingly used in urban areas. The implementation of biogas systems in India dates back to the 1960s, but it was only in 1981, that the National Project for Biogas Development was formed to step up dissemination. Until 1997, a total of 2.5 million biogas plants had been installed, primarily driven by household sized biogas systems (up to 10 m³), and in total over 4 million household digesters had been installed in India by 2012 (Schmidt & Dabur 2013).

China's success can be attributed to the formation of a nationwide network for research and application in the 1970s, once the government of China had formally identified biogas production as an effective and rational use of natural resources in the rural areas. China's recent 2003-2010 National Rural Biogas Construction Plan aims to increase biogas technology by 11 million new household installations. Announced in 2003, it contributed to the fast dissemination of biogas plants by providing a subsidy (equivalent to US\$ 150 per installation) on biogas digesters (Chen et al. 2010). In addition, China's 2005 Renewable Energy Law, which provides feed-in-tariffs for renewable technologies, has stimulated medium-scale livestock biogas projects in China's countryside (Chen et al. 2010). Currently, over 30 million household digesters have been installed in China, the highest number in the world, and the industry is showing steady growth (Chen et al. 2010). In Nepal, over 170 000 households have biogas plants installed, making it the world's highest number of installations per capita, outnumbering China and India (Gautam et al. 2009).

Successful biogas implementation and dissemination in Germany

More than 4 000 biogas plants are installed in Germany, with a capacity of 1200 MW_e (Braun et al. 2009). There are two types of biogas plants, namely the decentralised farm scale and the centralised large scale, with the smaller scale plants dominating at about 70% (Negro et al. 2007). The smaller scale plants, most of which are located in southern and south-western Germany, have capacities of less than 70 kW_e, while the centralised plants are mostly found in the northern and eastern parts of the country, with an average capacity of 200 kW_e (Negro 2007). The distinguishing factor between the plants is the relatively high density in the southern region compared to the north, hence most small-scale plants are set up on farms. In the south, manure and agricultural surplus are digested and the resultant heat and electricity are provided to farm buildings. In the north, the cooperation of more than two farmers ensures the provision of sufficient feedstock, the production and utilisation is centralised, and the electricity is fed into the electricity grid.

In view of the background outlined above, it is clear that simultaneous energy generation and waste management solutions are crucial to address health, environmental and economic agendas. However, there remains significant untapped potential to harness energy efficiently from agricultural crops and waste materials to meet some of these energy needs especially from biodegradable wastes (agricultural, industrial residues, municipal), but also from energy crops. Recent reports argue that waste-based bioenergy is a better option than crop-based bioenergy. This is because they have lesser environmental impacts (Champagne 2007), are cheaper (Amigun 2007) and potentially have meaningful social benefits (Nissing & von Blottnitz 2010b). Yet there has been little engagement on how this potential can be unlocked. The following section discusses approaches for understanding how this technology can be unlocked.

1.1.5 Insights into unlocking waste-based bioenergy via innovation

Technological innovation is key to understanding how waste-bioenergy potential can be unlocked. A broad definition of innovation, as defined by Garud et al. (2013), is adopted here, as opposed to just invention, i.e., the emergence of a novel idea. Rather, technological innovation is viewed as a process that covers any of the following aspects: '*invention, development and implementation*'. Recent work has pointed to the influence of the social system on technological innovation, and has given birth to a rapidly growing body of enquiry that attempts to understand the so-called 'socio-technical' transitions, which are detailed in

Chapter 2. Socio-technical transitions have received tremendous attention from policy makers and researchers alike (Breukers et al. 2014). The common feature shared by these approaches is their rejection of the linear techno-economic modelling of innovation; rather their interest lies in understanding the complex dynamics of innovation processes. The *innovation system approach* is one such approach that conceptualises the process of innovation as comprising a system (Lundvall et al. 2002; Carlsson et al. 2002).

The innovation system approach finds different expressions of analysis, depending on the unit of analysis. The unit of analysis can be as broad as a nation, in the so-called National Systems of Innovation (NIS). This form of analysis is, however, too broad for a specific technology and thus unable to address whether or not a specific technological innovation, e.g., biomass digestion, is successful (Carlsson & Stankiewicz 1991). This is better addressed when a technology is used as a unit of analysis. Hence, the characteristics of structures that make up a specific technological field are claimed to be important determinants of the success of technological innovation (Negro 2007). In the past decade, several empirical studies have been conducted, employing the Technology Innovation System (TIS) approach to understand specifically how technology develops and takes root in society. One of the early studies unpacked why Germany's biomass digestion industry has been successful, whereas failures have been experienced elsewhere (Negro 2007). The German Biogas Innovation System (BIS) is an example of a TIS comprising of a well-established structure of actors, institutions and networks, whose success could inform similar innovation systems that are emerging elsewhere. It also demonstrates how important key processes, also known as system functions, have built up over the years, resulting in the ability of the system to overcome technical and institutional hurdles (Hekkert et al. 2007). Upon this background the following problem statement is formulated.

1.2 Problem statement

Numerous studies estimating the bioenergy generation potential have been carried out in Africa and South Africa. Despite the repeatedly reported immense potential, Africa in general, and South Africa in particular, are still lagging behind in the implementation of bioenergy technologies. Regarding the generation of bioenergy from energy crops, sourced largely from agricultural and food production industries, Africa is still waiting for its so-called green revolution. However, recent studies have established that it is cheaper to obtain bioenergy from waste material than from energy crops (Amigun & von Blottnitz 2007); it is

also greener (Champagne 2007) and could result in socio-economic opportunities (Nissing & von Blottnitz 2010b). To understand the characteristics, current dynamics and potential developments of a well-functioning bioenergy innovation system in Africa, and specifically in South Africa, it is useful to apply a technological innovation systems approach. Such a framework has been successfully used, for example, to analyse the German biogas industry. Such a pivotal understanding that moves beyond mere estimations of the potential of the implementation of bioenergy projects has not yet been explored nor exploited in the African context. It is thus the main aim of this thesis to apply the innovation systems approach to provide a comprehensive analysis of the emerging bioenergy industry in South Africa.

1.3 Objectives

The central objective of the research work upon which this thesis is built is to proceed beyond the mere estimation of the potential towards the actual implementation of bioenergy using AD as an energy conversion technology in the South African context. The specific objectives of this thesis are twofold:

1. To explore the utility of an innovation systems approach to understand how to unlock the estimated waste-based bioenergy potential in South Africa – a country lagging behind the usage of available technologies.
2. To experiment with aspects of the TIS approach, so as to kick-off and observe the impact of experimentation toward the implementation a more mature innovation system.

1.4 Key questions

To accomplish these objectives, and against the background of the above discussions on the successful rural biogas installation programmes in Asia and the highly successful German biogas industry, which have been found to be a result of a well-functioning innovation system, the following key questions form the basis of this study:

1. *Can the technology innovation system approach be used to locate and describe elements of technological transition in South Africa's nascent energy-form-waste industry, using the seven functions proposed by Hekkert et al. (2007)? Can insights gained from testing the TIS approach on the more mature solar water heating*

technology be useful in describing the evolution of anaerobic digestion industry in South Africa?

2. *Which of the seven functions can academic research most influence and strengthen? How would one go about influencing identified functions, consequently contributing to improved operation of an innovation system?*

1.5 Outline of the thesis

In order to gather evidence to provide answers to the two key questions, a dual methodology is used. As shown in Figure 1.2 below, Sections 2 and 3 of this thesis address the first and second key questions, respectively.

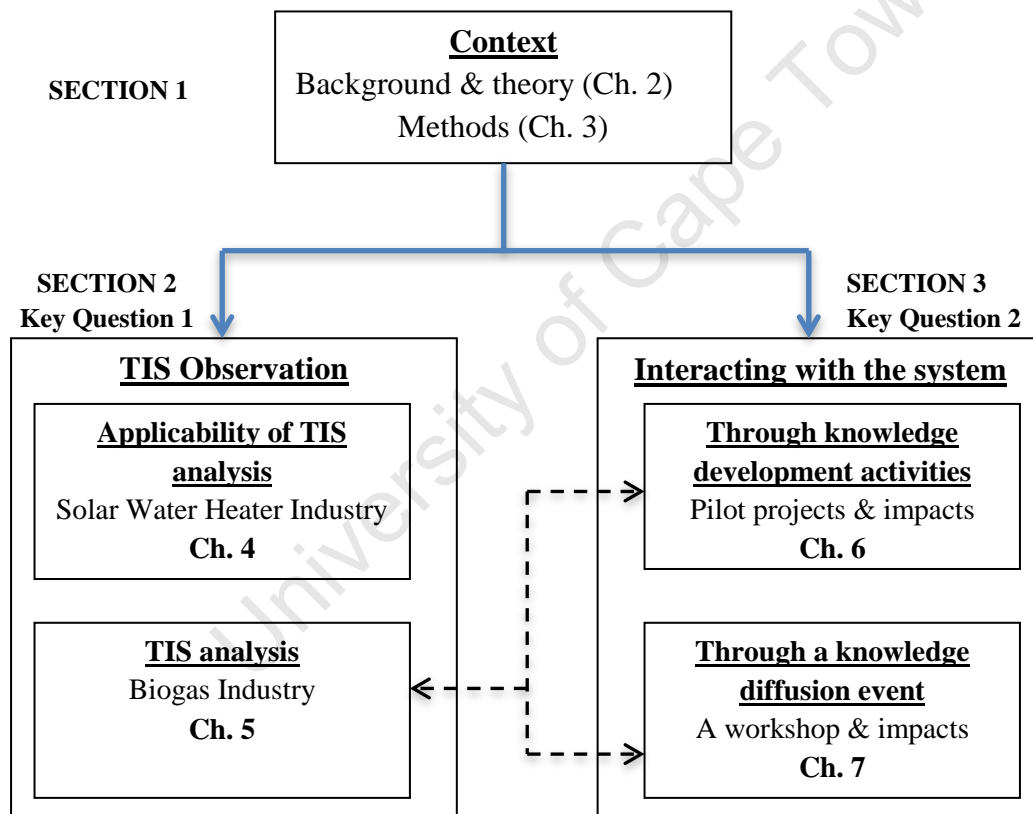


Figure 1.2: Schematic overview of the structure of the thesis and the thematic linkages

Theoretical approach and methods

The thesis is divided into 4 sections. The preliminaries, namely the theoretical approach and methods, are outlined in Section 1, which comprises the Introduction (Chapter 1), the Literature review (Chapter 2) and the Methodology (Chapter 3). Following this introduction (Chapter 1), the TIS framework is discussed in Chapter 2. This includes an extensive review

of the current conceptual discussions and empirical contributions in the literature. Chapter 3 lays out the methodological approach of this thesis and how the system functions approach is applied in this study.

Section 2 is titled *TIS Observation* and presents the results of the TIS analysis; it comprises Chapters 4 and 5. Since the approach had not been used to analyse technology trajectories in Africa when the thesis was conceptualised, the TIS framework's applicability is tested on a more mature renewable energy technology in South Africa, viz. the Solar Water Heater (SWH) industry in Chapter 4. As such, readers that are familiar with the TIS application may just skim over it and to some extent Chapter 5 and focus on Section 3 which comprises a novel approach. In Chapter 5, the evolution of the biogas technology in South Africa is looked at. The TIS framework is used in conjunction with system dynamics theory to gain insights into the dissemination of biogas digesters in South Africa and to identify areas that can be influenced and improved.

Section 3 is titled *Interaction with the System* and comprises Chapters 6 and 7. In the interest of going beyond the estimation of the bioenergy potential in South Africa, it was postulated that the mere observing of how TIS functions are served would not be sufficient to stimulate the implementation of the technology. The purpose of Section 3 of the thesis is to investigate whether an active research strategy that purposefully interacts with some elements of the system functions could have a desirable impact on the Biogas Innovation System (BIS). Since research and academia most likely influence the knowledge-based functions of the TIS framework, it was hypothesised that taking part in activities that would contribute to such knowledge development and diffusion, other TIS functions than solely the knowledge functions will be positively affected. To this end, activities were initiated and conducted by an academic research team, led or co-led by the author of this thesis. In fact, the three case studies were carefully chosen and designed to study the second key research question. The results of the two demonstration installations are outlined in Chapter 6, while Chapter 7 presents the results of a *knowledge diffusion* activity.

Conclusions are stated in the final section, Section 4 in which I reflect on the research questions, provide answers to the key questions and establish whether the objectives set at the beginning of the thesis have been met.

SECTION 1: THEORETICAL APPROACH AND METHODS

The intention of the thesis is to use an emerging field of enquiry to interrogate how the bioenergy potential can be unlocked in South Africa. This is all the more imperative for issues of sustainable development in transitioning economies, which are plagued by many developmental challenges. A well-founded understanding of these trajectories is becoming increasingly important due to the pressing need to improve the living conditions of millions of people – particularly in Sub-Saharan Africa.

Two unique contributions are attempted in this work. The first pertains to the use of state-of-the-art innovation theory to understand and describe the dynamics of an emerging industry in a lagging country, where *technology transfer* research approaches would normally be applied. The second pertains to the analysis of the impact of academic research and development (R&D) in stimulating and facilitating innovation within an emerging industry, in a transitioning country context.

University of Cape Town

CHAPTER 2 Literature review

2.1 Overview

In this chapter, the theoretical basis for the thesis is looked at. The chapter begins with a brief reiteration of the waste management and energy provision challenges of developing countries in general and South Africa specifically. This introduces the review and critical assessment of the body of literature on which the study's theoretical framework is founded. Lastly, conclusions are drawn from the literature review.

2.2 Summary of the energy and waste management issues

A more detailed account of these issues has been discussed in Chapter 1. In a nutshell, there are immense limitations regarding the provision of basic services to the majority of the people living in developing countries. These basic services include waste management and energy provision, which affect millions of people across Africa; only the South African context is considered in this thesis. The repercussions of these limitations are many, and they span health, environmental and economic spheres. With regard to health, the pollution induced by the inefficient burning of fossil fuels, for instance, seriously affects the health of those who still do not have access to modern energy. Poor waste management, e.g., illegal dumpsites, which are usually a breeding ground for flies and mosquitoes, transmit communicable diseases (Parrot et al. 2009). The environmental implications (e.g., global warming) are well-understood, and are covered extensively in Chapter 1 and elsewhere (Couth & Trois 2011). With regard to economic opportunities, the lack of modern sources of energy limits the ability of the populace to make full use of and exploit business opportunities.

Clean technology and eco-innovation have been identified as important for securing environmental sustainability in specific sectors, and even the entire economy, whilst improving economic competitiveness (Coenen & López 2010). As mentioned in Chapter 1, waste to energy technologies have been adopted more extensively elsewhere in world than in South Africa and in most of the Sub-Saharan African states, despite the magnitude of both energy provision and waste management challenges. The question of how these cleaner technologies can be developed and how they can take root in society is thus an important one for South Africa to ponder upon. The discourse of sustainability transitions attempts to

provide answers to this pertinent question. The rest of this chapter will give an overview of the main concepts in this field, and elaborate more fully on the ones that are used in this thesis.

2.3 Analyses of technological transitions

Against the background of energy and waste management challenges in the context of sustainable development as outlined above, it is evident that radical and timely solutions are needed to deal with these tricky societal challenges. Innovation is considered central for overcoming these obstacles and transitioning towards sustainability. Smith et al. (2010) note that debates on innovation as an option for mitigating environmental degradation issues date back to the 1970s. For instance, innovative capabilities as a strategy to extend the ecological *limit* were the crux of critical responses to the *Limits to Growth* report, which cautioned against unchecked exponential growth (Meadows et al. 1972). More recently, ideas about ecological rejuvenation have deliberated on how innovation can redirect production towards ‘*environmental goals and decouple economic growth from environmental degradation*’ (Murphy & Gouldson 2000; Smith et al. 2010).

(Coenen & López 2010) define innovation as ‘*technologically novel or enhanced material goods, immaterial services or ways of producing services and goods*’, e.g., cleaner technologies and methods (Foxon et al. 2005). Markard & Truffer (2008) distinguish between incremental and radical innovation. They describe the former as the continuous improvement of production processes and established product lines in a given system, whilst the latter can lead to entirely new production systems. Either way, as the concern for sustainable development broadens, the demands on innovation have been intense and ubiquitous (Smith et al. 2010). As Markard & Truffer (2008) put it, arriving at an improved understanding of the processes of innovation is vital but extremely difficult. It is significant because of the impact such processes may have on actors in a given field, e.g., suppliers, producers and users of the innovation. Similarly, it is demanding, as the ‘*underlying processes are complex and typically depend on the co-development of new socio-technical transitions*’ (ibid). As such ‘*Innovation can thus be understood as an outcome of the on-going alignment of technology and the user environment in a co-evolutionary manner, where adaptation takes place on either side*’ (Coenen & Díaz López 2010).

The analysis of innovation processes and fundamental transformations of whole economic sectors has generated a sizeable *innovation literature*. Central to the innovation studies in the context of *sustainability* is a desire to explain how and why *greener* production and indeed consumption practices arise, or why they do not, and to make suggestions on how these kinds of practices might be accelerated in order to replace environmentally more damaging options (Smith et al. 2010). Furthermore, innovation studies situated in evolutionary economics provide a useful corrective '*perspective to (neo-classical) environmental economics*,' which see the challenge of environmental innovation as '*resting mainly in fine-tuning price signals for goods and services*' (Smith et al. 2010). This body of literature ascribes innovative success to the ability of actors, e.g., policy-makers, firms, research institutions etc., to link capabilities, knowledge, resources and markets systematically (Smith et al. 2013).

Going beyond the innovative success of individual innovators, Truffer et al. (2012) define sustainability transitions (STs) as follows: '*Long-term, multi-dimensional and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption*.' Smith et al. (2005) point out, however, that transitions towards sustainability have some distinct features that make them '*different from many historical transitions*'. Firstly, the STs are goal-oriented, e.g., to address obstinate environmental problems, whereas many historical transitions were *emergent*, e.g., '*entrepreneurs exploring commercial opportunities related to new technologies*' (Geels 2011). Secondly, another distinctive characteristic of STs is that most *sustainable* solutions do not offer noticeable benefits to end users and, in some instances, '*score lower on price/performance dimensions than established technologies*' (Geels 2011). It is for this reason that (Markard et al. 2012) state that ST studies constitute a field of research '*of high societal significance, given the magnitude and pervasiveness of sustainability challenges that the world currently faces*'. This may explain the tremendous growth that this area of research has experienced in the past few years: for instance, more than 100 articles have appeared in this field between 2010 and 2011 (Markard et al. 2012).

According to Markard et al. (2012), four frameworks have thus far achieved some prominence in this area of enquiry. Namely: i) transition management, ii) strategic niche management (SNM), iii) the multi-level perspective (MLP) on socio-technical transitions, and iv) the analysis of technological innovation systems (TIS). Two of these have been dominant with regard to broader questions of technology transition. In TIS, the focus is on

the dynamics and the prospects of a specific innovation that can contribute to far-reaching changes (Hekkert et al. 2007; Bergek et al. 2008); alternatively, MLP considers broader ‘*transition processes at a more aggregated level involving a variety of innovations, which lead to the substitution of established technologies*’ (Markard & Truffer, 2008). These two strands (viz. multi-level perspective (MLP) and innovation systems (IS) approaches) have emerged ‘*largely independently of each other, although they aim to explain similar empirical phenomena*’ (*ibid*).

Figure 2.1 below gives a schematic overview of how the body of literature has been conceptualised:

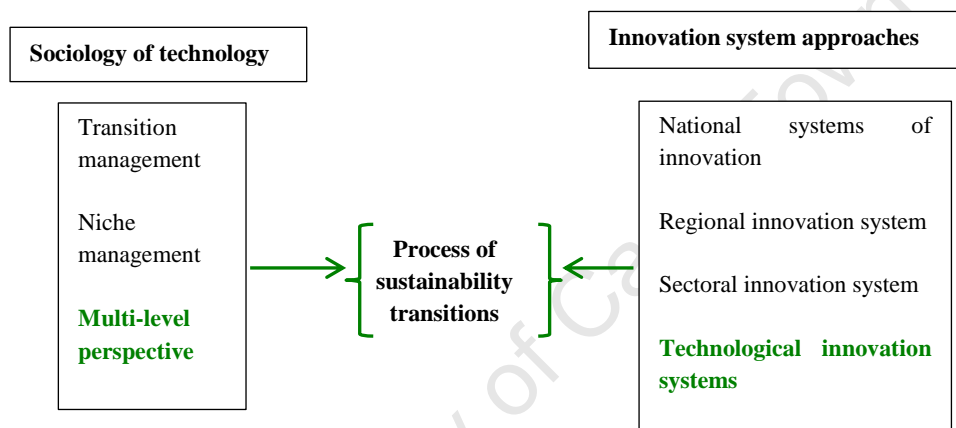


Figure 2.1: Schematic overview of some concepts in the Sustainable Transition literature

The subsequent sections will review and analyse the theoretical underpinnings of the two approaches, viz. MLP and TIS. It will be discussed how each body of literature has evolved, and the recent debates will be outlined. Thereafter, it will be critically interrogated how these system approaches to understanding innovation from a *sustainable development* perspective are evolving.

2.3.1 Multi-level perspective

The multi-level perspective is an analytical framework that conceptualises the overall dynamics of socio-technical transitions. According to Smith et al. (2010), MLP was birthed out of explanations for ‘*historic transitions to new socio-technical systems for mobility, sanitation, entertainment, food and lighting etc*’. The MLP framework draws on various concepts, viz. evolutionary economics (e.g., trajectories, path dependence), innovation studies, history of technology and sociology of technology (Geels 2011; Smith et al. 2010).

The MLP differentiates three analytical levels to understand system innovations, viz. niches, socio-technical regimes and an exogenous socio-technical landscape (Geels 2005; Markard & Truffer 2008). The MLP views sustainable transitions as non-linear processes that result from the interplay of developments between these three levels (Geels 2011). Each of the three elements of the MLP is outlined in more detail below.

2.3.1.1 Socio-technical regimes

A socio-technical regime is defined as a key concept of the MLP framework. At the heart of socio-technical regimes are stable and dominant configurations that are established as a way of achieving a specific societal function (Smith et al. 2010). Geels (2011) defines a socio-technical regime as a *'semi-coherent set of rules that orient and coordinate the activities of social groups that reproduce the various elements of a socio-technical systems'*. Examples of these rules include capabilities and competencies, favourable institutional arrangements and regulations, cognitive rules and shared beliefs (Geels, 2005). Socio-technical regimes are therefore understood as *deep structures*, accounting for the stability of existing socio-technical systems (Geels 2011). Some include artefacts and infrastructure in their definitions, e.g., Smith et al. (2005), whilst others maintain that actors may be included, for instance Verbong and Geels (2007). Based on these differences, Markard and Truffer (2008) note that the proponents of MLP *'do not apply the concept of socio-technical regime coherently'*. Still, socio-technical regimes are considered to *'impose a logic and direction for incremental socio-technical change along established pathways of development'* (Markard et al. 2012). Therefore, they are often characterised by lock-in, in which innovation occurs incrementally, as opposed to radically, *'with small adjustments seen to accumulate into stable trajectories'* (Geels 2011). *Regime shifts*, which is a term coined by Kemp et al. (1998), have always been concerned with how the structural persistence of dominant socio-technical regimes can be destabilised to give way to new, more sustainable, regimes (Markard et al. 2012). One of the ways that the regime can be destabilised lies in the protective spaces in which emerging technologies can grow; this is captured in another MLP analytical level, described in the following section.

2.3.1.2 Niches

Whilst socio-technical regimes are central to the concept of MLP, niches are viewed as their *'complementary elements'* (Markard & Truffer 2008). Niches have been conceptualised as sheltered spaces, i.e., specific markets or application fields, in which radical innovations can advance without the selection pressures that exists in the prevalent regime (Kemp et al.

1998). The protective spaces of niches safeguard innovations against untimely rejection by the incumbent regime, until they are robust enough to challenge and prosper in an unguarded market environment (Smith et al. 2013). Examples of niches are subsidised demonstration projects, R&D laboratories, *'and small market niches, where emerging innovations are supported and actors' special demands are addressed'* (Geels, 2011).

Smith et al. (2013) outline three key processes that niches facilitate: firstly, shielding innovations against dominant selection pressure; secondly, nurturing the innovation process; and thirdly, as recently proposed by Smith and Raven (2012), empowerment. Empowerment takes two distinctive forms. The first form involves empowering niche innovation to compete under *'prevailing selection environments, i.e., to be able to fit into and conform to the incumbent regime'*. The second form involves the establishment of *'protective measures, thus influencing reforms in prevailing selection environments'* (Smith et al. 2013).

Further distinction is made between market and technology niches (Smith et al. 2013). Market niches on the one hand comprise limited yet commercially viable opportunities for technologies to locate buyers willing to pay higher prices for the new technology (*ibid*). Technology niches for sustainable innovations on the other hand, are created with the objective to promote cleaner technology through processes such as expectation development, social learning and networking, so as to increase their chances of being widely diffused into the market (Smith et al. 2013). Niche actors, e.g., entrepreneurs, start-ups or spinoffs, typically work in radical innovations deviate from existing regimes, *'in the hope that they will eventually be used in the regime or even replace it'* (Geels 2011). Geels (2011) notes, however, that this is far from easy for at least two reasons. Firstly, there are likely to be *'mismatches with existing dimensions in the existing regimes'*, e.g., regulations and lack of appropriate infrastructure; secondly, regimes are usually stabilised by lock-in mechanisms (*ibid*). Moreover, due to the stability of the regime, radical innovations are only likely to break through when the regime is weak (Geels 2005). However, some destabilising factors may emerge outside regimes and niches, within the wider context of landscapes, which are outlined in more detail below.

2.3.1.3 Landscapes

The socio-technical landscape is another complementary element to the socio-technical regime. It is conceptualised as a wider context, which influences dynamics of the other two

MLP elements viz. niche and regime (Geels 2011). Processes that take place in the landscape include shifts in general political ideology, environmental and demographic change, emergence of new social movements, broad economic restructuring, cultural developments, etc. (Smith et al. 2010).

Changes in the landscape can often place pressure on the regime level to change. For instance, when regimes are put under tremendous amounts of stress based on dissatisfaction with their performance, it can initiate a process of niche consideration (Smith et al. 2010). As Smith et al. (2010) put it, *'these changes prompt responses from within the regime, while at the same time creating alternatives in the niches'*.

One of the socio-cultural developments that can be considered as a landscape process, is the growing environmental awareness: it is this very aspect that has led to the questioning of the performance of multiple regimes, e.g., fossil-based transport fuels and electricity, and that has generated opportunities for niches, e.g., renewable-resource based transport fuels and electricity (Smith et al. 2010).

In summary, MLP recognises that each socio-technical transition is unique; moreover, that it is characterised by transitions resulting from the interaction between processes at different levels of regimes, niches and landscapes. Geels (2005) summarises this as follows: *'niche innovations build up internal momentum, while, at the same time, changes at the landscape level put pressure on the regime, which in turn destabilises the regime and creates a window of opportunity for niche innovations'*. Smith et al. (2010) however caution that specific mechanisms underlying the interactions between the three levels are far more complicated than suggested in the earlier work of MLP conceptualisation.

2.3.2 Innovation systems concept and approaches

The innovation system approach for understanding the process of innovation was first conceptualised in the early 1980s. This approach recognises that innovations are *'iteratively enacted through networks of social relations, as opposed to singular events by isolated entities or bodies'* (Coenen & Díaz López 2010). This is contrary to the then popularised linear model (located in neoclassical economics) of innovation, which proposes that innovation starts with basic research, followed by applied R&D, and then production and diffusion (Godin 2006). Lundvall (2007) notes that the concept of innovation systems was

intended to help develop an alternative analytical framework to the standard neoclassical one and to criticize its disregard of dynamic processes connected to innovation and learning. In addition, Sharif (2006) observes that the concept was developed in the context of debates relating to the European industrial policy, as such, enjoys more application in Scandinavian countries and Western Europe.

As a concept, an innovation system may imply a collective and harmonised action, but Bergek et al. (2008) caution that it is just an analytical construct, *'a tool used best to understand the performance and the dynamics of a system, and that it therefore does not have to exist in reality as a fully-fledged system'*. Another important characteristic of an innovation system is that interaction between its components maybe both unplanned and unintentional *'rather than deliberate, even in more developed systems'* (Bergek et al. 2008).

Since the inception of the approach, several concepts that emphasize the systematic nature of innovation have emerged, each with a particular segment of the economy as a focus of analysis, viz. National Innovation System (NIS), Regional Innovation System (RIS), Sectoral Innovation System (SIS) and Technology Innovation System (TIS). Although these differ in terms of how their system boundaries are delineated, they do have a number of common characteristics, the central one being that the *'innovation and diffusion process is both an individual and a collective act'* (Jacobsson & Bergek 2011). In addition, the approaches can be seen as inherently interdependent: for instance, a technology specific innovation is located in a *'context of systems at higher levels of aggregation'* (e.g., RIS, NIS) (Markard & Truffer 2008). These varying innovation system approaches are outlined in more detail in the subsequent section.

The first of such conceptualisations is the National Innovation System (NIS). Although it emerged as early as 1982 (Lundvall 2007), it only became more popular after Freeman's book on Japan's National Innovation System (Freeman 1995a) was published. Freeman and Lundvall, the protagonists of the innovation system framework, attribute the first use of innovation systems to each other (Sharif 2006). NIS is defined as *'A network of institutions in the public and private sector, whose activities and interactions initiate, import, modify and use new technologies'* (Freeman 1995). NISs are delineated by country or nation boundaries and emphasise the role of the state to innovate. At the heart of this approach is the question of how learning can be supported to promote an innovation system (Lundvall et al. 2002). The

NIS approach does not typically focus on a particular technology or industry in its analysis; rather, it looks at how different technologies and industries contribute to the nation's innovation capabilities. Empirical studies on the role of sustainable energy technologies in the nation's system of innovation did not feature prominently in the early NIS literature (Truffer et al. 2012). There is a notable exception in Freeman's 1996 paper, though; in this, he investigates the possibility of clean technologies becoming the basis for a '*6th Kondratieff cycle, which could lead to a new wave of technological innovation and widespread success*' (Truffer et al. 2012).

The alternative concept variants of RIS, SIS and TIS started with a criticism of the original NIS literature: its major shortcoming was attributed to the way in which systems are delineated along national boundaries. Essentially, '*RIS, SIS and TIS argue that systemic coherences often follow regional, sectoral or technological logics, which could cross national boundaries*' (Truffer et al. 2012). Also, their reasoning is that the limited focus on innovation within '*specific national boundaries risks missing out on important boundary crossing structures and processes*' (Truffer et al. 2012).

Largely drawn from the NIS concept is the Regional Innovation System (RIS) approach, which recognises that local and regional government plays a critical role in processes of innovation. Cooke et al. (1997), define a Regional Innovation System (RIS) as '*interactive knowledge production and utilization sub-systems linked to other regional sub-systems to commercialise new knowledge*'. Cooke et al. (1997) argue that science and economic geography have a big influence on an RIS. Also, they propose that a two-dimensional structure of innovation activity can be defined for RIS, viz. governance and business dimensions. The RIS concept, however, has been criticised for being too broad and dependant on empirical studies as opposed to conceptual construction (Rosanis 2011). Moreover, the approach is limited in describing how specific sectors of the economy innovate, a question that is better addressed by the Sectoral Innovation System (SIS) approach.

The Sectoral Innovation System (SIS) approach was popularised by Malerba and colleagues (1997). Malerba et al. (2002) define a SIS as follows: '*A sectoral system of innovation and production is a set of new and established products for specific uses and the agents carrying out market and non-market interactions for creation, production and sale of those products*'.

In terms of boundary setting, the approach provides clear product-based guidelines. Sectoral systems of innovation encompass ‘*multiple technologies and transcend geographical boundaries*’ (Coenen & Díaz López 2010). Malerba (2005) views SIS as complementary to the other innovation systems approaches, in addition to being a descriptive tool for analysing innovation in sectors, which can transcend national boundaries. This approach does not necessarily explain how specific technology innovations emerge and are disseminated, a notion that is better addressed by a technology specific innovation systems approach. Since the main interest of this thesis is to understand how an emerging technology takes root in a society, this approach will be outlined in more detail in the subsequent section.

2.3.3 Technology innovation systems framework

Innovation system approaches to analyse specific technologies were first conceptualised in the early 1990s and referred to as *technological systems*. In their seminal paper, Carlsson and Stankiewicz (1991) defined *Technological Systems* as: ‘*networks of agents interacting in a specific technological area under a particular institutional infrastructure to generate, utilise and use technologies. Technology systems are defined in terms of knowledge or competence flows rather than goods and services*’. Hekkert et al. (2007) note that the term *technological system* is used elsewhere to refer to Large Technological System (LTS) (Hughes 1987), for instance, a national energy system that includes all technologies (e.g., wind energy, nuclear energy). Hence to avoid confusion, they coined the phrase *Technology Specific Innovation System* (TSIS), and more recently and in line with well-acknowledged usage in the research community, the *Technology Innovation System* (TIS) . The abbreviation TIS will be used from here on.

TIS cuts across geographical and sectoral dimensions: for instance, a particular technology (e.g., biogas technology) can be adopted in various sectors of the economy (e.g., agriculture, wastewater treatment and energy sectors). Moreover, it cuts across geographical boundaries: it is more advanced in some nations/regions (e.g., Germany, Nepal in the case of biogas) and emergent in others (e.g., in England and most Sub-Saharan Africa countries). Wieczorek & Hekkert (2012) sum up the TIS approach as follows: ‘*a global system with robust regional variations with regard to structure, which can be analysed at a global level but also a regional level*’.

The TIS approach has been used extensively on a variety of systems, which are described in various ways. For instance, in some studies the focus is on a specific field of knowledge, such as microwave engineering whilst others may focus on a particular product, e.g., fuel cells (Truffer et al. 2012). In both cases (knowledge and product), some of the studied systems are mature, although *'most tend to be in the early phase of development'* (Truffer et al. 2012). A distinct feature of the TIS approach, compared to that of the other innovation systems approaches, is its focus on emerging technologies as opposed to incremental innovations around mature technologies (Carlsson et al. 2002). TIS analyses are also considered the most dynamic of all the conceptualisations of the IS approaches. For instance, Negro (2007) argues that, in order to understand technological change, *'the underlying forces of a TIS need to be uncovered'*. In more aggregate approaches like the NIS, this is difficult to achieve, owing to the enormous number of actors, institutions, activities, etc. However, the number is significantly less for a TIS, which lends itself to easier tracking and mapping of the dynamics of change (*ibid*). The conceptual development and refinement of the TIS approach and related empirical application has dominated the entire innovation literature in the past few years. In the next sections, the structure of a TIS, and how it is analysed and applied empirically, will be outlined.

2.3.3.1 TIS structure

In the earlier studies, a TIS was said to comprise actors, networks and institutions (Carlsson et al. 2002; Hekkert et al. 2007; Bergek et al. 2008). Recent conceptual contributions, such as that of Truffer et al. (2012), for instance, have since argued that the actual technology and related artefacts are part of the system, as opposed to mere outcomes of the innovation process as assumed in earlier TIS studies. TIS scholars have since graciously acknowledged this in more recent empirical studies. For instance, Suurs & Hekkert (2009b) acknowledge that, although technological features were traditionally omitted as part of the TIS structure in their earlier work, *'disregarding such features implies that a critical feedback mechanism between technological change and institutional change is being ignored'*. Some of their subsequent work has since added technological features as part of the TIS structure (Suurs et al. 2009; Suurs et al. 2010). To sum up, a TIS is therefore understood to comprise actors and the networks they form, the institutions that govern the TIS, and related technological artefacts. The individual TIS constituents are discussed next.

2.3.3.2 Actors

There is a consensus in literature that actors play a critical role in innovation systems. The different scholars merely differ in how the actors being analysed are classified (Wieczorek & Hekkert 2012). Actors comprise all individuals and organisations involved in the development, diffusion and use of innovation, e.g., firms along the supply chain, universities and research institutions, financiers, influential research organisations, regulatory bodies etc. (Bergek et al. 2008; Hekkert et al. 2007; Suurs et al. 2010). Suurs et al. (2010) further separate actors into two categories, viz. enactors and selectors. They define enactors as those who are '*directly involved in the technology's development and who are dependent on its success, while selectors are actors who are drawn into an innovation system at a later stage through positive prospects raised by enactors*'.

2.3.3.3 Networks/Interactions

Networks play a crucial role in innovation processes. Generally, they can be differentiated into formal and informal networks (Musiolik & Markard 2011). Formal networks '*are those that have been purposefully established for strategic reasons*' (e.g., industry associations, standardisations networks), while informal ones have emerged in '*a less planned way through the interaction of organizations*' (university-industry links, buyer-seller links) (Suurs & Hekkert 2009; Musiolik & Markard 2011). Recent research has shown that formal networks can play a critical role for TIS formation and the development of supportive institutional structures (Musiolik et al. 2012). For instance, formal networks can develop and utilise resources to achieve their strategic goals, in a similar fashion to organization and firms; how resources are developed or strategically deployed, however, has only recently received attention (Musiolik et al. 2012). In addition, formal networks can influence institutional set-up through lobbying. Also, empirical analysis has shown that different networks play different roles in the formation of innovation systems and that they depend on different kinds of resources at their disposal to achieve their goals (Musiolik et al. 2012).

2.3.3.4 Institutions

Like networks/interactions, institutions too can be categorised into 'soft or informal' and 'hard or formal' (Edquist & Hommen 1999). On the one hand, they encompass a set of common habits, culture, routines and shared concepts used by humans in repetitive situations (so-called *soft institutions*) (Wieczorek & Hekkert 2012). These are said to confer values, duties and responsibilities, which set out what is right and what is wrong (Coenen & Díaz López 2010). On the other hand, *hard institutions* are organised by rules, and they encompass

norms and regulations (Wieczorek & Hekkert 2012). According to Coenen & Lopez (2010) regulative institutions (formal rules of the game) ‘*constrain behaviour and regulate interactions as they determine what is allowed and what is not allowed and are therefore often backed by sanctions*’. Suurs et al. (2009) caution against confusing institutions with organisations or firms, and suggest that they should rather be referred to as the rules of the game as suggested by North (1990). Truffer et al. (2012) note that the dynamic interplay between institutions and organizations is instrumental how technology trajectories develop. It is important to recognise, however, that in the TIS approach, institutions are primarily treated as signposts for innovators (Coenen & Díaz López 2010).

Technology/infrastructure

The last and increasingly important structural component of a TIS is technology and its associated features. Lately, some innovation system approaches are recognising technology as both a structural components in addition to being an output of the system (Jacobsson & Bergek 2011). According to Suurs et al. (2009), technologies comprise material infrastructure as well as artefacts within which they are embedded; moreover, they encompass techno-economic aspects the artefacts, e.g., reliability, costs and safety. Also recently, an encompassing term ‘infrastructure’ has been proposed for technological artefacts and related knowledge (Wieczorek & Hekkert 2012). Infrastructure, as proposed by Wieczorek & Hekkert (2012), is classified into three categories, viz. financial, physical and knowledge.

2.4 Analysis of a technology innovation system

The method of analysis of a TIS has undergone tremendous development since the start of the new millennium. In the early days of the conceptual development, most of the work focussed on the system failure caused by the so-called weakness in the structural composition of an IS (Johnson et al. 2003). In the late 2000s, a new process-based approach of analysis was proposed with i) the intention to supplement the structural focus and ii) a promise to unpack the dynamics of what is achieved in the system using the so-called system functions (Bergek et al. 2008; Hekkert et al. 2007). Several empirical studies have been conducted employing system functions (for instance, Negro 2007; Hekkert et al. 2007; Bergek 2010; Musiolik et al. 2012). The two approaches, structural and functional analysis, have developed independently of each other; but recent attempts have shown that the approaches are in fact complementary and thus should be combined. An example of this combined approach is portrayed in Wieczorek & Hekkert (2012): they investigate systemic failures with a view to inform policy

frameworks that will hopefully stimulate technological innovation. The suggested method of analysis has only been tested on a few studies, however the protagonists believe that the framework holds great potential for a *'new breed of policy makers that deals with complex issues, such as climate change'* (Wieczorek & Hekkert 2012). The next section will give an overview of structural and functional analysis of the TIS, and present the most recent approach that integrates the functional and structural analyses.

2.4.1 Structural analysis of a TIS

The point of departure in this approach is that the structural components of the TIS are *'intertwined and interdependent'* (Jacobsson & Bergek 2011). This implies that, altering a component of innovation is likely to induce changes in other components, which can result in a set of actions and reactions that can either propel the system forward or break it (Jacobsson & Bergek 2011). The main proposition of this approach is that *'weakness in any of the components of a TIS may obstruct its development'* (ibid). In innovation literature these are usually referred to as systemic weaknesses, problems and failures (Smith 2000; Wieczorek & Hekkert 2012). Early work on the analysis of an innovation system thus provides guidance as to which intervention would *'be needed to prevent system failures'* (Jacobsson & Bergek 2011).

Different scholars suggest different lists of system problems or failures; for instance, Smith (2000) suggests the following list: institutional failures, failures in the lack of infrastructural provision, lock-in and transition failures. Klein Woolthuis et al. (2005) revised various lists proposed by scholars, and suggested four general categories, viz. institutional, infrastructural, capabilities and interaction problems. Jacobsson and Bergek (2011) note that, whilst the concept of structural system weakness is beneficial from a policy viewpoint, the question that is not answered by the approach is how these system weaknesses that need to be addressed by public policy are precisely identified at any moment in time. Moreover, TIS scholars contended that it is difficult, if not impossible, *'to evaluate the goodness of that badness of a particular structural element without making reference to the effects it has on the innovation process'* (ibid). To complement the structural approach, a new so-called dynamic approach was thus proposed, employing system functions or activities in the analysis of the TIS. Wieczorek & Hekkert (2012) echo the same complementation sentiment of the functional and structural analyses, arguing that the functioning of a TIS is a manifestation of how it is organised. The following section presents how the functional analysis is applied.

2.4.2 Activities and function analysis of a TIS

Activities are conceptualised as '*factors that influence the development, diffusion and use of the innovation*' (Edquist 2005). Liu and White's (2001) list of activities includes: Research, which includes basic, development and engineering; implementation; end-use; linkages; education. On the other hand the last few years has seen system functions (also known as key processes) receive much attention (Markard & Truffer, 2008). Functions are defined as '*intermediate variables between the structure and the performance of a TIS*' (Jacobsson & Bergek 2011). The emphasis is on what the system does towards development, diffusion and implementation of a technology, over and above how it is structured (ibid).

Markard and Truffer (2008) argue that, while activities and functions have the same end goal, the notion of functions may be better aligned system concept, as functions can be '*ascribed to all elements of a TIS*' (viz. actors and their networks, institutions and technology as well as artefacts), whereas this cannot be said of activities. They also argue that activities in a narrow sense of description can only be performed by actors and not by networks and institutions, while functions are associated with a more holistic and systematic view that can be served by all components of the TIS structure (ibid). Bergek et al. (2008) also reason that activities tend to be structural in nature, one such example of an activity is the *creation of organisations* which can be interpreted as formation of networks/interactions. Since a functional analysis is adopted in this thesis, an overview of the functions literature is given next.

History of system functional analysis

The functional dynamics approach emerged out of a concern that innovation system frameworks were too heterogeneous (Bergek et al. 2008). Whilst some of the functions, e.g., *interactive learning*, popularised by Lundvall (2007), have been widely accepted from the very onset of functional conceptualisation, this has not always been the case for other system functions. Jacobsson and Johnson (2000) reviewed the innovation literature in order to identify '*what they said happened in the system*' and to determine the '*key processes that the various approaches agreed upon*'. The review established that some of the *key processes* were indeed shared. A list of eight of these shared system processes are summarised in Negro (2007) and Bergek (2008). A list of these functions has since been refined several times through empirical work, discussions with other researchers pursuing similar work and additional literature (Hekkert et al. 2007; Bergek et al. 2008). Insights from outside evolutionary economics were also incorporated in the revised lists of functions, e.g., from

sociology of technology, political science and organisation theory (Bergek et al. 2008; Jacobsson & Bergek 2011). There are two closely related lists of systems functions, both suggesting seven functions, one by Bergek and her colleagues (2008) and the other by Hekkert and his colleagues (2007). These differ slightly in their wording and aggregation, and are highlighted in the list of seven system described next.

List of system functions

It is worth revisiting what the functional approach offers: as per definition, functions are *‘intermediate variables between structure and system performance to contribute to the overall goal of the system, which is development, diffusion and utilisation of new technologies’* (Jacobsson & Bergek 2011). The idea is that each system function should *‘cover a specific aspect of the technology development’* (Suurs & Hekkert 2009a). The functions do not necessarily neglect the structural components of the TIS, but in fact contribute to how functions are served. As Hekkert et al. (2007) point out, the *‘dynamic nature of an innovation process requires a dynamic innovation system approach that will better understand its evolution and guide its direction’*. In recent work, ways of assessing the strength of various functions has been explored, i.e., the conceptualisation of processes that work within specific functions. Thus far, contributions have been made on the *entrepreneurial activities, guidance of search, market formation and knowledge creation and diffusion* functions (Truffer et al. 2012). In the following, the seven functions as suggested by Hekkert et al. (2007) will be detailed, with insights from Bergek et al. (2008). Recent suggestions on how processes within functions work for the above-mentioned functions will be discussed too.

Entrepreneurial experimentation

One of the fundamental features in the development of a technology is uncertainty. Whilst uncertainty is more pronounced in the early phase of technology development, it remains evident in more advanced phases (Bergek et al. 2008). Entrepreneurial experimentation reduces that uncertainty through probing into new technologies and their application (Bergek et al. 2008). In the process, the potential of new knowledge development, markets and networks can be turned into concrete actions that are able to create and take advantage of business prospects (Negro 2007). The presence of entrepreneurial activities in a TIS is therefore of paramount importance (Negro 2007). Bergek et al. (2008) go even further to suggest that *‘a TIS without vibrant experimentation will stagnate and, indeed, without initial*

experiments, it will not be formed.' Hekkert and colleagues (2007) refer to an 'entrepreneur' more broadly than as just a private actor; instead, they regard him or her as an individual or a group of public and private actors or their combination. Entrepreneurs are thus classified as entirely new players who recognise opportunities that lie in new markets, or alternatively as old/incumbent actors who seek to diversify into new spheres of business.

Meijer et al. (2010) point out that a systematic understanding is needed of the fundamental mechanisms that influence entrepreneurial action. This work is being explored in the area of renewable energy technologies that contribute to a low-emission energy infrastructure (*ibid*). Types of events that characterise this function are: projects with commercial gain, demonstration projects, portfolio expansion etc. (Suurs et al. 2009).

Knowledge development

Knowledge development has been regarded as central to the development of a TIS since the inception of the IS approach. As Lundvall (2007) states, '*knowledge is seen as the most strategic resource and learning the most fundamental activity*'. New knowledge is needed to address societal problems. Bergek et al. (2008) suggest two categorisations of knowledge, viz. different kinds of knowledge (e.g., technological, scientific, markets etc.) and different sources of knowledge development (e.g., R&D, learning by imitating, learning from novel applications). Negro (2007) adds that a combination of new and old knowledge in an innovative manner as well as the reusing of old knowledge by way of imitation is also included. Types of events that fulfil this function include: laboratory experiments and trials, studies, pilots etc. (Suurs et al. 2009).

Knowledge diffusion

Networks are viewed as channels through which knowledge is diffused. Suurs et al. (2009) reason that *knowledge diffusion* takes place the most where actors with different backgrounds meet and interact; they term this *interactive learning*. Moreover, learning through networks that exist in the innovation system encourages policy decisions to be made on the most recent technological insights (Negro 2007). The diffusion of knowledge can influence further R&D and knowledge development activities (*ibid*). Types of events that characterise this function include: workshops, conferences, formation of alliances etc. (Suurs et al. 2009).

Guidance of search

This function refers to those activities within an innovation that ‘*can positively affect the visibility and clarity of a specific technology amongst potential technology users*’ (Hekkert et al. 2007). One of the ways through which this is achieved is to provide enough incentives for actors (e.g., organisations) to enter the emerging TIS (Bergek et al. 2008). A related phenomenon is raising expectation of technology’s potential contribution to society. Negro (2007) acknowledges that this can be somewhat elusive, but proposes, for example, that *success stories* can influence the TIS to take a certain direction. Some of the factors that influence the direction are summarised by Bergek et al (2008) as: ‘*expectations and beliefs in growth potential, regulation and policy, articulation of demand from main customers, etc.*’

Another way of viewing this function is to contrast it with the *knowledge development* function, which promotes technology variations: *guidance of search* recognises that resources are limited and that only specific number of technologies are likely to be selected for further investments (Negro 2007). The selection of variants for further investigation is influenced by actors and structures in the TIS, including industry actors/bodies, government and market (*ibid*). Types of events that are said to fulfil this function include policies, standards, research outcomes such as Life Cycle Assessment (LCA), expectations and promises regarding the technology development, etc. (Suurs et al. 2009). More recently, Alkemade & Suurs (2012) investigated the role of expectation patterns in sustainable mobility technologies as a contribution to empirical description of the *guidance of search* function.

Market formation

Markets do not usually exist or are extremely underdeveloped for emerging technologies (Carlsson & Stankiewicz 1991) The reason for this, as pointed by Suurs et al. (2010), is that new technologies must compete against incumbent technologies. In her PhD thesis, Negro (2007) suggests two ways in which markets can be formed: i) By the formation of niche markets for the application of a technology and ii) by the introduction of favourable competitive advantageous measures. Tax incentives and market regulations are characterised as market forming activities (Suurs & Hekkert 2009).

Resource mobilisation

Resources considered in this function encompass human, material and financial capital, which are basic inputs in all TIS activities (Suurs & Hekkert 2009). Negro (2007) states that

analysis of this function using indicators is tricky, since the availability, or not, of resources is usually based on the perception of the actors in the field. Still, Suurs & Hekkert (2009b) suggest that subsidies and investments should be considered as indicators. In their recent study, in which they explore how networks mobilise resources, Musiolik et al. (Musiolik et al. 2012) acknowledge that earlier studies have already pointed out the importance of the fulfilment of the *resource mobilisation* function for successful technology development. They argue, however, that the resource concept has mainly remained broad and that the underlying processes have not been sufficiently explored. One of the ways in which *resource mobilisation* is conceptualised is by using a concept of *system resources* for resources that are mobilised within the system, which also contribute to the evolution of a TIS (Musiolik & Markard 2011). In other words, the mutual reinforcement of system functions is here also viewed as a mobilised resource. In system dynamics, this may be described as the *gain around a positive feedback loop* (e.g., Meadows (2004)).

Advocacy coalition

An emerging technology is usually faced with an enormous task of competing against incumbent technologies. Negro (2007) goes further to suggest that, in order for a new technology to develop well, it ought to be part of the incumbent regime or possess enough thrust to overthrow it. Actors in the incumbent regime usually oppose the force that comes from the emerging TIS. Actors within an emerging TIS will therefore need to raise a lobby of sorts, usually political, to counter this inertia (Suurs et al. 2010). Also, this function can act as a catalyst, stimulating action of the other system functions, for instance, lobbying for resources to be mobilised and for preferential tax regimes (Negro 2007), i.e., *market formation*. Event types that characterise this function are lobbies and advice (Suurs et al. 2010).

In order that the TIS be built up, Suurs and Hekkert (2009b) reason that the system functions outlined above should be realised in parallel and, in addition, reinforce one another into positive feedback cycles or cumulative causation, as suggested by Jacobsson and Bergek (2004). Suurs et al. (2010) suggest that the evolution of a TIS accelerates due to the functions being initially fulfilled individually, then interacting with one another and finally reinforcing one another into cumulative causation (also known as motors of innovation), over time. Previous studies have demonstrated the benefits of cumulative causation in the build-up of a TIS (Negro 2007; Suurs et al. 2009). An important aspect to understand in empirical studies

is under what conditions the motors of innovation come to be, and to recognise that functions are not independent of the TIS structure (Suurs et al. 2010)

2.4.3 Innovation system analysis of energy technologies

Numerous empirical studies have been conducted employing the innovation system approach to understand the evolution of energy technologies, the bulk of which focus on clean and renewable energy technologies. This field has seen tremendous growth in the past few years, so much so that this sub-category within the TIS was deemed robust enough to deserve further categorisation, viz. as *Energy Innovation Systems*, as suggested by Truffer and his colleagues (2012). These recent developments can be attributed to the increasing pursuit of renewable energy technologies as one of the efforts to address some global and societal issues, including the inter-related concerns of climate change, poverty alleviation and sustainable economic development. Truffer et al. (2012) contend that, regardless of policy intervention, the energy sector will most likely experience much pressure to transform as a result of *'communication technologies as well as new information, which permit radically different system layouts and open up opportunities for smarter grid distributions and distributed generation'*. Whilst most of the TIS analyses on energy systems have been conducted in European countries (Jacobsson & Johnson 2000; Negro et al. 2008; van Alphen et al. 2010; Suurs & Hekkert 2009b), there is increasing acknowledgement of the role that developing and emerging economies play in the future energy systems. One study has even considered how a developing country could leapfrog into higher shares of renewables (Binz et al. 2012).

Early contributions to the IS analysis of renewable energy technologies were rather generic and focused on the barriers to the development of several technologies (Jacobsson & Johnson 2000). Subsequent studies (Negro et al. 2007; Suurs & Hekkert 2009a; Bergek 2010) focused on more radical renewable energy innovation, specifically at the early stages of their development (Markard et al. 2012). A typical feature of the majority of recent studies is that a selected energy innovation is studied in the context of a certain country, which takes into considerations its industry and national regulatory structures (Truffer et al. 2012). It was not until very recently that TIS studies started to address the effects of regional embedding (Markard et al. 2012) and the international and global dimensions of technological innovation systems, asking, for instance, *'how global developments in a specific technological field affect the TIS in a selected country'* (Truffer et al. 2012).

In developing countries, there have been fewer empirical studies focused on energy and renewable technologies than there have been in developed countries. Furtado et al. (2011) use the national system of innovation approach to describe the success of the Brazilian sugarcane innovation system. Another Brazilian study based on the oil industry combines the different IS approaches and proposes a new framework that explains the coordination of innovation networks through an induction process (Pellegrin et al. 2010). A Chinese study combines TIS analysis with a concept of leapfrogging (*jumping over*) and seeks to answer the question of how future leapfrogging trajectories in Newly Industrialising Countries (NIC) can be analysed from a space-sensitive innovation system (Binz et al. 2012). In yet another study, Schmidt & Dabur (2013) combine the functional approach of the TIS framework with traditional technology transfer to identify the barriers to the diffusion of large-scale biogas projects in India, and to what extent the functioning of the innovation system can address some of the barriers. Mondal et al. (2010) propose to use an *innovation approach* and ‘appropriate technology’ frameworks to identify drivers, barriers and strategies for the implementation of renewable energy technologies in rural Bangladesh. It is not clear, however, which of the technology variants (NIS, RIS, SIS, TIS) they are employing in their study. Only one published study has been identified to have used the IS approach in Africa. The study was conducted by Szogs & Wilson (2008), in which the NIS approach was used to identify to what extent a so-called *biomass digestion* (which in fact turned out to be thermochemical treatment of biomass) innovation system and its constituencies can be identified in Tanzania. Although analyses of emerging energy technologies using an IS approach in general are increasing in developing countries, very few make explicit use of the TIS approach as summarised above. Markard et al (2012) emphasise that empirical studies of ‘sustainability transitions’ (STs) ought to be geographically representative so as to test the conceptual rigour. A summary of insights from the literature review is outlined below, identifying the contributions that this study can make to the body of literature.

2.5 Discussion

The provision of basic services to the growing population in developing countries, especially in urban areas, remains a challenge. Amongst the biggest hurdles are the provision of clean and sustainable modern energy and the provision of waste management infrastructure. Currently, moreover, the delivery of these services tends to have adverse environmental and health impacts as well as cost lock-ins for the continued provision of fossil fuels. Meanwhile, there is evidence to suggest that these two services can be improved concurrently. There are

countless examples in developing and developed countries where waste is used to generate energy. Whilst in some developed countries, waste-to-energy projects have been implemented in both rural and urban areas, e.g., Germany, they are largely rural-based in developing countries, e.g., Nepal, Ethiopia, India, China. Despite rising volumes of waste due to urban migration, there are still few waste-to-energy projects in developing cities, especially in Sub-Saharan Africa.

Innovation and the deployment of appropriate technologies have been central to the development of the waste-to-energy sector in some western countries and rural Asia – obviously so, since technical innovation in general has always played an important role in the economic growth of nations (Carlsson & Stankiewicz 1991; Lundvall 2007). The widely publicised approach of *analysing* innovation and deployment of technological innovations based on neoclassical models, however, has been heavily criticised for being linear and thus missing out on the very nature of innovation. As explained above, the systems method to understanding innovation is useful in unpacking why successful *‘innovations suffer difficult periods; or why what are termed hopeful monstrosities struggle on for decades’* (Smith et al. 2013). Indeed, the process of development of any industry can be lengthy, sometimes successful, e.g., in the case of the German biogas industry, and at other times not as successful, e.g., the Dutch biogas industry (Negro 2007). Truffer et al. (2012) caution that there is no optimum structure to develop a technology fruitfully, because each *‘technology and setting has its particularities, which need to be taken into consideration’*.

A large body of academic literature on technical innovation, viz. *sustainability transitions* (STs), have focused on the question: if and under what conditions a *sustainable transition* toward alternative and more sustainable development paths could be possible (Binz et al. 2012; Jacobsson 2004; Negro 2007; Geels 2005). For new energy technologies to develop and diffuse, emphasis is put on the importance of conducive institutional and organizational structures (Truffer et al. 2012). The approach also takes into consideration the fact that technology evolution involves quite a broad range of actors. Moreover, it usually *‘unfolds over considerable time-span’s* (could be 50 years or even longer), and it may have difficulties developing, for instance, in the case of the energy sector, which is locked into established technologies (Markard et al. 2012). As discussed above, there are several ST approaches, but two broad approaches have received significant attention with regard to renewable energy technologies, viz. Innovation Systems and the Multi-level Perspective (MLP).

The two approaches, namely, MLP and TIS, are relatively young concepts, having been conceptualised in the 1990s (Carlsson & Stankiewicz 1991; Kemp et al. 1998), and thus continue to undergo much theoretical refinement. There are some common features and differences between the two approaches. With regard to similarities, both regard actors, networks and institutions as important conceptual components (Markard & Truffer 2008). Some studies have gone further to compare the robustness of the approaches to understanding technological change and innovation (Markard & Truffer 2008; Coenen & Díaz López 2010). TIS tends to focus on emerging technologies that have not yet achieved a break through, whilst MLP is more interested in analysing change from a broad societal perspective. Coenen & Lopez (2010) attribute the difference in the approaches to micro-foundations, although both TIS and MLP originate from evolutionary economics. MLP, in addition, finds its roots in sociology.

Recent literature on sustainable transitions is increasingly looking at combining the two perspectives and drawing from related concepts, e.g., Strategic Niche Management (SNM). The rationale is to address some of the shortfalls of each approach. For example, some have proposed that the TIS approach be used as a tool to assess niche process from an MLP perspective, whilst other investigations have just focused on how to combine the two perspectives fruitfully (Truffer et al. 2012; Markard et al. 2009).

Whilst the TIS concept's strength lies in unpacking technology trajectories, its shortcomings lie in its limitation to explain how an emerging technology can induce '*broader structural changes for sustainable development*' (Smith et al. 2010). According to Smith et al (2010), these are addressed more appropriately by MLP approaches and are usually not considered in TIS approaches (Markard & Truffer 2008). In addition, Truffer et al. (2012) note that TIS researchers are yet to develop a conceptual framework that explicitly explains the evolution of '*innovation systems over time or that explains the multi-dimensional changes of established socio-technical systems*'. Such an approach could bring insights can enhance the approach as well complement the already established multi-level perspective. The shortcoming of the MLP, according to Markard & Truffer (2008), is the lack of consistency in how studies delineate a system, '*either using it in a rather descriptive way as a synonym for a sector or just in the form of a catch word*'.

The pros and cons of each of the approaches are well captured in Markard and Truffer (2008). There is a suggestion that, despite its shortcomings, that TIS has a more inclusive perspective on how an emerging technology gathers momentum over time through the inclusion of more actors, networks and institution (ibid). In contrast, the variant of MLP, a complementary theory that analyses the niche space, SNM, is not clear on how an emerging technology develops beyond the protected phase (Suurs & Hekkert 2009a). Also, since both concepts are undergoing theoretical refinement, Suurs & Hekkert (2009a) suggest that a choice of either of the frameworks is a matter of the focus of the study, as well as influenced by the particular researcher's taste and style.

The original objective of TIS-based studies has been to understand how technical innovation contributes to economic growth (Coenen & Díaz López 2010). The latest developments in this area of enquiry however have largely focused on the emergence of clean technologies that tackle sustainability issues (ibid). It is noteworthy that most of the conceptual development and empirical studies have been Eurocentric. Increasingly, however, IS approaches are being applied in transitioning countries and Newly Industrialising Countries (NICs) (Truffer et al. 2012). These studies tend to discuss development strategies as well as to investigate possible catching-up strategies (ibid). For instance, some studies interrogate whether NICs *'will be able to leapfrog conventional, carbon-intensive development steps and directly implement drastic options that are economically, ecologically and socially more sustainable'* (Binz et al. 2012). Still, such studies are few and far between, as summarised in the earlier section.

Markard et al. (2012) suggest that valuable insights stand to be gained as TIS researchers spread geographical reach of transition studies beyond the current focus on European countries. In a review of recently published literature, Truffer et al. (2012) suggest that the application of the concept is diffusing strongly to NICs. However, only three studies have thus far used the TIS approach amongst the tens of studies Truffer et al. (2012) have reviewed. Moreover, only one study was based in Africa, (Tanzania) and its rigour must be questioned. In agreement with Markard et al. (2012), the robustness of this framework to explain technical innovation can only be tested if its application transcends European borders and gains more geographical reach. Thus far, this seemingly useful approach is yet to be applied to an understanding of technology evolution in Africa. Its application will be an important step towards its theoretical testing. More important will be using it to explore why

sustainable technologies, e.g., biogas, have had a retarded growth in Africa, a question that this thesis seeks to explore further. The next chapter (Chapter 3: Methodology) will outline the approach followed to gather evidence in order to answer the questions posed at the beginning of the study (see Section 1.4).

2.6 Summary

The aim of this chapter was to present the background and the theoretical underpinnings, in which the remainder of the study is anchored. In the first section, the limitations with regard to the provision of sufficient waste management and energy services in transitioning economies were summarised. Opportunities to address the two issues concurrently, via the conversion of waste to energy, and additionally to tackle sustainability and societal problems, were highlighted. It was further stressed that the implementation of trajectories towards achieving such a goal, are tricky and yet their understanding can unlock the potential that resides in waste streams.

Attempts to unpack these problematic trajectories are afforded in the field of STs through several approaches, which were summarised in Section 2.3. The most widely applied concepts in the context of technology development of renewable energy are the Multi-Level Perspective (MLP) (and the related Strategic Niche Management (SNM)) and the Technology Innovation Systems (TIS). Since the study is based on the TIS approach, its background and empirical application has been discussed in detail. The centrality of the TIS structure and system functions to the development of a technology and how this development could possibly be accelerated was also highlighted. The build-up of system functions that could accelerate the development of a particular technology was also discussed in Section 2.4. Finally, a summary of some of the gaps in previous works were outlined, in particular the limited geographical representation of TIS empirical studies and the absence of its application in the African context.

CHAPTER 3 Methodology

The methodology developed to meet the objectives stated in Chapter 1 is based on the formulation and provision of answers to the two key questions of this study. The first key question, as stated in Chapter 1, is presented below:

- 1. Can the technology innovation system approach be used to locate and describe elements of technological transition in South Africa's nascent energy-form-waste industry, using the seven functions proposed by Hekkert et al. (2007)? Can insights gained from testing the TIS approach on the more mature solar water heating technology be useful in describing the evolution of anaerobic digestion industry in South Africa?*

Given that some of the seven system functions relate to acquiring and sharing of knowledge, research and academic institutions can play a crucial role in shaping the proposed BIS. The second key question seeks to interrogate this and is posed as follows:

- 2. Which of the seven functions can academic research most influence and strengthen? How would one go about influencing identified functions, consequently contributing to improved operation of an innovation system?*

The approach adopted to provide answers to the key questions is primarily based on the TIS framework but also borrows from the MLP for explanatory purposes. Figure 3.1 provides a schematic overview of the methodology, depicting the methods used to answer each of the two key questions.

This chapter begins with an overview of the approach adopted and the methods used to answer the two key questions in Section 3.1. Section 3.2 deliberates on the methods used to answer the first key question, whereas Section 3.3 explores the methods employed to answer the second key question. Lastly, Section 3.4 presents some concluding remarks.

3.1 Methodology overview

The approach used to answer the first key question is based on a well-developed TIS analysis, as elaborated in Chapter 2. Since the TIS framework has not yet been applied to a technology in South Africa, the research design includes testing its appropriateness on a more mature renewable energy technology before applying it to biogas technology. The only renewable energy technology that had reached market maturity at the time of planning this research was the Solar Water Heater (SWH) technology, which was thus deemed appropriate for the test. Empirical TIS analyses tend to be Eurocentric and mainly applied to renewable energy technologies, although they are increasingly being applied to other sectors too. The application of the TIS approach to the SWH technology in South African should thus add to the limited number of empirical TIS studies in developing countries. The testing of the TIS approach should moreover allow for modifications for context specific application of the framework, should that be necessary, and hence inform how it is applied to the biogas industry.

The approach for answering the second key question is more novel, as it had never been employed in previous TIS studies and is exploratory rather than confirmatory. It is noted that, of the seven TIS system functions, two speak directly to knowledge, viz. *knowledge development* (e.g. R&D, learning-by-doing, learning by interaction, etc.) and *knowledge diffusion* (e.g. workshops, conferences, etc.). See Chapter 2 for a detailed overview of the functions. It is thus postulated that these are the functions that academia will most likely be able to influence directly (although some functions maybe indirectly influenced too), and exploratory participatory action-based research was therefore designed around these functions.

To explore the impact that a particular knowledge development activity can have on the BIS, participatory action-based research based on exploratory case studies was conducted. The case studies entail the development, installation and operation of small-scale biogas digesters. Interviews were used to gather data to assess the impact that the two cases have had on the innovation system. In order to examine the impact of *knowledge diffusion* activity on the BIS, a workshop was organised, targeted at key actors identified for fulfilling one or more of the seven functions within the BIS. The research design foresaw examining the impact of the workshop on the BIS by tracking participants' post-workshop activity.

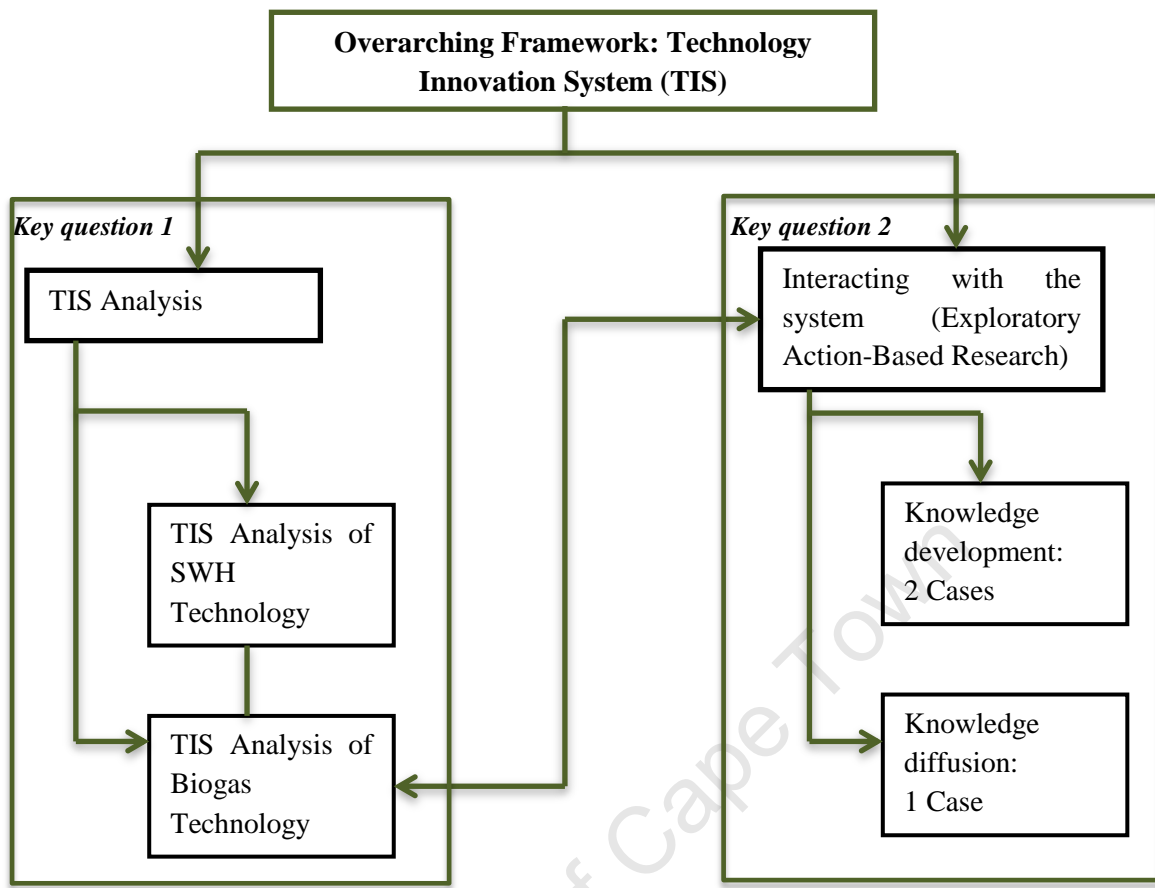


Figure 3.1: A schematic overview of the thesis research approach

3.2 TIS description and analysis

The strength of the TIS framework is mooted to lie in its ability to explain the process of technological change and innovation. This section describes the methods employed to observe and analyse the evolution of the biogas technology in South Africa, employing the TIS framework. However, that will be preceded by an analysis of the SWH technology as explained above.

The TIS analysis, based on the functional approach, will follow two steps:

- 1) First, the *process analysis* (also known as *event history analysis*), as adapted by Negro (2007) is conducted; and its applicability critiqued using a basic criteria
- 2) This is followed by the *analysis of the narrative*; in a novel contribution, depicted using causal loop diagrams (CLD).

Before the methods will be used, they are first reviewed in the subsequent sections. Section 3.2.3 then maps out how the two methods are combined and used in this study.

3.2.1 Process analysis

The *process analysis* approach has been conventionally employed in organisational change and innovation literature for more than 20 years (Poole et al. 2000). However, its application has been limited to studies that are oriented towards firm level innovation trajectories (Negro 2007). According to Suurs and Hekkert (2009b), through both quantitative and qualitative application of this method, '*a number of dynamic patterns have been identified for innovation trajectory's*', resulting in theoretical insights on the nature of innovation systems. This approach is applied by conceptualising change and development processes as sequences of events. Poole & Van de Ven (2004) state, firstly, that process analysis provides an in-depth understanding of how change comes about, by describing the generative mechanisms that energise the process. Secondly, they suggest that the process approach can account for trail dependence and identify the role of critical events in the process of change and innovation (Poole & Ven; Van de 2004). This approach also helps us to understand how forces and influences initiated in one event are transmitted to subsequent events. Lastly, it generates insights on how the combination of events produces interactions amongst the causal factors that '*can either build the momentum of a developmental or innovative process, or lead to its collapse*' (Van de Ven 2005).

The process approach or sequence analysis is achieved by gathering data that indicates how the process evolves; afterwards, it constructs a timeline of events in order to gain insight into the processes of change and development. The empirical basis for this approach is the *event*, which, according to Suurs and Hekkert (2009), '*is an instance of change with respect to actors, institutions and technology due to the work of one or more actors and that carries some significance to a TIS*'. Subsequently, a narrative based on the insights can describe the '*course of events and aggregations of causal forces that move the developing entity through its sequence*' (Poole, 2000). Also, a narrative provides a *big picture* that puts individual events and causes into context and assigns them their significance (*ibid*).

Negro (2007) notes that the system function approach assumes that the '*acceleration in the system is due to the interaction of the system functions*', which may lead to the formation of virtuous cycles. The sequence of events is therefore important in assessing which and how

the system functions have been fulfilled over time. Negro (2007) first identified the process approach or sequence analysis proposed by Poole et al. (2000) as a research approach that it is suitable for taking all relevant processes into account. This approach has subsequently been used in a number of empirical TIS analyses (Hekkert et al. 2007; Suurs & Hekkert 2009b; Negro et al. 2012; Alkemade & Suurs 2012).

In order to answer the first key question of the thesis, it is useful to set out criteria through which the applicability of the TIS approach in the transitioning economy context can be assessed. Here, the initial consideration is to establish whether there is a TIS structure, however poorly organised it may be, that can be linked to observable activities and events that lead to the development, diffusion and use of a technology in question. Secondly, a *process analysis* approach can be used to assess whether those activities and events are ascribable to any of the seven TIS system functions suggested by Hekkert et al (2007), barring those that can be considered external (landscape) to the TIS. Thirdly, are there obvious linkages between observed events and activities that demonstrate causality, for instance, is it obvious that an older event is likely to have led to a subsequent one, ultimately resulting in either virtuous or vicious causation? Fourthly, if there are observed cumulative causations, are they aligned with TIS approach proposition that positive causation propels an emerging TIS forward and that negative reinforcement of functions breaks it up?

A poorly performing TIS will have a few events and activities observed, and hence few functions fulfilled, or it may lack cumulative causality. The TIS approach cannot be considered applicable if most of the events and activities, except the landscape, are not ascribable to any of the seven functions.

The details of the process analysis as used in this study are described in Section 3.2.3. First, though, the next section outlines another component used to complement TIS analyses.

3.2.2 Use of Causal Loop Diagrams (CLDs) in system dynamic analysis

This tool is employed in the present research to complement the *event history analysis* method in the TIS analyses of SWH and biogas technologies in South Africa. Kim (1992) describes CLDs as a way of '*providing a language to express our understanding of the dynamic, interconnected nature of our world*'. CLDs are therefore useful for articulating intricate structures that often underlie complex situations in the field of System Dynamics, a

sub-research area of Systems Thinking. System dynamics views the key to system behaviour as lying in the inter-connected relationships between positive and negative feedback loops within the multitude of variables existing in a complex system that may become causally related in feedback loops. The identification of significant feedback loops and their causal structure is thus important for understanding system behaviours (Cavana & Maani 2000). Elements within a CLD can be seen as sentences, which are constructed by linking together key variables and showing the causal relationships between them. Through stringing together several loops, a coherent story about a particular issue or problem can be created (Kim 1992). This thus suggests that what *event history analysis* expresses narratively, CLDs articulates visually. Figure 3.2 below demonstrates how CLDs are drawn:

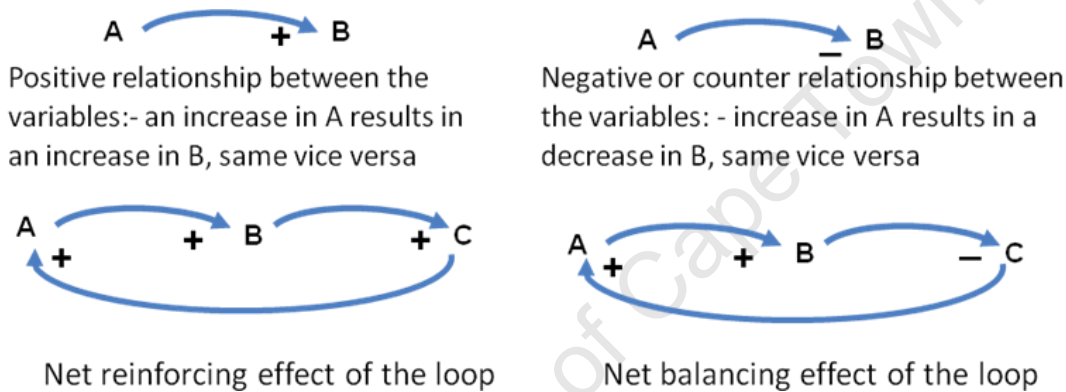


Figure 3.2: Depiction of variable relationships in Causal Loop Diagrams (Kasozi 2010)

There are general guidelines for creating CLDs, and the relevant ones are summarised below:

1. **Theme selection:** this entails carefully selecting a theme or a problem in order to understand it better.
2. **Time horizon:** this involves determining an appropriate time span for the issue to be investigated, one that it is long enough to observe the dynamics play out. Kim (1992) notes, however, that time in itself should not be depicted as an agent in CLDs
3. **Boundary issues:** it is important to set boundaries around the issue studied; one way of testing this is to determine whether an increase or decrease of a particular variable will have an impact on the issue at hand.

4. **Level of aggregation:** this is also determined by the problem at hand; for instance, if the issue being investigated spanned a few months, then variables that change slowly, e.g., that take years to change can be considered constant.
5. **Significant delays:** it is useful to show links with significant delays on causal diagrams.

The next section details the research approach followed and how it employs elements of the two methods discussed above.

3.2.3 Description of the approach

The approach adopted here is based on the event history analysis method as adapted by Negro (2007), with some slight modifications and also complemented with CLD analysis. The seven-step procedure employed in the study is described below and depicted in Figure 3.3.

1. **Literature search and data gathering:** Here, a thorough search was conducted of the literature for information related to events associated with the evolution of each of the two technologies. The information was sourced from different literature bodies for a specific period under consideration. In the case of the SWH industry, the period investigated was 1978-2012, and for the biogas industry, it was 2000-2013. Most of the data was sourced from the South Africa electronic database (*Sabinet*), which stores the following: electronic journals and newspaper archives using several key words; news articles on various websites, (e.g., www.engineeringnews.co.za); local and international journals; conference proceedings and government policy reports. Examples of data sourced were pilot studies, announcements and implementation of strategies and policies, company start-ups, the inception of industry bodies, etc. In some instances, unstructured interviews were conducted with industry players and experts to get more insights on previous and current activities.
2. **Database construction:** The events identified from the various sources were then listed chronologically in a database, in the form of an Excel spreadsheet. The database was structured as follows: the first column gave the date (or just the year in cases where exact dates were unavailable), the next column contained the event description and a summary of the event. The next column categorised the event using the system

functions (described in detail under the next step), and the last column noted a reference. See Appendices A and B for a full database of the event history of the two technologies.

3. **Allocation of system functions:** Here, events documented in a database were allocated to one of the seven system functions. Indicators as described in Section 2.4.2 will be used to allocate activities to projects, e.g., a workshop for *knowledge development*, a policy announcement for *guidance of search* etc. In cases where events were not attributable to any of the seven system functions, the event was documented as an external factor that indirectly influenced the innovation system under study. Some results and mapping were shared with other researchers in meetings to verify the mapping for reliability.
4. **Narrative construction:** Whilst a summary in the previous steps outline events in a studied period, and how the system functions have been fulfilled over the years, a narrative outlines the sequence of events over a period of the study and thus captures how the events have unfolded over time. Negro (2007) considers this stage a very crucial part of the analysis, as it presents the researcher's interpretation of the events. The narrative is separated into different periods; a period is signified/defined by vast differences in the type of activities and hence the frequency and, to some extent, the types of functions fulfilled.
5. **Analysis using CLDs:** The use of CLDs in articulating the narrative has not yet been explored in this line of research, despite having been found useful as a language that expresses our understanding of the dynamic, interconnected nature of our world (Kim 1992). CLDs were thus a useful step to precede the next step, namely, to identify the types of causal relationships that exist between the events. This step entailed depicting how the activities have led to the fulfilment of certain functions, and how those have subsequently influenced the fulfilment of others, whether positively or negatively.
6. **Identification and analysis of patterns:** The previous step began to map the various causalities of the system functions. This step endeavoured to identify the types of patterns or cycles that existed in the studied period; these cycles are also known as motors of innovation. It then went further to determine, investigate and discuss how the different motors followed on from another, thus determining the kinds of structures (actor, institutions, networks and technology) that underlie the observed patterns.

7. **Completeness of results:** The completeness of the data collected and the historical description was checked with key industry players and expert/s through interviews, to determine whether they may be deemed sufficient to meet the objectives of the study.

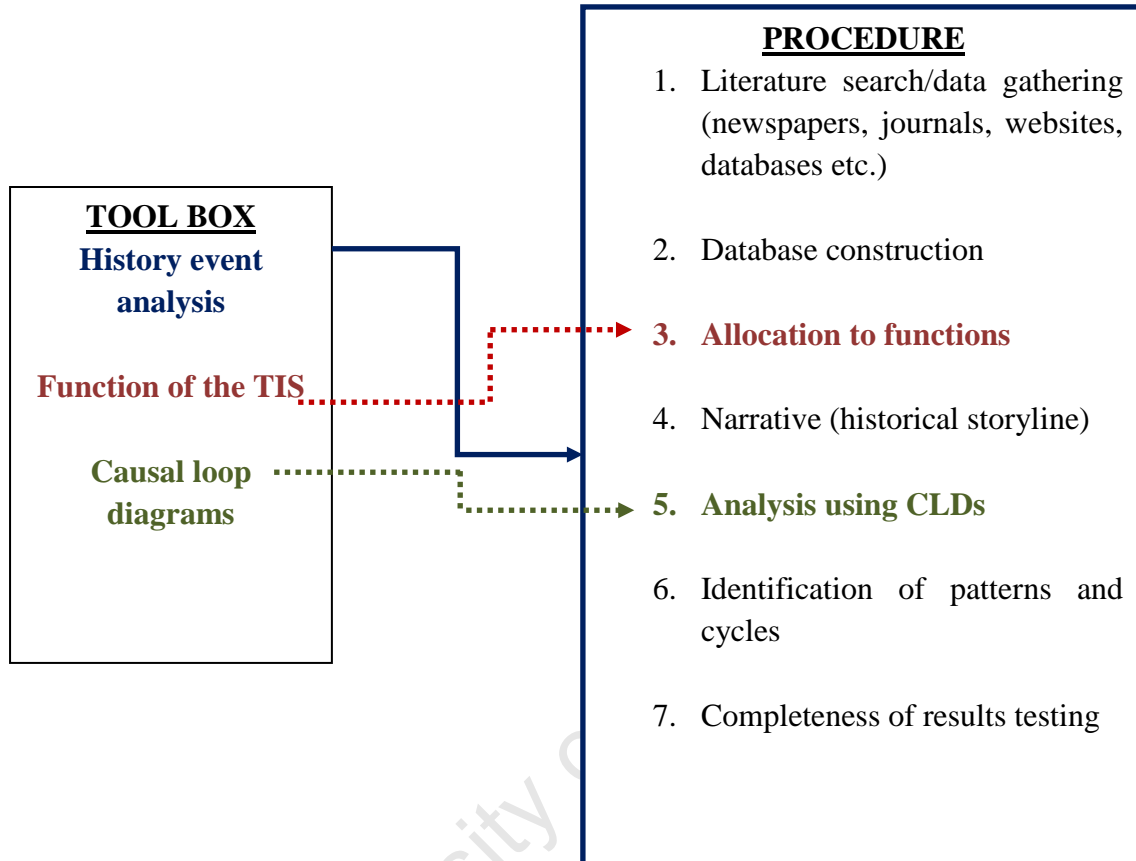


Figure 3.3 Tools for the Technology Innovation System Analysis

3.3 Interactive research methodologies

The approach used to address the second key question is *action research*, which is in some instances called *participatory action research* (PAR) research. Meyer (2000) states that action research is rather difficult to define, as it is an *approach*, as opposed to a specific research method. She broadly defines action research as ‘*A form of self-reflective enquiry undertaken by participants in a social situation in order to improve rationality and justice of their own practices*’. Koshy (2005) has a similar definition noting that the purpose of action research can be described as learning through action that subsequently leads to personal development. In a similar vein, Waterman et al. (2007) describe it as ‘*a period of enquiry which describes, interprets and explains social situations while executing a change of intervention aimed at improvement and involvement*.’ Couson (2009) suggests that such interventions should be made within an everyday, natural context, rather than within a

controlled settings. Whilst research in general is about generating knowledge, action research in particular creates knowledge based on enquiries conducted within specific and often practical contexts. The implementation of this research approach can be largely defined around the following steps, which are often cyclic: Initially, a plan for introducing a change is made; this is followed by acting to create such change, observing the consequences of change, reflecting on the consequences of change and then re-planning, observing and reflecting etc. (Kemmis & McTaggart 2005).

In addressing the second research question, the current work seeks to employ a variant of this research approach to investigate the role that researchers or academic institutions can play in fulfilling some of the system functions in the evolution of a TIS; here, the ultimate aim is the faster establishment of the biogas industry in South Africa. Of the seven system functions discussed in depth in Chapter 2, it is hypothesised that academic institutions will most likely be able to have a direct influence on the knowledge related functions (knowledge development and diffusion). The action research is therefore designed to test this premise by means of participatory activities for each of the two functions. With regard to knowledge development, activities are designed around *learning-by-doing*, and comprise two case studies. These case studies are demonstration activities; they are followed by an analysis of the impact on the BIS. With regard to knowledge diffusion, a workshop was designed and hosted; similarly, the impacts of the participants' subsequent activities on the BIS were analysed. Figure 3.4 below summarises these activities, which are detailed in the following sub-sections.

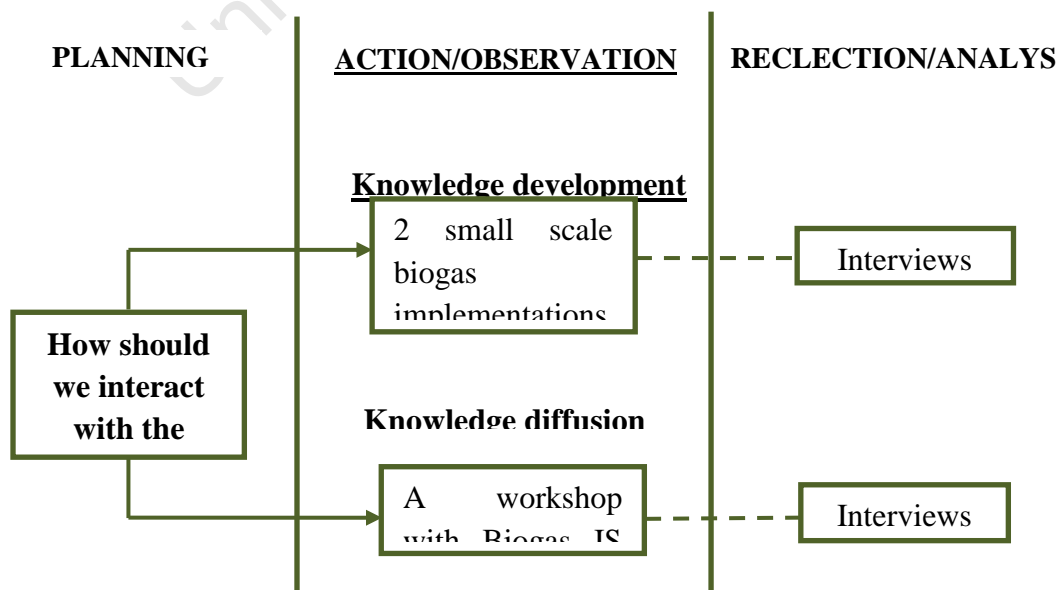


Figure 3.4: Overview of the Participatory Action Research

3.3.1 Impact on knowledge development: Notes on case study research method

In this section, a method of enquiry is detailed for activities that influence the knowledge development function. To answer the question of *how* the knowledge development function (F2) can be influenced, a case study-based approach was chosen as the most suitable method.

A *case study* can be defined as an in-depth study or investigation of a distinct single instance of a class of phenomena, such as an activity, an event, a person, or a group (Case & Light 2011). Yin (2003) describes a case study research approach as an empirical enquiry whose aim is to investigate contemporary phenomena within their real life context. Case and Light (2011) note that one of the strengths of the case study methodology is its appropriateness for addressing questions around innovative processes.

Yin (2003) states that there are five important components for conducting a case study, which are summarised below:

- i) ***A study's question:*** The first component is to state clearly the questions that a case study seeks to answer. Yin (2003) notes that the case study strategy is best suited to answer *how* and *why* questions.
- ii) ***Study proposition:*** Propositions are meant to guide the research in the right direction; making a proposition at the onset of a study also guides where the data to address the question may be sourced. Yin (2003) states, however, that not all studies will have propositions because of their exploratory nature. In such cases, the purpose of the study and the criteria by which an exploration will be judged successful should be stated.
- iii) ***Unit of analysis:*** This third component is said to be at the heart of defining a *case* for the study at hand. There are several examples of what may constitute a case, for instance, an individual, an organisation, an event, activity, any other entity, etc. The unit of analysis is usually related to how the initial research questions have been posed. One other important aspect in defining the unit of analysis is to define the beginning and the end of a case. This is important for determining the limits of data collection and analysis.
- iv) ***The logic linking the data and proposition:*** This component is one of the least developed in case study approaches. The approach called 'pattern making', where

pieces of information from a case study are related to a theoretical proposition, is one of the more advanced methods.

- v) ***Criteria for interpreting the finding:*** This is the other least developed component of case studies and relates directly to the fourth component. In this component, for instance, one would analyse whether the data matched one pattern better than another, provided that they were opposing propositions. However, methods around how close a match ought to be for it to be considered such a match are not yet fully developed.

In addition to the above-mentioned components of a case study, the construction of a preliminary theory is important too. Yin (2003) emphasises that a complete case study research design embodies a *theory* of what is being studied. He is quick to note, though, that theory, as stated here, should not be considered with the same kind of formality as a *grand theory* in social science. For the purposes of this research, a theory should merely be a sufficient blueprint for the study that requires a *theoretical proposition*. Sutton & Staw (1995) define this as a *hypothetical story* about why acts, events, structure and thoughts occur. Whilst an existing framework may provide a rich theoretical framework for designing the study, in other studies, the current knowledge base may be poor, and hence the existing literature may be unlikely to provide important conceptual framework or hypotheses from which a theory could be deduced.

Yet another important distinction in the case study approach is between single and multiple case studies. Which of the approaches is the more relevant is determined by the research questions and, to some extent, by the amount of resources and time available. A single case study is analogous to a single scientific experiment. A multiple case study, as the name suggests, is comprised of more than one case study. Yin (2003) states that, given a choice, multiple case studies, even only a *two case study* design, increases the chances of doing a good case study, compared to a single case study design.

As this research evolved, it became a multiple case study design, comprising 3 cases in the pursuit of answering the second key question. Cases 1 and 2 each involved the planning and installation of a demonstration biogas unit, as well as an investigation of the impact, which these may have had in the BIS. Case 3 was a workshop, held with selected potential biogas innovators. Within each of the case studies, the focus of interest was the impact of new

knowledge on individuals and how this might have stimulated their conception and execution of functions in the BIS. The research design thus focused on the individual as an embedded unit of analysis within each of the 3 cases. Due to the exploratory nature of the study, there was no formal proposition; rather, as stated above, the purpose of the study qualifies as such a proposition. In addition, due to the lack of literature in this emerging field of research, there was no overarching theory of the impact of intentionally intervening in a TIS on which this study could be based. Instead, a hypothesis of the foreseeable impact that the three case studies are most likely to have, will suffice.

3.3.2 Cases 1 and 2: Sharing learning-by-doing biogas installations

Whilst the main purpose for the case study is to investigate how academic institutions can contribute to the development of biogas industry in South Africa, this is further broken into two parts that will guide the enquiry and data collection. The first part is to document the procedures and to a limited extent the requirements that are essential for setting up a small-scale biogas digester, especially in an urban context. There are two reasons for emphasising the urban context: Firstly, the case studies are taking place in urban areas, and secondly, the university at which this work is conducted, identifies itself as an Afropolitan university whose research activities should endeavour to address some of the challenges faced in urban Africa.

The second research question is formulated as follows: Since the locations where the biogas digesters were installed were to serve as demonstration sites, it was envisaged that they would attract visitors. Some of these visitors might be encouraged and inspired to undertake activities at some level, and perhaps instigate change towards the adoption of the technology in their areas of influence. Hence, the knowledge dissemination impact of the pilot projects was to be investigated. The question is therefore posed as follows: *How will the visits to at least one of the demonstration sites have an impact on visitors' subsequent activities and how will that influence affect the BIS?* The impact of the abovementioned aspects was to be investigated by means of follow-up interviews.

These two cases were located in different contexts. The first took place in a more controlled and relatively formal setting, viz. outside a canteen at one of the university residences. The second one took place in a less formal context, closely mimicking transitioning economy conditions, viz. at a communal vegetable garden 30 km outside Cape Town. Data or evidence for the two case studies was primarily gathered from interviews; however, participant

observation methods were also employed in documenting the lessons for setting up an AD system in an urban context.

Data gathering by means of interviews will be described in more detail in the subsequent section, as this is an important method for gathering evidence for the second research question in all 3 cases. It also makes it possible to differentiate between knowledge development and knowledge diffusion. Yin (2003) defines participant observation as a special mode of observation in which the researcher is not a passive observer; instead he or she assumes a more active role in a case study situation, including actually participating in the events being studied. There are advantages and disadvantages to this form of collecting evidence for the questions being posed. The advantages include the ability to gain direct insights into how events unfold and also to perceive events as an insider instead of an outsider (Yin 2003). The disadvantage lies in the potential bias from not being able to work as an external observer, since one is directly involved (*ibid*).

The cases in this thesis entailed developing a concept design for the proposed sites; concept design reports to map a way forward were to be the culmination of the concept phase. The concept report outlines the permissions that need to be granted for the detailed design phase for the project to proceed. Once the detailed design was signed off and approved by a professional engineer, installation could commence. Construction and installation were followed by start-up and operation of the system was monitored for at least one year. Data was collected during the running of the system using mainly interviews and to a limited extent observation.

3.3.3 Case 3: Diffusing knowledge via workshop case study

The second component of the action research, as stated earlier, involved conducting a classic *knowledge diffusion* event, in this case a workshop, intended for / targeting carefully selected attendees, and thereafter tracking its impact on participants' subsequent activities.

The objective of the workshop was to bring together people whose activities contribute to at least one of the seven functions of the TIS. The roles that those invited should play in order to foster the successful evolution of the biogas industry in South Africa was also discussed during the workshop. The role and functions of stakeholders were analysed and discussed through a TIS framework. The workshop provides a platform to address issues that would

improve the dissemination of biogas technology in South Africa. The outcomes were expected to include activities that various actors ought to engage in to grow the BIS in the country. The evidence relating to this workshop was gathered by documenting the events during the workshop. Thereafter, the impact of the workshop was tracked by means of semi-interviews with participants; one year after the workshop was hosted.

It should be noted here that interviews are key to gathering data related to the second key question in general, with regard to activities that influence both knowledge development and knowledge diffusion. It is therefore important to describe how interviews are used generally and how they were used specifically for this study.

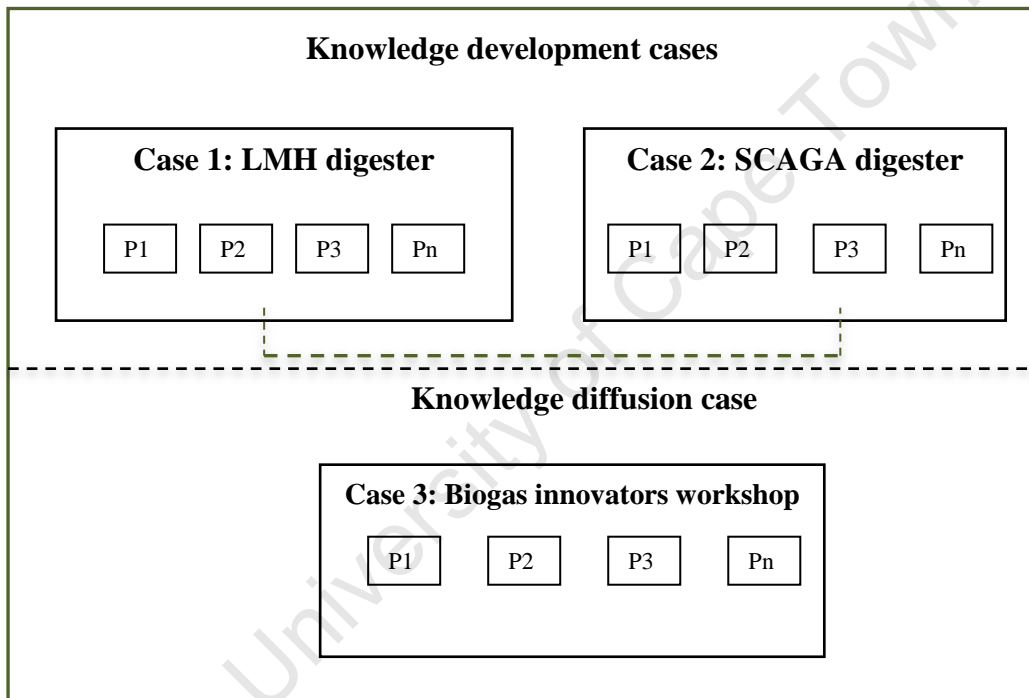


Figure 3.5: Units of analyses for ‘Participatory Action Research’ (where P denotes a person)

3.3.4 Overview of procedure in conducting an interview

An interview can be conceptualised as knowledge that it is created between / in the interplay between the points of view of the interviewer and interviewee (Kvale 1996). The role of an interviewer is therefore to obtain a qualitative description of the interviewee’s perspective and perception of the world. Kvale (1996) describes the role of the interviewer by means of two metaphors, viz. either as a miner or traveller. Using the metaphor of the miner, knowledge to be deduced from the interviewee is seen as valuable metal, with the miner mostly seeking objective facts that need to be quantified, whilst others seek so-called nuggets

of meaning. Using the traveller metaphor, in contrast, an interviewer is a traveller on a journey through an unfamiliar land; when the traveller returns home, he or she will tell the tale of his or her experiences or adventures there. Both or these approaches will be used to some degree, but in this case, the metaphor of the journey is better suited to the study.

There are different constructs of an interview, e.g., structured, semi-structured and non-structured. In this study, the semi-structured approach will be used. The semi-structured interview comprises themes to be covered including suggested questions, but it has the openness to change the sequence and form of question to follow the stories told by the subjects (Kvale 1996). In an interview context, the most important aspects are briefing before the interview and debriefing at the end. The role of briefing is to introduce the interviewee to the purpose of the interview and how the interview is to proceed. In addition it gives the interviewee a chance to ask questions prior to the commencement of the interview. The debriefing at the end of the interview can be in a form of main lessons from the interview and giving the interviewee a chance to comment on the findings.

Semi-structured interviews were conducted to answer the two research questions. In the case of the first research question, they were only be used to verify information gathered using methods described in Section 3.2.3. The target group for the interviews were entrepreneurs, government officials, researchers etc. Interviews were largely conducted face to face, otherwise telephonically where that it is not possible. For the second research question, interviews were central to gathering of evidence. They were conducted at least a year post either the visit to the pilot site/s or attending the workshop. A set of questions used as an interview guide are detailed in the Appendix C. The target group for the knowledge development case studies comprised visitors to the pilot project sites and only those who availed themselves were interviewed as detailed Chapter 6. With regard to the knowledge diffusion case, invitations for an interview were be sent to all workshop participants. The interviews were largely conducted face to face, otherwise telephonically. The interview responses were summarised and subsequently sent to the interviewees via email for factual verification. For both Chapters 6 and 7 interview questions as guided by Kvale (1996) were structured in such a way as to gain insights into participants' subsequent activities and their participation in events and subsequently which functions are fulfilled functions. Finally, qualitative data analysis methods suggested according Miles and Huberman (1994) are

employed to systematically code information (employing matrices/tables) and to analyse it using causal network model..

3.4 Concluding remarks

This chapter discussed the methodologies selected for this research, and specifically their design and the methods used to generate and analyse the evidence obtained, in support of the following:

1. Achieving the aims and objectives set out at the beginning of the study;
2. Answering the key questions set out at the start of this chapter.

In the first section of this chapter, an overview was presented of the methodology employed in the rest of the thesis. The second section looked at the process analysis method that creates the framework for Section 2 of the thesis. This was followed by a brief summary of the CLD approach and a motivation of its analytical contribution to the process analysis method, as used by Negro (2007). Thereafter, a modified process analysis approach as applied in Section 2 was proposed.

The third section of this chapter looked at the methodology on which Section 3 of the study, which aims to answer the second key question, is based. Of interest in this regard are the insights relating to the impact that interactions with some elements of the TIS framework may have on the nascent biogas industry in South Africa. The method used here is exploratory, and it is based on the PAR method. An embedded case study method was used alongside PAR to investigate the possible impacts of two of the seven system functions on the evolution of the biogas industry. The first two case studies explore one function, viz. knowledge development, and entail the design, implementation and impact of two biogas pilot projects. In addition, their knowledge dissemination impact is tracked. The third case investigates the impact of a *knowledge diffusion* event. Lastly, a summary of the primary data gathering method, viz. semi-structured interviews to collect the evidence with regard to the second key question was suggested.

In summary, the research combines, firstly, an observational analytical methodology in the established TIS approach, which is uniquely complemented by the CLD analysis of system thinking. Secondly, it entails an exploratory participatory action-based method using multiple

SECTION 1: THEORETICAL APPROACH AND METHODS

case studies. The rest of the thesis will proceed as follows: In Chapters 4 and 5, the modified TIS analysis will be applied to the SWH and Biogas industries respectively. In Chapters 6 and 7, the methods described in Section 3.3 will be applied to assess the impact of action-based intervention on the BIS through the three defined cases.

University of Cape Town

SECTION 2: TIS Observation

CHAPTER 4 The Development of Solar Water Heaters in South Africa

4.1 Introduction

In this chapter, the development of the SWH technology in South Africa will be analytically assessed using the TIS framework. As indicated in Chapter 2, there are two approaches to applying TIS framework employing system functions, one by Bergek et al. (2008) and another by Hekkert et al. (2007). The latter will be used in this study because it contains a greater number of empirical examples, with which the analysis herein can be compared. This chapter begins to address the first key question of the thesis, namely, to gain insight into how bioenergy from waste can be unlocked via AD in South Africa. In order to test the utility of the framework, the first key question as stated in Section 1.4 will be answered in connection with SWH technology.

Since this conceptual model has never before been used to explain the evolution of a technology in South Africa, it was deemed worthwhile to assess first whether it would be applicable to another renewable energy technology in the country. The only renewable energy technology that had reached market maturity at the time of planning this research was the SWH technology, and it was thus used to test the TIS approach. Moreover, if any new insights are gained through this analysis that may be unique to the South African context (and perhaps to that of other transitioning economies), they will be borne in mind when the analysis of the biogas industry is conducted.

The *process* or *event history* approach is used to track the evolution of the SWH industry innovation system, whilst *causal loop diagrams* (CLDs) are used to depict the fulfilment of the system functions, as discussed in the previous chapter. The system functions will be central and will be depicted by abbreviations, as explained in Chapter 2. Lastly, Multiple Level Perspective (MLP) concepts will be used for explicatory purposes as needed. The rest of the chapter will proceed as follows: an overview of the entire solar energy industry is presented in Section 4.2, followed by an account on the evolution of SWH industry,

chronologically narrated from 1978 to 2012 in Section 4.3. Discussions and conclusions are outlined in Sections 4.4 and 4.5 respectively.

4.2 The solar energy industry in South Africa

South Africa is geographically located in one of the highest solar radiation regions in the world, with an average sunshine of 2500 hours per annum (Adams 2012). Moreover, the annual 24-hour global solar radiation averages are 200 W/m^2 compared to Europe's 100 W/m^2 (Department of Energy n.d.). Despite this, the development of the solar industry in the country has generally been slow, until recently. Specifically, in the past few years, significant growth has been observed in the photo voltaic (PV) and solar water heating applications. According to Statistics SA, the annual PV assembly in South Africa is 5 MW (Statistics South Africa 2012), which is likely to increase due to recently introduced legislative frameworks and programmes that support renewable energy technologies in general and solar PV technology in particular. The SWH technology too has experienced substantial advancement. In the past 10 years alone, the number of SWH companies has increased hundred-fold. The next section will give a chronological account of the evolution of the SWH industry in South Africa. To achieve this, a significant effort was made to capture key events in the development of SWH industry; however, some of these events may have been omitted because they are not visible or mentioned in the mainstream media and literature. Nonetheless, the account was deemed sufficient to meet the objectives stated above.

4.3 Historical overview of the Solar Water Heater

This section is structured into 4 phases, which chronologically narrate the evolution of the SWH industry in South Africa from 1978 to 2012. Within each of the phases, events that are external (but nonetheless relevant and influential) to the development of the SWH industry are stated, together with events and activities that directly contribute to the fulfilment of system functions. At the end of each phase, the particular motor of innovation that played itself out in that phase is identified and analysed, and thereafter, structural barriers and drivers are identified.

4.3.1 Early Growth: 1978-1983

4.3.1.1 Overview

The history of SWHs in South Africa actually dates back to the 1930s. Early activities noted in the literature entail R&D of thermosyphon systems in the mid-20th century (Holm 2005).

The early adoption of household SWHs only began between 1978 and 1983, however. This was attributed in part to the two oil crises of the 1970s, viz. 1973 and 1978. Moreover, these oil crises coincided with the country's isolation from the international community due to the government's apartheid policy. As a result, energy security became entrenched at the heart of the country's energy policy (Winkler 2006). This led the government to prioritise national energy security by introducing various energy efficient programmes. One such programme entailed the adoption of household SWHs. The intervention to support the roll-out of SWHs through targeted promotion began in 1978 (Prasad 2007). The government mandated the Centre for Scientific and Industrial Research (CSIR) to facilitate this roll-out. The CSIR began to develop effective communication strategies, encouraging middle- to high-income household owners to install SWHs, by either using cash or taking out home improvement loans. This intervention ensured early industry development (Hardie 2011). As a result, the demand for SWHs began to grow, and so did the market for the units. At the end of this phase, there were six companies that manufacture, market and install SWHs. In 1983, a total of 27 000 m² of solar collectors had been installed (Prasad 2007). However, once the oil crises began to abate, the government, through the CSIR, halted the roll-out of the SWH project.

4.3.1.2 Functional analysis

There were few activities in the SWH industry; they tended to revolve around a single project. This is typical of a TIS in the formative phase, which is characterised by few actors, low level of activity, and hence limited fulfilment of functions. Still, the government, through its adoption of energy efficiency programmes (F4) that were aimed at securing the country's energy supply, did play a critical role in the development of the SWH innovation system (IS) during this period. The other functions served during this period were accomplished as a result of the fulfilment of the *guidance of search* function, and as such, they are considered a central and dominant function. As a result of the government's guidance and its appointment of the CSIR, other functions were subsequently fulfilled. For instance, the CSIR came up with effective communication strategies (F3) to disseminate technology information to potential adopters. The strategy adopted by the CSIR was successful and homeowners began to install SWHs. A few companies became active within the SWH IS over the five-year period between 1978 and 1983 and began to manufacture, market and install SWHs, leading to the fulfilment of entrepreneurial activities (F1) and *knowledge diffusion* (F3) through the companies' marketing initiatives. There was no direct injection of resources by government

to stimulate the industry beyond its intervention through the CSIR. Resources required to purchase the SWHs system were mobilised (F6) by customers, i.e., homeowners, themselves. As more people began to adopt the technology, and through targeted marketing by SWH companies, it generated optimism regarding the SWH industry's role in ensuring the country's energy security (F4). This positive sentiment led to even wider knowledge sharing (F3), which in turn led to an increase in the number of SWH companies to six by the end of this phase (F1). This led to further mobilisation of resources by homeowners, keen to purchase more SWH units. The *guidance of search* function thus activated the fulfilment of several functions, viz. knowledge diffusion, followed by entrepreneurial activities (F1) and *resource mobilisation* (F6). This gave rise to a reinforcing loop around the *guidance of search* function, due to its influence on the fulfilment of other functions; the dynamic observed in this phase was called the *Guidance Motor*, shown in Figure 4.1. It is important to note that this motor is not robust, however, and that it revolves around only one project, albeit a big national project.

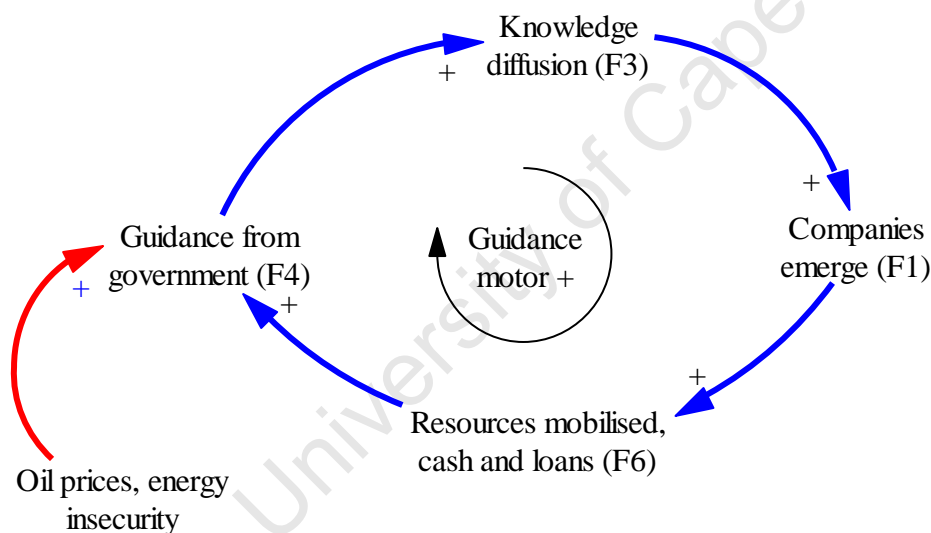


Figure 4.1: Guidance Motor

The reinforcing loop around the SWH industry in South Africa is referred to as the *Guidance Motor*. Influenced by high oil prices and energy securities issues, the government initiated a SWH project, facilitated by the CSIR through various *knowledge diffusion* activities. This led to companies joining the industry and customers taking loans or using cash to purchase SWHs, improving project visibility.

4.3.1.3 Structural drivers and barriers

Matters both internal and external to the SWH IS are drivers behind the so-called *Guidance Motor*. With regard to the internal drivers, the government is key, as it was chiefly motivated by a need to ensure national energy security. With regard to the external drivers (referred to as landscape conditions in MLP), the two oil crises of the 1970s were particularly influential. The government responded to these by formulating a strategy that promoted SWHs to manage the electricity demand side. The CSIR was solely tasked with the responsibility to diffuse knowledge and market SWHs. They did so by means of good communication strategies, which were able to influence companies (selectors) to begin manufacturing SWHs and customers (selectors) to purchase them. These drivers played a critical role in providing an enabling environment for enactors to attract selectors into the innovation system in general – a process that is described as the alignment of enactors with the selectors (Suurs et al. 2010).

The disadvantage of this motor is that there are few actors; in addition, it hinges on the *guidance of search* function facilitated through one single project. This led to limited albeit nonetheless effective *knowledge diffusion* fulfilling activities. Moreover, only six SWH companies were at the time participating in the industry. This number of companies was too low to achieve an envisaged national roll-out to middle- and high-income households. Furthermore, other structural aspects such as institutions around the technology were not yet developed and networks were mostly still under construction. The other institutional hurdle at the end of this phase was a lack of long-term government vision regarding the SWH industry; this would become obvious when the CSIR-funded project ended, and might have led to the collapse of the SWH IS

4.3.1.4 Impact on the SWH IS

This motor furthermore has little impact on strengthening the SWH IS structure. However, it can be viewed as the noteworthy beginning of the emergent SWH IS. It would however take another 25 years to develop to a sizeable industry. Although enactors, e.g., government through the CSIR, were able to draw in selectors, e.g., SWH companies, the scale was not robust enough to make a significant impact on the structure of the SWH IS.

4.3.2 The collapse of the SWH industry: 1984-1998

4.3.2.1 Overview

This period followed a relatively successful initial period, which was curtailed by the termination of the CSIR education programme. Glazed SWHs, the ones used for household water heating, began to decrease in use. Specifically, the number of installations declined by less than half, compared with the previous period (Prasad 2007; Holm 2005). A decade after the oil crises and the subsequent termination of the CSIR project, South Africa went into a relaxed mode and the interest in SWHs faded (Holm 2005). In addition, all the sanctions that had been imposed on the apartheid government were lifted in the early 1990s. Therefore, maintaining the country's energy security was no longer urgent. Electricity prices were also low due to the abundant coal reserves from which South African electricity was generated.

Despite this, there remained haphazard activities within the SWH IS. For instance, according to Holm (2005), W.N. Cawood developed and patented an integral low-cost SWH for low-income housing in 1992 for a project commissioned by the National Energy Council. Moreover, in 1995, the Department of Minerals and Energy (DME) commissioned a workshop titled *Solar Water Heating Action Workshop*. Emerging out of this workshop was an action plan with identified priorities for government and other relevant stakeholders, e.g., entrepreneurs, suppliers, financiers etc. (Holm 2005). Nonetheless, the *Action Workshop* did not lead to any meaningful actions; instead, it left most SWH IS actors more disillusioned (Holm 2005). At the very least, concedes Holm (2005), it produced a list of action plans that remained valid in the subsequent phases of the evolution of the SWH IS. At the end of this period, the newly formed democratic government published a White Paper on Energy Policy (Department of Minerals and Energy 1998), which acknowledged the role of renewable energy including solar-based energy; however, one of its primary aims was to redress the injustices of the apartheid regime (Winkler 2006).

4.3.2.2 Functional analysis

This period was dominated by negative fulfilment of functions. The collapse observed in this period was in fact a result of negative guidance (-F4) due to the termination of the CSIR programme and other external (landscape) conditions. When the SWH educational project was halted, a negative impact on the *knowledge diffusion* activities (-F3) was observed, as fewer customers were investing in SWHs. This negatively affected the *resource mobilisation* (-F6), as only few new customers were willing to invest in SWHs, leading to stagnancy in

entrepreneurial activities (-F1). The system functions observed in the previous period were negatively fulfilled and reinforcing each other downwards; this motor was thus termed the *Break-down Motor*. The motor is analogous to the one Suurs et al. (2010) observe in the early stages of the development of natural gas as an automotive fuel in the Netherlands. Figure 2 below depicts the *Break-down Motor* dominant in this period and also shows some of the external drivers that were discussed above. Despite this, a couple of functions were fulfilled, for instance, at least one knowledge development activity (F2) was noted, i.e., the patenting of a low-cost SWH, although this design was never taken up on a large scale. Also, a relatively unsuccessful *knowledge diffusion* event, viz. a *Solar Water Heating Action Workshop* (F3), was organised.

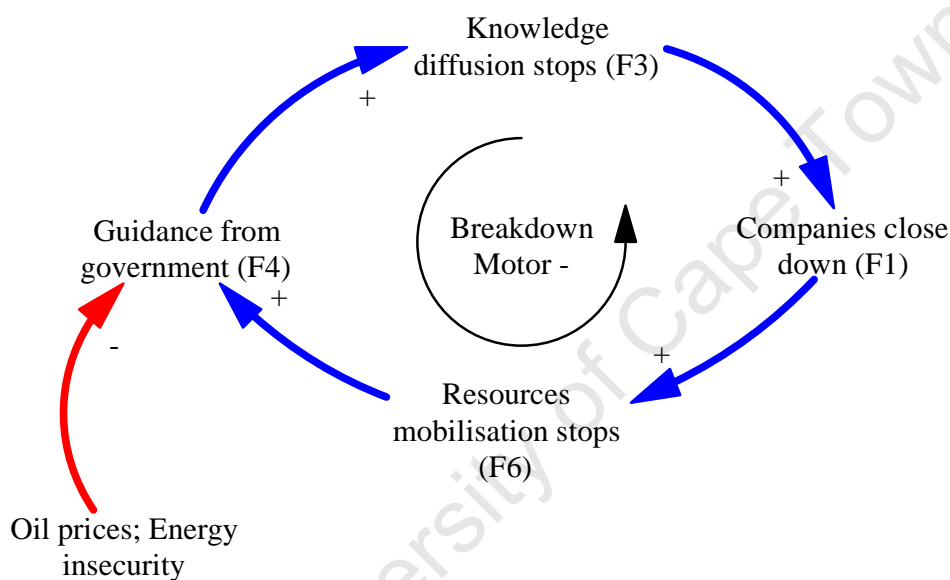


Figure 4.2: Breakdown Motor

Vicious cycle around the SWH industry in South African, referred to as the *Break-down Motor*. Following the drop in oil prices, the government terminated the SWH project facilitated by the CSIR and associated *knowledge diffusion* activities. This led to some companies closing down and subsequently reduced mobilisation of resources into the industry, resulting in further negative sentiment about the potential of SWHs.

4.3.2.3 Structural drivers and barriers

This motor is mainly driven by landscape factors. The initial driver was the drop in international oil prices, coupled with cheap South African electricity. The stabilisation of the oil market and cheap electricity prices rendered the renewable and energy efficient projects

redundant. Another institutional driver was the lifting of sanctions following the election of the new democratic government into power.

The main enactor of the previous period, the government through the CSIR, became less active in drawing selectors into the innovation system. It is interesting to note, that despite the decline in interest, the government did not entirely abandon its role in SWH industry. A few activities are observed over 10 years into the *Break-down Motor* and at the dawn of the new democratic government. One such activity is the workshop organised in 1995, an attempt to resuscitate the SWH conversation, facilitated by the DME. The workshop turnout was decent, an indication that some actors remained active within the SWH IS despite the decline. This may be attributed to the lasting impact of the *Guidance Motor* of the previous period. Another notable event was the publishing of government's energy policy in 1998. Fundamentally, it sought to redress the injustices imposed on the majority of the population by the apartheid regime (Winkler 2006). SWHs featured as one of the ways in which to achieve this ideal.

4.3.2.4 Motor impact on the SWH IS

The *Break-down Motor* distorts the structure of the innovation SWH IS; for example, some of the actors exited the SWH IS. Moreover, there were no evident networks and the rules of the industry (institutions) were loosely defined. Despite the breakdown, there was an indication that some enactors had remained active, e.g., some government departments, and companies such as *Solahart* and *Kwikot* continued to contribute towards the build-up of the SWH IS, albeit at a much slower pace.

4.3.3 The build-up phase: 1999-2007

4.3.3.1 Overview

The dawn of the new democracy saw the country's energy policy change to focus more on equity and justice. From the late 1990s into the 2000s, it became more focused on meeting targets set after the 1994 elections. Two of these priority areas were sustainable development and environmental protection. These and other issues were addressed in a White Paper on Energy released at the end of 1998 (Winkler 2006). Solar water heating was being seriously considered as one of the technologies that could meet key policy objectives, and there was in fact a renewed interest in SWHs from 1999 onwards.

The early days of this period saw the inception of several donor funded SWH projects. The focus of these projects, unlike those of the first period, was on low-income households (Holm 2005). The first of such projects was located in Llwandle in the Helderberg, Cape Town, where workers' hostels had been transformed into family units (Prasad 2007). A total of 295 SWH units were installed, and accompanying these installations was a maintenance plan (Holm 2005). A similar project was launched in Ivory Park, an informal settlement in the Gauteng region, where a R6 million grant was used for a pilot project to test the viability of SWHs in low-income areas (Barry 2001; Monyai 2001). Another project was in eThekweni municipality in the Durban area; this project saw 100 50% subsidised systems installed in 2002. Yet another example was that of the Kuyasa project in Cape Town, where 10 Reconstruction and Development Programme (RDP) houses were retrofitted with SWHs in 2003 to test to for a bigger roll-out (Holm 2005; Prasad & Visagie 2005). The Kuyasa project consortia and The City of Cape Town (CoCT) began with plans to roll out the SWHs to 2 300 households shortly after the pilot (Salgado 2005; Davidson et al. 2006). The project received recognition shortly afterwards, when it became the first CDM project to be awarded a gold standard for its contribution to curbing GHG emissions (Thorne 2007). The Nelson Mandela Bay Metro in Port Elizabeth also had plans to roll out 100 000 SWHs (Hayward 2007). Meanwhile, the summit on Sustainable Development held in Johannesburg in 2002 also went a long way in raising public awareness on issues of sustainability.

Regulations, policies and strategies that promote renewable energy technologies in general and SWHs specifically also came to the fore in this period. Following the publishing of the White Paper on Energy (Department of Minerals and Energy 1998) at the end of the last period, the government published the White Paper on Renewable Energy (Department of Minerals and Energy 2003), five years later. This policy document gave better guidance to the renewable energy sector. It proposed a 10 000 GWh target of renewable energy based electricity, including solar energy, to be added to the national grid by 2013. This revived interest within the renewable energy sector. Together these two pieces of legislation did much to raise expectations among renewable energy actors. In fact, an established bioenergy sector was seen as one the areas of the economy that could address some of the societal problems, such as the high rate of unemployment (Williams 2004). Yet, it was envisaged to take almost a decade for any meaningful action to be taken towards achieving the renewable energy target. By the end of this period, another noteworthy policy document was published. The Long-Term Mitigation Scenario document mapped out scenarios for economic growth vs.

carbon emissions (Winkler 2007); this later informed the climate change policy direction captured in the White Paper on Climate Change (South Africa 2011). With regard to the SWH industry specifically, a momentous step was taken as a standard (SANS 62111:2003) for testing the thermal performance of domestic SWHs was published in 2003 (SABS Standards Division 2011).

In a parallel and related policy development, the government realised that technological innovation was key for the country's economic development. As a result, the national legislation set up the National Advisory Council on Innovation (NACI) Act 55, 1997 (Republic of South Africa 1997) with a mandate to advise the Minister of Science and Technology on issues around the National System of Innovation. One of the products of this body was the enacting of the Technology Innovation Agency Act 2008 (Republic of South Africa 2008), which culminated in the establishment of the Technology Innovation Agency (TIA). The TIA's aim is to stimulate technological innovation as well as to provide funding to bridge the gap between formal knowledge and commercialisation of ideas. A related avenue that the government also pursues is an increased focus on shifting the country towards a knowledge-based economy, using the Global Change Grand Challenge (GCGC) programme spearheaded by the Department of Science and Technology (Department of Science and Technology 2008) as a vehicle. This culminated in a strategy that was summarised in a report called *Innovation towards a knowledge-based economy: Ten year plan for South Africa*, and realised through the Global Change, Society and Sustainability Research Programme (GCSSRP) (*ibid*), through which the current research is funded. Amongst the aims of this strategy is to create an innovation friendly environment. These developments create an environment that is conducive to developing renewable energy technologies in general and encouraging innovation around the entire solar energy sector specifically.

Knowledge development activities and *knowledge diffusion* events also became more prominent in this period. The knowledge development activities entailed investigations into the market potential of the SWH as opposed to the traditional R&D. The Energy Development Corporation (EDC), a division of the Central Energy Fund (CEF) commissioned a market feasibility study funded by the United Nations Development Programme (UNDP). The outcome pointed to a huge national SWH potential (Holm 2005). This project, called SWH 500, was designed to remove the following barriers: limitations

regarding the standardisation of SWHs, financing, affordability and awareness (Schäffler 2008). One of the strategies through which the objectives were to be achieved entailed the installation of 165 SWHs in each of the 3 metros, viz. Johannesburg, Durban and Cape Town; these were indeed installed in the first half of 2007 (Prasad 2007). Moreover, there were plans to monitor and measure the effectiveness of 50 of these 500 SWHs (Star 2007). Other studies conducted around SWH technology investigate strategies that influence its demand; an example was a study commissioned by the CoCT in 2005 (Essop 2005). The SWH projects received extensive media coverage in local and national newspapers, which revived the public's interest in the technology (Enslin 2007; Star 2007). Meanwhile, the government purchased its own test rig to test the outdoor performance of all the systems that needed to be SABS (South African Bureau of Standards) accredited in an effort to improve the performance of the SWHs (Star 2007).

Knowledge diffusion function events and activities were also becoming more prevalent during this period. Just in the first half of 2007, three workshops were held, one organised by ESKOM, the other by REEEP/CEF and the last and biggest of all the gatherings, a workshop that was part of the International Domestic Energy Use Conference. The aim of the workshop was to deliberate on how best to influence growth in SWH industry (Prasad 2007).

Meanwhile, most of the SWHs activities observed towards the end of this period were conducted by local governments, especially in large municipalities. Some of them embarked on their own strategies to promote SWHs through the drafting of by-laws (Prasad & Visagie 2005; Gosling 2006; Gosling 2008b). For example, the CoCT municipality set itself a target to install SWHs in 10% of households by 2010. In addition, they drafted a by-law to encourage the use of SWHs in middle- to high-income households (Prasad 2007). Other metros have various SWHs programmes; the Nelson Mandela project mentioned earlier is another example, but it is not as advanced as that of the CoCT in drafting by-laws (Matavire 2007).

The industry received a further boost when the solar heating division under the Sustainable Energy Society of Southern Africa (SESSA) was established (Star 2007). This interest group began to play a critical role within the industry in lobbying government for better market conditions on behalf of its members (Star 2007). The solar heating division is diverse, consisting of suppliers, academics and interested members of the public. It played several

supportive roles, assisting Eskom in its future planning, and SABS with updating SWHs standards, and it also backed pilot studies that the government was conducting, for instance the SWH 500 Project (Star 2007). In addition, it ran a project known as SESSA50, in which they installed subsidized SWH units with the aim of collecting data to help carry out a detailed analysis that would inform the SWH SABS standards (Holm 2005; Prasad 2007). Another initiative formed in this period was called Ubushushu Bendalo, *Heat from Nature*, formed between civil society and the CoCT with plans to implement renewable energy and energy efficiency initiatives effectively, with a specific focus on SWHs (Hardie 2011; Prasad & Visagie 2005).

As this period came to an end in 2006, the CoCT was experiencing rolling blackouts (Marrs 2006). This was followed shortly thereafter by a national power crisis in the following year, propelling Eskom to come up with speedy solutions urgently. Eskom was indeed looking to SWHs as one of the ways of addressing the current crisis and it was mooted that a R2-billion investment in the roll-out of SWHs was imminent, an announcement that was widely publicised (Davie 2007; Enslin-Payne 2007; Financial Mail 2007a).

4.3.3.2 Functional analysis

Dominant system functions in this period were knowledge development, knowledge diffusion, *resource mobilisation*, *guidance of search* and, towards the end, entrepreneurial activities. However, knowledge development remained central due its impact in unlocking other activities. It was observed as either *learning-by-doing* through pilot projects but also in quality testing of SWHs and market surveys. The momentum around knowledge development activities was provided by grants from international donor agencies (F6) which funded some public sector departments to conduct market surveys and pilot projects (F2). Market surveys and pilot projects were regarded as catalysts to the observed increase in the number of entrepreneurial activities towards the end of this period.

The *guidance of search* function in this period was also becoming stronger than it had been in the previous periods. This guidance came from different spheres of government, i.e., from national departments all the way to local government. For instance, municipalities were actively drafting by-laws that would enable the roll-out of SWHs; a good example was that of the CoCT, which was active in setting targets and drafting by-laws. Other municipalities, such as Nelson Mandela Bay and eThekweni, were also actively embarking on SWHs

projects. Furthermore, national government was providing some guidance (F4), albeit only indirectly at this stage, by drafting policy papers on energy. One was a general paper (White Paper on Energy), but the White Paper on Renewable Energy was more relevant to the renewable energy sector and SWH in particular. In the latter, solar energy would contribute towards a broader renewable energy target of 10 000 GWh by 2013. Other government initiatives such as the Technology Innovation Act and the Global Change Grand Challenge programme indirectly provided guidance through their strong support of renewable energy technologies.

Other activities and events that offered further guidance included the publishing of the first SWH standards in 2003 and the setting up of a facility to test the thermal efficiency of SWH systems available in the South African market. Meanwhile, SABS, aided by pilot projects, embarked on further activities to improve industry standards for SWH systems, such as the quality assurance measure. In 2007, Eskom made a noteworthy announcement on its plans to invest R2 billion in a SWH programme as part of demand side management. This period also saw the formation of industrial bodies to serve the advocacy role (F7). For instance, the SWH division of SESSA was set up as a platform for voicing industrial concerns, whilst working alongside Eskom and Ubushushu Bendalo initiatives. These constellations became increasingly active in the next phase. Summits and knowledge sharing platforms also featured more prominently in this period than in previous ones (F3). With regard to entrepreneurial activities, there were less than 10 recognised companies in the early 2000s and hardly any new ones joining the SWH IS (Holm 2005). From 2005 onwards, however, this number increased, as new companies joined the industry and became members of SESSA; the total number of SWH companies had reached about 100 by the end of 2007 (Hardie 2011).

Due to the centrality of knowledge development and supporting functions, this dynamic has been termed the *Knowledge Building Motor*; this is similar to what Suurs et al. (2009) term the *Science and Technology Push Motor*. The same functions are fulfilled in their study on understanding the build-up of the hydrogen and fuel cell technologies in the Netherlands. The difference lies in how the knowledge development and *resource mobilisation* functions were fulfilled, as explained and discussed above. Figure 4.3 below depicts how this knowledge building motor played out using a CLD.

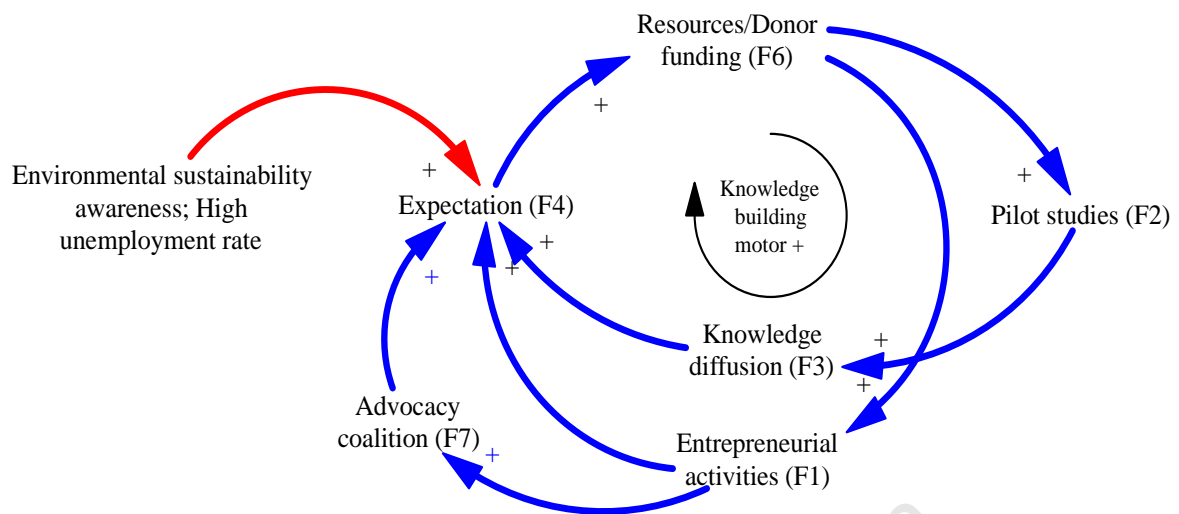


Figure 4.3: Knowledge Building Motor

Reinforcing loop around the SWH industry, referred to as the *Knowledge Building Motor*. Landscape conditions raised positive expectations with regard to the SWH potential. This led to the mobilisation of resources, which, when injected into either knowledge development or entrepreneurial activities, led to increased expectation and further guidance.

4.3.3.3 Structural drivers and barriers

Landscape factors were the main drivers in SWH IS in this period. Sustainability and climate change issues became national and international priorities and influenced how the SWH IS evolved in this period. There were high levels of unemployment in South Africa, and the SWH industry was viewed as one of the strategies that would address this national challenge. Municipalities were drawn into the SWH IS early on and assumed the role of enactors. Moreover, they viewed the technology as crucial to them achieving their own strategic goals, for example, reducing electricity usage in an effort to avert the recurrence of rolling blackouts and meeting GHG emissions reductions targets. For instance, the CoCT had a target to install SWHs in 10% of households within the metro. In addition, the rolling blackouts in the Western Cape drew selectors such as new SWH companies into the SWH IS, as customers began to seek alternative energy sources. As more selectors were drawn into the SWH IS industry, a few enactors organised themselves into a coalition, viz. the SWH division of SESSA, which became more active in the government's SWH promotion project. It also ensured that SWH systems used in South Africa were accredited, hence contributing to a more structured SWH IS.

Other drivers in terms of actors in this phase were Eskom and CEF, which have since assumed the role of enactors. Through their programme and project respectively, they attracted selectors, i.e. companies, to join the industry and become part of the SWH division of SESSA; some of these selectors became enactors themselves. Through their pilot projects and research studies, Eskom and CEF were also able to influence the knowledge development function. An institutional driver was the decision that Eskom made towards the end of this period to make SWH part of their Demand Side Management (DSM) and to set aside funds to stimulate the market.

There were, however, still few SWHs companies that realised the estimated national potential, therefore entrepreneurial experimentation (F1) remained inadequate. This could be due to limited fulfilment of the *market formation* (F5) and *resource mobilisation* (F6) functions. This was likely to improve at the back of Eskom's announcement of the R2 billion (F6) to be injected into the SWH roll-out programme. Another institutional barrier remained the lack of long-term policy direction for the industry.

4.3.3.4 Motor impact on the SWH IS

The most significant impact that the *Knowledge Building Motor* had on the TIS structure was the ability to strengthen the knowledge within the SWH IS; in this case, it has focused mainly on the performance of SWHs. For instance, market surveys were able to point to the market potential within the sector, whilst performance of the technology was determined by a pilot study. In addition, the knowledge building exercises led to the establishment of standards for SWH systems. The dynamic has to some extent been able to draw in more actors e.g., municipalities and new companies, and has begun to revive belief in the SWH IS. Moreover, stronger networks were being forged through the SWH division in SESSA, and collaborations between Eskom and industry. Overall, by the end of this period, the structure of the SW IS had become more developed.

4.3.4 A new dawn for the SWH industry (2008-2012)

4.3.4.1 Overview

Sustainable development and climate change issues remained high on the international and national agendas (Madzwamuse 2010). Nationally, there was an added pressure (Hardie 2011), to reach the 2013 renewable energy target set in the White Paper on Renewable Energy to (Department of Minerals and Energy 2003). This period began with the electricity

supply crisis of January 2008, which was experienced in rolling blackouts nationwide (Odhiambo 2009; le Roux 2008). This gave impetus to adopt SWHs as one of the technologies that can address the above mentioned challenges.

Meanwhile, the SWH market began to grow of its own accord, as customers scrambled for alternative energy sources from early 2008. For instance, a survey conducted in 2009 found that the number of recognised SWH companies had increased from 11 in 2005 to over 100 in 2009 (Hardie 2011). In the same survey, some respondents claimed an expansion of up to 400% in sales in the first four months of 2008 (Hardie 2011). Another industry survey conducted in 2008 established that the number of unglazed systems (specific for SWHs) installation had reached an all-time industry high, 34 000 m² compared with 27 000 m² in 1983, which was largely attributed to load-shedding in the early months of 2008 (Eskom 2011).

The pursuit of speedy dissemination of SWHs was also evident in Eskom's intensified efforts to establish the SWH programme as a key DSM strategy. Following the announcement at the end of the previous period that R2 billion was being mobilised for a SWH rebate programme, efforts were channelled towards making it a reality early in this period (Bega 2008; Kritzinger 2011). Details on the programme were communicated at the beginning of 2008, and it was envisaged to subsidize 925 000 SWHs over a period of 5 years (with an average subsidy of R4200 per installation) (Mthethwa 2008). To track the progress and to provide legitimacy to the programme, entrepreneurs and companies that wished to qualify for a subsidy needed to have their solar geysers Eskom-accredited. Towards the end of 2008, Eskom only had 26 accredited SWH suppliers but that number increased to more than 400 in 2011 (Bega 2008; Hardie 2011). Despite all these efforts, there seemed to be a drawback in the early days of the programme, which can be deduced from its low impact in the first year, where just 800 installations were reported (Yeld 2009; Hardie 2011).

Meanwhile, provincial and municipal SWH programmes continued to progress. In Cape Town, however, efforts to pass a by-law that would make installing solar water geysers in new buildings mandatory was still experiencing problems three years after its drafted (Gosling 2008b). Nonetheless, the CoCT embarked on a project that would see 200 000 SWHs installed in the city. Moreover, a significant development was that of Kuyasa CDM Project. Following the pilot project, which saw 10 RDP house retrofitted with energy

efficiency measures including SWH in the previous period, a further 2 300 SWHs systems were installed between 2008 and 2010 (Hardie 2011). The funding was made possible by the Department of Environment and Tourism (DEAT) and the Western Cape's Department of Housing (Du Toit 2010). Other initiatives in the Western Cape included the installation of 300 SWHs in Darling as part of the World Cup Green Goal programme (Tadena 2010). Meanwhile, new metros were also initiating SWH programmes; the Ekurhuleni municipality, for instance, approved R500 million to install low pressure systems in low-cost housing developments (Carvalho 2011). The Mandela Bay SWH programme was also on track (Hayward 2010b), following initial hiccups (Hayward 2010a).

In a parallel development, the Department of Energy (DoE) sought to unpack reasons for the low uptake of SWH technology. To gain some insights, DoE through its Renewable Energy Market Transformation (REMT) Unit organised a SWH workshop towards the end of 2008. One of the main calls at this workshop was for government to establish financing mechanisms that would facilitate the mass roll out of SWHs. This workshop informed and resulted in a nationwide workshop held in February 2009, viz. the *National SWH Workshop*, also organised by REMT. This workshop is lauded a great success by the majority of the 155 industry players who attended (REMT Unit 2009). Most of the workshop delegates are active industry actors, whose aim is lobby government for improved industry support (REMT Unit 2009). Following the SWH workshop, the DoE organises a *National Solar Water Heaters Conference*, which was held in November of the same year. It was at this conference that the Minister of DoE first announced plans to launch a National Solar Water Heater Programme (NSWHP), which aimed to roll out 1 million SWHs by 2014 via incentivised programmes, including the on-going programme by Eskom.

Subsequent to the National SWH Conference and the announcement of the NSWHP, an increase in the number of various activities was observed. Firstly, the number of new companies that entered the SWH industry, perhaps to take advantage of a huge market potential as a result of the NSWHP announcement, increased (Delonno et al. 2010). Even traditional water geyser companies e.g., Kwikot considered diversifying into the SWH market (STAR 2009) and indeed began to manufacture SWH units shortly afterwards. The media also played an important role in writing positively about the potential of the SWH industry (Thakali 2008; Yeld 2008; Salgado 2010). Other observed activities includes the setting up of maintenance and training facilities to increase the industry relevant skills pool; one of those

was based in Soweto, Gauteng (Hardie 2011). Interestingly, other sector players (selectors) also contemplated joining the SWH IS. One such selector was the South African Insurance Association, which announced that the short term industry was investigating a value proposition for replacing electric geysers with more energy efficient SWHs (Kritzinger 2011). Shortly after the announcement, a short term insurance company, Santam, set up a pilot project to investigate business opportunities in the sector. The knowledge gained in this pilot project was shared with interested actors, some of whom have since been inspired to join the industry. Whilst the NSWHP was announced at the end of 2009, it was only officially launched by the president of the Republic of South Africa in the first quarter of 2010. The official launch was held in the Tshwane municipality, where 270 SWH systems financed through CEF were show-cased (Salgado, 2010). These developments seem to catalyse the expansion of the industry, as the number of companies joining the SWH IS continued to grow (Hardie 2011). A further catalytic impact on the industry was the pronouncement that mandated all new buildings to be fitted with SWHs (Njobeni 2010b).

The demand for SWH systems grew to an extent where the local manufacturing sector was struggling to supply the growing sector (Salgado 2009). This led to the importation of cheaper priced SWH systems from abroad e.g., from China (Kritzinger 2011). These imports have had a negative impact on the local manufacturing industry, so much that local manufacturers laid a complaint with Eskom. They argued that they were taking strain due to cheap imported SWHs, which were still enjoying the Eskom subsidies. The impact of the import market negatively affected the SWH industry to such an extent that a few companies were forced to close down (Gosling 2011). Local manufacturers thus lobby government and Eskom for better incentives. Remarkably, their plea was supported by the Congress of South African Trade Unions (COSATU) who held a protest in support of local SWH manufactures, lobbying for better incentives for locally manufactured units over imported units (Fakir 2012). Their lobbying was somewhat successful; in her 2012 budget speech, the Minister of DoE announced that, as of 2012, the SWH programme would work on a different model. In essence, only those suppliers who committed to localising their products / to using local producers would be able to participate in the government funded subsidy programme. This was well received by local manufacturers, but a few companies were still forced to close down before the intervention was put in place. In the meantime, Treasury allocated R4.7 billion to promote the SWH programme, as the Minister of Finance announced in his annual budget speech (Department of Energy 2012). This further encouraged growth of the SWH IS,

and in 2012, more than 260 000 SWH had been installed, with savings of about 250 GWh (I-Net Bridge 2012).

4.3.4.2 Functional analysis

Guidance of search and *resource mobilisation* system functions featured more prominently in this phase compared to the other three. This was most likely due to industry-targeted strategies that were absent in previous periods. Moreover, Eskom subsidies (F6) invigorated activity within the country and created a positive profile of the SWH sector's role (F4). Also, entrepreneurial activities (F1) generally increased; for example, there were more SWH companies in this period than in any previous stage of SWH IS development. In addition, SABS began to assure the quality of SWHs, which also improved customer confidence in the goods. Alongside this, the accreditation of SWHs required by Eskom, and facilitated by the SWH division of SESSA, further removed uncertainties around quality issues.

Progressive industry outlook was further strengthened by activities observed in several municipalities, e.g., the CoCT, Ekurhuleni, Nelson Mandela Bay, and eThekweni, as they intensified efforts around their SWH programmes (F4). *Advocacy coalition* (F7) also began to feature strongly; an example was the pronouncement of dissatisfaction with regard to imported SWHs by the local SWH manufacturers who, with the support of COSATU, were able to influence the government to protect the local market (F7), although this came a bit late for small manufacturers. Moreover, the SWH division of SESSA played an important facilitating role between the entrepreneurs, Eskom and SABS. Knowledge development was not fulfilled as strongly as in the previous period, as the technical and market aspects of the SWHs were better understood by now. Still, the insurance pilot project was an important *learning-by-doing* activity that was undertaken in this period (F2). More influential *knowledge diffusion* activities were, however, observed. In particular, the National Solar Water Heater Workshop organised by REMT on behalf of the DoE injected the necessary energy that had a tremendous impact on subsequent activities in the SWH IS. So successful was the workshop that it led to a much larger gathering in the national conference organised by the same entity a few months later. At the National Solar Heater Conference, the Minister of the DoE announced a programme that would see a roll-out of 1 million SWH units; this was followed by an official launch by the President in early 2010. These activities provided the necessary guidance to the industry (F4) and led to the further mobilisation of resources into the SWH IS, for instance, the R4.7 billion that was set aside to aid the industry (F6). In

addition, *market formation* activities began to feature through the creation of niche markets; an example of this was the introduction of a new building by-law (F5), which mandated all new buildings to install SWHs or heat pumps.

The dominant dynamic here was that of an emerging *Market Motor*, with all the functions being fulfilled and reinforcing each other into virtuous cycles. It is important to note that this motor was still in its infancy, as *advocacy coalition* still featured strongly and could still affect the trajectory of the industry. In the previous studies (Suurs & Hekkert 2009b; Suurs et al. 2010), this motor was characterised by low or no fulfilment of advocacy, as the needs of the government and the market tended to be more aligned. Still, there was a strong reason to label this motor a *Market Motor* because of the greater fulfilment of *guidance of search*, *market formation*, *resource mobilisation* and *entrepreneurial activities*, which increased drastically compared to previous periods. Figure 4 below shows how the various system functions reinforced one another in this period.

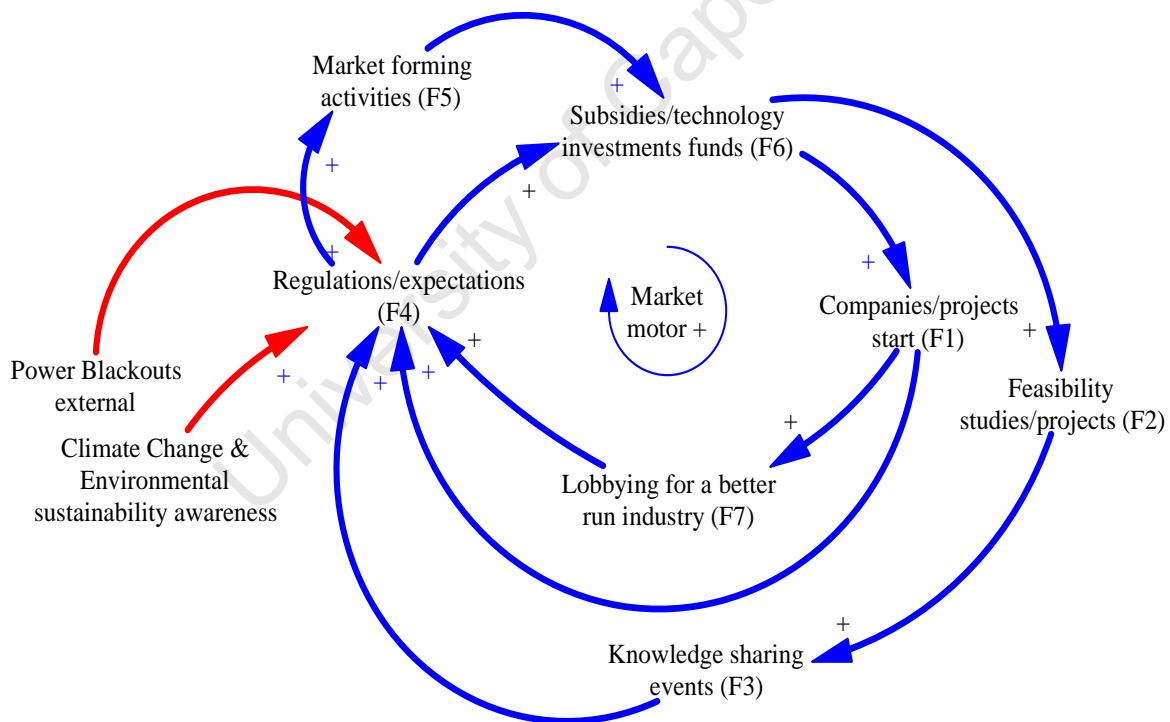


Figure 4.4: Market Motor

Reinforcing loop around the SWH industry, referred to as a *Market Motor*. Landscape conditions continued to provide legitimacy for supporting the SWH IS. Niche markets began to form around new building by-laws, leading to *resource mobilisation*. Availability of resources in the form of rebates, for example, led to the

entry of new companies or to investment in studies to establish SWH market standards. As the number of companies increased, actors organised themselves into coalitions; they became more able to influence government for better regulatory conditions and to raise positive industry sentiments. Feasibility studies led to greater clarity with regard to market potential, which led to further guidance and further *resource mobilisation* when communicated entrepreneurs and potential adopters.

4.3.4.3 Structural drivers and barriers

Landscape factors that were prevalent in the previous two periods, viz. climate change and issues of sustainability, continued to feature in this period. Locally, the main driver at the beginning of this period were the rolling blackouts, which propelled the government to take decisive measures to promote the SWH industry as part of demand side management. This led to the announcement of the NSWHP, which set an optimistic target to install 1 million SWH units by 2014. Other external drivers included pressure on government to fulfil its mandate of creating *green* jobs as a strategy to curb the high levels of unemployment.

The main institutional driver came from government through the setup of the NSWHP. This resulted in increased numbers of various types of actors in the SWH IS. Also, through the national publicity of SWH and positive reporting, some media have managed to communicate the potential of the SWH technology (F3).

Structurally, many positive changes could be observed, although it was mainly an increase in the number of actors in the SWH IS. Most of the actors who were selectors in the previous periods had been transformed into enactors, e.g., SWH companies, some municipalities and government departments etc. It can be deduced, therefore, that to some extent, SWH IS enactors have been able to draw in selectors; these were mostly new firms, which have since become part of the industry association (SESSA). As a result of this increase, SESSA has more mass and more power to lobby for improved industry conditions. An example early in this period was SESSA's success in lobbying for funds for a study to test the technical performance of the SWH systems in the market.

The barrier in this period continued to be a relatively low uptake of the technology relative to the proposed government target. Strategies on how to unlock the potential on a large scale were required if the set target was to be realised.

4.3.4.4 Motor impact on the SWH IS

The picture in this dynamic was that of a maturing SWH IS. The SWH industry appeared to be transitioning from the formative stage into the market phase. The number of SWH companies increased drastically, from less than 10 in the mid-2000s to well over 400 in 2012. Moreover, the impact the motor could be observed in the formation of stronger networks, with the SWH division of SESSA being one such example. In terms of impact on the technology and artefacts, technical glitches had been largely solved. The impact of the dynamic on the structure was positive, resulting in the most robust TIS structure in the history of the SWH industry in South Africa.

Government's strategy has played a key role in shaping the SWH IS in this period. It seems to have been able to communicate the relevance of the technology as a solution to some of the local social problems, such as high level of unemployment. Government has moreover backed up its strategy with an injection of R4.7 billion towards subsidies and industry support. All these dynamics have had a positive impact on the structure of the SWH IS.

4.4 Discussions

It was the objective of this chapter to test the utility of the Technological Innovation System (TIS) framework in a context of transitioning economy. The reason why the SWH technology was chosen for the test was explained earlier in the chapter. The notion of system functions was central to the analysis, through the employment of *event-history analysis* method (Van de Ven et al. 2000), as adapted by Negro (2007), and complemented by the CLDs, both of which were detailed in Chapters 2 and 3. In essence, this chapter began to address, in part, the first research question of this thesis. To test the utility of the approach, events and activities (and by inference other structural components of the TIS) within the SWH IS were tracked from 1978 to 2012.

The utility of the TIS approach was first tested by establishing whether events that unfolded in the development of the SWH industry during the period studied could be attributed to the seven system functions proposed by Hekkert et al. (2007). The results of the analysis indicate that, indeed, apart from activities and events that were found to be external to the SWH IS, the events documented do fulfil all seven system functions. Differences were however noted in how some of the functions were fulfilled. For instance, in the very early years of the period studied, the *resource mobilisation* function was fulfilled differently from most European-

based empirical studies. Resources were mainly in the form of donor grants from developmental agencies, such as the UNDP, as opposed to research funds from government or firms. These funds were instrumental in supporting the SWH500 project, for instance, which saw 500 SWH systems installed in three metros in the mid-2000s. Moreover, these donor funds were usually used to fulfil knowledge development functions. Ultimately, donor resources are able to unlock resources within some national structures, as can be observed when some government entities, e.g., CEF also invest their human capital to co-drive the SWH500 project. Moreover, these knowledge development fulfilling activities are characterised by feasibility and pilot studies as opposed to technical R&D projects observed in European-based empirical studies. Finally, the *advocacy coalition* function did not feature as prominently in the early phases of a TIS, as it did in previous studies (Negro et al. 2007; Hekkert et al. 2007; Suurs et al. 2009; Suurs and Hekkert, 2009); rather, external (landscape) conditions played a more critical role in how the industry was shaped. *Advocacy coalition* only featured strongly at the back of clearer industry direction, such as the announcement of government's SWH strategy.

In line with the first key question, the second aspect to be tested was whether or not the system functions reinforced one another. The analysis showed that the system functions did reinforce one another, and this can either be into virtuous or vicious cycles, as depicted using CLD diagrams in Figures 4.1 to 4.4. Four different *motors of innovation* were identified during the period studied, viz. the *Guidance Motor* in the first period, the *Breakdown Motor* during the second, the *Knowledge Building Motor* in the third, and *Market Motor* in the fourth period. Of the 4 periods studied, virtuous cycles (positive reinforcing loops) were observed in 3, with a vicious cycle being observed in only one. The first positive reinforcing loop was observed in the first period (1978-1983). External drivers e.g., two oil crises of the 1970s, were key to the observed dynamic. The first dynamic revolved around one government project that had been introduced to address the energy security issues induced by external factors. The dynamic was termed the *Guidance Motor* due to the centrality of the *guidance of search* function in that period. The limitation of this motor was the exclusive focus on a single project as opposed to an industry-wide strategy. As a result, an improvement in dire external conditions led to a collapse of the *Guidance Motor*, as the system functions observed in the previous period began to reinforce each other downwards into the only vicious cycle of the period studied. This motor was referred to as the *Breakdown Motor*.

The two other motors are referred to as *Knowledge Building Motor* and *Market Motor*, observed in the 3rd and 4th periods respectively. A noteworthy observation is that both dynamics are analogous to those observed in previous studies. The *Knowledge Building Motor* is analogous to the *Science and Technology Push Motor* (Suurs et al. 2009), as the same functions were fulfilled, though they differed in the types of knowledge development activities and events, as discussed earlier and hence a distinction in the naming of motors. The *Market formation Motor* is also similar and defined in the same way as the one observed by Suurs et al. (2010). The difference is that the advocacy function is still actively fulfilled in the SWH IS context, implying that the SWH IS market is just emerging and industry needs not yet well articulated. For these two dynamics, both in transitioning and developed countries contexts, external (landscape) issues played a critical role in how they came about. Other drivers were common, viz. environmental related drivers, such as commitments to reduce GHG emissions. Others were not common and entailed issues characteristic of transitioning economies, such as high levels of unemployment and the need to improve the provision of basic services to a majority of the population. A unique South African characteristic has been the low cost of electricity, which has been changing, following the rolling blackouts. The observed growth and alignment within the SWH IS can attributed in part to this crisis and ensuing electricity price hikes.

The dynamics referred to here as motors of innovations are influenced by structural drivers and barriers, and at the same time influence the configuration of the structure. Various impacts were noted to have influenced the dynamics in each of the periods, and this dictated the types of functions that dominated during a particular period. For example, in the 1st period, in which energy security and oil crises were external drivers, the government introduced a project that led to a notable emergence of the Solar Water Heating Innovation Systems (SWH IS). However, as external conditions improved, the momentum was halted, since the intervention did not have a long-term SWH strategy. This led to a collapse in the SWH IS structure and, consequently, of activities and events that led to the fulfilment of functions. The positive outcome of the 1st period was that some enactors (SWH companies) remained within the SWH IS and were instrumental in its revival years later.

The external drivers in the next two periods came from international and national pressures, as discussed above. The same pressures are seen to play a key role in other empirical studies,

for instance, climate change issues in Suurs and Hekkert (2009b). The dynamics observed in the 3rd and the 4th periods particularly were key to how the SWH IS structure was shaped. Specifically, activities by CEF, Eskom and municipalities and, in the later part of the period, activities by national government, fulfilled various system functions and ultimately led to a more robust SWH IS structure. Through the NSWHP, more actors were drawn into the SWH IS; related institutions, known here as *rules of the game*, became clearer. In the last period, whilst the external drivers provided some guidance with regard to the direction of the technology, the national thrust discussed above became more influential. This led to a more mature structure of the SWH IS with numerous actors, enactors and selectors, stronger networks (for example, the creation of the SWH division of SESSA), and better-developed institutions. The rules of the game became clearer and were better understood by the majority of the SWH IS. In a nutshell, the *Market Motor* played a critical role in how SWH IS was shaped at the end of 2012.

4.5 Conclusions

The main objective of this chapter was to test the utility of the Technological Innovation System (TIS) in an attempt to answer the first research question in part. Based on the criteria for applicability outlined in Section 3.2.1, the analysis and discussions above, the following conclusions can be drawn:

The first question entailed discussing whether there is an identifiable Solar Water Heater Innovation System (SWH IS):

1. In line with the definition of a TIS structure discussed in Chapter 2, it can be concluded that there is an indeed identifiable SWH IS in South Africa. The structure was initially weak in the early stages of the industry, but over the years it grew, despite being in decline for about a decade. By the end of the most recent period, however, the structure had become robust, and all the elements, viz. actors and their networks, institutions and technical artefacts, were relatively well developed. The activities that occurred within this structure moreover fulfilled the seven system functions.

The second aspect of testing the applicability is to identify whether the system functions are evident:

2. It can be concluded that the events and activities in which the structure of the SWH IS participated led to the fulfilment of all the seven functions proposed by Hekkert et al. (2007). Exceptions were events and activities outside the SWH itself, which have been classified elsewhere (Negro 2007) as external (landscape) and there to provide context. The fulfilment of functions varied according the period studied. In the early stages, for instance, not all the functions were served, but in the last period, all the functions were fulfilled.

The third aspect investigated is whether the functions, if observed, reinforced one another and if so how:

3. It was found that the system functions did reinforce each other, into both positive and negative feedback loops, as referred to in this thesis and elsewhere as motors of innovation. Four motors of innovation were identified. The overall trend is that, as the SWH IS developed, the motors of innovation evolved from the less mature *Guidance* and *Knowledge Building Motors* (with the exception of the *Breakdown Motor*) to the more mature motors, viz. *Market Motor*. In the last period, the observed dynamic (viz. *Market Motor*) saw all seven system functions reinforce one another. Remarkably, some of the motors observed in the SWH IS industry mimic those found in other empirical studies, (Farla, et al. 2010; Suurs et al. 2009; Suurs & Hekkert 2009). Finally, there is some agreement that stronger dynamics tend to follow on from weaker ones.

Lastly, no additional functions were identified in this study. Rather, the way in which some of the functions are fulfilled, was different. The events and activities relating to knowledge development and *resource mobilisation* functions were the most noteworthy. There was only a small R&D component associated with knowledge development, in the case of the SWH, during the 24-year period studied; rather this period was dominated by feasibility studies and pilot projects (*learning-by-doing*). Donor funding and developmental grants featured predominantly in determining how resources were mobilised, at least in the early stages of SWH IS development. This could be seen to some extent in the Kuyasa project in Cape

Town. These types of resources usually helped to unlock national resources such as human capital in the early phases. National funds from within the country in the form of subsidies only came to the fore in the last 5 years of the entire period studied.

Overall, the analysis of the SWH demonstrated that the TIS approach could be used to understand the evolution of a technology in a transitioning economy context, using the system functions framework. Moreover, CLDs were found to be useful in visually depicting the motors of innovation observed in different periods of the analysis. Based on the insights gained in this chapter, the next chapter will continue to address the first key question.

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CHAPTER 5 The Development of the Biogas Industry in South Africa

5.1 Introduction

In Chapters 2 and 3, the theoretical background and methods adopted in this thesis were discussed respectively. In Chapter 4, a TIS approach was applied to the SWH industry in South Africa to assess whether the TIS approach would be applicable in a transitioning economy context. In this chapter, another TIS analysis of the currently emerging South African biogas industry is presented, with the aim of answering the first key question of this dissertation:

Can the technology innovation system approach be used to locate and describe elements of technological transition in South Africa's nascent energy-form-waste industry, using the seven functions proposed by Hekkert et al. (2007)? Can insights gained from testing the TIS approach on the more mature solar water heating technology be useful in describing the evolution of anaerobic digestion industry in South Africa?

The primary objective of this chapter is to shed light on how the biogas industry has been and is developing in South Africa. A second objective, together with key findings from Chapter 4, is to gain insights into the nature of technical transitions in transitioning economies, using South Africa as an example.

5.2 Scope and notes on methodology

This chapter aims to employ the TIS framework described in Chapters 2 and 3 to investigate the evolution of the entire biogas industry in South Africa, i.e., covering different contexts (namely, rural and urban areas) and possible organic waste sectors (both solid and water treatment sectors). In addition, some aspects of the MLP, also described in Chapter 2, will be referred to for explanatory purposes and where deemed appropriate to complement the TIS analysis. It may be argued that the different sectors under consideration could constitute at least two TISs, e.g., one focusing on wastewater and another on solid waste. Whilst that may be a valid assessment, the biogas technology in South Africa is a sufficiently small system, especially in the formative phase of development, to be considered as a single TIS.

The rest of the chapter comprises a chronological account of the biogas industry's development. The account is divided into two phases (see Section 5.3). In each of the phases, a narrative is presented, followed by a functional analysis and an identification of functional patterns. Drivers and barriers that enable or hinder the BIS structure from fulfilling the functions are also highlighted. Discussions and conclusions will be presented to close off the chapter in Sections 5.4 and 5.5 respectively. It is important to note that, although an extensive attempt was made to collate major events in the development of the biogas industry, some incidents may have been omitted because they were invisible in the mainstream media, or because relevant information was not publically available.

5.3 Historical overview of the biogas technology in South Africa

The biogas industry was tracked from 1997 to 2013; it can be divided into two phases, with the first phase from 1997 to 2007 and the second phase from 2007 to 2013. The distinction between these two periods was made due to changes in key events between the two phases. In general, more limited activities could be observed in the first phase than in the second phase.

5.3.1 Early beginnings: 2000-2007

5.3.1.1 Overview

This first phase began a few years after South Africa's first democratic elections. Equality and social justice were high on the South African government's agenda and thus guided most of the government's early activities. Meanwhile, environmental sustainability began to feature as a national and international discourse, and renewable energy technologies in general, amongst various options that promote sustainable development, were being legitimised (Winkler 2007). Moreover, the 2002 World Summit on Sustainable Development (WSSD) hosted in Johannesburg gave considerable exposure to this agenda. AD technology had been in use in South Africa prior to this period; however, it was predominantly utilised in municipal wastewater facilities to stabilise sewage sludge, as opposed to addressing environment and sustainability issues. In these facilities, biogas was either inefficiently utilised, flared or vented (Ross 1992). Besides its application in wastewater treatment, very few AD related activities could be observed in the country prior to 1997. The very early activities observed were around knowledge development through technical studies, investigating the viability of AD in various applications. For instance, Strydom et al. (1997), investigated the viability of the AD technology in farms and abattoirs. Conversely, AGAMA Energy assessed the market in the small-scale biodigester sector, and began to install a few

fixed-dome household systems in the early 2000s, though this was only in niche applications, e.g., homesteads and farms off the grid (AGAMA Energy (Pty) Ltd 2007).

Local government also played a part in the early stages of the BIS development, namely, by assessing bioenergy potential from municipalities' waste streams. The CoCT in collaboration with the UNDP, for instance, commissioned such a study from the University of Stellenbosch, and AGAMA Energy formed an energy consultancy with expertise in biogas technology. The aim of the study was to assess the bioenergy potential of the organic fraction of the MSW (AGAMA Energy (Pty) Ltd 2006). The study reported that a 2.1 MW_e power plant fed on the biogas produced by AD could be installed in Cape Town. In yet another study, whose focus was on local government potential, Austin et al. (2006) conducted a 'waste-to-energy' pre-feasibility study for the Department of Science and Technology (DST). The study attempted to assess the potential of recovering energy from MSW streams in six South African metros. It estimated that the inherent energy disposed with waste in these metros was twice the 10 000 GWh target proposed in the White Paper on Renewable Energy – and that AD would be a competitive technology platform to harness much of it.

Towards the end of this period, a gradual increase in the number of activities could be observed within the BIS. However, actors were largely operating independently and unaware of each other, and there were hardly any collaborations and interactions amongst them. Moreover, activities were scattered all over the country and across sectors. Small-scale pilot plants were being installed in schools and continued to find applications in rural settings (Sibisi & Green 2005). The developments in the medium- to large-scale sectors were driven by landscape factors, mainly the carbon markets. For instance, when the carbon market initially opened up, international companies looked to emerging economies to develop projects that would earn carbon credits under the Clean Development Mechanism (CDM) of the Kyoto Protocol. A US agricultural multinational, Cargill, is a good example, as it was the first company to seize an opportunity around the biogas technology by investing in a medium-scale project to turn manure into biogas and then power at Humphries farm in Bela Bela (Financial Mail 2007b). At a large-scale level, a 4.2 MW power plant was installed at the state-owned gas-to-liquid company PetroSA in Mossel Bay (Engineering News 2007), becoming the largest biogas digester in the country. The project was funded by a consortium comprising Methcap, a subsidiary of an international environmental company WSP, the CEF and a group of empowerment actors (Engineering News 2007).

At the small scale, biogas digesters were used in niche applications, most of which were installed by AGAMA Energy in rural areas (Boyd 2010). In urban areas, the use of biogas for poorer communities also came into the spotlight. For example, the eco-village in Ivory Park, a township outside Johannesburg, worked towards installing a biogas digester primarily for wastewater but plans were in place to use the resultant gas for thermal purposes, e.g., cooking (Marshall 2007).

Meanwhile, biogas produced at old wastewater works and landfill sites came under the spotlight towards the end of this phase. With regard to the ageing wastewater facilities, energy specialists advised that, where biogas was produced, it should rather be flared instead of being vented, to reduce the global warming impact by about 21 times (Gosling 2007). Similarly, harvesting of landfill gas (similar to biogas) was being explored at three major metros, viz. Ethekewini municipality in KwaZulu-Natal, the CoCT and Johannesburg municipality. In 2003, a project for extracting landfill gas for electricity generation at three landfill sites was conceptualised by the Durban Solid Waste (DSW). By the end of 2007, the projects at two landfills, viz. La Mercy and Mariannahill were operational, and up to 500 MWh of electricity were said to be generated per month at the Marianhill landfill (Wright 2008). In addition, the CoCT noted that landfill gas-to-electricity projects would be important for the city's energy security and climate change goals as early as 2003 (City of Cape Town 2005), but an announcement to conduct an Environmental Impact Assessment (EIA), made possible by collaboration between the City and the CEF, was only made four years later in 2007 (Gosling 2007). In Johannesburg, five landfills were identified as potential sites for implementing a gas-to-electricity project in 2005, but this only officially commenced in 2007.

The World Business Council on Sustainable Development (WBCSD) began to inspire business to create eco-efficiency and sustainability pillars for conducting business (Timberlake 2006). Five industrial scale biogas digesters were installed during this period. One of these was the PetroSA plant, and the other four were installed at South African Breweries (SAB) by Talbot & Talbot (T&T) towards the end of this period in Ibhayi, Newlands, Alrode and Rosslyn. T&T is one of the few companies in South Africa that has and continues successfully to build and operate Up-flow Anaerobic Sludge Blanket (UASB) digester treatment systems across various industrial sectors in South Africa. At the SAB Alrode plant, situated south of Johannesburg, for instance, biogas was used to power the boilers and to generate steam that was then used during the brewing process, thus reducing

their reliance on fossil fuels. 90% of 25 tons of Chemical Oxygen Demand (COD) produced daily were being converted into biogas, and a high methane content of 85% was reported. Through this process SAB, avoided burning 10.4 tons of coal daily, which translated into daily savings of R7 000 (Erasmus 2009). Moreover, a new biomass-to-energy company called Bio2Watt was established in 2007 (Bio2Watt 2012). Its focus was on harnessing industrial organic waste for electricity production via AD, and it was planning to add to the number of large-scale installations.

In general, there was an increase in the number of biogas installations over the years in this first phase (see Figure 5.1 for the trend). Still, most of the biogas digesters were installed in rural areas; for example, two farmers in KwaZulu Natal designed and installed a biogas digester in 2006. The system started off as a 25 cubic metre system, but the farmers have since expanded this operation to produce up to 150 cubic metres of biogas daily in summer and 110 cubic metres in winter (Phillips 2011).

5.3.1.2 Functional analysis

There was no overarching dynamic in this period, rather sporadic activities that fulfilled some of the seven functions. *Knowledge development* was one of the few functions fulfilled in this period. Activities that fulfilled this function included fundamental research, feasibility studies and pilot projects. There were a couple of examples of fundamental research, e.g., one study explored the AD of dairy effluents and the impact on reactor configuration (Strydom et al. 1997). Feasibility studies as noted above have been instrumental in assessing the potential of the technology mostly in urban areas, e.g., in the CoCT. With regard to pilot studies, an example was a floating drum reactor installed at a rural school in KwaZulu Natal, which formed the basis of a study that investigated the perceptions of energisation in that context (Sibisi & Green 2005).

Some *resource mobilisation* initiatives were also evident in this period, viz. CDM based carbon finance and foreign aid from developmental agencies. Foreign aid was directed towards conducting feasibility studies (F2); for instance, the UNDP funded study assessed the potential of energy generation from organic waste in 2002. In a larger installation at PetroSA, prospects of earning carbon credits made the 4.2 MWe biogas plant feasible. In addition, the biogas digester mooted at the Bela Bela's Humphries Piggeries was to be funded via carbon finance by Cargill International, a multinational agricultural company.

The entrepreneurial experimentation function was fulfilled to a limited extent, as only a few companies entered the industry and displayed innovation. AGAMA Energy remained the main knowledge provider across the industry and a technology supplier for small to medium-sized systems. On the industrial scale, local players were the newly formed Bio2Watt (F1) and the more established T&T. T&T's expertise lay in the wastewater treatment sector in general, but they were extending their operations into the food and beverage industry, installing, as mentioned above, four SAB systems during this period (F1).

Some activities fulfilled the *guidance of search* function (F4). Worth mentioning on this front were the publication of the White Papers on Energy (1998) and Renewable Energy (2003), detailed in Chapter 4, although neither gave strong guidance regarding AD technology specifically.

Activities observed in this period largely occurred independently of one another; moreover, no reinforcing patterns could be observed. In addition, knowledge diffusion, *market formation* and *advocacy coalition* activities were not observed at all. Overall, a gradual increase in activities was observed in the last few years of this phase.

5.3.1.3 Structural drivers and barriers

A few institutional drivers were observed in this phase. The White Paper on Renewable Energy represented the government's effort to stimulate the renewable energy sector, primarily for developmental purposes such as job creation, but also for curbing GHG emissions. The policy paper might have inspired entrepreneurial activities; as a result, new companies such as Bio2Watt subsequently entered the innovation system and older players such as AGAMA Energy continued to persevere. Another institutional driver observed towards the end of the phase was carbon financing, a Clean Mechanism initiative birthed out of the Kyoto Protocol.

Structurally, there were few enactors; they included AGAMA Energy, T&T, Bio2Watt and a few municipalities and some researchers. Apart from some local authorities, government involvement was largely that of a spectator. The CEF was the only government entity that had been involved in the BIS through its participation in the PetroSA project and landfill gas extraction. At this stage, there was no evidence to suggest that enactors were drawing

selectors into the industry; rather newly formed companies such as Bio2Watt were drawn into the innovation system due to the promising potential of bioenergy.

The structural barriers in this phase remained the absence of a framework that would guide the renewable energy industry in general. Also, until recently, the cost of energy had been low, which had for a long time dis-incentivised the development of the renewable energy sector in general and biogas technology specifically. At the end of this period, there appeared to be some urgency to explore renewable energy options, evidenced, for instance, by the rapid growth of the SWH industry (see Chapter 4). Essentially, as the gap between electricity demand and supply narrowed, there were signs of a looming energy crisis and consequently a greater interest in alternatives. The next section narrates how events unfolded from 2008 onwards, beyond the signs of the looming energy crisis into its shocking reality.

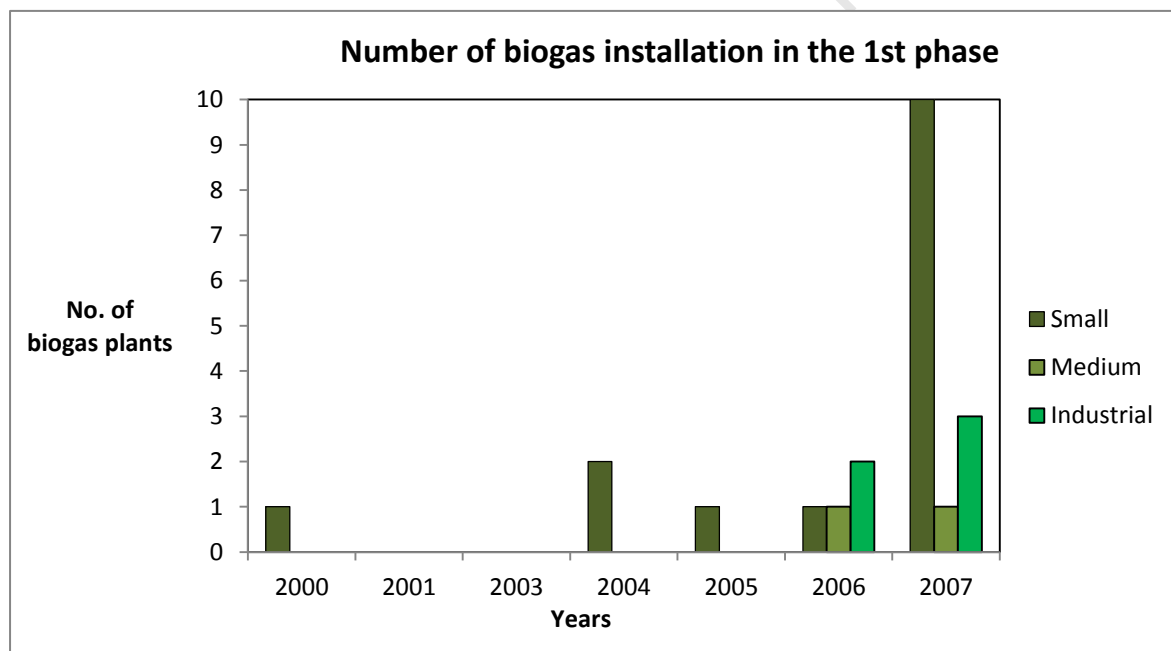


Figure 5.1: An estimate of new biogas installations per annum from 200 to 2007

5.3.2 Second phase: 2008-2013

The second phase has been divided into two parts for ease of reading, due to the flux of activities in this phase. However, the activities are not sufficiently different to warrant division into a further distinct phase.

5.3.2.1 Overview

The energy crisis era: 2008-2009

The national energy crisis made landfall in 2008, which can be identified as the beginning of this phase. It was experienced in rolling power blackouts, as Eskom, a state-owned power utility, struggled to keep up with the national electricity demand. Initial activities in this phase were geared towards addressing the energy crisis, as a more concerted pursuit for alternative energy sources began. Renewable energy technologies were being seriously pursued as options to address both the demand side (e.g., energy efficiency initiatives) and the supply side (e.g., wind energy, bioenergy, including biogas, etc.) (Parker 2009).

Landfill gas harvesting from anaerobically digested landfill organic waste was one of the options that continued to feature from the last period. At the forefront of this development was the Ethekewini municipality, which continued to generate electricity from landfill gas (Wright 2008). However, other cities were making progress on plans started in the previous period. For instance, Gosling (2008a) reported that the CoCT was hoping to generate carbon credits that could be traded on the international carbon markets from harvesting landfill gas and using it to generate electricity; indeed, an EIA exercise was commissioned shortly afterwards (Gosling 2009). Likewise, the City of Johannesburg commissioned EIA studies for the five identified sites (City of Johannesburg n.d.).

Meanwhile, the number of small-scale biogas digester installations continued to grow, and so did experimentation around the technology by local companies and, in some cases, through Do-it-Yourself (DIY) projects. At the beginning of this period, AGAMA Energy was still the biggest player nationally for the small-scale biogas digester market. The primary objective for most installations at this scale was for household energy security on the one hand and to reduce the impact of Eskom blackouts on the household energy supply on the other. For instance, a KwaZulu-Natal farmer managed to keep afloat during the power crisis because of a biogas digester installed by AGAMA Energy. This farmer was using biogas for cooking and ran a small generator that generated enough power to charge mobile electronics (Khanyile 2008). Another example of DIY systems, a collaborative effort between actors with different but complementary expertise, was also observed in KwaZulu Natal. The actors in question were a university professor and two farmers who collaborated to install and operate a biogas 30 cubic bladder system with a 50 kW capacity (Myrtle 2008).

In some cases, the adoption of technology was primarily for waste management purposes; for instance, in the rural areas of the Eastern Cape province, a household used dung from 17 head of cattle, 3 pigs and a flock of chicken to generate sufficient biogas for cooking (Stent 2009). Also mooted in the Eastern Cape was a rural biogas programme by the DME. The proposed project aimed to install 10 000 household systems in 5 years (Hayward 2008); however, this goal is yet to be realised 5 years later.

Parallel to the upward trend observed in the small-scale sector, medium-scale projects were also gaining momentum early in the phase. At the forefront of this development was Humphries Piggeries in Bela Bala, Limpopo province, a project that was initiated in the previous period. It was the first biogas digester in the country to be installed at a commercial piggery with funding (carbon-based) from a US agricultural multi-international company, Cargill. The system was predicted to be the first biogas to power plant that would be embedded into the national grid. The piggery was using farm waste from 17 000 pigs to produce biogas, which was in turn used to generate electricity. The farm was said to generate 70 kW of power using a technology provided by a local gas engine company, Cape Advanced Engineering (CAE), which continued to provide technical support to the piggery to date (Taylor n.d.).

This development inspired the biggest piggery in the country, situated in Kanhym near Middleburg, to work towards implementing its own biogas digester in 2008. As with Humphries farm, biogas would be used to generate electricity, primarily to meet the facility's needs, and the surplus would be exported onto the national grid. For this project too, it was hoped that costs would be covered by selling carbon credits under Kyoto Protocols CDM (Financial Mail 2008). Inspired by these developments around the two piggeries, Premier Pork Producers appointed AGAMA Energy to conduct a feasibility study of 10 pig units at three piggeries. The findings of that study were largely positive, and suggested that, the larger the piggery farm, the more viable the biogas project would be. In addition, if the nutrients were recovered, the payback time could be less than two years (Engineering News 2008). Meanwhile, CAE was in talks with up to 20 piggeries to apply the biogas to electricity model that it had implemented at Humphries farm (Taylor n.d.).

New companies joined the BIS from 2008 onwards, primarily to exploit farm waste. One such company was Olive Tree Systems, which was created with the aim of rolling out medium-scale digesters in the Eastern Cape Province. Olive Tree Systems, for instance, planned to install biogas digesters at a major poultry farm in the Eastern Cape province and at a number of other farms in the same province, but also at a 5-star hotel on the Garden Route (Hayward 2008). In addition, international biogas companies were also considering entering the South African biogas market that same year. For instance, the German biogas plant manufacturer Weltec BioPower was looking to have one of its plants installed in South Africa (Engineering News 2008). In the wake of the power crisis, the company believed that South Africa was more ready than ever to explore renewable energy technologies in general and biogas technology in particular. The company believed that the energy crisis of 2008 and hiking electricity prices would be sufficiently important to encourage biogas technology development, despite the absence of energy credits to business that were already enjoyed in most European countries. They argued that the effectiveness of the plants could make up for the lack of incentives (Parker 2009).

Developments in the industrial-scale systems began to gather some momentum, but in addition to wastewater treatment observed in the previous period, the use of solid waste was now being considered at MW scale. Two examples of the projects could be noted here. One project was the Lesedi Biogas Project (LBP), which planned to use feedlot manure to generate 3.8 MW base load and 6.8 MW of peak power. The LBP, an independent power producer, was predicted to be the biggest open-air feedlot manure-to-power plant in the country. The location for the project was Karan Feedlot, and it was in proximity to the feedstock, 110 000 tpa of cattle manure. The project costs were estimated at \$15 million. LBP planned to use the then REFIT programme to generate revenue from selling electricity to Eskom (Harcout 2009). The project, however, stalled due to onerous project development process, lack of legislative direction, and ever increasing upfront investment costs. Five years after the development was temporarily abandoned, the project was rumoured to have been resuscitated, under the Small REIPPP programme detailed in Chapter 4. Another company that began to develop large-scale biogas project utilising waste biomass was Bio2Watt formed at the end of the last phase. The first project under development would be situated in Bronkhorstspuit, near Pretoria.

The Bronkhorstspuit Biogas Project (BBP) was the first and most advanced large-scale commercial project to tap into the immense bioenergy potential from biomass in the country. The BBP was situated at the Beefcor Feedlot in Bronkhorstspuit, one of the largest in the country, housing in excess of 20 000 heads of cattle and producing over 40 000 tonnes of manure per annum. The target capacity of BBP was 3 MWe, to be generated from biogas produced primarily from cattle dung but also from other waste streams, such as dairy waste. The development of the BBP from the concept phase until it had reached financial closure was mainly supported by the NL Agency Global Sustainable Biomass Fund. Upon reaching financial closure, NL Agency required Bio2Watt to document lessons for developing a commercial biogas plant in order to provide guidance for similar future projects. Our research group at UCT, in which this thesis is based, was contracted to document these lessons on behalf of Bio2Watt; see Appendix B, a report that I lead-authored, summarising the lessons learned.

Meanwhile, small-scale biogas digester installations continued to grow faster than those at other scales, even though efforts were still not coordinated, for instance, by any sphere of government. In 2009 alone, more than 20 household-scale biogas digesters were installed in rural areas across the country (see Figure 5.2 below). Amongst them was a community-based project in a Limpopo village, Mpfuneko. The objective of the Mpfuneko project was to provide clean energy to 180 households through the support of the Netherlands Wild Geese Development Organisation, with funding from a church organisation in the Netherlands. The beneficiaries were reportedly *'thrilled with the difference that the biogas technology has made in their lives'* (Hlungwani 2010). One of the beneficiaries said, *'Biogas is a good alternative, it cooks faster than when using wood – without the smoke'* (Hlungwani 2010). Moreover, the project provided skills and employment to the rural villagers, and a total of 10 people had been employed since the beginning of the project (Chauke 2011). Another example of how the biogas technology had positively affected people's lives could be found in the Upper Thukela area in Kwazulu Natal (SESSA 2012b), where AGAMA Biogas (a subsidiary of AGAMA Energy) had installed several of its patented BiogasPro AD systems. The beneficiaries were impressed by the smokeless and clean burn of biogas, but also by significantly reduced energy expenditure. For instance, one family used to spend up to R800 on energy per month, R100 of which was on electricity and the remaining R700 on wood, before a biogas digester was installed. This household, which has 5 cows, was able to cut

down their Eskom bill by R50 and no longer had to purchase wood; their savings amounted to R750 a month, excluding digester payback (SESSA 2012b).

Similarly, knowledge development activities had also increased; they comprised feasibility studies, typical R&D and learning-by-doing projects. Most of the key feasibility studies that informed this thesis and that were detailed in Chapter 1, were conducted in this period. For example, a feasibility study was conducted on energy from wastewater (Burton et al. 2008). Another one was conducted by AGAMA Energy on Sustainable Cities: Biogas Energy from Waste Guidelines Report: This entailed the development of a toolkit geared at assisting municipal officials to evaluate the energy potential from sludge and liquid waste (AGAMA Biogas 2009). In yet another study, in which AGAMA Energy was involved, the biogas potential in rural South Africa was assessed. This formed part of a 13-country programme in Africa called Biogas for Better Life. The feasibility study estimated that more than 300 000 households in SA alone could benefit from the installation of biogas systems (AGAMA Biogas et al. 2008). One other key recommendation that emerged from the study was that a realistic and modest introductory phase was key for the successful implementation of the rural biogas technology programme. On the R&D side of knowledge development, a noteworthy development in 2009 was the patenting of the pre-fabricated biogas system of AGAMA Biogas (a subsidiary of AGAMA Energy), called the Biogas Pro; a few years later, they introduced a Smart-Top design.

There were also notable academic contributions published in this phase. Some studies proposed looking into how the bioenergy potential could be unlocked. For example, a study conducted by Greben & Oelofse (2009) proposed to understand how the resource potential of organic waste in South Africa could be unlocked. This study was, however, simply a review of the current waste management practices in South Africa and of biogas technology implementation in Europe and Asia. Their main conclusion was that the success of the biogas technology in South Africa depended mainly on an enabling governance environment, in particular energy and environment legislation. (We show later on in this chapter why legislation alone is unable to lead to the development of an industry.) Another study investigated why biogas was not widely adopted in Africa despite its potential; the study attributes this to a lack of human resources and inadequate maintenance of essential equipment (Makoni & Scott 2009).

Despite such a positive albeit uncoordinated trajectory of the biogas sector, there was still no policy framework to guide the renewable energy sector in general and biogas in particular. The White Paper on Renewable Energy announced in 2003 set a renewable energy target that was viewed by some as ambitious, and denounced by others from the outset as insignificant. For instance, a study commissioned by Earthlife Johannesburg concluded that a higher renewable energy target was needed by the South African economy, if maximum job benefits were to be derived (Austin et al. 2003). Moreover, the target remained just that: a target. The government still had to put in place a regulatory framework to enable independent power producers to undertake projects. That remained the case until the energy crisis of 2008. Market incentives that were announced at the beginning of 2008 were not implemented, to the frustration of industrial players and even members of parliament. For instance, a total of R2-billion was earmarked for renewable energy programmes in the 2008 national budget speech, but at the end of the year, the proposals for the use of the money were still under consideration (Groenewald 2008).

Also, the government proposed a Renewable Energy Feed-in Tariff (REFIT) programme, but there was no sense of urgency to implement it. This prompted a highly critical faction of national parliamentarians to draft a private feed-in-tariff bill and in the process lash out at the Minister of Finance for his so-called *‘lacklustre* towards renewable energy technologies (Groenewald 2008). This turned out to be a critical move, as it propelled government to set a deadline of February 2009 to publish a draft strategy for a renewable energy procurement programme. In early 2009, a probable tax incentive for renewable energy projects including biogas (e.g., Humphries piggery) was announced. This was known as the Taxation Laws Amendment Bill, whose aim it was to assist businesses that wished to make environmentally conscious investments (Naidoo 2009). For one, the legislation allowed for receipts of CDM carbon credits sales to be tax-free until the end of 2012, which would benefit projects similar to Humphries Piggery, while the second amendment proposed deductions from income tax energy use savings, as long as that they provided proof that they had been certified by the National Energy Efficiency Agency (NEEA) (Naidoo 2009). Also announced in 2009 was the government's commitment to the United Nations Framework Convention on Climate Change (UNFCCC) to reduce GHG emissions by 34% below *business as usual* scenario by 2020.

In 2009, the REFIT programme commenced as per government's earlier promise; prospective developers warmly welcomed this progress. Following the REFIT announcement early in

2009, the second phase of REFIT tariffs i.e. was announced towards the end of the same year. This came shortly after the government announced the first round of the Integrated Resource Plan (IRP), which proposed that renewable energy contribute 7 200 MW of electricity by 2030. However, the power purchasing agreements process allocated the highest tariffs to wind and solar technologies, compared to biogas. Biogas actors were unhappy with the proposed tariff of 96c/kWh that the National Energy Regulator of South Africa (NERSA 2009) had set for biogas, and noted that it was less than half of what the German government offered for biogas electricity.

Current legislation developments raised cautious optimism amongst biogas enactors, some of whom began to advocate clearer policy directions. The potential contribution that biogas could make to the South African renewable energy mix was cautiously estimated at about 200 MW, with some projects estimating to generate up to 10 MW power onsite (Engineering News 2009). Since the announcement of the REFIT programme, actors in the biogas industry believed the onus was on NERSA to make it a reality. Another noteworthy piece of legislation for the BIS the NEM: WA 2008. It is believed that this Act and the related NWMS could be an important ingredient in the biogas industry develops, by supporting waste to energy projects.

Whilst biogas developments had largely been limited to the private sector, the public sector also began to participate actively from 2009 onwards. For instance, the *Working for Energy* programme coordinated by the DoE and managed by the NEEA planned to explore the technology for rural development (SANEDI n.d.). The *Working for Energy* programme was inspired by its sister programme *Working for Water*, and aimed to address both the demand and supply side components of energy provision, which involved labour-intensive activities. On the demand side, the programme aimed to include processes that would include the collection of invasive species biomass and biogas generation from various organic waste streams. In addition to its aim of empowering the poorer fraction of the population, the *Working for Energy* programme mainly aimed to contribute to the reduction of GHG emissions through its various initiatives. In this regard, the programme believed that it was well placed to attract carbon credits, which could help to finance its initiatives (Financial Mail 2009b). Moreover, the programme echoed the private sector's sentiments regarding the suitability of commercial farms to turn the bulk of their waste into energy. In addition, they

could also produce fertilizer material that could be sold to crop farmers. According to the programme managers, '*biogas produced from manure can generate up to 500 MW of power in the country*', double the 200 MW estimated by biogas protagonists (Financial Mail 2009a).

The incline period: 2010-2013

The announcement of the REFIT programme caused great optimism amongst private companies and banks, as they considered entering the renewable energy market. This was in anticipation of the government finalising the rules of engagement at the end of 2010 (Financial Mail 2011b). Those eager to get into the industry were energy companies, construction companies and finance companies, such as Sasol, Exxaro etc. (Faull 2010). At the same time, the government assessed the readiness of the private energy sector to participate in the renewable energy market. It mandated the DoE to conduct a *request for information* exercise; this found that up to 24 000 MW could be generated through various renewable energy technologies. The response was said to have influenced the second version of the IRP, which directed the expansion of the electricity supply over 20 years (Njobeni 2010a).

Despite these positive developments within the BIS, the lack of policy direction, induced by conflicting messages with regard to the recently announced REFIT programme, stunted progress within the renewable energy sector in general and biogas specifically. Firstly, it was announced that only projects that generated in excess of 1 MW would qualify for the REFIT programme, as smaller projects tended to be onerous (Jourbert 2011a). Biogas protagonists warned that this would exclude the majority of potential biogas projects (*ibid*). Also, NERSA proposed considerable tariff cuts for renewable energy installations that generated more than 1 MW of power (*ibid*). The tariff cut was by up to 39.2%, with biogas receiving a relatively low reduction of 12.9%. Meanwhile, renewable energy actors across the board labelled this move as confusing and one that was likely to result in disinvestment. Ironically, the tariff cut came shortly after government forecast that 42% of new electricity capacity in South Africa would be met by renewable energy, with new capacity of 17 000 MW being established over the next 20 years (Report 2011). In 2010, the state seemed to go back on its commitment to build a renewable energy industry. Although the REFIT programme raised cautious optimism within the renewable energy sector, a year and six months later, the National Treasury declared the programme illegal, uncompetitive, unprocedural and therefore unconstitutional

(Financial Mail 2011b). It would be a few months before a new programme to replace REFIT was announced, in mid-2011.

Meanwhile, advocacy for biogas began to emerge from 2010 onwards. Firstly, biogas was considered as one of the second-generation biofuels e.g., cellulosic ethanol or algal biodiesel that mainly utilised waste feedstock, as they steered away from food vs. fuel debates. Moreover, in 2010, the Southern African Bioenergy Association (SABA), an industry association, began to promote AD of animal manure, waste plant material, municipal waste and sewage for biogas production (Financial Mail 2010). Furthermore, SABA worked with NERSA to explore the possibility of integrating biogas into the conventional gas distribution system (*ibid*).

Still in 2010, biogas came into the national spotlight, as plans to wean off Robben Island, the iconic political site, from its total dependence on diesel ferried from Cape Town were mooted. The energy needs were envisaged to be met by a host of renewable energy technologies, including biogas, solar, wind and other biofuels. Biogas was to be produced from sewage and other organic wastes, and to be used for thermal purposes or generating electricity. The South African National Energy Development Institute (SANEDI), a subsidiary of the CEF, was heading the projects and plans to use the *Working for Energy* funds together with donations to make the vision a reality. Some projects were hoped to be ready for the UNFCCC COP17 meeting, for which Cape Town was a candidate host. The UNFCCC venue was ultimately agreed to be Durban, and the projects are yet to see the light of day (McAlister 2010).

Also evident in this period was innovation in research institutions. One of these research endeavours culminated in a patent in 2010. The patented biogas digester was a result of several years of R&D at the CSIR in Pretoria. Specifically, it formed the second part of a larger research project funded by SANEDI; the first part was to investigate the biodigestibility of waste paper. The unit that was provisionally patented, had 360 litre capacity to process any form of municipal waste (e.g., organic waste, human and animal sludge etc.) (CSIR 2010), and was specifically designed for rural application. The design could be scaled-up to treat separated sludge from up to 50 households. One of the attractive features of this digester was suggested to be its material of construction, which could be

purchased off the hardware shelf, making them readily available in remote areas. Another beneficial design feature was that the equipment ran on an automated system, which reduced the retention time of the sludge by maintaining parameters that assisted in the biological breakdown of organic waste. The patent was finally awarded in March 2012 (CSIR 2013).

Towards the end of 2010, collaborations between different actors increased. For instance, municipalities embarked on joint projects with academic institutions. One example was collaboration between the Ethekwini municipality and the University KwaZulu Natal, which looked at co-digestion of sewage sludge and other organic waste streams (UKZN School of Engineering 2011). In a similar collaborative initiative, the CoCT appointed the University of Cape Town (UCT) to investigate the bio-methane potential (BMP) of various organic fraction of municipal waste (Munganga et al. 2010). Another example of collaboration was a partnership between an NGO Trade Plus Aid (TPA) and the South African arm of a Swiss biogas technology company (Acrona), who together launched a project known as the South African Biogas Project in 2010 (Trade Plus Aid n.d.).

The Trade Plus Aid Biogas Project had two focus areas, viz. the Agricultural Biogas Project and the Domestic Biogas project. The Agricultural Biogas Project planned to convert open lagoons that were currently being used to manage effluents in animal farms into closed biogas digesters. The biogas produced was to be scrubbed off the hydrogen sulphide and then used as a fuel for electricity generation. The project hoped to install digital monitoring systems at all of the digesters linked to a central server for ease of systems monitoring. TradePlusAid pronounced that it was collaborating with Premier Pork Producers, and already had 13 farms lined up to become biogas producers under the commercial arm of their work (Financial Mail, 2011). The Domestic Biogas Project however would be implemented by the revenue generated from the agricultural component of the project throughout rural South Africa. At the end of 2011, TPA had installed more than 20 of the small-scale digesters in the KwaZulu Natal Richmond area with a grant from UNDP (Trade Plus Aid n.d.). The project was progressing slowly due to the long turn-around of submitted EIAs from the Department of Environmental Affairs (DEA) (Makholwa 2011).

Meanwhile, a number of pilot and demonstration projects were springing up all over the country. Our food waste digester, discussed in detail in Chapter 6, installed at a student

residence at UCT was one such example. This digester used plate scrapings generated from the Leo Marquard Hall (LMH) university residence canteen to produce biogas, which was piped back into the kitchen and used as fuel for cooking. Most of the project funding came from the Vice Chancellor's strategic fund because of its linkages with the university's broader goals of reducing GHG emissions and being a carbon-neutral campus. Another demonstration project was implemented at the Johannesburg Zoo, the first for a South African zoo (Joburg 2011). This demonstration was meant to educate visitors about the benefits of the technology. Other examples included pilot plants installed at a farm in the township of Philippi outside Cape Town and a few others at the University of Fort Hare and the surrounding villages (Mr. D. Mahuma, 31st May 2013).

For large-scale applications, a pilot project that was hoped to be up and running by February 2011, was announced by a company called Novo Energy (Steyn 2010). This company planned to harvest landfill gas from the East Rand landfill site to use as a vehicle fuel (*ibid*). Novo Energy planned to achieve this by building a dispensing station for demonstration on a landfill site next to OR Tambo International Airport. Moreover, it was offering free a petrol-to-gas conversion to motorists, claiming that fuel savings to the motorists would be in the region of 15% to 25%. Meanwhile, other government funding agencies, such as the Industrial Development Corporation were also optimistic about the role that large-scale biogas projects could play in South Africa; they estimated that biogas could add up to 5% to the South African electricity mix (Financial Mail 2011c).

Despite these encouraging developments within the BIS, solid legislation and support from the government with regard to biofuels remained elusive, as detailed in Chapter 4. Things turned around, however, when the Renewable Energy Independent Power Producers Procurement Programme (REIPPPP) was announced in June 2011 (Financial Mail 2011b), following the termination of the REFIT programme. REFIT had targeted larger renewable energy projects, aimed at alleviating supply pressure, given the constrained Eskom capacity since the energy crisis of 2008. The announcement restored confidence in the industry. For instance, in the first month of the bid's announcement, the DoE received over 400 registrations, of which 200 had already paid a non-refundable registration fee of R15 000 (Finweek, 2011). It was noted, however, that small local businesses would need to play smart in order to take part in the project. In fact, the programme was heavily criticised by smaller project developers including biogas actors. They argued that the government's Request for

Proposal (RFP) documentation access fee of R15 000, together with the guarantee fee of R100 000/MW bid, *created an unnecessary barrier to entry*. A few months later, the government acknowledged that the legal, financial and environmental stipulations contained in the main REIPPPP were too stringent and therefore made it difficult for smaller businesses and entrepreneurs to participate in the market. They announced that a simplified tender for projects between 1MW and 5MW was being prepared (Creamer 2011). This process was said to be far simpler, with many lower barriers to entry (*ibid*).

At the beginning of 2012, the DoE announced that the tender for small renewable energy projects under the REIPPPP would soon be released, with a scope of 100 MW. The bidding was focused on co-generation opportunities from waste biomass, including those from sugar and paper industries, biogas technology, harvesting of landfill gas and small hydro plants. In the last half of 2012, the DoE initiated the long-awaited process by sending Request for Information (RFI) to test the market appetite for small-scale projects to assess their readiness. Accompanying the RFI is the request for proposal (RFP).

Meanwhile, towards the end of the phase, biogas was enjoying more coverage in the local media and academic journals with audience-focused treatment. For example, farmers' articles tended to put much emphasis on the fertilizer benefits of the technology, but at the same time raised awareness of the limitations of the absence of supportive legislation (Roux 2011). Industry protagonists were increasingly given a platform in the media and communicated the benefits of the biogas technology (Jourbert 2011a). Some advocated the production and roll-out of small pre-fabricated units, whilst others clarified safety issues (McKenzie 2013). Although advocacy for the technology was increasing, this remained largely uncoordinated, except for earlier initiatives by SABA. Moreover, apart from the SANEDI-led *Working for Energy* programme, the government did not have clear direction and support for household biogas digesters. This was ironic, as the government was in full support of the Dutch-funded study led by AGAMA that found that up to 310 000 households in South Africa could benefit from the technology (Financial Mail 2011a)

Capabilities in laboratories also began to feature in this period. Farmsecure Carbon, a subsidiary of Farmsecure Research and Test Solutions, was one such entity, whose focus was to assess GHG emissions mitigation for AD technology. Farmsecure Carbon had a pipeline of projects and was driving the implementation of a first few projects. Environmental Impact

Assessments (EIA) were underway for seven farms throughout the country that planned to generate electricity from biogas under a joint venture with commercial farmers (Joubert 2011b). At the end of 2011, Farmsecure Carbon already had off-take agreements of 15 MW. Power produced would be fed into the grid and the end user would draw from Eskom's network. All seven projects would be based at piggeries, dairies and feedlots, based in the Mpumalanga, KwaZulu Natal, Gauteng and Western Cape provinces (Joubert 2011b). Moreover, Farmsecure had a laboratory where BMP tests were conducted on various feedstock samples. They also saw the AD technology as a perfect solution to help them achieve their sustainability and profitability targets in the farming sector in South Africa (Leske 2011).

The number of activities in the BIS increased drastically in 2012. Biogas began to feature in clean technology and renewable energy national competitions. Two AD designs of an old industry player, AGAMA Biogas, viz. BiogasPro and Smart Top pre-fabricated digesters, earned their inventors a second place in SA Cleantech competition (SESSA 2012a). Moreover, AGAMA Biogas became the first small-scale digester to obtain certification from the South African Pipeline Association (*ibid*). They remained a strong and reputable player in the field; their first installation, a brick-fixed dome digester in Kwazulu Natal province, was still in operation 10 years after the installation (SESSA 2012b).

Another system that received national acknowledgement was the integrated system installed at the Three Crowns Primary School in the Lady Frere district. This project won several awards. One of those was the Netherlands-sponsored *Moola for Amanzi* award for best concept in water and sanitation projects, as well as two Eskom *eta* awards (awarded for excellency in the field of energy efficiency) and lastly, the Eastern Cape flagship award (Matthews 2012). Three Crowns Primary School had a *zero waste* system, which fed organic waste from the school's kitchen, garden and toilets into the anaerobic digester. The resultant biogas was used for cooking, while the digested effluent was used in ponds, where it was converted to a nutrient-rich *algal slurry* that was used as a fertilizer. The water from the pond was supposedly pathogen-free and hence used for irrigation purposes. Due to its immense success and recognition, the project inspired four neighbouring schools to investigate the viability of a similar type of installation. Some neighbouring communities were also looking at installing a similar but larger system.

Meanwhile, interest in industrial scale installations continued to grow within the BIS, with foreign companies joining the industry to exploit the potential. A South African-based German company Zest Weg through its subsidiary Zest Energy and in collaboration with an engineering, procurement and construction management contractor (WEC projects) was awarded a contract by water and sanitation service provider, Johannesburg Water, for the delivery of 1.2 MW biogas power plants in November 2011 (Kotze 2012). The power produced supplemented the utility's power and therefore its operating costs. The project was completed towards the end of 2012. Moreover, this company believed that the independence of these systems from the national grid would make it possible to recoup the costs in four to seven years (Kotze 2012).

Networking and demonstration projects continued into 2012. For instance, our research group, the Environmental and Process Systems Engineering (E&PSE) Group collaborated with a rural-based university, the University of Venda (UniVen). The objective of the project was to stimulate industry development both in the rural and urban areas through pilot scale biogas digesters. Also, government institutions such as SANEDI supported biogas related research at some universities (e.g., University of Fort Hare). SANEDI saw the university as a strategic entry point for implementing the technology in neighbouring communities (SANEDI n.d.).

Resource mobilisation initiatives also came to the fore, and small bioenergy projects such as biogas technology were incentivised. One such funding instrument was Eskom's Standard Offer Programme (SOP) (SESSA 2012c). This programme funded small-scale renewable energy produced from low or zero carbon technologies. Technologies considered included biomass waste, wind energy, solar, geothermal, ground source heat, and thermal gradient. Excluded were solar thermal liquid heat and MSW. The projects were restricted to between 10 kW to 1 MW. This pilot project was introduced in collaboration with NERSA, and its aim was to achieve a total capacity of 10 MW in the first phase. Moreover, this project was in line with Eskom's ambition to broaden the scope of optimal energy usage through the range of energy efficiency programmes. Initially, funding would be available for systems that did not feed onto the grid at R1.20/kWh (SESSA 2012c). The Department of Trade and Industry (DTI) also introduced a financing instrument called the Manufacturing Competitiveness Enhancement Programme (MCEP), which was to support small- to medium-size businesses in the area of green technology and energy efficiency.

Towards the end of 2012, a momentous event happened within the BIS, when biogas actors came together to form an industry association body. The Southern African Biogas Industry Association (SABIA) was officially launched at the Energy Indaba in February 2013. One of the hurdles that it planned to tackle with responsible authorities was the problematic Municipal Financial Management Act, which limited municipalities from signing off a waste contract of more than 3 years with private companies (Blaine 2013). SABIA was however optimistic and believed that the rebate programmes offered by Eskom (SOP) and the Department of Trade and Industry's (DTI), MCEP were creating the right environment for biogas technology. It saw great opportunities in, for instance, piggeries, chicken and cattle farms, abattoirs, food manufacturing companies etc.

The rest of 2013 saw a buzz of activity in the industry; this mostly consisted of companies joining the industry, mobilisation of resources, workshops, and lobbying of authorities for better industry conditions. The most important event of 2013 was the hosting of the first ever National Biogas Conference in October 2013, organised by SABIA and financially and institutionally supported by the DoE; more than 100 delegates attended over the two days. The purpose was to facilitate dialogue amongst stakeholders. It was apparent from the conference that some of the identified barriers could only be addressed collectively. As result, GIZ, a German development agency, felt that it was best positioned to facilitate discussions among multiple stakeholders. This gave birth to what is known as the biogas platform, created to facilitate discussions between various stakeholders, including industry players, government, research and financiers with the aim of addressing barriers and exploiting opportunities.

Moreover, installations increased per annum throughout the period, as shown in Figure 5.2. Figure 5.2 should not be considered definitive; rather, it depicts the general trends in installations during this period. It is likely that not all the installations were captured, primarily because the thesis author had no knowledge of them.

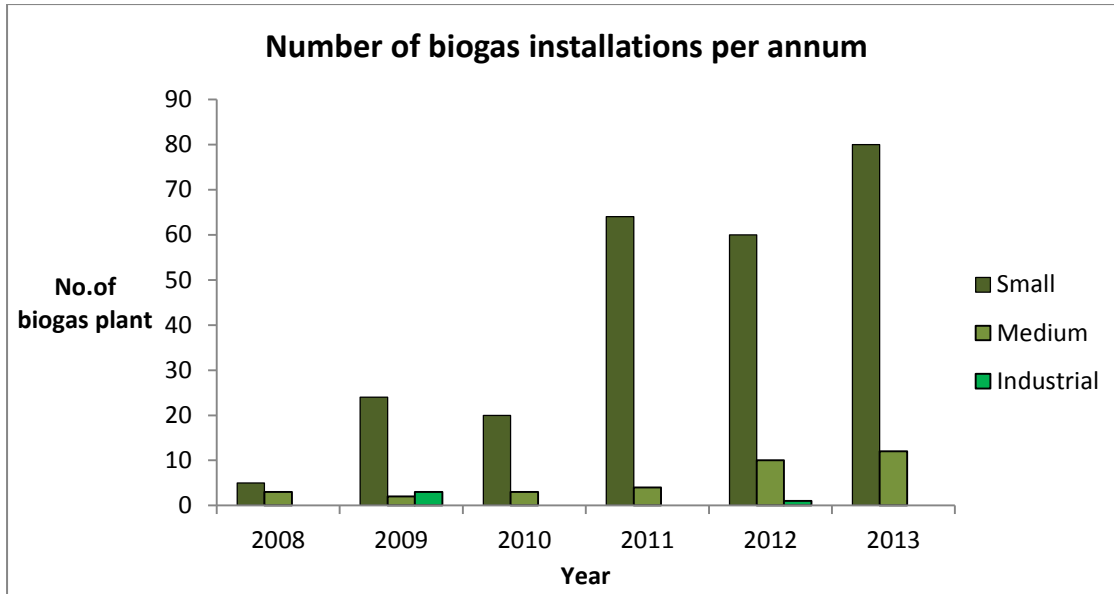


Figure 5.2: An estimate of new biogas installation per annum from 2008-2013

5.3.2.2 Functional analysis

Factors external to the BIS contributed significantly to the observed bustle of activity around renewable energy projects programmes in general and AD technology in particular. Amongst them were the rolling power blackouts of 2008, which led to a scramble for solutions that put renewable energy on the agenda. Also related were issues of sustainability and climate change, which featured strongly in the global and national agendas.

On the policy side, the position of government with regard to renewable energy went through several ups and downs, sometimes giving negative and sometimes positive *guidance of search*. Initially, the announcement of the REFIT programme was met with great expectation and excitement; it soon led to despondency amongst biogas actors. At first, biogas was not included on the list of REFIT tariffs; when it was included in the second phase, the proposed tariffs were considered low by industry protagonists. It took a further 3 years until 2011 for the current renewable energy programme (REIPPPP) to be implemented and later on the small REIPPPP, which was more relevant to biogas technology. Also providing guidance for the future is the waste management law reform, the NEM: Waste Act (Act 59 of 2008) and the promulgation of its regulations over the next few years give further impetus to *guidance of search* (F4), as it is likely to open up possibilities for AD treatment of organic wastes

Early in this period, climate finance had a positive impact on the BIS trajectory. A noteworthy momentum was observed around farm-based systems, initially implemented with

the support of CDM carbon finance. This was first seen when a multinational agricultural company Cargill mobilised resources (F6) to help install the first medium-scale AD system in the country at Humphries farm in Bela Bela. Subsequently, a series of similar activities could be observed from 2008 onwards. A noteworthy example in this regard was the construction of another CDM funded (F6) farm-scale project (F1), at the Kanhym piggery.

Meanwhile, national and regional media houses covered these early projects widely and disseminated the knowledge about the technology (F3); reporting was often positive, with advisory and advocacy undertones. Premier Pork Producers, inspired by these developments, commissioned AGAMA Energy (prior to the formation of its subsidiary AGAMA Biogas) to conduct a feasibility study (F2) in three piggeries. The outcomes of the study were shared (F3) at the association's AGM in 2008 (SAPPO 2008). To date, the momentum around farm-scale projects continued in piggeries and animal farms around the country. For instance, between 2010 and 2012, some of the more established biogas companies, viz. Biogas SA, CAE, and TradePlusAid installed several AD systems at piggeries and animal farms. Moreover, there were currently tens of EIAs being conducted on farm-based AD systems, e.g., Farmsecure Technologies. As more projects came online, they received extensive coverage not only in the media but also through *learning by interactions* amongst some of the industry players, e.g., FarmSecure and farmers (F3) and Tradeplus Aid with piggeries (Trade Plus Aid n.d.).

The dynamic observed early in this phase around the medium-scale piggery systems is depicted in Figure 5.1 below, using CLD diagrams described in Chapter 3. The reinforcing loop illustrated is referred to as the *Imitator Motor*. This is different to what is generally observed in European-based empirical studies, where technical R&D is more prominent in the formative phases of a specific technology, e.g., in the German biogas industry (Negro 2007), as opposed to *learning by imitating*, which is observed in the South African BIS. Nevertheless, later in this period, applied biogas research projects were being funded.

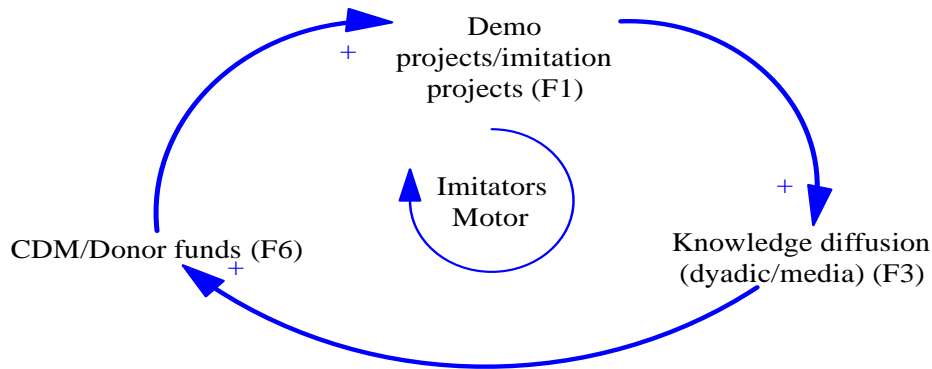


Figure 5.3 Imitator Motor

Reinforcing loop around farm-based AD systems in the South African biogas industry, referred to as *Imitator Motor*. More farm-scale AD installations led to *knowledge diffusion* through media coverage, for instance; this attracted more potential imitators through various funding mechanisms, which led to more knowledge diffusion

Resource mobilisation (F6) took several forms in this phase. As mentioned earlier, carbon finance played a critical role in supporting the first medium-scale projects. Towards the end of the period, however, resources were mobilised by government departments and parastatals. For example, as one of its demand side management strategies, Eskom piloted the SOP to support off-grid projects that were less than 1 MW (F6). In a similar vein, the DTI through its MCEP mobilised resources to stimulate activity amongst small- to medium-scale businesses in the area of green technologies and energy efficiency (F6). With these resources made available and accessible, the biogas projects became viable and more commercial projects were rendered feasible. This raised positive expectations regarding industry prospects, as support became available for emerging entrepreneurs (F4). The announcements of these funding vehicles increased the number of biogas projects developments (F1). Moreover, *resource mobilisation* from international donor funding continued to enable various activities over and above entrepreneurial activities stimulated by carbon financing (F6).

A noteworthy observation that is seemingly unique in developing countries is that resources mobilised via donor funding tend to support knowledge development activities (F2). More often than not, R&D budget allocations in developing countries are limited, due to other pressing developmental challenges. Against this background, it is not surprising that

knowledge development activities appear to be backed by developmental funds, with several studies in this and the previous phase financed by developmental agencies and donors. For instance, two of AGAMA Energy's feasibility studies were funded by developmental agencies. One was funded by the Dutch government (F6), to assess the viability of biogas in rural South Africa (F2), whilst the other, an *energy from waste* study (F2) for the CoCT, was sponsored by the UNDP (F6) (Boyd 2010). The findings of these studies aroused interest amongst some selectors who even considered participating in the BIS. For example, the Biogas for Better Life rural household study (AGAMA Energy (Pty) Ltd et al. 2008) inspired the then DME to propose a roll-out of small-scale biogas digesters in the Eastern Cape (Tzoneva 2008). Unfortunately, the momentum was lost due to changes in the government administration after the national elections; as a result, this project is yet to commence five years later. In other instances, resources (F6) support entrepreneurs who operate in the social space. The Mpfuneko project in Giyani is such an example; it was made possible by donations from a Dutch church, as summarised in the narrative above.

Knowledge sharing activities (F3) within the BIS increased in this period too. Different types were observed, viz. workshops, a national biogas conference, dyadic meetings, etc. As a result of more widely disseminated knowledge regarding biogas and its benefits, expectations on potential growth of the BIS were high (F4). Moreover, entrepreneurial activities were increasing, as more biogas companies joined the BIS (F1), e.g., BiogasSA, Novo, Biogas Africa, IBert South Africa etc.. The cumulative number of biogas installations across various scales is shown in Figure 5.3.

Despite the increased momentum within the BIS, industry activities took place in silos and were not coordinated until late 2012. In November of the same year, an instrumental event, viz. the National Biogas Workshop hosted by the Industrial Developmental Corporation (IDC) (F3), took place. Active actors within the BIS, who until then had not closely interacted, attended this workshop. This event became instrumental, as discussions focused on the formation of a biogas industry association. SABIA was birthed a mere month later, in December 2012, and officially launched at the Energy Indaba in February 2013. SABIA has since been able to put the biogas technology on the national renewable energy agenda (F4). It also immediately lobbied for the legitimising of the technology in South Africa (F7) on various platforms. For instance, they approached Eskom to persuade them to extent the pilot

Standard Offer Project in a meeting, which I attended. They also managed to collaborate with the IDC, which has been instrumental in providing infrastructure for hosting their monthly meetings. Moreover, they were able to attract resources (F6) from the DoE and, through the DBSA, the World Bank to finance two days of conversations around biogas in Johannesburg in September 2013 (F3).

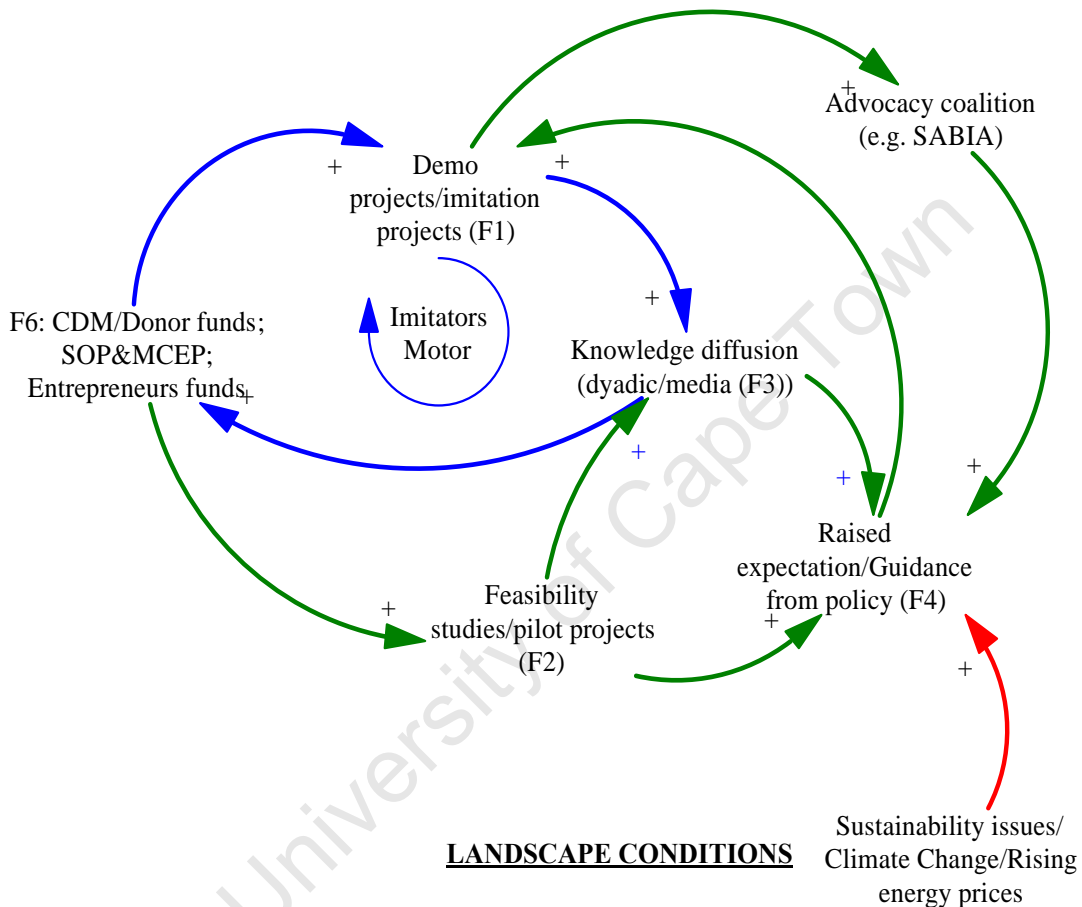


Figure 5.4: System Building Motor

Building on the *Imitator Motor*, the reinforcing loop was further observed when resources were mobilised (F6) to conduct feasibility studies (F2), which when disseminated (F3) raised positive sentiments, moreover, some policy direction which guided the BIS towards a positive trajectory(F4). The positive expectation resulted in increased entrepreneurial activities (F1). As more entrepreneurs joined the BIS, an advocacy group was formed (F7) and lobbied for funds to be made available (F1).Entrepreneurs also invested their own funds (F6) to start or expand businesses (F1).

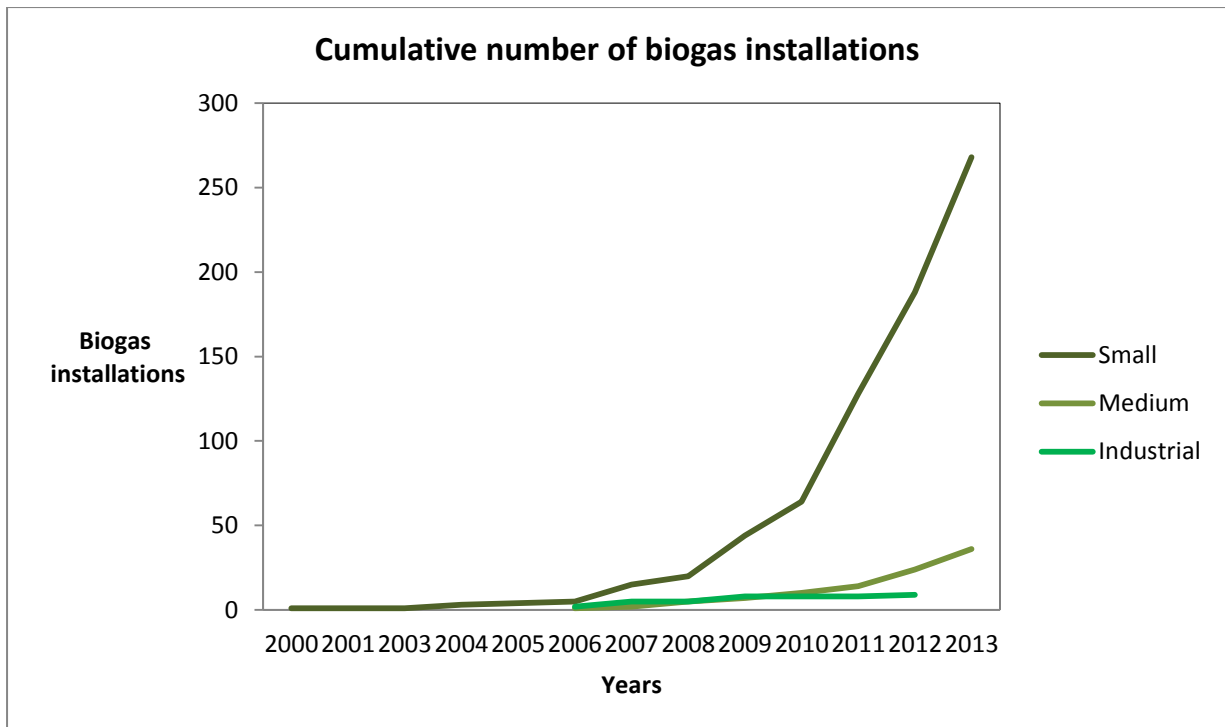


Figure 5.5: Cumulative number of biogas installation in the 2nd phase

Overall, it was clear that *resource mobilisation* and to some *advocacy coalition* catalysed the fulfilment of other functions. For instance, more *entrepreneurial activities* were enabled, as more actors joined the BIS (F1) and *knowledge diffusion* events grew in number and impact (F3). Knowledge development activities also increased, with academic participation observed in applied research, the implementation of pilot projects (F2) and *knowledge diffusion* activities (F3). Successful demonstration projects also led to further activities, for instance, business ventures were borne from pilot/demonstration earnings (e.g., CAE, Farmsecure, AGAMA Biogas); subsequently, they reinvested their earnings into further projects (F1) and into advocacy, when given an opportunity (F7). Although industry guidance from government went up and down due to unclear policy early in the period, towards the end, however, there was cautious optimism (F4) as conditions rendered some projects viable. This was also due to legitimisation and advocacy endeavours by SABIA, and positive covering of the technology in the media, which in itself attracted more actors into the BIS, as will be detailed in Chapter 6.

In short, landscape conditions such as the pressure on government to create more jobs, the importance of sustainability, the prevalence of climate issues and electricity crises all influenced the *resource mobilisation* (F6) function. The fulfilment of these functions led to

further knowledge development (F2), entrepreneurial activities (F1) and *guidance of search* (F4); later on, successful entrepreneurs in turn started to reinvest resources (F6) and to lobby (F7) for more *market formation* initiatives. This tentative formation of a reinforcing cycle of activities was initiated through the energy crisis of late 2008, which destabilised the incumbent coal-intensive energy regime that had been dominating the electricity market. This realisation that renewable energy technologies could contribute to the country's future energy mix put such technologies on the agenda.

In summary, due to the fulfilment of all the functions besides *market formation*, the dynamic observed through the various events and activities was that of a system being built, and as such, it has been termed the *System Building Motor*. The *System Building Motor* first emerged as a smaller virtuous cycle around medium-scale farm digesters, especially around the piggeries; it was coined an *Imitator Motor*, as the observed knowledge development and entrepreneurial activities were birthed out of observing and imitating, rather than innovation in the R&D sense. The *Imitator Motor* only involved a few functions reinforcing one another, viz. demonstration projects (F1), initially with the support of carbon finance and donor grants (F6), and *knowledge diffusion* (F3) through the dissemination of knowledge, e.g., presentation of the results from a study that AGAMA conducted for Premier Pork Producers and in different media platforms. What followed to constitute the main dynamic in this phase, in addition to activities around the *Imitator Motor*, which continued throughout the period, was the fulfilment of three other system functions. These included knowledge development (through patents, feasibility studies and pilot projects) (F2), and to some extent fulfilment of *advocacy coalition*, mainly through SABIA (F7) but also by SABA, and *resource mobilisation* (F6) (SOP, MCEP, donor funds and grants and entrepreneurs' own finance). The fulfilment of the *guidance of search* function (F4) took on different forms in this period, besides optimism that was inspired by imminent growth, legislative framework such as NEM: Waste Act 59 2008, which promoted waste to energy project, the small REIPPPP also provided a conducive environment for industry growth.

5.3.2.3 Structural drivers and barriers

Enactors were some of the key drivers of the *System Building Motor*; they comprised entrepreneurs (e.g., AGAMA, Bio2Watt), industrial bodies (e.g., SABA, SABIA), research institutions (e.g., UCT, CSIR, UniVen), and to a lesser extent the national power utility, Eskom. Some enactors managed to convince government departments to support the industry.

For example, SABIA lobbied Eskom to extend SOP, whilst SABA encouraged NERSA to consider integrating biogas into the conventional gas distribution system. Some of the lobbying was successful, as SABIA managed to secure funding to run a *knowledge diffusion* event, which was attended by more than 100 people, who took part in two days of conversations on the national biogas prospects in the country. Other structural drivers were linked to landscape conditions, viz. the national electricity crisis, climate change issues and the high rate of unemployment. These drivers were influential through their various strategies to draw new actors into the BIS, e.g., farmers and new companies, which have since enhanced the effectiveness of SABIA. Selectors such as the DoE became more active, as they recognised that the biogas technology could potentially address the issues of alignment between external pressure (e.g., climate change) and government goals (e.g., job creation, energy security), and bring them closer together. Overall, there was a shared belief in the potential of the biogas technology amongst the BIS enactors. In terms of institutional drivers, the policy frameworks that govern the renewable energy sector in general, were becoming clearer. Moreover, the recently promulgated NEM: Waste Act, gave confidence to risk takers who had been waiting on the sidelines to enter the BIS. Technology-wise, local designs were being recognised for their innovation, and some rural systems were becoming more efficient, with less failures being reported.

Several barriers were identified in this period. The main one remained the lack of a specific national policy or strategy for biogas technology. In terms of the BIS structure, the number of actors was still far too small relative to the estimated technology potential. So far, the growth of the industry had been guided under a broad umbrella of renewable energy, which was likely to promote only projects that could be connected to the grid. However, for small-scale projects and especially for rural installations, there were still no guiding policies. Although prospects were positive for the industry, the structure was not robust enough, networks and institutions were weak and still under construction, and more specific industry guidance was needed if the full potential was to be realised.

5.3.2.4 Motor impact on the BIS

The *System Building Motor* depicts the development of the BIS for about six years. The biggest impact of this motor is its ability to draw in actors. At the end of this phase, the number of participants in the form of enactors and selectors had increased drastically from the previous period; the formation of SABIA is testament to this development. Another

important outcome of this motor was government's increased support of entrepreneurial activities through relatively new funding schemes. The third impact was that the biogas technology was finding application beyond small-scale rural installations and increasingly spreading into medium- to large-scale applications. Moreover, there were more local technologies on offer; AGAMA had an established track record in the small-scale market, and T&T dominated the large-scale sector of the BIS. The negative impact of this motor was that some financing mechanism to make biogas projects viable were only in the pilot phases and their longevity was thus not guaranteed.

5.4 Discussions

In this chapter, a TIS approach was used to gain insights into the development of biogas technology in South Africa. History event analysis, as developed by Van de Ven et al. (2000) and adapted by Negro (2007) for TIS analyses, was used for data gathering, whereas system functions was used for analysis. The development of the BIS was divided into two phases. In the first phase, prior to 2008, few system functions were fulfilled, and hardly any reinforcing cycles could be observed amongst the seven system functions. In the second phase, however, from 2008 onwards, a bustle of activity was observed, particularly so in the last few years. Overall, six of the seven systems functions were involved and began to reinforce one other into virtuous cycles. The virtuous cycle emerged around AD on farms, where an *imitation/learning-by-doing* phenomenon was observed; technical innovation was not an early main driver in the traditional R&D sense.

Generally, landscape conditions influenced events and activities, and ultimately affected how the system functions were fulfilled. The most notable of these conditions was the electricity crisis, which occurred at the beginning of this phase. It was observed that, as long as the landscape conditions did not threaten the dominant fossil-based energy regime, the status quo prevailed and the biogas technology only found very few applications in niche markets. However, when the electricity crisis hit in 2008, the fossil-based energy regime was destabilised, and this made it easier for renewable energy technologies to enter the mainstream. The SWH technology, the subject of Chapter 4, was the most significant of these, but biogas technology also began to gather momentum. The instability in the fossil-dominated energy regime resulted in the fulfilment of *guidance of search* for emerging TISs, and the establishment of a firmer renewable policy direction. The White Paper on Renewable

Energy, published in the first phase, was the foundation for other activities around establishing various industry strategies to attain the set targets. In a similar vein, the NEM: Waste Act (2008) was seen as a catalyst for biogas technology as one of a recommended waste treatment technology.

The *resource mobilisation* function (F6) was driven mainly by climate change and sustainable development issues, but also in response to changing landscape conditions. These resources came in the form of carbon finance and donor funds (which were sometimes linked to sustainability projects). These were mainly deployed for feasibility studies (Austin et al. 2003; AGAMA Energy (Pty) Ltd et al. 2008); they kick-started entrepreneurial activities around farm scale digesters (F1). This is in agreement with the functional analysis of biogas technology in India, where donor grants are instrumental in building capabilities (Schmidt & Dabur 2013). Towards the end of the period under consideration, resources were mobilised to address the power crisis as part of Eskom's demand side management (e.g., SOP) but also driven by government's responsibility to create sustainable jobs, e.g., through mechanisms such as the MCEP. It is important to note though that the landscape conditions alone did not explain the trajectory of BIS development. For instance, landscape conditions could not explain how an industry body that supports better market conditions (F7) on behalf of its members came about, nor does it explain how one farm scale digester inspired the development of tens of others (F1). This is also in agreement with findings in Suurs et al. (2010) who observed that external factors only provided partial explanations of technology innovation development.

A system functions analysis does help explain the observed development in each of the two periods of the BIS studied. Both periods display the characteristics of an emerging TIS. However, the progress in the first period was extremely slow, it exhibited fluidity and it was typified by what Suurs et al. (2010) describe as the weakness or absence of institutional and technology structures to support themselves. The second period was characterised by increased momentum, as functions began to reinforce one another, in agreement with previous studies that propose that a build-up in the TIS would benefit from reinforcing cycles or cumulative causation (Bergek et al. 2008; Suurs & Hekkert 2009a; Suurs & Hekkert 2009b). Moreover, it has been evident that the TIS structure is closely related to the observed cumulative causation. Suurs et al. (2009; 2010) have done extensive work in systematically relating the TIS structural drivers and barriers with motors of innovation, which was also

observed in this study. For instance, in the first period, the structure was weakly formed, characterised by few actors, weak networks, institutions and technology capabilities. Moreover, there was no notable influence from landscape conditions. The contrary is observed in the second period. The structure was now more robust and structural components had strengthened with time (due to various factors e.g., landscape conditions, legislations). The key feature was that entrepreneurs were able to draw more actors into the BIS. At the same time, they organised themselves into networks, which led to the formation and fostering of industrial bodies, these bodies then support the advocacy of coalition for the advancement of a TIS, also observed in Suurs et al. (2010). Activities that the BIS structure undertook did not only fulfil functions but sometimes inspired the fulfilment of others, leading to cumulative causation of system functions and hence system build-up.

In the early empirical TIS analyses, the fulfilment of functions was usually graphically analysed as in Negro (2007). This was useful in identifying the trends of functional fulfilment over a given period. Whilst that step of analysis is important, later work (Suurs et al. 2009) focused more on understanding the build-up of an innovation system, i.e., how functions were individually fulfilled and how they reinforce each other into the so-called *motors of innovation*. This aspect of the work is important, as the motors of innovation can be illustrated visually. To this end the system-thinking tool of CLDs was used to illustrate the TIS build-up graphically. It was not possible to show how functions played out in the first phase, as causality was not observed. In the second phase, however, it was possible to show how the functions were being fulfilled over time. One overarching dynamic was observed, viz. that of the *System Building Motor*, which showed how six of the seven functions reinforced one another. This dynamic is analogous to what Suurs et al. (2010) observed in a study, in which they sought to understand the build-up of natural gas as an automotive fuel in the Netherlands. The *System Building Motor* was, however, kick-started around a dynamic observed around farm-scale digesters, referred to as an *Imitator Motor*, as detailed above. Interestingly, and in agreement with previous studies, for example that of Suurs et al. (2009), there was some evidence to imply that stronger motors of innovation are generally preceded by weaker motors. In this analysis, it changed from the absence of a dynamic in the first phase to the *System Building Motor* in the second phase.

5.5 Conclusions

It was the aim of this chapter to provide answers to the first research question as stated in Sections 1.4 and 5.1. Based on the analysis and discussion the following conclusions were arrived at:

1. Following the testing of applicability of TIS framework the development of the biogas industry in each of the two periods studied could be described. The structural components of the industry, viz. actors, networks, institutions and technical capabilities within the industry at a given time, could also be identified. Moreover, events and activities undertaken by the BIS structure were established and ascribed to functions in each phase.
2. The system functions were observed in both phases, albeit to different extents. In the first period (1997-2007), only two system functions were observed, viz. entrepreneurial experimentation (F1) and knowledge development (F2), which may be attributable to the weak BIS structure. The fulfilment of the functions was not strong enough to trigger the fulfilment of the other five functions, hence no causality in the form of reinforcing loops was observed. The first phase paved the way for a build-up of a more robust structure in the next period. In the second phase (2008-2013), therefore, six of the seven system functions were fulfilled; moreover, the six functions reinforced one another into virtuous cycles.
3. No motor of innovation was observed in the first period as described above. This is not a unique feature; in one of the previous empirical studies by Suurs et al. (2010), no reinforcing loops were observed either. However, one overarching dynamic was observed in the second phase, viz. a *System Building Motor* that had been kick-started by another dynamic termed the *Imitator Motor*. This second period is marked by an acceleration of activities and the fulfilment of six of the seven functions, analogous to a dynamic observed in another study (Suurs et al. 2010). In this study, the dynamic of the *System Building Motor* emerged due to a conscious orientation of actors poised to exploit the potential in the TIS in question.

4. New or additional functions were not identified in this work; however, some of the functions were fulfilled in unique ways, which may be unique to transitioning economies. The two relevant functions are knowledge development (F2), and *resource mobilisation* (F6), and to some extent *knowledge diffusion* (F3). (F2) was dominated by feasibility studies as opposed to technical studies, which was observed in most European-based empirical studies. With regard to *resource mobilisation* (F6), foreign aid and carbon finance were useful for supporting and diffusion activities, as well as some entrepreneurial activities. With regard to *knowledge diffusion* (F3), it was established that, in addition to typical *knowledge diffusion* events and activities, the media (printed and broadcast) played a critical a role in the dissemination of basic technology knowledge and BIS developments, oftentimes with advocacy tones.

Lastly, this study has begun to apply systemic approach to understanding technology innovation and evolution in transitioning economies. The first step to influencing any trajectory is to understand its dynamics in line with what others have articulated (Suurs & Hekkert 2009a). By identifying the constituents of the structure and its resultant key activities, it is possible to identify where systemic interventions need to be directed. The outcomes of the analysis point to a need for planners and policy makers to design and implement systemic policies that address different facets of technology development. Policies should first be geared to strengthening the BIS structure; only a robust and resilient structure is able to undertake activities that fulfil some or all of the systems functions. Subsequently, functions reinforce one another into cumulative causations and therefore propel an emerging technology into a market phase. Moreover, there is a need to influence the trajectory of the innovation system consciously in order for the sustainable development ideal to be realised. This aspect is addressed by the next section of this thesis.

SECTION 3: Interacting with the system

CHAPTER 6 Impact of pilot projects

6.1 Introduction

This chapter begins Section 3, whose objective is to answer the second key question of this thesis. In Sections 1 and 2, the background and the theoretical foundation on which the thesis is based, and the application thereof, were discussed respectively. The theoretical underpinning is that of TIS, which is located in the broad body of literature that looks at *sustainability transitions* (STs) (Markard et al. 2012). The TIS framework was used to analyse the evolution of the nascent South African biogas industry in Chapter 5, after being calibrated on the more mature SWH industry in Chapter 4. In this section, purposeful interactions with elements of the TIS are presented.

Central to the TIS approach, is the notion of the so-called system functions, outlined in detail in the previous chapters, and described as key processes critical for the development of an emerging industry. Seven system functions have been proposed in literature, and activities performed by actors and their networks within a specific industry are ascribed to at least one of the functions. A TIS comprises different types of actors with different roles, e.g., entrepreneurs, researchers, state employees, etc., whose activities fulfil different, and sometimes, same functions. Section 3 investigates whether and how a specific group of actors, such as researchers and academics, through their activities can catalyse the development of a TIS, as illustrated by the case of the biogas industry in South Africa. Key questions that guide the rest of this chapter and section have been stated as follows:

Which of the seven functions can academic research most influence and strengthen? How would one go about influencing identified functions, consequently contributing to improved operation of an innovation system?

Academic and research institutions are considered national and international knowledge hubs. TIS actors from these institutions thus primarily engage in activities that fulfil knowledge development and diffusion functions. Still, some of the other seven functions hinge on the provision of technically sound knowledge and expertise. For instance, knowledge

development is considered a catalyst for entrepreneurial activities. Hekkert and Negro (2009) suggest that entrepreneurs dare invest in new technological trajectories when there is an established knowledge base. *Guidance of search* is usually informed by diffused (F3) technical knowledge (F2), which enables other actors, e.g., from government, to better give guidance to the industry (F4). Reliable knowledge can inform how resources are mobilised (F6) as well as inform how tax incentives (F5) and policies that support the development of a TIS are structured. A knowledgeable group of actors can better lobby on behalf of industry (F7) if equipped with reliable, well-researched information. It is evident that, whilst research is considered a knowledge development activity, it should also lead to the fulfilment of most of the other seven functions.

There are currently no published studies in mainstream ST literature that have attempted to assess the impact that this body of enquiry has on the development of emerging industries in transitioning economies at the time of writing this thesis. This may be attributed to the retrospective nature of most TIS empirical analyses, which tend to focus on either the success, or the failure, of a particular technology in a given context. Conversely, a TIS analysis conducted as major technology developments unfold, presents an opportunity for assessing the impact of ST approaches such as a TIS on the actual technology trajectory. The case of the biogas industry in South Africa, whose development has been taking place alongside this thesis project, presents such an opportunity.

A premise that inspired the work presented in this section is that strategically structured intervention around knowledge related functions can lead to increasing fulfilment of the system functions and consequently strengthen the BIS. As already indicated in the earlier chapters, this section will explore the effect of strategically planned knowledge-based activities on the development of a TIS. In this chapter, the impact of knowledge development activities will be assessed, whilst the impact of a *knowledge diffusion* event will be discussed in Chapter 7.

The remainder of this chapter starts with a summary of the approach used, which is outlined in Section 6.2. An overview of knowledge development activities embarked on follows in Section 6.3: The relevant knowledge development activities entail the design, implementation and operation of anaerobic digester pilot projects. In Section 6.4, the impact of stimulation is outlined as follows: Firstly, the impact of the pilot projects on visitors is presented; secondly,

other outcomes of the projects, such as news coverage, are outlined. Discussions and concluding remarks are given in Sections 6.5 and 6.6 respectively.

6.2 Approach

Biogas technology, as stated earlier, has seen major technical advancements in the last few decades elsewhere in world. In South Africa, this has occurred to a far lesser extent, with just a couple of patents being filed in the period studied in Chapter 5. Moreover, biogas research in general remains limited. Specifically, pilot projects, which are typical examples of *learning-by-doing*, remain scarce. However, such pilot projects are considered critical by innovation systems protagonists (Lundvall et al. 2002), as they offer an opportunity to acquire knowledge and experience concurrently. In terms of functions, *learning-by-doing* is categorised as a knowledge development activity (Hekkert et al. 2007). Since the objective of this part of the thesis is to investigate the impact that a knowledge development activity has on a South African BIS, pilot projects were thus deemed suitable to achieve the aim.

As described in Chapter 3, the research methodology employed here is exploratory; it is also based on a PAR approach, briefly defined as an enquiry that explains, interprets and describes social conditions, while executing an intervention aimed at improvement and involvement. A case study approach was used alongside PAR, and is defined as an in-depth investigation of an activity. The study entailed two knowledge development based cases entailing the design and implementation of biogas pilot projects from conceptualisation through to detailed design, commissioning of the projects, and lastly operating each system for at least a year.

The first pilot project is based on the UCT premises; the second is at an urban community garden in a township 35 km from the centre of Cape Town. In order to assess the impact of biogas pilot projects on the activities within the BIS, visitors to the projects were used as units of analysis in the investigation. This was achieved through semi-structured interviews with those willing to be interviewed with an intention of tracking their subsequent activities following the visit/s. The interviews were conducted either face to face or telephonically. A total of 13 people were interviewed and their responses are captured and analysed in Section 6.4. The two pilot projects are detailed in the next section.

6.3 Pilot projects

6.3.1 Leo Marquard Hall biogas digester

The Leo Marquard Hall (LMH) biogas digester project commenced in 2010. Besides stimulating the development of the BIS, one of the founding objectives of the project was to demonstrate that it is technically feasible to produce methane gas from source-separated wet waste on a university campus, and to use the gas for cooking purposes at a university canteen. Secondly, it was to demonstrate that small-scale decentralised biogas technology could be successfully deployed in an urban setting. AD technology is popular as a rural technology in Sub-Saharan Africa, yet there is a potential to deploy it in urban areas too, considering the significant solid waste challenges in these contexts (Munganga et al. 2010). Lastly, the project is well aligned with UCT's green campus initiative.

This project set out to install a 6m³ pre-fabricated biogas digester near one residence canteen where waste is already sorted into recyclables and wet waste. The biogas unit was designed to take 20 to 40 kg of kitchen waste per day. The project followed a conventional engineering project development process, viz. concept and detailed design phases, construction, commissioning and start-up. In the concept phase, a task team was put together with the aim of identifying the key stakeholders and also to work as a collective towards attaining permissions to install the digester from key decision makers within the institution. Upon completion of the concept phase, a concept design report was compiled for sign-off by key decision makers, reproduced in Appendix C. The concept phase was the more institutionally challenging and lengthier phase compared to other pre-installation phases and spanned 8 months. A conference paper on these challenges was presented at an international conference (see Appendix C for a complete abstract). The detailed design, in contrast, took less than two months for it to be signed off and installation approved. The installation of the anaerobic digester commenced shortly afterwards, in December 2010, and it was completed in January 2011. The project was commissioned in 2011; the author of the thesis managed the operation of the digester in the first year, and continues to provide technical support to date. Figure 6.1 below shows the picture LMH:



Figure 6.1: The Leo Marquard Hall Biogas Digester

The biogas digester began operation in February 2011, and has been in use ever since. Since the digester is of a household scale, the resultant gas is mainly used to prepare vegetarian or breakfast meals for about 20 students. The official project launch was held in May 2011 and members of the media were amongst the people present. Tens of visitors from different sectors (e.g., government, private sector, universities, consultancies) have since visited the pilot project site. Follow-up interviews with visitors who agreed to be interviewed were conducted to gain insights on the impact the visit had on their subsequent activities and the entire BIS in general. UCT students in various university courses also included a visit to the digester project as part of their module, but the impact of this particular *knowledge diffusion* activity is not tracked in this thesis.

6.3.2 SCAGA digester

The second pilot project is called the *Siyazama Community Allotment Garden Association* (SCAGA) Biogas Project. The SCAGA – BP came about as a collaboration between the Environmental and Process Systems (E&PSE) Research Group, in which this research project is based, and the UCT chapter of Engineers Without Borders (EwB). EwB had, for some time prior to this project, been fascinated with various aspects of the biogas technology including its potential to improve livelihoods. When a renewable energy company approached EwB with a biogas digester donation, they eagerly accepted. EwB identified *Abalimi Bezekhaya*, widely known in Cape Town as just Abalimi, an entity that owns and manages organic vegetable gardens in various Cape Town townships, as the biogas digester beneficiary. One of their biggest gardens in Khayelitsha, SCAGA was selected as a site for the pilot project. EwB realised early on in the project that they needed technical support if they were to

implement the biogas project successfully. Since they had never embarked on a similar project previously, they had to find such expertise outside their organisation. They approached the E&PSE research group as project development partners and knowledge providers, as the E&PSE had embarked on a similar project before, viz. the LMH biogas project.

The EwB request was aligned with the plans for this thesis research to implement two biogas pilot project cases. Instead of designing a different pilot project altogether, it was decided that the SCAGA project presented a great opportunity and a different yet interesting project team constellation and context. Moreover, the garden was already attracting quite a number of visitors who were interested in organic farming. E&PSE and EwB co-managed the development of the SCAGA biogas project from concept through to start-up phase.

E&PSE involvement entailed running educational workshops at SCAGA and monitoring these as part of the concept design process. The selected site for the biogas installation was deemed ideal for a number of reasons. Firstly, organic waste produced at community gardens in Cape Town is usually composted and the compost used as fertilizer material; however, there was the potential to divert some of it for use as feedstock in the AD process and still receive some fertilizer benefits from the effluent and the sludge. Secondly, the project was further meant to demonstrate that decentralised biogas technology can be deployed in an urban setting as a vehicle for facilitating social change, although the extent of this change is not investigated in this study. Some of the benefits to the beneficiaries include using clean energy for meeting the garden's cooking needs, recycled nutrients for fertilizer use, and possibly generating income. The latter was proposed on the basis that, should there be more than enough gas for meeting the garden's needs, there would be a possibility to prepare and sell food (e.g., soup, *vetkoek* etc.) to generate additional income.

This project involved the construction of an 8 m³ bladder digester near the community garden's kitchen and in the proximity of one of the compost piles. The unit requires 20 to 35 kg of organic waste per day and twice the amount of water. A combination of borehole and grey water is used as a water source. Vegetable waste, comprising garden waste generated daily and reject vegetables from Abalimi's market in the neighbouring township of Philippi, which are delivered to the community garden weekly, are used as feedstock for the digester. The digester itself is housed in a brick structure and a roof is mounted above to protect it

from harsh weather conditions. The resultant effluent is used alongside some waste vegetables for composting and occasionally used directly in the vegetable garden. For a detailed concept design report, see Appendix C. The SCAGA biogas digester is presented below:



Figure 6.2: Siyazama Community Allotment Garden Association

The biogas digester began operation in January 2012, and the biogas was used for cooking the gardeners' meals. The SCAGA garden is a popular site with green and business tourists interested in organic farming. As a result, tens of people have had the opportunity to see the biogas system, most without our awareness. In the early days post the installation, the E&PSE Research Group, facilitated by the thesis author, would usually be present to explain how the system operates to visitors. In time, however, the gardeners were able to do so themselves. As was the case with like the LMH digester, people from various sectors of the economy visited the SCAGA digester. Moreover, SCAGA also attracted some media coverage. Follow-up interviews with visitors were also conducted to track the impact of the visit.

6.4 Stimulation and impacts

The effect of the two pilot projects on the BIS was investigated in two ways. Firstly, a follow-up interview was conducted with visitors to either or both pilot projects sites, at least six months after their visit. Secondly, a basic analysis of the reach and exposure that the project has had in the public and scientific domains is outlined.

SECTION 3: INTERACTING WITH THE SYSTEM

Table 6:1: Summary of interview responses from visitors to pilot projects

Visitors	Sector affiliation	Prior engagement with AD technology	Actor categorisation	Subsequent activities
Thabo	Private sector	Large scale	Enactor	Installed a small-scale AD system, Organised a seminar
Mary	Academia	Laboratory systems	Enactor	Research
Paul	Consultancy	Large scale	Selector	Planning to install a household AD system
Vuyo	Government	None	Selector	Participated in the AD WRC project
Thomas	Private sector	None	Selector	Developing pilot project
Susan	Private sector	None	Selector	Developing pilot project
Robert	Consultancy	Read about it only	Selector	Advised on planning of industrial zone
George	Academia	Read about it only	Selector	Shared his experience with colleagues
Lisebo	Government	Read about it only	Selector	Purchased and installed digester, co-founded the Biogas Centre of excellence in her province
Joshua	Academic	Read about it only	Selector	Nothing yet
Daniel	Private sector	Read about it only	Selector	Disseminated information to colleagues
Reddy	Academia	Read about it only	Enactor	Planning project
Khotso	Private sector	Read about it only	Selector	Planning pilot project

*Note: names changed to keep identity of respondents anonymous for ethical reasons

6.4.1 Analysis of visitors subsequent activities

Results of the follow-up interviews to the two-biogas project sites are presented here. The objective of the interviews was to gain insights on the visitors' level of exposure to the biogas technology prior to the visit on the one hand, and to identify whether the visit inspired any subsequent activities on the other hand.

The interviewees had visited either one of the two sites (LMH or SCAGA), whilst a few had visited both project sites within a year of the installations. With regard to prior exposure to AD technology, most of the respondents said they knew about the biogas technology either from their affiliation or out of individual interest. Two of the visitors had seen a large-scale facility, but most had just read about it. Moreover, most of the interviewed visitors had not seen a small-scale biogas digester in operation.

Inspired partly and in some instances wholly by the visit to the biogas digester projects, all the 13 respondents embarked on biogas related activities in different capacities (as indicated in Table 6.1). To get insights into these activities, visitors were asked to share their activities post their visit to one of the digester projects. The insights from the interviews are discussed below and structured according to the system functions, which those activities fulfilled. A sample of interview summaries is offered in Appendix C.

Knowledge development

Three respondents were planning or just embarking on activities that fulfil the knowledge development function at the time of the interview. All activities involved setting up a biogas pilot project. Two respondents were embarking on the installations of small-scale biogas systems; interestingly, both respondents work for consulting companies that facilitate installations of large-scale digesters and neither had seen a small-scale biogas digester in operation. Impressed by the simplicity with which the technology operated at small scale, they each decided to install similar systems at their homes. Thabo, a manager at a wastewater consulting company, had already designed and installed a small-scale biogas digester at the time of his interview:

'... Secondly, I was able to build one digester in my garden using a 44-gallon drum; I plan to use biogas as fuel for my braai (meat grilling). The digester is still in the start-up phase.'

Robert was still in the planning phase of his home project:

'... I am also working towards installing the system in my home.' (Robert's interview)

A mining corporation is pursuing the third pilot project, which if successful, might be rolled out on a large scale. The introduction of the technology is envisaged as a possible component of a social responsibility project of a mining corporation to small villages in the vicinity of one of their mining operations. The pilot project was at the concept design phase at the time of the interview. The plan was to implement a system similar to the LMH digester. Susan, an environmental manager at the company, outlined the initial plans for the project as follows:

'We are considering implementing a similar system as a pilot/demonstration in the next few months. We have so far discussed amongst the colleagues the potential site for the pilot study. We had hoped that we would have the pilot up and running for the World Environment Day; this year's theme is 'Think and Save...'.' (Susan's interview)

The location of the pilot project was also being discussed and this had progressed well when Susan and her colleague Daniel were interviewed. Daniel particularly emphasised the importance of piloting the project before it was rolled out on a large scale:

'... we see the project as being more relevant for community centres. For us to pursue the project on a large-scale, we need to pilot it first. We are actually working on the concept design on the project. We have provisionally selected a site in Northern Cape Province, possibly in Thaba-Zimbi.' (Daniel's interview)

Representatives from neighbouring universities also visited the LMH biogas project with the intention of implementing a similar project. However, no planning had commenced at the time of the interview. One of the visitors who was contacted for a follow-up interview (not captured in the 12 interviewees above) was already deployed elsewhere within the university structure and no longer involved in waste management, but he mentioned that the project was yet to take off.

Knowledge diffusion

Knowledge diffusion activities that followed were mostly dyadic interactions, with respondents claiming to have shared the knowledge they gained about the technology in general with colleagues and those close to them. Khotso, who had visited the SCAGA facility as part of one of UCT programme's education tour, provides a good example. Khotso's class had primarily visited SCAGA to be exposed to organic farming within Cape Town boundaries, but they also got see the SCAGA biogas digester. Khotso was so intrigued by the low-tech yet beneficial system that he told his office team when he got back to the office at the end of his course. The objective was to suggest the installation of a similar system in their area of influence.

'When I came back from our course in Cape Town, which included the visit to the biogas system, I shared it with some of my colleagues who later came to visit the facility. So we have discussed about giving a similar system a try.' (Khotso's interview)

The team responsible for the environmental management portfolio at the corporation indeed visited the two pilot projects thereafter, and as already mentioned, were in the concept design phase of a pilot project in one of the villages next to their mining operation.

In some instances, *knowledge diffusion* by visitors inspired others to visit the facility. For instance, after one of the respondents, Thabo, visited the LMH digester, he felt that it would be of interest to invite members of his professional association, the Western Cape chapter of the Water Institute of Southern Africa (WISA). He thus invited his association members as part of their quarterly meetings:

'After the first visit to the digester, I thought the technology was interesting for WISA and therefore decided to visit during one of our quarterly meetings. WISA scheduled the visit to the digester at their next meeting, which was held at the university. Moreover we asked the LMH project leader to give a 20-minute presentation to the members after the site visit to share experiences on operating the LMH digester.' (Thabo's interview)

The project leader on the LMH project, who is also the author of this thesis, gave a 20-minute presentation, followed by an interactive session. In total, knowledge was disseminated to

more than 40 people that afternoon, the bulk of whom had visited the LMH biogas project prior to the seminar.

Knowledge diffusion apparently also took place outside the professional space, with respondents claiming to have shared what they learnt from the visit with other interested parties. For instance, Thabo was one such respondent:

'... Over and above spreading the word from the professional point of view, I have also told others about the technology on the personal level.' (Thabo's interview)

Another respondent, Joshua, an academic, shared similar sentiments to those of Thabo:

'... although I haven't done anything visible, I have spoken to several people about it, I think it is a good technology for wider dissemination.' (Joshua's interview)

Yet another respondent, Robert, a consultant had this to say when asked about his post visit activities:

'I have shared my experience and what I learnt with colleagues, business associates and friends and of course it is a nice example to use as a point of reference.'

There seems to be some evidence to suggest that a wider audience has come to learn about the biogas technology through visits to either one of the two biogas projects. Moreover, early visitors to the pilot projects aided in *knowledge diffusion* to more people, some of whom subsequently visited one of the pilot sites and even embarked on pilot projects of their own.

Guidance of search

In terms of the *guidance of search* function, evidence of activities that fulfilled the function was found in two interviewees' subsequent activities. The relevant respondents were a government official and a consultant. Lisebo, a manager in charge of the green economy portfolio in her home province, used the LMH AD model to kick-start a coordinated biogas initiative in her province. She was so impressed with how the LMH biogas digester operated, that she motivated her department to purchase the same system to be trialled at one of the universities in her province (University of Venda). She has since helped to set up a biogas centre of excellence at the University of Venda:

'We bought a similar system from the same company, which we donated to the University of Venda, one of the major universities in our province. This is because we saw it working well at the university and we thought we could trial it in the same environment. We have since signed a MOU (Memorandum of Understanding) with the same university and we fund most of their biogas activities. The University of Venda has since been earmarked as the Centre of Excellence in Biogas. The donated digester has been installed, after it had gone through the different stages of engineering designs and approvals from a number of stakeholders including university management.' (Lisebo's interview)

This has increasingly put the biogas technology in the spotlight in Lisebo's province. In addition to government, consulting companies are also playing a critical role in advising industries on sustainable waste management strategies. The deployment of the AD technology for biogas production is increasingly being put forward among the suggested waste treatment technologies. For instance, Robert, a consultant, mentioned that he used the knowledge he had gained through his previous visit to the LMH biogas project in his consulting work to advise the project that his team was working on to consider the deployment of the biogas technology.

'My current work on energy policy is a joint venture of high-level strategy, an industrial symbiosis type approach at an industrial complex in the Eastern Cape province. In this context, we are recommending the use of anaerobic digestion technology to treat waste for biogas generation as part of our contribution.' (Robert's interview).

From the above feedback, there is evidence to suggest that the visits to the pilot project sites resulted in several activities that have made or will in the near future make some contribution to the evolution of the biogas industry in South Africa. At the time of the follow-up interviews, the activities that some of the visitors engaged in had led to the fulfilment of at least three system functions, viz. knowledge development, *knowledge diffusion* and *guidance of search*. It is also important to note that these functions enable activities that fulfil other functions; for instance, more pilot activities usually lead to large-scale demonstration projects, categorised as entrepreneurial activities, whilst *knowledge diffusion* and *guidance of search* help in the formulation of strategies and ultimately policies.

The impact of such visits is likely to take time, and a few months to a year may not adequately capture the extent of the impact or its longevity. Nonetheless, there is some evidence, however small, to suggest that these activities may have had a catalytic effect on the development of the BIS, also from observing how the biogas industry has developed in the past year and a half. The next section will look at the impact of the pilot projects through various *knowledge diffusion* platforms.

6.4.2 Other impacts of the pilot projects

Up to this point, this chapter has attempted to describe and assess the impact of a particular type of knowledge development intervention, i.e., biogas pilot projects, on the emergent BIS in South Africa, through follow-up interviews with visitors to the pilot projects. Over and above the deliberate use of the pilot projects as activities to stimulate visitors' subsequent activities, several *knowledge diffusion* activities around the pilot projects arose. These were primarily in the form of media coverage, in printed, broadcast and web formats. The places in which the projects were covered in the media are presented in Table 6.2 below. Moreover, the LMH biogas project received peer recognition in the form of two awards: one from the UCT Green Campus Initiative, the other from the SA Institution of Chemical Engineers.

The projects received coverage that spanned local to international media. For instance, both projects received coverage from UCT's weekly publication, the Monday Paper, which has an international reach through its online presence. News of the two pilot projects was also published in regional newspapers, viz. the *Cape Times* and the *Cape Argus*. The national exposure came in the form of broadcast media and periodicals. News regarding the two projects and, related to that, funding for further installations of small-scale rural and urban projects were broadcast in an interview on a national news-based radio station. Moreover, the SCAGA project received prime time exposure on a national television news channel. Daily routines at SCAGA and LMH systems were broadcast on a knowledge portal channel on South African satellite television. Lastly, the daily routine at the LMH biogas project was recorded and placed on Youtube, where it has been viewed more than 1700 times at the time of writing. Moreover, a news video clip with both projects was done for a news agency and also posted on Youtube; at the time of writing, it had received over 200 views.

It is the objective of the remainder of this section to demonstrate that the two pilot projects had a wider exposure than anticipated. It is not meant to assess the impact that the coverage

summarised above had on the BIS, but rather to give a broad picture of how the projects were reported on in the media. The first thing to note in this regard is the positive light in which the media generally reported on these projects. This can be observed in the catchy and yet positive headlines that accompanied the news. For instance, in its reporting on the SCAGA biogas project, the *Sunday Argus* of 22nd July 2012 carried the following headline: '*Biogas generates a miracle*'. By the same token, the *Cape Argus* and *Cape Times* had positive headlines regarding the LMH biogas project: The *Cape Argus* of 11th June 2011 carried the following headline for the story '*Reusing food is a gas*'. The *Cape Times* of 12th June 2012 stated that '*It is not just hot air as UCT wins grant*', referring to the grant that the work secured as part of the DST's 'Global Change, Society and Sustainability Programme'.

Another observation about the news in the printed media is that the headlines had advocacy undertones. In some instances, the reporting had *guidance of search* undertones (F4), through the way it reported the waste management capabilities of the AD technology: '*There is nothing wasteful about food waste at UCT thanks to the ... initiative, which will see it being used to produce methane gas*' (*Cape Argus*, Sept, 2011).

It can be seen from Table 6.2 that these two biogas pilot projects have contributed to the dissemination of knowledge about the technology in South Africa, which at the time was rather limited. From 2011 onwards, there has been an extensive coverage of biogas activities in general in comparison to earlier years, as studied in Chapter 5. Moreover, the coverage of the projects gave more exposure to the urban potential of the biogas technology. Before then, most of the limited coverage focused on rural household applications and medium-scale sized systems installed in piggeries. However, there was very little reported on the potential of small-scale urban systems, though this has now changed.

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Table 6:2: Knowledge dissemination activities

Projects	Coverage/Media platform	Details
LMH	Cape Argus	11 th June 2011: ‘Reusing food is a gas’
Biogas Project	Cape Times	12 th July 2012: ‘It is not just hot air as UCT wins grant’
	Farmer’s Weekly	19 th July 2012
	The New Age	14 th July 2012
	www.researchsa.co.za	UCT team awarded R2,5 million NRF grant for SA biogas projects’ Available from 23 rd July 2012
	UCT’s Monday Paper	6 th August 2012: Waste to Power – It’s a gas
	Youtube video	Posted on the 28 th June 2011: https://www.youtube.com/watch?v=SbiBUu-2tpY#t=10
	Youtube channel	Posted on the 23 rd January 2013: https://www.youtube.com/watch?v=hlSvsWrGAoM
	SA FM	Interview on UCT biogas project on the Enviro Show 30 th August 2012
SCAGA	Sunday Argus	22 nd July 2012: ‘Biogas generates a miracle’
Biogas Project	UCT’s Monday Paper	23 rd July 2012: ‘Biodigester fuels sustainable livelihoods’
	Africajournalismtheworld.co.za	‘SA research into urban biogas projects’: <i>Accessed on 1st September 2012</i>
	www.irinnews.co.za	South Africa: Smells like a bargain – money-saving biogas: <i>Accessed on 1st September 2012</i>
	www.mediaclubsouthafrica.com	Biogas project uplifts South Africa
	Youtube video	Posted on: 23 rd January 2013: https://www.youtube.com/watch?v=hlSvsWrGAoM
	eNCA (e News Channel Africa)	Prime time interview about the project (24 th July 2012)

Lastly, a slightly related impact of the pilot project is that it enabled others within the research group, in which this thesis is based, to undertake research to assess the stability of

small-scale urban biogas project. For instance, Naik et al. (2012) reflected on the experiences of the Marquard Hall (LMH) digester over its first year of operation.

6.5 Discussions

The discourse in the field of STs has shifted somewhat in the past year. The debate seems to be moving away from discussing either the superiority or the limitations of the various approaches and frameworks employed within this relatively new yet rapidly growing field of enquiry. Protagonists have since established and acknowledged the limitations and complementarities of the key approaches. For instance, an assessment of the strengths and shortcomings of MLP and TIS approaches has received extensive attention (Markard et al. 2012), and it has even been suggested that the two approaches should be integrated. In any case, it is widely acknowledged that, since most of the approaches are relatively new, they are continuously undergoing conceptual development and modifications; analytical rigour is thus being promoted.

A different discussion has recently emerged: it seeks to interrogate whether this field of enquiry is having any impact at all on the evolution of sustainable transitions. This question is important and formed the crux of the proposal for this thesis, when it was developed a few years ago. Using one of the ST frameworks, the TIS, the aim of this project was to establish how strides could be made to move beyond assessments of potential and identification of missing activities to actually embarking on research activities that would positively influence technology trajectories. This motivated the second set of key questions of this work, which this third section of the thesis is trying to answer.

This chapter has begun to interrogate how and whether the academic work employing the TIS framework can have an impact on how a technology under study develops on the ground. Figure 6.1 below gives a schematic overview of the objective and the outcomes of the analysis in this chapter. A participatory action research was used to set up two biogas projects. By following up with the visitors to the pilot projects and observing other related impacts in the media, the influence of these activities had on the development on the BIS were assessed. It was established that visitors were inspired to undertake certain activities after visiting the pilot project. From interviews with 13 visitors, representing approximately 15% of all the visitors in the first year of these projects, a total of three *knowledge development* post visit/s activities were identified, all of which were further pilot projects. In

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addition, both projects led to visitors embarking on activities that fulfilled *knowledge diffusion* and *guidance of search* functions, though the latter to a more limited extent. Similarly, extensive media coverage of the projects led to technology knowledge dissemination, which at times possessed guidance and advocacy undertones.

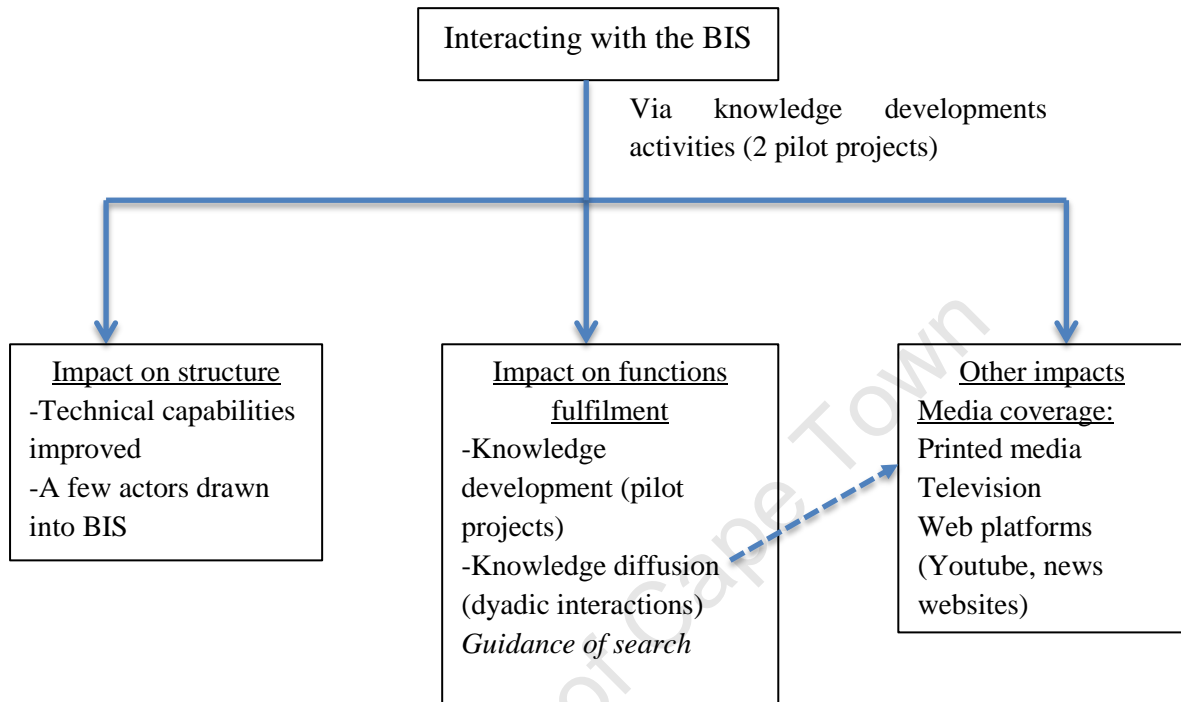


Figure 6.3: A summary of the impacts of knowledge development activities on the South African Biogas Innovation System (BIS)

Whether and how the ST studies affect an emerging industry or technology seems to depend on the aims of each study undertaken. For instance, the aim could be to observe and understand how a technology develops, as discussed in Chapter 5 of this thesis. Although this approach is valuable in determining barriers and enablers for an emergent TIS, its impact on the development of a given industry is usually studied and observed in retrospect. Such an impact may take a long time to manifest into observable changes during the course of the study. Conversely, interacting with the system with the aim of influencing and perhaps instigating change that would address some of the perceived limitations in the formative phase of a TIS trajectory could have observable results during the course of the study, although it is of course difficult to imagine a *control* study in which the evolution of the same TIS would be studied without deliberate participant observation. By interacting with some elements of the innovation system that are mooted to shape a given TIS, however, evidence has been produced that suggests that the evolution of a TIS can be influenced.

In summary, Figure 6.1 shows how this was achieved. A knowledge development activity inspired further *knowledge development* activities, but also some *knowledge diffusion* and to some extent *guidance of search* fulfilling activities. A notable outcome of the pilot projects was the appetite of different media platforms to cover the pilot projects, hence disseminating technology knowledge to a broader audience. Whilst the biogas technology existed in South Africa and was reported on in the media, this happened to a much lesser extent than was the case for other types of renewable energy technologies. Implementing the pilot project seems to have given it legitimacy and credibility, which made it worthy of reporting, resulting in knowledge thereof being disseminated (F3). As mentioned earlier, coverage of the pilot projects was observed on various media platforms. Moreover, the media at times had some advocacy undertones, and therefore some *guidance of search* function was stimulated too.

From the above analyses and discussions, it has been demonstrated that research in this field of enquiry can indeed influence the trajectory of a BIS. The actual extent to which such activities shape the development of the BIS, however, is less clear at this stage. It was further found that involving others, especially those who are active in the BIS (enactors) and those who are contemplating entering (selectors) the BIS, was significant in informing the degree of influence. For instance, having people come visit the pilot projects was instrumental in how some changes occurred.

6.6 Conclusions

In this chapter, an attempt was made to provide answers to the second key question of the thesis. Based on the analysis and discussions above, the following conclusions can be drawn:

1. The work has demonstrated that, through participatory action research (PAR), a knowledge development activity can lead to further activities that fulfil some of the seven functions of the TIS approach. The intervention has inspired the visitors to the selected pilot projects to engage in further *knowledge development*, *knowledge diffusion* and *guidance of search* fulfilling activities. There is evidence to suggest that some of these activities were influenced by their visits.
2. The media can play an influential role in disseminating the knowledge widely; moreover, when it reports positively on the technology, it helps to fulfil in part the *guidance of search* function.

3. Lastly, it seems that some of the elements of the nascent South African BIS structure were strengthened through the activities. The deliberately developed activities resulted in more actors participating in the BIS and interactions. Moreover, the pilot projects provided an opportunity for further R&D on the stability of small-scale urban biogas digesters.

It has thus been established that using knowledge development activities, a deliberate intervention can influence the direction and trajectory of the BIS. In the next chapter, the impact of a *knowledge diffusion* event on the development of the nascent biogas industry in South Africa is explored.

University of Cape Town

CHAPTER 7 Impact of the workshop

7.1 Introduction

In the previous chapter, an initial attempt was made to provide answers to the second key question of this thesis as stated in Sections 1.4 and 6.1.

This chapter sets out to answer the same question. The motivation for the choice of functions that this work can influence has been outlined in Chapter 6. In a nutshell, while academic activities can contribute to the fulfilment of several of the seven system functions, they are most likely to do so through knowledge related activities. It was therefore decided to design events and conduct activities that fulfil knowledge development and diffusion functions with the aim of stimulating activity in the nascent SA BIS and thereafter to assess their impact. In Chapter 6, the impact of the knowledge development activities on the BIS was analysed. In this chapter, the impact of a *knowledge diffusion* intervention on the BIS is investigated.

This chapter is structured as follows: In Section 7.1, an overview of the methodology adopted is given, as a reminder of the detail presented in Chapter 3. Section 7.2 introduces the *knowledge diffusion* event, which is followed by insights deduced from the event itself, specifically participants' activities and challenges. The impacts of this *knowledge diffusion* activity on participants' subsequent activities and the resultant impact of these activities on the BIS are discussed in Section 7.3. Lastly, the discussions and the concluding remarks make up Sections 7.4 and 7.5 respectively.

7.2 Methodology and approach

Knowledge diffusion is an essential function for exchanging knowledge amongst actors and networks in a given TIS. Whilst Hekkert and colleagues (2007) earlier proposed that the fulfilment of this function can be mapped out by the number of workshops, conferences and technology platforms around a technology in question, they later acknowledged that such an approach is incomplete (Hekkert & Negro 2009). This is because *knowledge diffusion* tends to happen in dyadic relations, most of which are not reported in literature (*ibid*). Furthermore, they suggest that more insights regarding the fulfilment of this function can be gained through interviewing of agents. Cognisant of these depictions of *knowledge diffusion* in

literature, an event was thus planned and data collected and analysed accordingly to reflect these insights.

The methodology adopted to answer the question posed above is an exploratory participatory action-based research, as outlined in more detail in Chapter 3. The approach entailed organising and participating in a one-day specialist biogas workshop, coined the ‘Biogas Innovators Workshop’. The workshop was held on the 11th of May 2012. The purpose of the workshop was two-fold: The first objective was to facilitate knowledge sharing amongst the delegates, who had been purposefully selected to represent actors with interests in different functions relevant to the nascent South African BIS. This was done so as to identify activities and hence functions that needed strengthening within the BIS. The second objective was to provide a networking and interaction platform for participants, and thereafter to investigate the impact of those interaction on the BIS a year after the workshop. The evidence needed to answer the key question and to meet these objectives was gathered in two ways. Firstly, it was gathered during the workshop by documenting the proceedings, and secondly, semi-structured interviews were held approximately a year after the event. Figure 7.1 below summarises the approach followed in this chapter.

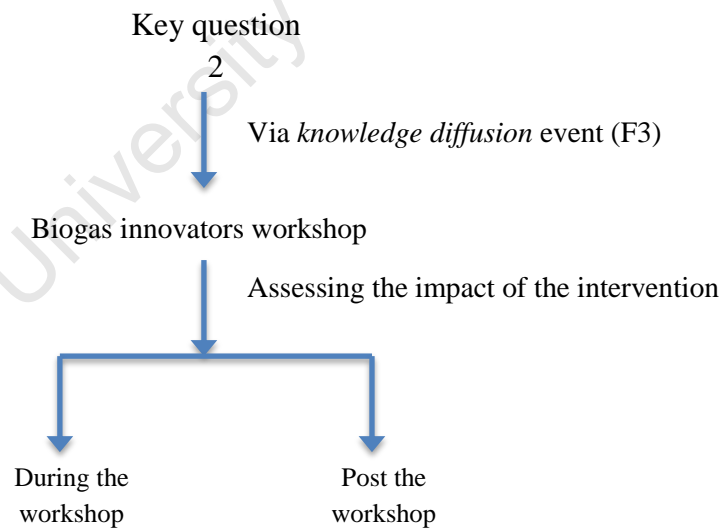


Figure 7.1: A summary of the chapter’s research approach

7.3 The biogas innovators workshop

In this section, more details of the workshop are outlined, followed by an analysis of the actors’ interactions during the workshop.

The Biogas Innovators Workshop was targeted at key actors in the South African BIS, and as such, was by invitation only. A total of 28 invites were sent out to identified key actors who played different roles within the BIS; they included entrepreneurs, representatives from local, provincial and national governments, technology agencies, academic institutions and non-government organisations. Please refer to Appendix C for the invite, a summary of the workshop objectives and the workshop minutes. Whilst the Biogas Innovators Workshop was designed to accommodate 20-25 people, in the end a total number of 15 people attended.

The workshop was designed to allow for both information sharing via presentations and interactive breakaway sessions for discussions. The objective of the information sharing session was to reiterate the national biogas potential, to hear from key participants about their related innovations, and to introduce the participants to the idea that they might be part of a nascent TIS. The TIS concept was used to direct discussions in interactive sessions, including gauging the current state of the SA BIS. This entailed identifying functions that were being fulfilled at that time and those that were still lagging behind, leading to propositions on how the development of the BIS could be catalysed. In the next section, participants' interactions in breakaway sessions and general discussions are presented. Post-workshop activities are described in Section 7.4.

7.3.1 Workshop structure

In order to assess the current functional fulfilment within the BIS, a set of questions was proposed to guide the interactive/breakaway sessions; see Appendix C for a comprehensive list. Essentially, the questions were geared at finding out how participants' activities fulfilled the system functions before the workshop, and identifying any hindrances to their optimum fulfilment. In planning the workshop, an effort was made to invite representative delegations whose activities are likely to fulfil as many of the seven functions as possible, and proceedings were designed with this in mind. The breakaway session was designed such that people whose activities fulfilled the same function(s) would be grouped together. In the end, it was not possible to achieve these groupings, because for some functions only one representative was present. Ultimately, the following 3 groups were possible:

- i) Participants whose activities largely fulfil *advocacy coalition & guidance of search* were grouped together,

ii) There was also a knowledge development grouping, and

iii) The last one comprised actors whose activities tended to be dominated by *knowledge diffusion* and entrepreneurial experimentation.

The outcome of the discussion is summarised in Section 7.3.2. The workshop was wrapped up with a general discussion, which allowed all the participants to identify the ideal functional pattern; outcomes of this discussion are summarised in Section 7.3.3.

7.3.2 Insights from breakaway session

The primary objective of the breakaway session was to get a better indication of actors' current activities, over and above what has been collated from academic and so-called grey literature. In so doing, insights could also be gained on the structure of the BIS and the functions it fulfils. Moreover, the secondary objective was to identify which of the functions limited different actors from fulfilling their functions. The discussions at each of the three breakaway groups are summarised in the rest of this sub-section. Insights gained here were also helpful in narrating the evolution of the biogas industry in South Africa discussed in Chapter 5 and also for triangulation of data.

i) *The guidance and advocacy group*

This group was comprised of actors working for a non-governmental organisation (NGO) as well as some government representatives. This group primarily advocates the increased use of renewable energy in general as opposed to promoting any specific technology. Specifically, their activities endeavour to ensure that there is mutual understanding of existing renewable energy related policies amongst stakeholders, both in the Western Cape and nationally. This is achieved through the facilitation of dialogue between the stakeholders, including specific community interactions and public capacity building programmes. The NGOs also engage with officials, politicians and media directly in an attempt to unpack the role of renewable energy in society. They also strongly advocate the decentralisation of the energy sector and urge the relevant parties to be sensitive to consumer needs. With regard to the biogas technology specifically, some NGOs have hands-on experience; for instance, Project90 by 2030 facilitated the installation of a pilot scale biogas digester at the Johannesburg Zoo. Most of these activities give legitimacy to renewable energy technologies in general and biogas specifically and can therefore provide guidance to different structures

of society (F4), while also fulfilling *advocacy coalition* as and when needed, as well as, to some extent, *knowledge diffusion* functions.

Functional and structural analysis

The guidance and advocacy group attributed the underdeveloped BIS and generally the weak fulfilment of system functions to several factors. Firstly, with regard to the BIS structure, as per definition of TIS structure given in Chapter 2, they felt that the *technology and related artefacts* aspect of it was weak, especially with regard to adapting the biogas technology to the South African context. This is especially pertinent for small-scale projects that generally suffer from a bad track record of technical failures.

With regard to the fulfilment of functions, interestingly, they attributed the slow development of the industry to poor fulfilment of the *guidance of search* function, especially, by relevant government entities. For instance, they suggested that none of the government departments was mandated to support the biogas sector directly. Moreover, the issue of centralised decision-making and current legislation on renewable energy projects was seen as limiting local government's ability to take on new ventures. Another function that the group identified as important yet poorly fulfilled is *resource mobilisation*; they identified land on which some of the projects are to be implemented as one of highly contested resources in the country, which will be crucial in the long term. They further suggested that financial resources (F6) are key to fulfilling other functions. In conclusion, the group noted that the guidance and advocacy role is often challenging, as identifying the exact audience to guide or advocate on behalf of is not always obvious. However, the group also believed that the *fulfilment of guidance of search* and *advocacy coalition* functions hinges on the better fulfilment of *knowledge development* and *entrepreneurial activities*.

ii) Knowledge developers

Represented in this breakaway group were knowledge developers, i.e., academic and government research institutions, and biogas companies. Actors' activities ranged from basic Research & Development (R&D) work to *learning-by-doing initiatives*, such as pilot projects.

Functional and structural analyses

According to this group, the stunted growth of the biogas sector can be attributed to weakly formed structures and the absence of certain activities within the BIS. Similar to the guidance and advocacy group, this group also identified the actual technology and related artefacts as the most lacking component of the BIS structure. They suggested that the technical reliability of biogas digesters is yet to be guaranteed, especially at small-scale, household level. Inadequate upfront planning prior to installation is blamed for the poor performance of these systems. There is thus a need to ensure better functioning and performance of digesters and to work towards bringing the costs down for wider adoption of the technology.

In terms of the functions that the group identified as limiting the development of the BIS, the first was *advocacy coalition*, which, if increasingly fulfilled, should give the technology some legitimacy. Secondly, *guidance of search* through local and national legislations was identified as inhibiting the development of the BIS. Furthermore, processes for sourcing funding for setting up pilot studies, if available, tend to involve cumbersome procurement processes. Insufficient resources (F6), in some cases, to conduct relevant research, hamper the fulfilment of the *knowledge development* function.

iii) Entrepreneurs and knowledge diffusers

This breakaway group was made up of representatives from biogas companies and individual entrepreneurs. It is important to note that the guidance and advocacy group tend to fulfil the *knowledge diffusion* function (though, as noted above, they work on the renewable energies in general with limited depth in biogas). This group's activities, in contrast, are quite versatile, varying from diffusing knowledge about the biogas technology specifically to identifying market needs and appropriate technology variants for a specific service. Moreover, some of them ensure that the right and factual message is communicated to consumers to encourage their buy-in.

Functional and structural analyses

This group also attributed the slow development of the industry to several factors. In terms of the structure, and typical of an emerging industry, they suggested that the number of actors relative to the potential was too low. As a result, a few of the active actors were stretched, and were spending more time than would be considered sufficient if the BIS was more mature. For example, entrepreneurs tend to take on knowledge development, *knowledge*

diffusion and advocacy roles over and above their primary entrepreneurial experimentation and innovation roles. (This was the case prior to the formation of the biogas industrial body half a year after this workshop; this body has been able to take on the advocacy role on behalf of the BIS). This group identified several activities and hence related functions as inhibiting the development of the BIS. They felt that activities around advocacy (F7) were limited and that there were not enough knowledge dissemination events (F3). They also said that the limited number of pilot projects (F2) was problematic, as most of those keen to adopt the technology preferred to visit a pilot site first. Lastly, a lack of resources (F6) was also limiting the fulfilment of other functions, e.g., *knowledge diffusion* and entrepreneurial activities. In the next section, the functional analysis that emerged from the general discussion is presented.

7.3.3 Identifying stumbling blocks and enabling environment

The aim of the wrap-up session was to identify collectively some of the enablers and stumbling blocks that are currently hindering the development of the biogas industry in South Africa. Several suggestions were put forward as potential enablers. First was the development of biogas industry standards that would provide guidelines for the industry and potentially catalyse *entrepreneurial experimentation*. Moreover, the availability of such standards would further provide positive guidance (F4), inspire resource mobilisers to inject funds (F6) into the BIS, and encourage market forming activities, such as tax incentives to come to the fore (F5).

The second activity that participants identified as an enabler is increased *knowledge development* activities. Participants considered learning activities central to the fulfilment of the other functions, and as such, government should support them. For example, it was suggested that government entities such as the TIA, which was represented at workshop, could mobilise resources (F6) to support more focused and impactful *knowledge development* activities. The newly acquired knowledge, if well used (F3), could provide legitimacy for the industry. At the same time, it could help government to provide better guidance to the industry (F4), which could in turn lead to the introduction of market stimulating initiatives, such as tax incentives (F5). Gaps in knowledge could also be identified during knowledge sharing activities (F3), thus leading to further *knowledge development activities*.

The delegates also suggested that two barriers were hampering the development of the BIS. Mainly, they felt that *entrepreneurial activities* were far too low, and that there should be platforms that encourage more entrepreneurial experimentation. They saw increased entrepreneurial activities as having the potential to increase coalitions and consequently its advocacy, which could in turn influence relevant authorities to consider introducing *market formation* incentives (F5). The participants also identified *knowledge diffusion* activities as predecessors to more effective *advocacy coalition* activities. Finally, the participants proposed that the lack of biogas specific national strategy and policy were hampering industry development. Overall, the discussion highlighted the significance of all seven functions in the development of the biogas industry. In both the breakaway and plenary sessions, all seven functions were considered critical in the BIS trajectory; moreover, their interdependence was also observed.

7.4 Analysis of participants' post-workshop activities

7.4.1 Participants post-workshop activities

Data for post-workshop activities was gathered via semi-structured interviews approximately a year after the workshop. There were two objectives for conducting these interviews. The first was to investigate how participants' activities had changed since the workshop, as an attempt to assess progress within the BIS. The second objective was to establish the effect of participants' interactions and networking at the workshop on their subsequent activities. The interview data is summarised in Table 7.1 below. Of the 15 workshop attendees, 11 participants agreed to be interviewed; the main reason why not all of them could be interviewed was that some of the attendees had made complete career changes in the year following the workshop and were thus not reachable. The interactions between workshop participants with the research group (E&PSE) in which the author of the thesis is based are also captured.

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Table 7:1: Analysis of workshop attendees’ subsequent activities

*Workshop delegates	Functions fulfilled by their activities	Number of activities in the past year	Post-workshop interactions	Outcomes due to interactions and other activities	Critical functions for delegates’ work
<i>Mary</i>	F4	0	No	Shared insights with 3 entities	F2
<i>Dennis</i>	F3; F4; F7	-	Yes, Stanley	Shared the knowledge with various platforms <i>Energy Efficiency Committee</i>	F4; F5
<i>Stanley</i>	F3; F4;F7	+	Yes, E&PSE, Dennis, Company X	- Building a biogas system - Hosted UCT for knowledge sharing	F2; F5
<i>John</i>	F2; F4	++	Yes, Company X, Thandi, E&PSE	Partnering with some of the workshop attendees on various projects	F4; F5
<i>George</i>	F1	-	Yes, Thandi, John	- Projects in the pipeline, - Introduced AD to the his new portfolio	F3; F5
<i>Thandi</i>	F3; F6	++	Yes, John, E&PSE	Interactions with others who attended, led to other <i>knowledge diffusion</i> activities	F4; F5

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<i>Peter</i>	F4	++	Yes, E&PSE	Not him directly, his colleagues at Green-Cape have continued to diffuse the knowledge	F4 (esp. lack of understanding of MFMA)
<i>Grace</i>	F3; F4	+	Yes, Timothy, Thandi	Exploring synergies with Thandi's organisation. Timothy assisted with info.	F3;F4 (esp. MFMA, MSA)
<i>Company X</i>	F1; F3		Yes, John	Working with John on demonstration project	
<i>Timothy</i>	F1; F3; F4	++	Yes, Grace	Shared the knowledge about the technology on various platforms	F3
<i>Seba</i>	F2	++	0	Planning to install a system similar to LMH digester	F2; F3

*Note: names changed to keep identity of respondents anonymous for ethical reasons

Legend:

F: Functions of the innovation system

+ = Increase; - = decrease; 0 = no change

To address the first objective of the interview, participants were asked to indicate whether or not their biogas related activities and/or energy from waste initiatives had changed since they attended the workshop. They were asked to comment and reflect on how their activities had changed as follows: whether such activities had decreased, remained the same, increased, or increased drastically. Table 7.1 above summarises the results over the year for the 10 interviewees. Two indicated that their activities were decreasing. One of these two

interviewees, an entrepreneur, felt, however, that there was highly likely that their activities would increase in the near future. The other interviewee whose activities were declining, an NGO representative, suggested that there was no proper guidance in the industry, and that they would wait until the climate was conducive to explore the technology again. One interviewee submitted that their activities had remained the same. In contrast, seven of the participants suggested that their activities had increased, with five suggesting that they had increased drastically. Overall, there was thus some indication that there is an upward momentum in the BIS.

It is not possible to attribute the increased activity solely to being a consequence of the *Biogas Innovators Workshop*. Several other factors may have contributed to the observed increase in the level of activity; for instance, landscape conditions in the form of industry favourable acts (e.g., NEM: Waste Act) may have contributed to the observed trend. Moreover, the formation of an industry body, the Southern African Biogas Association (SABIA), a few months after the workshop, may have given the industry more legitimacy through its advocacy. However, there is still evidence to suggest that some of the workshop participants' subsequent activities were due to on-going interactions and networks that had been forged at the workshop; these interactions and outcomes are detailed in Section 7.4.2. Despite a positive trend in the BIS trajectory in the past year, all the interviewees admitted that they could better play their part within the BIS, if other organisations were more supportive. To unpack this further, participants were asked to point out structures and activities that would enable them to be more effective in their role within the BIS. In line with the TIS framework and system functions analytical approach, the interviewees were asked to identify which of the seven system functions would enable them to fulfil their functions better.

All the participants identified four functions that were particularly crucial. Most of them, as can be seen in Table 7.1, regarded the fulfilment of the *guidance of search* function as critical to fulfilling their roles within the BIS. *Guidance of search* refers to those activities within an innovation system that affect the visibility and the clarity of specific wants amongst those who use the technology (Negro 2007). Four interviewees felt strongly about legislation and policy from relevant government entities, both nationally and locally. For instance, Grace strongly pointed out the limitations of some Acts on municipalities' abilities to embark on waste to energy projects:

'Two Acts are said to be responsible for these limitations, namely, Municipal Financial Management Act (MFMA) and Municipal System Act (MSA). For one, municipalities claim that they can only supply their solid waste for a maximum of 3 years or a contract value R300 000. The MFMA also requires that several financial and technical feasibility studies be conducted as an initial step' (Grace's interview).

However, Peter argued that there was nothing in the MFMA that prohibited municipalities from entering into long-term agreement with project developers. Rather, he said:

'It requires advanced administrative and managerial capacity to comply with the process, and there has to be Council approval of the entire contract. Therefore municipalities have reportedly preferred to interpret the section as prohibiting contracts of longer than three years' (Peter's interview)

Participants affiliated to government institutions stated that the knowledge development function (F2) was critical to their activities. They argued that it could enable them to better play their part within the BIS. Mary, who works for a provincial government entity, emphasised the importance of F2:

'...Once again we have to work very closely with universities, because universities have the technical knowledge that can aid us in advancing our work...' (Mary's interview)

Government officials suggested that they could better fulfil their functions, which included providing guidance to the industry (F4) and making informed decisions in stimulating the market (F5), if they were equipped with well-researched and sound technical knowledge. Interestingly, one of the academics, Thabo, echoed this sentiment, stating that knowledge development (F2) could equip the government to devise strategies that can make a meaningful contribution in technology development. His concern was this:

'...that African bioenergy policies and strategies are formulated and based respectively on wrong data. There is a need to generate context specific data for us to better inform policy...' (Thabo's Interview).

The need for *market formation* (F5) activities was highlighted by at least four interviewees; some believed that local government was in a position to catalyse the industry growth. An example of that is forming a niche market, as one of the entrepreneurs, George, suggested:

‘The City can adopt the technology at its waste and solid waste facilities, and use it to operate the bus fleets etc. and that... the legal framework is required that needs to recognise ways of procuring energy, in particular, thermal energy, which I feel has been undermined up to this point...’ (George’s interview)

Lastly, quite a few also believed that *knowledge diffusion* would enable them to perform their respective mandates better. A representative from a consulting company, Tim, noted that:

‘... One of the functions that I feel will enable my work is knowledge dissemination. This is important for consulting companies, since the more platforms are available to disseminate the knowledge; the better and more informed the advice that we can offer to our clients...’ (Timothy’s interview).

7.4.2 Analysis of actors’ interactions

In the previous section, it was reported that most of the workshop participants indicated that their activities regarding waste to energy and biogas technology, specifically, had increased since the workshop. It was suggested also, that some of this incline could be attributed to actors’ interactions and the networks they had formed at the workshop. It is the objective of this section to explore further how this was achieved, in line with the second objective of conducting follow-up interviews. Specifically, the objective was to investigate whether or not the interactions led to the fulfilment of any of the seven system functions and whether, in so doing, it strengthened the structure of the BIS. Since the interactions also involved representatives from the research group that hosted the workshop, those interactions were also included. These interactions and their outcomes have been mapped in Figure 7.1 below. The rest of the section is structured according to the functions that participants’ interactions fulfilled.

Impact on entrepreneurial activities and effect on the BIS structure

Suurs et al. (2009) describe events that fulfil the entrepreneurial activities function as projects with commercial aim or demonstration projects. The interaction between participants from

two organisations has led to a probable demonstration project, which is at an advanced stage of concept design. The interaction is between a government-based research institution, SANEDI, and a biogas company. SANEDI is a state-owned entity with a mandate to stimulate and promote the uptake of green energy. The research institution has been in interactions with a biogas company since the workshop. The probable entrepreneurial activity is a programme that will see the roll-out of small-scale biogas digesters in schools around South Africa. The institution is making this possible through funds from an already existing programme, and the biogas company in question is intimated as the potential technology provider. John from SANEDI had this to say about their current project:

'... We are looking at introducing renewable energy packages at schools. We are planning to install digesters from 'The Biogas company X' in more than 200 schools around the country...' (John's interview)

The project summarised above is the only advanced entrepreneurial activity that appears to have resulted from connections made at the workshop; however, another one is being alleged from an on-going bilateral interaction. This will most likely come from interactions between a different pair of participants, viz. a biogas entrepreneur and another government entity, a technology development agency TIA, whose mandate it is to offer financial and non-financial support for commercial start-ups. The two participants have been in close contact since the workshop and the biogas entrepreneur, George, is highly positive about that interaction:

'I am also in touch with the representative from TIA. TIA has been a very good connection for me for potential projects...' (George's interview)

If this demonstration project goes ahead, it is likely to draw more actors into the BIS, as it gains more exposure around the country.

Impact on the knowledge diffusion function and effect on the BIS structure

Participants' interactions during and after the workshop led to several *knowledge diffusion* activities. It is important to note that besides a few relationships that existed before the workshop, e.g., between the workshop hosts and a few other participants, most of the other relationships between participants only started at the workshop. Some of the interactions between participants were dyadic, whilst some involved the participation of several

participants, as can be seen in Figure 7.1. One such *knowledge diffusion* event involved the participation and input of four of the biogas innovators' workshop attendees. TIA, which had a representative at the workshop, was instrumental in getting three other participants involved in this event. Due to these newly established relationships, TIA was able to call on some of these contacts for expert input at a regional workshop they were co-organising. TIA's representative Thandi had this to say:

'Through the workshop, I was able to make a few contacts. These are the contacts that we would otherwise not have made, had we not attended the biogas innovators workshop. It was through that workshop that I was able to invite 3 of the workshop participants to a TIA/UNIDO workshop'. (Thandi's interview)

Said workshop was on the potential of generating energy from agricultural residues and algae in the Southern African Development Community (SADC) region, and TIA had co-organised it with the United Nation Industrial Development Organisation (UNIDO); it was held in Centurion Gauteng, South Africa. The three participants made a total of four presentation contributions (see Appendix C for a copy of the workshop proceedings). All four presentations highlighted the activities around generating energy from waste in the South African context, with a specific focus on the biogas technology from the perspectives of government, academia and the private sector. The interactions between these parties continued post the TIA/UNIDO workshop. A representative from a government affiliated research agency, John, found that the biogas innovators workshop was instrumental in strengthening its relationship with TIA:

'... Another important link has been with representatives from TIA. In fact, through the link, we were called to present at a SADC bioenergy workshop hosted by TIA and UNIDO. We are also considering partnerships with TIA on bigger projects going forward...' (John's interview)

Another *knowledge diffusion* event resulted from the interaction between the non-governmental Wildlife and Environment Society of South Africa (WESSA) and the organisers of the Biogas Innovators Workshop, UCT. WESSA invited the author of this thesis to give a presentation at one of its lectures to a Leadership Course on Sustainability. The lecture shared experiences gained from installing and operating a small-scale biogas digester. Stanley reflected upon his latest activities since the workshop and the lecture:

'I have added a bioenergy/biogas component to our training modules for the Leadership course on Sustainability this year. We have also been working with Zero Organics to Landfills, a composting company that is also toying with small-scale anaerobic digesters, of approximately 200 litres.' (Stanley's interview)

There is some evidence to suggest that more knowledge dissemination activities took place, mainly dyadic in nature. For instance, as stated earlier, the interaction between TIA's and SANEDI's affiliated representatives strengthened over the year, and there are discussions to formalise their relationship in the near future. Moreover, participants used their various platforms to disseminate knowledge about the technology. For instance, Thandi shared some of what she learnt at the workshop with her colleagues:

'... I have been able to share what I took from the workshop with some of the people I work with... I have also been involved with more knowledge dissemination activities related to the energy from waste in recent times. I have managed to establish contacts with colleagues within the City of Cape Town innovation hub and would like to exchange ideas with the UCT E&PSE Research Group and a project developer on industrial biogas projects...' (Thandi's interview)

Biogas technology entrepreneur George reported that he had disseminated knowledge about transforming waste to energy in general and biogas specifically in different capacities after the biogas innovators workshop:

*'... In general, I have told a whole lot of people who knew very little about the technology or nothing at all about the potential that the technology holds. Especially in my recent assignment at **The Innovation Hub.**'* (George's interview)

Yet another participant, Timothy, who works for a consulting company that offers biogas consultancy services, had this to say about his post-workshop activities:

'I have been able to share knowledge on biogas and some insights from the workshop and prior knowledge in the industry, to 4-5 companies that I have worked on bioenergy related projects with. I have also shared the message with all the relevant parties for a particular

project. These include the general public, academic institutions, commercial companies working in the waste solutions area, private business, farmers etc. (Timothy's interview)

Another entity that was represented at the workshop is the Sector Development Agency, GreenCape. They confirmed that they had continued to diffuse the knowledge they gained at the workshop, together with other workshop participants. They notes that, although they had previously interacted with three of the participants prior to the workshop, new connections emerged from the Biogas Innovators Workshop . Grace, GreenCape's representative at the workshop, noted that those relationships were further strengthened by the interactions at workshop:

'Some of the interactions, e.g., with 'Biogas Company X' had been established prior to the workshop, but we continue to interact closely after the workshop... A MoU has since been signed between Green Cape and SANEDI, the government affiliated research institution, although this link was not a result of the workshop, the contact was partly provided by workshop organisers'. (Grace's interview).

Of these new interactions, some had started at the workshop, whilst some started months after the workshop; in both cases, the relationships continued to strengthen over time. GreenCape established further relationships and therefore knowledge exchanges, as Grace notes:

'The main contact that we were able to establish through the workshop is with the Technology Innovation Agency (TIA) and we are beginning to identify synergies with regard to our activities. We have also interacted with a consulting company which has been instrumental for introducing us to other industry actors that we can better support.' (Grace's interview, pg 8).

Finally, the NGOs represented at the workshop, viz. WESSA and Project90 by 2030, have continued to share new insights from the workshop and previous knowledge with other stakeholders. Dennis from Project90 by 2030 had this to say about their post-workshop activities:

'Knowledge of energy from waste that we gained at the workshop and what we have already has been shared in various platforms in Energy Efficiency Committees since the workshop.' (Dennis's interview).

In summary, it is evident that the Biogas Innovators Workshop has had a significant effect on the *knowledge diffusion* function. As observed, this is not only achieved through formal *knowledge diffusion* events, such as the TIA/UNIDO workshop, but also via dyadic *knowledge diffusion* amongst participants, and between participants and the public at large. Although not all *knowledge diffusion* activities in which participants participated can be attributed to attending the workshop, there is evidence that it strengthened existing networks and aided plans to formalise them. It could be suggested that, through the relationships that emerged at the workshop, and the formation of new interactions and networks, there was some structural strengthening of the BIS. These are all important structural components of any TIS, and, if organised, they can lead to the formation of coalitions that lobby for better industry conditions.

Impact on knowledge development function and effect on the BIS structure

A few knowledge development activities that emerged from participants' interactions were reported. For instance, John from a government affiliated research institution expressed the usefulness of interacting with academic institutions on a continuous basis:

'It was also important to get some insights from the academic crowd, which is largely useful for the work that we do.' (John's interview)

One of the academic participants echoed this sentiment by suggesting that academic and research institutions can play an important role in advancing the work of others within the BIS. Inspired by a site visit to a LMH biogas digester, the same academic is planning to set-up a similar pilot project on his university campus with input and advice from E&PSE UCT, who hosted the workshop. The pilot project will be made possible by research funding at his disposal and will most likely involve one of the companies that they met at the workshop.

'We currently have an equipment budget of R8 million and are planning on installing a system similar to the one installed outside the UCT residence in the near future. We are also working at simulating solar for the Advanced Photo-degradation that precedes or follows the AD process... and therefore may need to contact some of the people we met at the workshop.' (Thabo's interview)

Overall, then, there is some evidence to suggest that the Biogas Innovators Workshop has had, and will most likely still have, an impact on the knowledge development function. Further knowledge development activities should strengthen the structure of the BIS, and strong technical capabilities should lead to a more structurally robust BIS. Moreover, the knowledge development function usually has spin-offs and can play an important role in the *guidance of search* and providing legitimacy for the technology (F7).

Impact on the guidance of search and effect on the BIS structure

Activities or events that characterise this function include the raising of positive expectations about the technology. This also entails activities that positively affect the clarity and visibility of the technology (Hekkert et al. 2007). There is evidence to suggest that some of the participants have contributed to placing the technology in a positive light. This was achieved at the ICS-UNIDO/TIA workshop that has been discussed previously under the impact on knowledge diffusion. By giving a presentation on the potential of the technology to national and regional representatives, the industry was placed in a positive light.

Another organisation that has been instrumental in providing guidance to the industry is GreenCape, assisted in some instances by Timothy, a consultant. Grace highlighted the importance of this continuous relationship in better fulfilling their function to guide the industry:

‘We have also interacted with Consultancy Y which has been instrumental for introducing us to other industry actors.’

Commenting on this interaction, they added:

We have continued to play a facilitating role between the private and other sectors of the economy. We are also several on-going research projects that envisaged to assist develop strategic approach on how best to support the waste economy.’ (Grace’s interview)

In general, there is evidence that at least one of the interactions. i.e., between GreenCape and Consultancy Y aided GreenCape to fulfil the *guidance of search* function, as the interaction went beyond facilitating and sharing of knowledge. The exchanged information enabled GreenCape to direct the industry better, by giving advice on how to acquire permits, legislation requirements etc. It can also be argued that the *knowledge diffusion* activities that

have already been discussed have helped to guide the industry. An example is the interaction between WESSA and the workshop hosts, which first led to knowledge sharing as discussed earlier, and subsequently inspired learners to work towards setting up their own pilot projects (F2). The WESSA participants had this to say about the learners:

‘The students have learnt about biogas and they are also taking a challenge to build their own biogas digesters (Dennis’s interview).’

More actors have been drawn into the innovation system by the guidance and knowledge sharing activities, thus increasing the number of BIS actors and creating more robust networks, which will in turn strengthen the BIS.

Impact on advocacy coalition and impact on the BIS structure

At the time that the Biogas Innovators Workshop was hosted, a unified voice advocating for the biogas industry in South Africa was still lacking. Due to new relationships and strengthening of older ones at the Biogas Innovators Workshop, participants used various platforms to legitimise the biogas technology, either individually or collectively. Eight months after the workshop, an industrial association, Southern African Biogas Industry Association (SABIA) was formed, in December 2012. As soon as the industrial association had been formed, some of workshop attendees through their continued interactions on various platforms informed each other about the association’s founding. Several of the workshop attendees, including the author of the thesis, thus joined SABIA early on and became part of the early advocacy activities. Moreover, Thandi, the TIA representative, acknowledged the insights inspired by the TIS approach, and the importance placed on *advocacy coalition*:

‘I have also been in touch with SABIA’s president and his colleagues. Overall I want to remain informed and also work out how I can possibly contribute towards the development of the biogas industry in South Africa.’ (Thandi’s interview)

Most workshop attendees have since become part of SABIA, whether due to their roles in their own organisations, or due to associated activities within the BIS. It is suggested, however, that the centrality of *advocacy coalition* was emphasised during discussions at the workshop, and thus participants considered SABIA an entity worthy of support, if the BIS is to develop from the formative stage into the market phase. Finally, a BIS with a well-

established *advocacy coalition* is able to draw in actors and strengthen networks amongst them. They are also able to advocate the creation of better institutions.

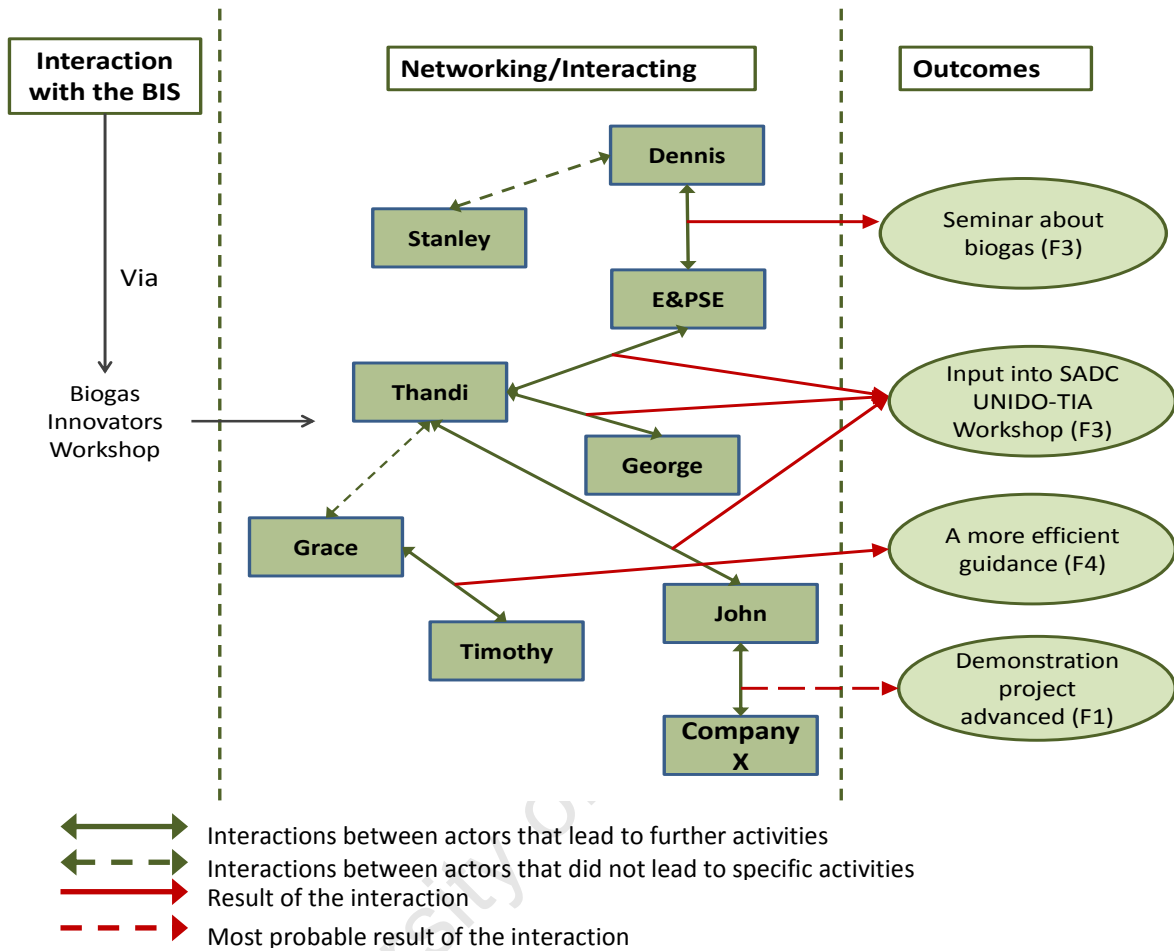


Figure 7.2: A schematic overview of workshop participants' interactions and related outcomes

Overall, there is evidence to suggest that the interactions at the workshop have led or will in the near future lead to activities that will fulfil five of the seven system functions, viz. *entrepreneurial activities*, *knowledge development and diffusion*, *guidance of search*, and *advocating for the technology*. The function that was fulfilled the most by subsequent activities was the *knowledge diffusion* function; more than half of the participants became involved in one or several activities. as depicted in Table 7.1 and Figure 7.2. Some of these *knowledge diffusion* activities had guidance or advocacy undertones and could be seen as fulfilling the *guidance of search* function. One interaction led to a likely fulfilment of *entrepreneurial activity*; potentially an outcome with significant impact that, if successful, will see more than 200 small-scale biogas digesters installed in schools around the country.

Finally, further knowledge development activities in the form of *learning-by-doing* were inspired by site visits, which were part of the biogas innovators workshop's proceedings.

7.5 Discussions

It was the aim of Chapters 6 and 7 to investigate the impact of PAR interventions on the evolution of the South African BIS. The TIS framework and associated system functions informed the design of the action-based research. It was postulated that academia would instigate change through activities that fulfil knowledge related functions. Whilst the previous chapter looked at the impact of a knowledge development intervention, this chapter discussed an action-based activity that fulfilled the *knowledge diffusion* (F3) function. A *Biogas Innovators Workshop* was organised and participation was by invitation only. The objective of this workshop was two-fold: Firstly, it was to facilitate knowledge dissemination amongst participants on the day of the workshop and identify possible hurdles to the observed stunted growth. Secondly, it was to investigate the outcomes of the participants' interactions approximately a year after the workshop.

The workshop was effective in facilitating the transfer of biogas related knowledge between the participants. The interactions during the workshop were crucial in identifying functions that could enable different types of actors to better undertake their own activities. The participants identified four of the seven functions as potential enablers, viz. knowledge development and diffusion (F2, F3), *guidance of search* (F4), and *market formation* (F5). Most, however, identified *guidance of search* as the most important enabler for their mandated activities within their entities. It is important to note that all the seven functions were identified as crucial for enabling the participants' activities in their respective entities, when evidence from during and after the workshop is taken into consideration. This further confirms that all seven functions are important in the development of any TIS.

Follow-up interviews with workshop participants were used to track post-workshop activities. The objective was to gauge the progress made in a year, based on the feedback from participants. Seven of the 10 respondents indicated that their activities had indeed increased over the past year, and this can therefore be associated with an increase in functional fulfilment and hence strengthening of the BIS. It is also important to note that the increased momentum can be partly attributed to the interactions and relationships that were formed at or after the workshop. These relationships have contributed to further fulfilment of the other

system functions. Activities of newly established and strengthened relationships led to near or complete fulfilment of five of the seven system function, viz. *entrepreneurial experimentation, knowledge development and diffusion, guidance of search* and some *advocacy* (F7). Of the additional activities that emerged from these interactions, *knowledge diffusion* was the most prominent. This was evident in the number of workshop delegates participated in subsequent to knowledge sharing events. The reason for this could be that *knowledge diffusion* events, especially dyadic ones, do not require large resource investments compared to other functions e.g., *entrepreneurial activities* or *knowledge development*. Conversely, the *guidance of search* and *advocacy* functions are closely related to *knowledge diffusion* in some cases.

Two of the seven functions that were not observed are *market formation* and *resource mobilisation*. At least three reasons may be attributable to this observation. Firstly, a period of a year might be too short to observe a shift in legislation that promotes *market formation* on the one hand and that results in notable *resource mobilisation* on the other. It is worth noting that there are likely to be some *resource mobilisation* activities between government and the private sector, if some of the mooted entrepreneurial projects are successful. However, this had not occurred at the time of the follow-up interviews. Still, a year might be too short a time to notice major shifts. The second reason may be that activities that fulfil functions are instigated by actors within robust and complex structures. Often, for *market formation* (F5) instruments to be implemented and, by the same token resources to be mobilised, consultation with stakeholders may be necessary. These processes do not only tend to be complex but they also take considerable amounts of time. Lastly, the delegation represented at the workshop only had one entity that could have contributed to sizeable *resource mobilisation*, TIA, which means that this one player can only have a limited impact on the BIS, at least over the period of a year. Moreover, with regard to *market formation*, policy making bodies were underrepresented at the workshop, with representatives coming only from provincial government.

The *market formation* fulfilling activities have in the past been associated with a TIS that was shifting into a mature (or market) phase as opposed to one in the formative phase (Suurs et al. 2009). This further confirms that the BIS is indeed in a formative stage. *Resource mobilisation* on a large scale depends on finance cycles of government and other donor organisations, and this too would only have reflected at least a year after agreements had been

reached and signed. Effectively, if the delegates at the workshop had been interviewed and assessed an additional year later, this might have picked up activities that fulfil these function; however, this was outside the duration of the projects.

7.6 Conclusions

Based on the discussions above, the following conclusions can be drawn with regard to the answers to the second key question, following on from Chapter 6:

1. The workshop was able to facilitate discussions and interactions and forge networks amongst BIS actors, most of which continued after the workshop and have since contributed to the strengthening of the structure of the BIS.
2. Through interactive discussions during the workshop, crucial functions that were limiting the progress of the South African BIS were collectively identified, and suggestions on how to address them were put forward. *Guidance of search* featured prominently amongst functions that were considered to limit the development of the BIS. Despite that, all of the functions were considered important by the delegates. In part, this confirmed that all seven functions are important, as had already been established in previous TIS empirical studies (Negro 2007; Negro et al. 2007). With regard to structure, a couple of limitations came to the fore. Firstly, there are still too few actors to fulfil all seven system functions, and certain actors thus had to over-extend themselves beyond their primary activities to aid in BIS development. For instance, entrepreneurs had to participate actively in *knowledge diffusion* activities beyond mere marketing, rather than being able to focus primarily on innovation and technology development. Another weak aspect of the structure is associated with technical artefacts and technological know-how. The existence of malfunctioning household biogas systems was also found to hamper the growth within the industry.
3. There is evidence to suggest that some participants' activities increased over the year and that some of these increases were due to relationships having been established at the workshop. Of the ten participants interviewed, seven said that their activities increased a year after the workshop, with five of them reporting drastic increases.

4. Finally, the interactions between workshop attendees led to further fulfilment of five of the seven system functions and the establishment of networks, which in turn contributed to building a more robust BIS structure, which has since started to experience significant growth. It was further suggested that the other two functions that were not observed, viz. *market formation* and *resource mobilisation*, confirmed that the BIS system was still in the formative phase. It also indicated that such activities are likely to require more than a year to become apparent due to the complex structure of actors or institutions that tend to fulfil them.

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SECTION 4: Final perspectives

CHAPTER 8 Conclusions

This thesis has come about as a result of attempts to understand the sluggish development of the waste-based bioenergy sector in South Africa, to identify means to overcome this situation, and to facilitate the establishment of a dynamic bioenergy industry, which has a significant and quantified potential to contribute to sustainable development in this country. The purpose of this final chapter is to summarise the results of the thesis and to present conclusions as to how the findings contributed to achieving the objectives of the study, and how they answered the key research questions. The chapter closes by providing some recommendations and an outlook for the future.

The objective of this dissertation was two-fold, namely i) to explore the utility of an innovation systems approach to understand how to unlock the estimated waste-based bioenergy potential in South Africa – a country lagging behind the usage of available technologies, and ii) to experiment with aspects of the TIS approach, so as to kick-off and observe the impact of experimentation. Based on these objectives, two research questions were formulated. Subsequently, a two-module methodology was developed to answer each research question. The rest of this chapter is developed as follows: Section 8.1 briefly reviews the thesis, Sections 8.2 and 8.3 present the conclusions and the recommendations for the two research questions respectively, and Section 8.4 ends the thesis with an outlook for the future.

8.1 Thesis review

The first chapter of this dissertation introduced the context of the state of energy and waste management services in transitioning economies in general, and in South Africa specifically. This was followed by a summary of the bioenergy potential in South Africa, sourced from several key studies. The tremendous potential of bioenergy was highlighted and the current state of development discussed and contrasted with the success observed elsewhere, specifically in various Asian countries and in Germany. Subsequently, the rationale was given for focusing on a single technology, viz. anaerobic digestion (AD) for the purposes of the study. Finally, it was proposed that a technology-specific innovation system approach was a useful tool for understanding the evolution of an emerging technology in a given context. It

was suggested that this approach, detailed in Chapter 2, might be useful to explain the slow development of the biogas technology in South Africa.

Chapter 2 served two purposes. Firstly, it briefly reflected upon the challenges of both waste management and energy provision that were detailed in Chapter 1. Secondly, it provided an exposé of the theoretical underpinnings for the study. An overview of the broad body of STs (also termed socio-technical transitions) literature was given, and the Technology Innovation Systems (TIS) concept was located therein. The TIS framework was found to be the best suited to address the objectives of this thesis. Despite the potentially high explanatory power of sustainability transition frameworks in general, and the TIS approach in particular, only a few studies in developing countries have employed these; none had done so in South Africa at the time of writing this thesis.

A two-module methodology was accordingly developed in Chapter 3, with each module designed to answer one of the research questions. The first module entailed an observational analytical methodology within the established TIS framework, namely, the systems functions approach; this was employed using an *event history analysis*, as adapted from Negro (2007), uniquely complemented by the systems thinking tool known as a causal loop diagram (CLD). The results of this module were presented in Section 2 of this thesis, comprising Chapters 4 and 5. The second module of the study made use of a participatory action-based research method, using multiple case studies. Of interest here are insights of how some purposefully induced activities among bioenergy stakeholder triggered interactions of various specific elements of the TIS framework, and how this, in turn, affected the nascent biogas industry in South Africa. The purpose of the participatory action-based research (PAR) was to investigate specifically what impact well-designed interventions, in the form of activities and events, would have on the emergent BIS. The first two case studies explored the knowledge development function and entailed the design and implementation of two biogas pilot projects, and an evaluation of their impact. The third case study investigated the impact of a knowledge diffusion-fulfilling event. Interviews were used to gather evidence on the impact of the two interventions a year later. The results regarding the second question were presented in Section 3, comprising Chapters 6 and 7. Conclusions with regard to the two research questions are offered in the next section.

8.2 Conclusions

8.2.1 TIS observation

The first set of research questions as detailed in Sections 1.4 and 4.1 was addressed in Section 2, termed *TIS Observation*. TIS framework had not yet been applied in an African context or, specifically to an emerging technology in South Africa, it was considered worthwhile to test its utility on a more mature renewable energy technology in the country, viz. the Solar Water Heater (SWH) industry, which was discussed in Chapter 4. Subsequently, in Chapter 5, the TIS analysis was used to unpack the slow development of South Africa's BIS.

Using the *process* analysis (also termed the *event history analysis*) adapted in Negro's PhD thesis for TIS applications to acquire data for this study, and using the TIS functions to structure the data, insights were gained into the developments of the two TISs. Moreover, whilst Negro (2007) found that graphical illustrations were supportive of the narrative, she also found the graphical illustrations limited with respect to explaining causal relations. Therefore, in this dissertation, a unique way of articulating and presenting causalities using CLDs to support the narrative was employed. Furthermore, interviews were used to triangulate some of the data, especially in cases where there was conflicting reporting on some sources.

After the utility of the TIS framework had been tested on the SWH industry, the following results were obtained. Firstly, the analysis of the SWH industry demonstrated and confirmed the usefulness of the approach in unpacking emerging technologies in transitioning economy contexts. Moreover, the CLDs were found useful for visually depicting the motors of innovation observed in different periods of the analysis. Through this analysis, the development of the structure of the SWH Innovation System (SWH IS) could be tracked. It was established that a robust structure ensued over time and thus, in the last period, all structural elements, viz. actors and their networks, institutions and technical artefacts, were more developed than they had been in the earlier stages. The structure was instrumental in undertaking activities that fulfilled all system functions, which led them to reinforce one another into virtuous cycles.

The key part of the response to the first research question was then developed in Chapter 5. As established from Chapter 4, the chosen TIS approach was indeed able to locate and

describe the observed BIS development in each of the two periods studied. In the first phase, the observed inertia could be explained in part by the underdeveloped BIS structure. For instance, there were very few actors, viz. a couple of companies and a few researchers. Moreover, they were not yet linked into networks and the rules of the game (institutions) were not well formed. Such a weakly formed sector structure was unable to participate in or undertake activities that fulfilled most system functions, even more so when these were not linked in networks. This aspect was also observed in the early stages of the SWH IS development, in which only a few functions were fulfilled compared to the last period, due to a weak sector structure in the early stages. In the second period, however, the number of actors had increased and networks amongst the various stakeholders had been established (e.g., through the formation of SABIA). Moreover, the institutions were becoming more developed and technology issues were being addressed over time. As a result, there were more activities and events fulfilling most of the seven functions. It was established that a robust and well-developed TIS structure lent itself to more activities and hence the fulfilment of functions and consequently to a high likelihood that they would reinforce one another into virtuous cycles. A TIS began to emerge and grow. Nevertheless, at the end of the second period, the structure of the BIS was still less developed than that of the SWH IS. But the findings of this study indicated that the BIS was indeed maturing.

The fulfilment of the system functions over time offers insights and explanation as to why the BIS development was slow in the first period and faster in the second period. In the first period (1997-2007), only two system functions were observed, viz. entrepreneurial experimentation (F1) and knowledge development (F2), which could perhaps be attributed to the weak BIS structure, as alluded to earlier. The fulfilment of the functions did not trigger the fulfilment of the other five functions; hence cumulative causation was not observed. Nonetheless, as weak as the BIS structure was at the end of the first phase, it paved the way for the build-up of a more robust BIS structure as observed in the second period.

Only one overarching motor of innovation was identified in the second phase. This was a process kick-started by a reinforcing cycle of activities around the installation of farm scale digesters, which was referred to as the *Imitator Motor*. In total, six out of seven system functions were fulfilled in the period between 2008 and 2013, though yet not extensive enough to fully exploit the potential. Moreover, the six system functions reinforced one another into virtuous cycles. In addition to functions fulfilled in the previous period, the

critical functions known as *guidance of search* (F4), *resource mobilisation* (F6), and *advocacy coalition* (F7) featured strongly in the second phase. The observation here is comparable to what was spotted elsewhere, in Suurs et al. (2010) who describe the *System Building Motor* as a motor that emerges due to a conscious orientation of actors. It is worth noting that four motors of innovation were identified for the SWH IS, one (3rd phase) was similar to the one described in the 2nd BIS phase. The first and second phases of the SWH IS exhibited the same types of dynamic; however, in the first phase, functions reinforced one another into virtuous cycles in a motor referred to as the *Guidance Motor*, due to the centrality of the *guidance of search* function (F4). In the second phase, the same functions reinforced one another downwards due to issues external to the SWH IS into a dynamic called the *Break-down Motor*, as detailed in Chapter 4. In the last phase of the SWH IS, the *Market Motor*, in which all the seven system functions reinforced one another positively, was observed. Interestingly, some of the motors observed in the SWH IS industry mimic those found in other empirical studies (e.g., Farla, et al. 2010; Suurs et al. 2009; Suurs & Hekkert 2009).

Landscape conditions also had some influence on which types of activities were undertaken and hence which functions were fulfilled within the BIS. Unsurprisingly, as long as the fossil-based regime was stable, both the BIS and the SWH IS failed to gain momentum beyond their niche applications. It was the electricity crisis, increasingly pressing issues related to climate change and ever-growing pressure to achieve social justice that all contributed to the momentum for the biogas sector to build-up. Still, the virtuous cycles that were triggered by the fulfilment of the functions were instrumental in the observed progress in the BIS, and indeed in the SWH IS.

In terms of whether additional functions were identified in this work, neither the SWH IS nor the BIS analyses identified any additional system functions. Markedly different from European-based studies, however, was how the two functions of *knowledge development* (F2) and *resource mobilisation* (F6) were fulfilled. *Knowledge development* (F2) was dominated by feasibility studies and pilot projects (*learning-by-doing*), as opposed to technical research, as was observed in European-based studies. In the case of the BIS, for instance, only two patents were identified in the entire period studied spanning 20 years. Secondly, with regard to *resource mobilisation* (F6), foreign aid and carbon finance enabled knowledge

development and entrepreneurial experimentation activities. These types of resources usually acted as a catalyst that unlocked local resources and, later on, government resources. Another interesting but not entirely unique aspect is how knowledge was diffused (F3) via the printed media. Previous TIS studies did not consider or capture the dissemination of knowledge activities via media, especially printed, beyond just seeing them as a source of data for event history analysis. In our case, it was observed that the voice of media was instrumental in diffusing knowledge: In both cases, it often carried advisory and advocacy undertones, as detailed in Chapters 4 and 5.

The results from these two chapters showed that the TIS analysis using the *event history analysis* approach is indeed applicable in the South African context (which fuses transitioning economy with developing country elements, giving a potentially broader relevance to this finding). The first section of the study also confirmed that technology innovation does not follow a linear progression, where laboratory research is followed by experimentation and subsequently market testing. Rather, it is an interplay between various actors and their functions within the TIS. And as such, the support of an emerging TIS is crucial, if it is to undertake the key processes (system functions) essential for a technology to take off.

Whilst it was important to establish that elements of a TIS could be located in the BIS and to explain how the BIS evolved over the years, the real novelty in this research was that it explored how such knowledge could be used to further stimulate this TIS towards a better use of its potential. The second section of this thesis endeavoured to achieve that by adopting a participatory research approach, the conclusions of which will be drawn together in the next section.

8.2.2 Interacting with the system

The second set of research questions as outlined in Sections 1.4 and 6.1 was addressed in Section 3 of the thesis titled *Interacting with the System* and presented in Chapters 6 and 7.

Section 3 investigated whether and how a specific group of actors, viz. researchers and academics – through their activities – could catalyse the development of a TIS. A premise that inspired the work is that strategically structured intervention around knowledge related functions can lead to increasing fulfilment of the system functions and consequently strengthen a nascent TIS – in this case, the BIS in South Africa. Moreover, the discourse in

the field of sustainable transitions has shifted somewhat in the past year. A different discussion has recently emerged, which seeks to interrogate whether this field of enquiry is having any impact at all in how sustainable transitions evolve.

In Chapter 6, impacts of knowledge development activities were discussed. The results demonstrate that, through PAR, a knowledge development activity can lead to further activities that fulfil some of the seven functions in a TIS. It was established that visitors to the bioenergy project sites were inspired to undertake certain activities after visiting the pilot project sites. A total of three knowledge development activities were identified as result of the visits. In fact, all three activities were new pilot projects. In addition, both projects led to visitors embarking on activities that fulfilled *knowledge diffusion* (F3) and *guidance of search* (F4) functions, the latter to a more limited extent. Similarly, extensive media coverage of the projects led to extensive *knowledge diffusion*, which at times possessed guidance and advocacy undertones. This study established that pilot projects hold the potential to disseminate widely knowledge of the technology, especially in transitioning economies, where technical research is scarce. The dissemination is achieved through various means, viz. by word of mouth by pilot projects visitors, presentations to diverse audiences by the project leader and also through diverse media coverage of the projects.

Chapter 7 presented the impacts of a *knowledge diffusion* event, the *Biogas Innovators Workshop* assessed both during and after the workshop. Through interactive discussions during the workshop, crucial functions that are limiting the progress of the South African BIS were identified collectively, and suggestions on how to address them were put forward. *Guidance of search* (F4) featured prominently amongst the functions that were considered as limiting the development of the BIS. Despite that, the delegates considered all of the seven functions important, confirming earlier TIS empirical studies (Negro 2007; Negro et al. 2007). With regard to TIS structure, specific limitations came to the fore. Firstly, there were still too few actors to fulfil all seven system functions. For instance, a few entrepreneurs had to divide their time between developing their technology and actively participating in *knowledge diffusion* activities. Moreover, for these entrepreneurs, the *knowledge diffusion* activities took more time than they usually did, when the diffusion function was already fulfilled through events (e.g., workshops, conferences) as, for instance, happened in a mature TIS. Another aspect of the deficiency of the TIS structure was associated with technical

artefacts and know-how. The malfunctioning of household biogas systems was given as an example of a phenomenon that was hampering the progress of the BIS.

With regard to the post-workshop activities, these were tracked a year later through semi-structured interviews. The results established that interactions and networks formed at the workshop led to the further fulfilment of five of the seven system functions. Stronger networks are one of the signs of a maturing TIS, and it is suggested that these were partially instigated by the workshop. It was further suggested that the other two functions that were not observed, viz. *market formation* (F5) and *resource mobilisation* (F6), confirmed that the BIS system was in the formative stages. Also, it suggested that such activities are likely to require more than a year to be observed due to the complex structure of entities that fulfil them.

In comparing the results of the Chapters 6 and 7, it became clear that the impact of the interventions was tracked by employing the same data gathering method, viz. semi-structured interviews. Each type of interaction strengthened the structure differently. In the case of knowledge development, it entailed building capabilities and led to a few people joining the BIS and participating mostly in knowledge development activities. The *knowledge diffusion* events, in contrast, led to the formation and/or strengthening of existing interactions and networks. The interactions with the system led to the further fulfilment of functions through subsequent activities. Figure 8.1 below summarises the impact of the interaction with the system through knowledge development and diffusion activities.

In conclusion, it has been demonstrated that research in this field of enquiry can influence some of the activities in a TIS. The extent to which such activities ultimately shape the development of the TIS is less clear at this stage, and may vary depending on factors not explored here, such as research approaches and scale. It was further found that involving those who are active in the BIS (enactors) and those who are contemplating entering (selectors) was critical in how the influence manifested and what impact it had. Notably, some of the interviewees played an instrumental role in the formation of the industry association Southern African Biogas Industrial Association (SABIA) a few months later.

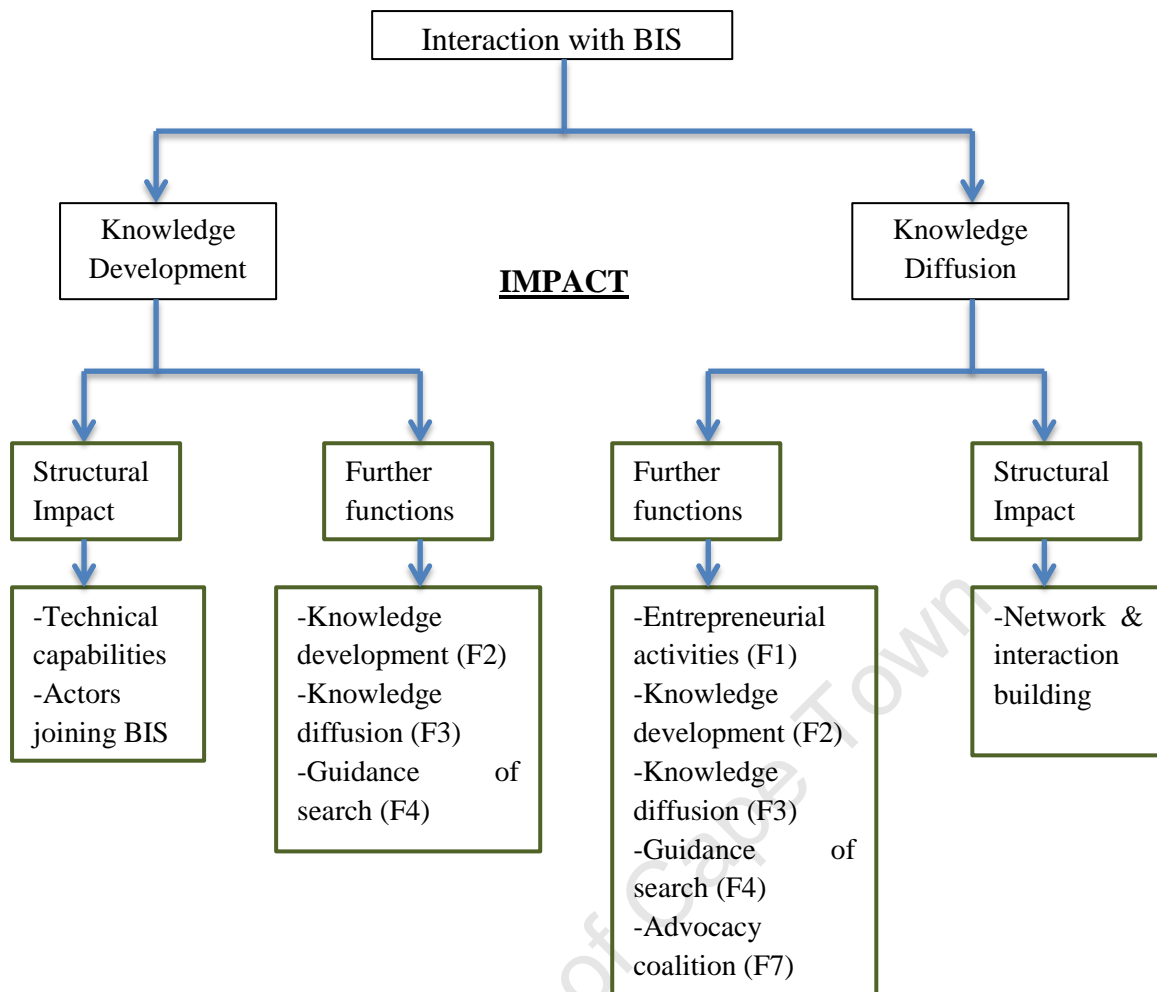


Figure 8.1: A summary of impacts observed after interacting with the nascent South African BIS

8.3 Recommendations

Based on the conclusions pertaining to the two key research questions, recommendations are summarised below for each research question, with regard to i) further research and ii) guidance for practitioners.

Regarding the first research question, the following recommendations are made for further research:

1. It was established by means of the TIS analysis that two functions (*knowledge development* and *knowledge diffusion*) appear to have different expressions in transitioning economies contexts than they do in developed countries. Specifically, resources directed towards a specific technology tended to be limited. This implies that such resources should be directed towards activities that would have the most impact on a TIS. Further research can investigate the extent to which TIS development in transitioning economies depends on development-linked grants and

donations. Linked to that would be the question of establishing how best such funds could be deployed, if the evolution of the TIS was to have the most impact. There seems to be a strong causality between the *resource mobilisation* and knowledge development functions for the two empirical analyses in this thesis. This applies particularly to its apparent ability to influence the technology trajectory positively by unblocking some of the barriers. Further investigations regarding the extent of the impact of *resource mobilisation* on *knowledge development* and *diffusion* functions but on also other functions of the TIS in general could also be insightful in designing policy interventions.

2. The role of media in the dissemination of knowledge and the fulfilment of functions has not been explicitly considered in previous studies. Rather, publications were mainly used as knowledge sources, either to identify TIS structures and the functions of the TIS and/or to construct a technology trajectory narrative. Further research could investigate the role of the media, both printed and broadcast, in disseminating knowledge and hence fulfilling the *knowledge diffusion* function and the extent to which this fulfils other system functions, such as *guidance of search* and *advocacy*.

Based on the outcome of the analyses and the conclusions with regard to the first research question, the following recommendation is put forward to practitioners, especially policy makers:

- Renewable energy technologies undergo long trajectories of development, diffusion and implementation. As such, policymaking entities within government need to consider flexible long-term policies, which allow government agencies to support specific technology (as was observed with regard to SWH IS and BIS) through different stages of development, especially in the formative stages. This requires a different skill set of those drafting policies, namely, to take a systemic outlook on how processes evolve. In a nutshell, systemic policies to innovation, as opposed to the linear models currently adopted in the South African context, should be prioritised.

Regarding the second research question, the following recommendations are made for further research:

1. Whilst the objective of this study was to establish whether the interactive activities could catalyse the BIS, it did not assess the extent of the impact. Further research could attempt to quantify the extent of the impact induced by similar types of interventions. For instance, with regard to knowledge development activities, tens of people visited the two pilot projects digesters, but only 13 were available to be interviewed. Further research could design a survey facilitated via email to all (or at least a majority) of the people that visited either one or both of the units. Moreover, estimating the reach of the media when reporting about the pilot projects and how much this contributed to *knowledge diffusion* is another potentially fruitful way of quantifying the impact of the pilot projects. For instance, by quantifying the listenership of a TV or radio programme.
2. The research regarding the second question was exploratory in nature, and targeted activities that academics specifically are likely to influence. In deciding which functions to influence most, activities that fulfilled the two knowledge functions were deemed the most accessible for academics. The results in this work seem to imply that the *knowledge diffusion* event had more of an impact on the BIS than knowledge development activities, when the activities that resulted from the interventions were taken into consideration (see Figure 8.1). Exploring the effectiveness of the intervention strategies could benefit from further research. For that, a more detailed comparison of the two knowledge intervention strategies (*viz. knowledge development or knowledge diffusion* activities) employed would be a good starting point.

With regard to recommendations for practitioners that have emerged from the second research question, the following is suggested:

- Strategic interventions by actors, such as *knowledge diffusion* events to stimulate the development of an emergent TIS, should be promoted and resourced, as this has been shown to have a positive impact on its development. Funding should be made available by all relevant actors in the BIS, *viz.* the private sector and state organisations, but it could also be supported by donor funds. It is interesting to note that the GIZ has stepped into the SA BIS by supporting the creation of a Biogas

Platform, and it would be worthwhile to evaluate the impacts of this intervention after some time.

8.4 Outlook

The theoretical underpinning of this thesis is the TIS framework. Various tools have been used, firstly, to locate and unpack and, secondly, to influence the trajectory of a waste-based bioenergy sector in South Africa. These tools span various fields of enquiry including economics, social sciences, systems thinking and engineering.

This study applied systemic approaches in order to understand technology development and innovation in transitioning economies. The first step to influence any trajectory is understanding its specific dynamics, as these have been laid out elsewhere (Suurs & Hekkert 2009a); Meadows (2004) symbolically describes this as *dancing with the system*. By identifying the constituents of the structure and the key activities that the structure undertakes it is possible to identify where systemic interventions need to be directed. The outcomes of the analysis point to a need for planners and policy makers to design and implement systemic policies that address different facets of technology innovation. Policies should first be geared towards strengthening the TIS structure because a robust and resilient structure is able to fulfil TIS functions that then reinforce each other into cumulative causations and therefore propel an emerging technology into a market phase. Moreover, there is a need to consciously influence the trajectory of the innovation system in order for the sustainable development ideal to be realised.

It is my hope that some of the insights gained in this thesis will be used to influence technology development and innovation policy. As to the recovery of energy from wastes in South Africa, utilising biogas technology, unless socio-economic conditions change drastically, we should indeed observe much growth over the next decade. It has been exciting to observe – and to participate in – the formative stages.

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APPENDICES

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APPENDIX A: The Solar Water Heaters Industry

APPENDIX A1: An extract from a SWH IS database

An extract from the database is given in the table below, within an intention of giving examples of activities and events that fulfilled all the seven system functions and those that merely provided context

Year	Summary	Activity type/System function	Reference
Nov-97	Government sets a National Advisory Council on Innovation to advise the Minister on Science and Technology about innovation. This is an indication of governments commitment to explore new development and service provision paths including renewable energy	Context	Republic of South Africa. National Advisory Council on Innovation. , Pub. L. No. Act No. 55 (1997). Republic of South Africa.
Dec-98	The government publishes a White Paper on Energy and recognizes the role of renewable energy technologies in general and solar technologies in addressing energy and developmental issues	<i>Guidance of search (F4)</i>	Department of Minerals and Energy. White Paper on the Energy Policy (1998). Republic of South Africa.
Jun-99	UNDP/CEF 500 Project is mooted and it hoped to unlock the solar water heater potential in South Africa is announced	<i>Guidance of search (F4)</i>	REMT Unit. (2009). <i>THE NATIONAL SOLAR WATER HEATING WORKSHOP</i> (pp. 1–32). Johannesburg.

Aug-01	An informal settlement in the Gauteng province sets aside R5.6 million pilot study investigating whether solar water heating in South African homes can be viable in low-income areas. This project will entail installation of SWH in 200 to 500 homes in this area for a 2.5 year study conducted by the Department of Minerals and Energy Affairs. The project has been made possible by the UNDP Finisse funding. The project was it its pilot phase	Demonstration/Pilot Study (F2)	Barry, S. (2001). Ivory park tries solar heating.pdf. <i>Weekly Mail and Guardian</i> , p. 15.
Jun-03	Solar water heaters are installed in 10 households in Kuyasa Khayelitsha as part of a pilot for a roll out to 2306 households. An on-going study of the energy patterns was being conducted to document the extend of energy and financial savings	Pilot project (F2)	Gophe, M. (2003, June 26). Residents warm to solar water heaters. <i>Cape Argus</i> , p. 8. Cape Town.
Nov-03	A White Paper on Renewable Energy is published. It sets and ambitious target to add 10 000 GWh of electricity to the energy mix by 2013	Guidance of search (F4)	Department of Minerals and Energy. White Paper on Renewable Energy (2003). Republic of South Africa.
Mar-05	The Kuyasa project receives international recognition for its contribution for using in using renewable energy and curbing air pollution. The pilot project has been recognised as a gold	This puts the SWH in a positive light (F4)	Cape Times. (2005). City houses recognised for cutting energy, pollution. <i>Cape Times</i> , p. 5.

	standard CDM project. The installation of solar water geysers, ceilings and compact florescent light in 10 households will be rolled over 2000 households		
May-05	A Market survey on the Solar Water Heating potential in South Africa by SolaSure on behalf of the Energy Development Corporation, a subsidiary of the Central Energy Fund	Knowledge development (F2)	Holm, D. (2005). <i>Market Survey of Solar Water Heating in South Africa for the Energy Development Corporation (EDC) of the Central Energy Fund (CEF)</i> (pp. 1–105). Pretoria.
Jan-06	A call by labour and environmental organisations (e.g., Cosatu) to the City of Cape Town to start acting on their renewable energy promises, which includes the installation of SWH in 10% of the homes within the city by 2010	Advocacy coalition(F7)	Gosling, M. (2006, January 27). Solar Heater the answer: Call for city to act now on renewable energy. <i>Cape Times</i> , p. 5. Cape Town.
Jan-07	Eskom organises a workshop for Solar Water Heater suppliers with a primary focus of explaining the Demand Side Management (DSM)	Knowledge diffusion event (F3)	Prasad, G. (2007). <i>Case 19 : Solar water heaters (SWH)</i> (pp. 1–15). Cape Town.
Mar-07	A pilot project to encourage middle- to high-income homes to install solar water heaters in Durban under a R2.5 million project funded by CEF, UNDP and Global Environmental Facility. This is a 6 month project, the learning will be communicated	Pilot project (F2)	Enslin, S. (2007, March 16). Households warm up to solar heating plan. <i>STAR</i> , p. 5.

Jun-07	Eskom is mooted to be finalising a financial programme to set aside R2 billion to roll-out 100 000 solar water heaters around the country over 5 years	Announcement raises optimism within the SHW IS (F4)	Davie, K. (2007, June 7). Sunny side up. <i>Mail and Guardian</i> , p. 1.
Nov-07	Energy planning discussions is dominating the energy sector as Eskom plans to meet energy supply responsibilities mainly via coal fired plants that are proposed (Medupi and Khusile),and also via concentrated solar power plant in the Northern province of SA. On the demand, Eskom is promoting the solar water heater programme	Context	Enslin-Payne, S. (2007, November 30). Not looking at the sun. <i>Diamond Fields Advertiser</i> , p. 18. Kimberly.
Oct-07	Eskom sets aside R2 billion to subsidise the installation of solar water heaters to cut on the electricity usage of the electric geysers. All the solar water heaters need to meet the South African Bureau of Standards (SABS). The target market for the fund is the middle- to high-income and later a low-income	Resource mobilisation (F6)	Robertson, D. (2007, December 16). Eskom goes green with solar heaters. <i>Sunday Times</i> , p. 6. Johannesburg.
Jan-08	Eskom announces that it is on the verge of registering the first group of suppliers to roll out the SWH technology. Eskom's auditors had sent an expression of interest request to 80 suppliers and were	Increased entrepreneurial activities (F1)	Bega, S. (2008, January 26). Eskom to go green with hot water. <i>Saturday Star</i> , p. 5.

	currently being reviewed		
Feb-09	An entrepreneur from the media field, Zwalakhe Sisulu has seen a gap in the market and started a new company, Matla Solar that will manufacturer tens of thousands of these systems per annum	An example of entrepreneurial activities (F1)	Njobeni, S. (2009, February 3). Blue sky's the limit for small solar manufacturer. <i>Business Day</i> , p. 4. Johannesburg.
Feb-09	A year after Eskom has introduced the solar water heater programme, only 800 systems had been installed. One of the biggest obstacles apart from public awareness, is the lack of funding and skilled workers to produce and install the systems	Concern over Eskom's solar slow start of the solar heater programme, not great good for potential investors(-F4)	Modise, B. (2009, February 5). Eskom fails to ignite solar power demand. <i>The Star</i> , p. 1. Johannesburg.
Nov-09	The National Solar Water Heating Conference organised by the Department of Energy. In this workshop a framework which helps roll out 1 million SWH by 2014 is mentioned. Experts from countries with the most successful SWH programmes are invited to share experiences (Israel). Insurance company Santam reports on their pilot plant	Knowledge diffusion event (F3)	Department of Energy. (2009). <i>THE NATIONAL SOLAR WATER HEATING CONFERENCE</i> (pp. 1-48). Johannesburg.

Nov-09	The SWH programme that set out to install 1 million SWHs in 5 years is on track despite the details of how households will access the subsidies being sketchy	Positive news for the industry, and potential opportunities (F4)	Bega, S. (2009, November 14). Plumber shortage takes heat out of solar geyser dream. <i>Saturday Star</i> , p. 8.
Nov-09	A 106 year water geyser company diversifies into the solar heater market. Production of these units reportedly started in 2007.	Entrepreneurial activities (F1)	STAR. (2009, November 27). SA's Renewable Energy: One million solar heating systems could make or break local industry; A 106 years pedigree. <i>STAR</i> , p. 6. Johannesburg.
Jan-10	Eskom increases solar water heating rebates by up to 120 %. The subsidies range from R2100 to R12500 depending on the size and the type.	Rebates(F6)	Rudi, M. (2010, January 29). Eskom increases rebates for solar heating, p. 26.
Feb-10	Short term insurance company Santam is the first in its industry to promote green energy by opting to offer its customers a choice between electric geysers and SWH	Diversification into SWH industry (F1)	Kritzinger, K., 2011. <i>Exploring the possibility of the insurance industry as a solar water heater driver in South Africa</i> . Cape Town: Stellenbosch University.
Apr-10	The SA president officially launches the SWH National Programme which has a target to install 1 million solar water heaters by 2014.The solar water heater industry is seen by	Regulation/Policy announcement (F4)	Salgado, I. (2010). Zuma begins hopeful plan for solar geysers. <i>STAR</i> , p. 17.

	government as a priority sector for addressing the country's energy shortages as well unemployment		
Jun-10	All new buildings in South Africa are to be fitted with renewable energy water heating systems such as Solar Water Heating Systems which also need to comply with the South African National Standards.	Niche market facilitating pronouncement (F5)	Njobeni, S. (2010, June 15). New buildings must follow energy laws. <i>Business Day</i> , p. 2. Johannesburg.
Apr-11	Eskom announces that the solar water heater rebate will be reduced by up to 40%. Quoting that the earlier increase in the rebate tariff has achieved its objective of stimulating the market	Rebates/subsidies cut (-F6)	Ndaliso, C. (2011, April 15). Eskom slashes solar rebates. <i>The Witness</i> , p. 4. Pietermaritzburg.
Nov-11	Local SWH manufactures raises concern with government over SWH heater import market, they lobby government and Eskom to limit the incentives and rebates to local manufacturers	Lobbying (F7)	Naidoo, B. (2011). Local solar water heater manufacturers taking strain. <i>Engineering News</i> . Retrieved from http://www.engineeringnews.co.za/article/local-solar-water-heater-manufacturers-taking-strain-2011-11-11
Nov-11	A 42 year old SWH closes down, reportedly due inability to compete with SWH imports. Moreover red tape (e.g., SABS testing) is said to be responsible	Negative entrepreneurial activity as one of the oldest solar water heater industry closes down (F1)	Gosling, M. (2011, November 11). Sun sets on solar heating factory. <i>Cape Times</i> , p. 8.

May-12	The Minister of Finance announced that Treasury would allocate R4.7 billion to promote SWH programme, the in his annual budget speech	<i>Resource mobilisation (F6)</i>	Peters, D. (2012). Minister of Energy's New Age Business/SABC Breakfast Briefing. Sandton.
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APPENDIX B: The Biogas Industry

APPENDIX B1: An extract from a BIS database

An extract from the database is given in the table below, within an intention of giving examples of activities and events that fulfilled all the seven system functions and those that merely provided context

Year	Summary	Activity type/Category	Reference
Jul-04	Bioenergy in general, and that generated from waste in particular, can play a huge role towards poverty alleviation and sustainable development. This positive outlook on the non-existent bioenergy sector is externally motivated by FAO, which promotes biogas for cooking in countries such as Nepal	Context	Williams, G., 2004. Bioenergy may benefit SA. Daily Dispatch, p.1.
Apr-07	Ivory Park Eco-village plans to install one of the country's biggest biogas digesters to provide energy for the eco-village dwellers while providing sanitation services and reducing greenhouse gas emissions to substitute fossil fuels	Guidance of search (F4)	Marshall, L., 2007. Eco Village provides sustainable living, escape from poverty. STAR, p.33.
Oct-07	A US Agricultural multinational initiate a project in which they will earn carbon credits by investing in a project that converts pig manure into biogas at Humphries in Bela-	Resource mobilisation (F4)	Financial Mail, 2007. Unlikely collaborations. Financial Mail, p.15.

	Bela South Africa. The project involves the construction of the AD and converting the biogas into power		
May-08	Olive Tree Systems biogas company enters the BIS with several projects lined up, including the 5 star garden route hotel, a major Eastern Cape poultry farm and several dairy farms. biogas in the rural areas	Entrepreneurial activities (F1)	Khanyile, S., 2008. Dung provides farm with reliable gas supply. STAR, p.5.
Aug-08	A collaboration between a University Professor and two farmers all based in Kwa-Zulu Natal leads into the construction of a trial 30 cubic metre(bag/balloon) digester, the farm is generating 50kW of power. The Professor suggests that AD could play a key role in farms around South Africa	Pilot project; Knowledge development (F2)	Myrtle, R., 2008. Dung-fuelled power could flush Eskom out. Sunday Tribune, p.27.
Aug-08	A German biogas plant manufacturer Weltec BioPower hopes to join the South African Biogas market. The company's reasons that the prevailing climate of energy scarcity evident by the power shortages provides a conducive environment for investment despite the lack of government incentives	A mooted investment opportunities is positive for the BIS (F4)	Engineering News, 2008. Biogas plant manufacturer hopes to find foothold in South Africa. Engineering News. Available at: http://www.engineeringnews.co.za/article/biogas-plant-manufacturer-hopes-to-find-foothold-in-sa-2008-08-29

			[Accessed May 14, 2013]
	Two farm scale biogas projects are being developed through CDM funding. The two projects are, firstly, a family owned piggery called Humphries farm in Bela-Bela, Limpopo. and another developed months later, is based at the biggest piggery in the country based called Kanhym in Middleburg	Entrepreneurial activities (F1)	Financial Mail, 2008. The power of pigs. Financial Mail, p.38.
Nov-08	A group of parliamentarians get frustrated with the slow pace regarding the announcement of feed-in systems that had been mooted for years. As a result, come up with and handed over their own Private Members Bill on feed-in-tariffs. This prompted government to act swiftly and work towards a three month deadline of February 2010	Advocacy coalition (F7)	Groenewald, Y., 2008. Govt caught napping on renewable energy. Mail and Guardian, p.2.
Apr-09	The National Energy Regulator of South Africa (Nersa) approves the Renewable Energy Feed-In Tariffs (REFIT) Guidelines which are envisaged to encourage investment in the Sector. The	Regulation announcement (F4)	Butler, L.-A., 2010. Boost for green energy plan. THE HERALD (EP HERALD), p.8.

	<p>news is received with great optimism by the lobby groups such as WWF following the 2007 study that Nersa commissioned. Some lobbyists however feel that the draft regulation to promote competitive pricing in the energy sector appears to conflict with the Refit programme and may scare investors away</p>		
Sep-09	<p>A biggest biogas digester linked to a feedlot is being developed. The 3.8 MW facilities will be situated at Karan Feedlot by Independent power producer Lesedi Biogas Project (LBP). The 110 000 tonnes of manure would allow generation of 3.8MW base load and 6.8 MW peak. The project is said to cost \$15million dollars to develop. Eskom, under the Refit programme, is seen as the big off-taker</p>	<p>A project with commercial interest starts (F1)</p>	<p>Harcout, D., 2009. Lesedi Biogas to build \$15m manure-to- plant in Heidelberg, South Africa. Simply Green.</p>
Oct-09	<p>Working for Energy Programme commences, It is spearheaded by the Department of Energy and SANERI, and focuses on labour intensive supply and demand sides of energy provision. From the</p>	<p>The initiative puts biogas technology for purposes of job creation on the national agenda (F4)</p>	<p>Financial Mail, 2009. Efficiency: Energising communities. Financial Mail.</p>

	supply side this includes the production of biogas from farm waste, municipal solid waste, household etc. The projects looks to get some carbon credits from the CDM project		
Oct-10	A biogas digester designed and constructed by researchers at the CSIR Pretoria campus is granted provisional patent. This digester aims to improve energy provision in rural areas that are off the national grid. This digester is designed to treat separated sludge from up to 50 households. The unit that has been provisionally patented has 360 litre capacity of municipal waste (e.g. organic waste, human and animal sludge etc.). The equipment runs on an automated system which reduces the retention time of the sludge by maintaining parameters that assist in the biological breakdown of organic waste. The current project is a follow-up to the CSIR and SANERI funded research which commenced with an investigation of whether the paper sludge can be digested	Knowledge development (F3)	CSIR, 2010. CSIR's biodigester gets provisional patent. CSIR enews.

Jul-12	UCT student organisation Engineers without Borders (EWB) with UCT E&PSE Research Group install an eight cubic metre biogas digester at the Abalimi SCAGA in Khayelitsha. Garden waste is used as a feedstock and the resultant gas piped back to the kitchen where is is used for cooking	Knowledge development (F2)	IRIN News, 2012. South Africa: Smells like a bargain - money-saving biogas. IRIN News. Available at: http://www.irinnews.org/report/96400/south-africa-smells-like-a-bargain-money-saving-biogas .
Jul-12	E&PSE Research Group at UCT wins a grant in collaboration with UniVen to do demonstration projects in urban areas (Cape Town) and rural areas (Venda)	Resource mobilisation (F6)	Lucas, P., 2012. UCT team awarded R2.5m NRF grant for SA biogas projects. <i>Research SA</i> . Available at: http://www.researchsa.co.za/news.php?id=1220 .
Sep-12	Small scale renewable energy technologies produced from low or zero carbon technologies are the latest to be added to energy efficient technologies funded via Eskom's Standard Offer's programme. This is a pilot project introduced with Nersa with the aim of achieving a total capacity of 10 MW in the first phase. This project is in line with Eskom's ambition to broaden the scope of optimal energy usage through the range	Resource mobilisation (F6)	Anon, 2012. Small-scale renewable energy funded through Eskom's Standard Offer Programme. <i>ESI-AFRICA</i> . Available at: http://www.esi-africa.com/small-scale-renewable-energy-funded-through-eskom-s-standard-offer-programme/

	<p>of energy efficiency programmes. Technologies considered include biomass waste, wind energy, solar, geothermal, ground source heat, and thermal gradient. Excluded are a solar thermal liquid heat and municipal solid waste. The projects are restricted to between 10 kW to 1MW. Initially funding will be available for systems that do not feed onto the grid at R1.20/kWh</p>		
Feb-13	<p>The Southern African Biogas Industrial Association (SABIA) is launched on the 8th February 2013 at the Africa Energy Indaba in Johannesburg. Eskom rebate and the Dti have rendered some biogas projects viable. Also, pertinent issues of the availability municipal waste as feedstock needs to be addressed due to perceived problems with the so-called Municipal Financial Management Act (MFMA) which does not allow municipalities to sign a waste contract of more than 3 years with private companies. There is a lots of red tape if exception</p>	Advocacy coalition (F7)	<p>Anon, 2013. New South African biogas association upbeat on growth. Southern African Alternative Energy Association. Available at: http://www.saaea.org/news/new-south-african-biogas-association-upbeat-on-growth-potential</p>

	to the act was to be made		
Oct-13	SABIA in partnership with DoE hosts the first ever National Biogas Conference in Johannesburg. The conference was by invitation to almost 120 delegates. The purpose of the conference was to bring the private and public sectors together. The discussions centred around policy and legislation	Knowledge diffusion event (F3)	SABIA website: http://biogasassociation.co.za/national-biogas-conference-2013/

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APPENDIX C: SECTION 3 – INTERACTING WITH THE SYSTEM

APPENDIX C1: Pilot Projects Concept Design Reports

C1.1: Leo Marquard Hall

Background and project overview

UCT's green campus initiative has as one of its aims a carbon-neutral campus. Organic waste produced on campus ends up in landfill sites where it generates methane, a potent greenhouse gas. Anaerobic digestion technology can be used to produce methane under controlled conditions, and this methane could be used to replace fossil fuels currently used, or even to generate electricity. Research in this area so far has shown that energy from organic waste via biogas would be an important contributor to the ambition of low-carbon urban living - and thus also to the vision of a low-carbon campus.

Objectives and approaches

This project aims to demonstrate that it is technically feasible to produce methane gas from source-separated wet waste on campus, and to use this gas for cooking purposes. Beyond the potential wider application of this technology at UCT, it is important for several current research projects to demonstrate that decentralised biogas technology can be deployed in an urban setting; it is so far regarded to have mainly rural applications.

This project foresees bringing onto campus a 6m³ pre-fabricated biogas digester, near one of the residence kitchens where waste is already sorted into recyclables and wet waste. The unit would take between 20 and 40 kg of kitchen waste per day. The unit can be installed above-ground although a below-ground installation is usually preferred. Treated effluent should go to sewer, and sludge will have to be recovered and disposed of (or utilised for composting) from time to time.

Approach and status

Task team

The project is the academic responsibility of A-Prof. Harro von Blottnitz (E&PSE, Chemical Engineering), and was project managed by a team consisting of:

Ms. Rethabile Melamu (E&PSE, Chemical Engineering), as a Project Manager, Ms. Anya Boyd (Energy Research Centre), Ms Holle Linnea Wlokas (Energy Research Centre) Mr. Brett Roden (UCT's Environmental Officer) and Mr. Greg Austin (AGAMA Energy, the technology supplier).

Stakeholder consultation

Relevant stakeholders were consulted with regards to installing a biogas digester at one of the university's residences. Two of the university departments, Properties and Services (P&S) and Student Housing and Residence Life, were identified as important stakeholders to engage for a successful implementation of the project. P&S is mandated by the university to approve new developments and are primarily responsible for property's maintenance; in addition they are able to avail survey maps if required for design purposes, hence were crucial to engage at early stages of the project. The Student Housing and Residence Life department is another vital stakeholder as it is responsible for management of residences including coordination of residence catering in, although the catering in itself outsourced to a private company (FEDICS).

After a general engagement of stakeholders that was meant to introduce the idea to them, discussions on identifying a suitable catering residence where the biogas digester would be installed were held between the task team and stake-holder representatives. Leo Marquard Hall catering residence was selected as a pilot site; it was qualified ideal because of its kitchen's close proximity to an open outer space and large number of students it services. P&S department provided the task team with a map of the space outside Marquard Hall that it is meant to aid with detailed design. Once the pilot site had been identified, a decision was taken to carry out a formal monitoring and quantifying of food waste generated per meal.

Waste Monitoring

It was recommend that the kitchen staff be given a training session on source separation of waste prior to waste monitoring, which was adhered to. Although Marquard Hall residence, a male residence, was selected as a pilot site, it was decided that Tugwell Hall, a twin female residence be included in the waste be monitoring process for research interests. Bins into which food waste was to be separated into were provided for both kitchens. Two research assistants were employed to facilitate the waste monitoring which was carried out on a daily.

The monitoring was done over 3 weeks, in the first week, only breakfast food waste was monitored and the lunch food waste was monitored in the last week. As much as 38 kg of food waste was generated per meal which is sufficient waste for the pre-fabricated digester to be used.

Site visit

During the initial stakeholder engagements, several concerns were raised; these included odours problems and probability of perpetuation of existing flies' problem at Marquard Hall, the maintenance of the bio-digester once installed, and quality control of the resultant biogas. A consensus was reached for relevant stake-holder representatives to pay a site visit where one of the bio-digesters installed by technology supplier is in operation. The chosen site was Goedgedacht Trust farm in Riebeek Kasteel where both a pre-fabricated and concrete-constructed digesters are installed. The visit addressed the issues raised in the previous meeting of odours, flies, maintenance and gas quality. The observation was that impotent odours that emanated from digesters were only perceivable when the digester lid was opened, while there were no flies identified around both digesters. Both digesters need low maintenance while the biogas generated from a 6 m³ pre-fabricated digester is able to provide more than three cooking hours for 2 households and has never ran out since the digester's installation, while the 150 m³ concrete constructed is able provide up to 8 hours of cooking. After this site visit, stake-holders representatives recommended that construction start as soon as possible, preferably during the university vacation to minimise distractions to the residents and kitchen staff.

Implementation plan:

The next stage is to get a formal consent from the Property and Services department to go ahead with the proposed plan. Next, the technology providers (AGAMA Energy) will be employed by E&PSE research group as consultants to initially carry out a detailed survey of Marquard Hall residence kitchen and outer area where the digester will be installed. Subsequent to a site survey, the consultants will carry a detailed engineering design tailor-made for Marquard Hall to be approved either internally by P&S, however, should there be a need for an external approval probably by the local municipality, the same consultants will be employed by E&PSE to get such an approval.

The Environmental and Process Systems Engineering Group (E&PSE) will drive this pilot activity and take responsibility of the survey and design phases. The preliminary project

activities including consulting relevant stakeholders and monitoring organic waste volumes have already commenced. Should the proposal and the detailed designs be approved internally, the installation could be done during the mid-term break of 2nd semester; the installation usually takes 2-3 working days, external influences such as weather permitting. The digester would then begin its operation at the beginning of 4th quarter.

Once installed, the digester would be operated on monitored diets for a period of 12 months, and its performance regularly evaluated by the E&PSE research assistants, with an option of being shadowed by the kitchen staff to take over at a time that will be discussed at a later stage. However, our team will continue to monitor the performance of the digester from a research perspective. Upon completion of the research phase, the unit could either be handed over to Properties and Services and UCT Residences departments, or removed for research elsewhere in the event that it is found to be inconvenient, undesirable or non-functional. However, after these 12 months there will be a better understanding of the ongoing maintenance routing and cost, and this will be negotiated with the relevant UCT departments.

Resource implications:

The E&PSE research group undertakes to secure funding for the acquisition and installation of the unit, and also to employ research and technical personnel for a period of 12 months to operate and monitor the unit.

C1.2: Siyazama Community Allotment Garden Association (SCAGA) Conceptual Design Report

Background and project overview

The University of Cape Town (UCT) branch of Engineers Without Borders (EwB), a student organisation, has been showing interest in the biogas technology and its potential to facilitate social change for some time. Due to their curiosity, EwB has been in correspondence with a renewable energy company called Green Africa Energy Technologies, which has interests to donate a biogas digester to be installed at a community garden centre in the Cape Town area. For technical support, EwB approached the Environmental and Process Systems Engineering (E&PSE) Research Group at UCT due to its knowledge and technical experience with the implementation of a similar biogas system. Organic waste produced at community gardens in Cape Town is usually composted and used as fertilizer; however there is potential to divert some of it for use as a feedstock for anaerobic digestion and still get some fertilizer benefits.

Anaerobic digestion technology (biogas technology) produces biogas (methane-rich gas) under controlled conditions, biogas can be used for cooking and therefore replace or reduce the amount of commonly used fossil fuels (e.g. paraffin, LPG), in addition the resultant slurry and sludge can be used as fertilizer material.

Objectives and approaches

This project aims to demonstrate the feasibility of biogas technology deployment in a township setting as a vehicle for facilitating social change viz. using waste to generate clean energy for meeting the garden's cooking needs and recycling nutrients from the resultant slurry and sludge to be used as fertilizer in a vegetable garden. If there is more than enough gas for the garden's needs then there is a possibility using it to prepare food (soup, fat cakes) to sell for additional income. This project will further demonstrate that decentralised biogas technology can be deployed in an urban setting; it is so far regarded as more suited to rural environment.

This project foresees the construction of a 8 m³ plastic bag digester, near the community garden's kitchen and in close proximity to one of the compost piles. The unit requires 20 to 35 kg of organic waste per day and twice the amount water, a combination of borehole and grey water will be used. The type of waste to be used as feedstock is vegetable waste, comprising garden waste generated daily and rejects vegetables from the Abalimi market in Phillipi which are delivered to the community garden weekly. The digester will be housed in a concrete structure and a roof will be mounted above to protect it from harsh weather conditions. The resultant effluent and sludge will be used for composting and directly onto the vegetable garden.

Approach and status

Task team

The project is the idea and responsibility of Engineers without Borders (EwB) and it has been made possible by a biogas unit donation from Africa Green Energy Technologies. E&PSE, Chemical Engineering, provides EwB with technical and project management support. The task team has been assembled to ensure successful installation and start-up of the digester. The task team comprises of:

Mr. P. Mesarcik (EwB), Mr. F. Petousis (EwB), M. Nzioki (EwB), Ms. Rethabile Melamu (E&PSE, Chemical Engineering), Mr. Linus Naik (E&PSE, Chemical Engineering), A. Prof. Harro von Blottnitz (E&PSE, Chemical Engineering) Ms Shannon Royden-Turner (Urban Infrastructure, UCT), Mr P. Parks (Africa Green Energy Technologies).

Stakeholder consultation

EwB began with a preliminary scoping exercise to identify potential recipients of the biogas digester donated by Africa Green Energy Technologies company. The scoping culminated in the selection of one of the Abalimi Bezekhaya's (The People's Garden Centre) community garden, as recipients. The first stakeholder consultation with Abalimi was informal and was between Paul (EwB) and Rob Small (founder/director of Abalimi Bezekhaya who then took Paul to visit a few of their community gardens (Fezeka, Scaga and Garden Centre) Cristina (Abalimi's coordinator) was also present at these initial stages. The follow-up stakeholder meeting was more formal and included a capacity building session with representatives from Abalimi management team. The capacity building session was facilitated by E&PSE and held at the Business Place, Centre for Harvest for Hope (Parking and distribution centre) in Philippi. It comprised of a presentation which gave an overview of the biogas technology and its benefits, experiences from elsewhere in Africa and from E&PSE Group from involvement with a similar system installed in an urban area. There was also a question and answer session to clarify issues around the technology functionality, potential benefits of the slurry for use as a fertilizer and different roles for various stakeholders.

The subsequent consultations were done by E&PSE mainly engaging garden coordinator and garden staff, initially to bring them up to speed with the project progress, and the proposed roles that will enable successful installation and operation of the biogas digester. The first visit to the garden by E&PSE was to also identify the exact location within the garden where the digester will be constructed and to work out how waste monitoring will be facilitated. Waste monitoring which takes place once a week is currently underway.

Waste Monitoring

The waste monitoring was facilitated by E&PSE Research Group representatives with the assistance of the garden's staff. The garden staff was requested to collect the waste around the garden for E&PSE Research Group's easy access and put it in a pile for easy access. Different types of waste were weighed (e.g. carrots, potatoes, vegetable leaves etc.) in order

to estimate bag/s or bucket/s of different types of garden waste that would be required to feed the digester. The monitoring was done over 4 weeks, with 5 visits to the garden. From the waste monitoring which entailed just estimating the amount of waste visually and weighing, between 120-150 kg of organic waste is generated weekly, and that comprises of reject vegetables from the Philipi market which is delivered once or twice depending on the volumes and garden waste generated at the community garden.

In addition to quantifying the waste, assessment of the type of waste generated on site is important, from experience with a recent biogas installation; the type of digester feed is of paramount importance, e.g. diet high in carbohydrates could result in the biogas digester being susceptible to acidity and hence result in the production of a carbon dioxide-rich incombustible gas. If such an incident arises, builders lime can be added to neutralize the acidity, failing which the digester would require re-priming (addition of fresh cow dung). Thus far from monitoring, there has been an abundance of leafy vegetables in the waste, although there are different components every week and an also the type of waste is subject to change seasonally.

Site visit

The recipients of the technology are receptive of the technology, however, a site visit is being planned for a few stakeholders who will be operating the digester (feeding) and using the gas to visit Marquard digester to get a feel of how it operates. This will help identify the amount of work required for daily operation of the digester, and possibly address some of the issues that they may have not been voiced out to date.

Implementation plan:

The next stage is to get a formal consent from responsible parties, which Abalimi has identified as the whole Abalimi's Scagar's team. Next, EwB students with the support of Ms Royden-Turner, together and the technology provider (Africa Green Energy Technologies) will facilitate a detailed survey of the exact location where the digester will be installed. Subsequent to a site survey, a detailed engineering design tailor-made for the site to be approved either internally by Abalimi will be put together. However, should there be a need for an external approval, probably by the local municipality, Abalimi, EwB and E&PSE will work together to identify responsible parties.

The detailed design should include the design around incorporating the slurry into the composting and garden operations (e.g. connecting to the overflow slurry into composting operations and directly to one of the plots in the garden). Should the proposal and the detailed designs be approved internally, the installation will commence on in December and the installation is envisaged to be completed in 2 weeks. The start-up of the biogas digester will need to be decided upon by stakeholders:

Once installed, the digester start-up will commence at the beginning of 2012 depending on the the availability of the community garden's supervisor's availability. The start-up phase will entail priming the digester with cow dung and introducing the waste once the digester starts producing gas. The performance will be monitored regularly by EwB with the support of E&PSE for the first 2 months after the start-up. Thereafter, the unit will be formally handed/signed to Abalimi, however E&PSE would like to be involved in remote monitoring as part of the ongoing research and will be on standby on behalf of EwB should assistance be required with regards to the operation of the digester. Africa Green Energy Technologies will provide guarantee on the unit's and should be available if there a major fault with the unit and the gas line.

Resource implications:

EwB undertakes to secure funding for the acquisition and installation of the unit, and for the start-up of the digester. Thereafter the unit will be in full responsibility of Abalimi.

APPENDIX C2: Lessons learnt from setting up LMH biogas digester reference

Stakeholder collaboration and learning during the concept design phase of an urban biogas project

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Abstract

Anaerobic digestion (AD) of organic matter to produce biogas is a waste management option for waste streams high in organic matter which are unsuitable for thermal treatment. In Africa, the implementation of this technology is slow compared to developed countries, more so in the urban areas in contrast with rural areas. An understanding of factors behind the low rate of implementation of this technology is needed. As a response to this challenge a research group at the University of Cape Town (UCT) set-up a multi-disciplinary team to implement a biogas digester on the UCT campus as a demonstration project. This paper aims at documenting notes on stakeholder collaboration and learning during the concept design phase to implement an urban biogas project. One of the findings of the project thus far is that a significant proportion of time needs to be dedicated to establishing key stakeholders and decision makers. Education, training and good relationship with stakeholders and the technology provider were also found to be important in the concept design of the project.

Keywords

Anaerobic digester, Biogas, Stakeholders, Consultation

APPENDIX C3: Workshop documentation

Workshop Invite & Programme

Biogas Innovators Workshop

Invitation to a 1-day workshop on the role various stakeholders should play to foster a successful evolution of the Biogas Industry in South Africa. The role and functions that stakeholders need to perform will be analysed and discussed through a technology innovation system (TIS) framework. The workshop provides a platform to address issues that would improve the dissemination of biogas technology in South Africa. The outcomes are expected to include activities that various stakeholders represented can engage in post the workshop to influence the growth of the industry. By invitation.

Workshop agenda:

09h00-09h15: Welcome (Prof. H. von Blottnitz)

09h15-10h00: Overview of the TIS framework & German biogas experience (Ms R. Melamu)

10h00-11h00: Introduction show & tell/ tea & coffee

11h00-12h30: Breakaway (SWOT analysis of 7 functions) & Report

12h30-13h30: Lunch

13h30-14h30 Breakaway session (Network analysis)

14h45-16h00 Site visits (Marquard Digester, SAB)

Time: 09h00-16h00
Date: Friday, 11th May 2012
Cost: R800
Address: Belmont Square
Belmont Rd
Rondebosch



Environmental & Process Systems Engineering

Workshop Outline

Biogas Innovators Workshop Minutes: Friday, 11th May 2012 (09h00-16h00)

Welcome and Background presentation: A/Prof. H. von Blottnitz

He mentioned that good things are happening in the South African bio-energy sector; however they are far too slow, despite having been found to happen faster elsewhere (e.g. Asia, Europe etc.). A system theory called ‘technology specific innovation system’ has been used elsewhere to understand the innovation process. It was obvious for most of present why biogas technology was an obvious choice to study.

He showed bioenergy estimates as predicted in 4 recent studies viz. (Marrison and Larson, 1996; Lynd et al, 2002; Austin et al, 2006; Burton et al, 2009). He worked out that 5000GWh final energy can be produced from municipal solid waste in the metros alone and energy from waste water to at 9000GWh which could exceed the estimated 10000GWh from renewables

by 2013 (White Paper of Renewable Energy) however there was a consensus amongst those present that this is most unlikely to be realised by 2013.

He also shed a light at the dangers associated with some crop-based biofuels (e.g. corn based ethanol) which they was predicted in even earlier of our studies but confirmed in a recent study published in Environmental Science and Technology titled 'Replacing Gasoline with Corn Ethanol Results in Significant Burden Shifting. He concluded by broadly outlining the scale of biogas activities which could be classified by size viz. small decentralised (e.g. Farms, homesteads, parks and gardens etc.) and large 'industrial (e.g. Breweries, food processing, silage maize etc) or feedstock crop-based (e.g. algae etc.) or waste streams (e.g. cow manure).

A presentation on 'The theory of technology innovation system – and how it has been found to apply to biogas: Ms Rethabile Melamu

She began by summarising recent activities in biogas space in South Africa. One of the things that she highlighted was how the number of biogas plants installations has increased from less than 10 at in early 2000s to hundreds a year and counting a decade later. She also suggested supporting structures and policies that may have contributed the upward trend in biogas installations observed. These include the publishing of the White Paper on Renewable Energy in 2003, the announcement of Working for Energy Programme in 2009, the announcements of the Technology Innovation Act and National Energy Act legislations. One of the highlights in the past 10 years was using carbon credits to set up 2 industrial biogas plants, one, a 4.2MW plant at a PetroSA plant Mosselbay another at a SABMiller Rosslyn Brewery.

She mentioned that more than 100 small decentralised biogas plants have been installed in the country (e.g. Biogas Pro (a pre-fabricated fixed dome digester by AGAMA Biogas), the TradePlusAid programmes, Nova programmes, Giyani Programme, Biogas Africa etc). The large scale biogas plants include 3 SABMiller Breweries (Newlands, Rosslyn, Alrode), Petro SA, Humphries Piggery farm. There are a few that are in line or installation including Bronkhorstspruit project (a 3 MW plant to be fed on farm waste), UKZN-IDC-KAREBO project, Hassequa municipality (500kW to be fed on municipal solid waste). There isn't much happening on the use of crop-based feedstock and use of algae is not an experimental level.

She introduced the theory of ‘technology specific innovation system’ (TSIS) and how it has been found to apply to understand the success of the German biogas industry. TIS is defined as ‘actors, their networks and institutions arranged around a specific technology for the development, diffusion and use of the technology or product thereof’. She highlighted that the TSIS is usually embedded in National Innovation Systems which themselves can be part of Supranational Innovation System contributing to the global innovation. TSIS can be dynamically analysed using 7 system functions viz. i) Entrepreneurial activities, ii) Knowledge development iii) Knowledge diffusion iv) Guidance of Search v) Market formation vi) Resource mobilisation and vii) Advocacy coalition. For a TSIS to grow from formative phase to market phase activities by actors, networks and institutions need to fulfil the seven functions and they should reinforce each another into virtuous cycles over time. That it is exactly what happened with the German Biogas Industry, in its formative stages advocacy coalition and knowledge diffusion were the driving functions whilst in the market phase the drivers were the guidance of search, company formation with resource mobilisation and market formation functions which were not present in the formative stage, outcomes of the system.

Show and tell session: All participants

This part of the workshop was interactive with those present show-casing and presenting their biogas related activities.

Breakaway session’s outcomes:

1st breakaway session:

In this session, participants were grouped into functions they felt their activities were most aligned to; 4 functions (knowledge development, knowledge diffusion, market formation, advocacy coalition) were represented and deliberated on the following questions: their current activities, who else is fulfilling the activities and on their challenges?

Functions 3 and 7

Their current activities include: Facilitation of mutual understanding of policy and practice in the Western Cape relating to renewable energy and sustainability. Some of the representatives had set-up demonstration projects for generating energy from waste (e.g. Johannesburg zoo). In addition they facilitate dialogue between the stakeholders, including

specific community interactions and public capacity building. They engage with officials, politician, media to unpack power/energy nexus, advocate for decentralisation and consumer needs.

Others who were not present at the workshop and thought to fulfil the same include: (WWF); SESSA; ELA, Energy Caucus, Wild Lauds Trust, EMG, SAFCEI, SLN. Some of the challenges that are limiting to fulfilling functions include: weak guidance of search from the government, the centralised nature of decision making is also seen to limit change. In addition, there are challenges for setting up small scale demonstration projects especially as there have been a number of failed examples. Issues of land use are still very high on the bio-energy debates also. Lastly, it is sometimes not so straight forward to identify who is be advocated for and related to that funds to properly advocate are limited. The functions that were identified instrumental to the proper functioning of the 2 discussed above are knowledge development and entrepreneurial activities.

Function 2: Knowledge development

The following entities represented summarised their activities SANEDI; Pilot plants; VUT; Basic and applied research; E&PSE (UCT); Scientific methods, application , knowledge support; AGAMA; technical consulting, innovation, R&D, investment; City of Cape Town: R&D in waste optimisation. There are many more players/actors who fulfil this function, they include other academic institutions (e.g. University of Pretoria, UKZN), other biogas companies. Some of the challenges that limit this group to fulfil their function are political issues, legislation both locally and nationally, procurement processes are cumbersome. The prices and functionality of the digesters can and should be improved. Lastly, there is inadequate upfront planning for some pilot plants, i.e. no system approach in planning (e.g. biomass availability).

Function 6: Resource Mobiliser

Some of the current activities by actors who fulfil function F6 include; access to technology and expertise, identifying market needs and adapting/tailoring the technology offering to suit the need, ensuring good communication and education /consumer buy-in, being involved in implementation and demonstration activities and in some instance funding. Others who would fulfil the same function include: funding agencies like IDC, DBSA; other biogas companies, e.g. Cape Advanced Engineering, NGOs Department of Energy (DoE). Some of

the challenges that hinder the fulfilment of the function include; advocacy, limited awareness regarding the technology, limited number of demonstration facilities and time and money relative to market formation.

2nd Breakaway session:

This was an open session with everyone giving input on the posed questions; what should each of the actors be doing to fulfil to better fulfil the functions and generally a way forward for all of all in the industry. The inputs are presented in the Table below for each of the functions:

Functions	Recommendations
Entrepreneurial activities	
Knowledge development and diffusion	<ul style="list-style-type: none"> • Need for more knowledge development, for instance biogas/gas standards are non-existent; there is a even need to grow more capacity around the biogas technology • Easy to use tools that will aid in decision making, e.g. similar to the one AGAMA developed for the South African Cities Networks are needed • Biogas training can be incorporated into the existing Skill Education Training Authorities (SETA) • Key decision makers (e.g. senior managers) also need to be trained so that they can be agents of change • Regional specific data that can be easily disseminated to locals would be useful • Abilities to communicate with municipalities need to be improved • Communicate technologies to

	communities early on in their dissemination
Guidance of Search	<ul style="list-style-type: none"> • It was also pointed out that non-electricity uses of biogas do not fall under IRP, and thus much more capacity can be generated for other energy application e.g. thermal applications • Incorporate bio-energy in within the activities of National Planning Commission
Market formation & resource mobilisation	<ul style="list-style-type: none"> • Biogas has a place and role to play in creating climate change related/green jobs
Advocacy coalition	<ul style="list-style-type: none"> • Bio-energy has traditionally been poorly advocated for in comparison to solar and wind energies hence the IRP favours the latter technologies • A strong indication to increasingly advocate for bio-energy and as opportunities arise • Getting buy-in from people who make decisions is important

Generally, the following functions are currently being fulfilled in the South African Biogas Specific Innovation System; viz. knowledge development and diffusion, some guidance of search and advocacy coalition but with weak linkages between them.

Site visits

There were 2 site visits, one to a big one at Newlands Brewery Biogas Plant and a smaller one at Marquard Hall, UCT.

APPENDIX C4:

The purpose of the interview is to primarily collect data for Module 2 which answers the second question of the study viz. which of the seven functions can this work most influence or strengthen? And how would one go about influencing identified functions, consequently contributing to improve the operation of an innovation system. Guiding questions for the knowledge development activities and sample interview summaries are detailed first followed by thematic questions on the impact of knowledge diffusion event followed by sample interviews summaries

APPENDIX C4.2 Guiding questions for semi-structured interviews with pilot projects' visitors

Guiding questions for semi-structured interview with pilot projects' visitors:

1. What does your current job entail? Specifically, what are some of activities does your organisation take part in with regard to bioenergy from waste?
2. How long have you been part of the Bioenergy Sector in South Africa and how have your activities changed (if so) over that period?
3. What you have been up to in relation to the biogas since you visited the digester or attended the workshop?
4. Have your activities increased/decline in the past few months?
5. Why do you think that your activities will either increase/decline in the few months/next year?
6. Did you learn anything new from the visit to the pilot project/s? If so what is it? And has that shaped the way you participate in the BIS through your everyday job
7. Did the visit inspire you to take part in any activity either in your professional or personal capacity?

Examples of interviews summaries:

Sample interview summaries from workshop attendees from various sectors viz. government, consultancies, private sector and academia

Lisebo's summary of the follow-up interview: 28th February 2013: Government

What does your job entail?

I work for the Department of Economic, Environment and Tourism in the province of Limpopo. We have a mandate to promote the economic development and the green economy.

The pursuit of green economy opportunities commenced in the 2012-2013 financial year. My work entails ensuring economic opportunities in the green economy are exploited and jobs created.

When did you visit the LMH digester?

I visited the digester about a year ago. We had just heard about the potential of the biogas technology and the role it can play in the green economy and job creation. We felt this might be a great opportunity for us to create jobs in the province, when we heard about the type of digester installed at LMH we approached the company that manufactured them and we subsequently visited LMH digester.

Did you do any biogas work before you came to visit the LMH digester?

No, we did not do any biogas work at all before we came to visit the digester, our biogas related activities only started after our visit and I learnt new things

Did the visit inspire any activity? If so what kind?

We bought a similar system to the one installed at LMH, which we donated to the University of Venda, one of the major universities in our province. Inspired the setting of the LMH digester, we felt a university was a context to trial the digester. We have since signed an MOU with the same university and we now fund most of their biogas activities. Our department has identified the University of Venda's Centre of Excellence in biogas related work in the province. The donated digester has already been installed, after it has gone through the different stages of engineering designs and approvals from a number of stakeholders including the university management. Moreover, University of Venda is documenting lessons learnt from setting up a pilot project which they intend to share it at the official launch of the project in the near future. UniVen has also helped with the roll-out of fixed-dome digesters in the households around the province. Province is also planning to train 10 artisans to build biogas digester for rolling out in the province through the UniVen centre of excellence.

What other activities has your job entailed?

We have continued with our biogas projects through the University of Venda, but have also been working on the installation of Solar Water Heaters as part of our drive to promote the green economy.

Did you impact or influence change in any way since your visit to LMH?

Indeed, through our activities we have started promoting biogas in the province, through the University of Venda.

Have your current activities increased? And how is the outlook going forward?

Our current activities have increased drastically since we visited the digester and continue to increase. Through the training of 10 people who will help install the digester we believe we will have a far reaching impact going forward.

Paul's summary of the follow-up interview: 28th May 2013: Consultancy

Did your work entail anaerobic digesters/biogas prior to your visit to the workshop?

I was only involved marginally before I visited the biogas digester. However, I had visited biogas digesters overseas. For instance, in Germany, I got to see the large and medium scale systems while in Spain I visited large scale systems. But I had never seen a small scale system until I visited LMH digester.

So what did you make of the digester?

The visit was just outstanding; I was really struck by the simplicity with which the system operated. I like the fact that it wasn't in people's faces, totally out of sight, yet delivering useful energy. I was really struck by the potential that this technology can have on a broader scale in South Africa. In this country we tend to centralise services, e.g., centralised waste water facilities, solid waste facilities etc. and we miss the impact that the decentralised systems can have in addressing some of our current problems.

There are good examples of decentralised systems however, one such example composting of organic waste at a garden scale. That has really made think how crucial it is that we ought to change the way we think about treating/dealing with our waste stream from the conventional centralised approach to treating our waste.

The main challenge however will be the cost of adopting these alternatives, currently they are quite pricey. We should also deliberate on how to bring the price of biogas systems down, for instance, we need to ask ourselves questions like, how did the Asian countries that have widely adopted the technology manage to bring the prices down? A more in-depth understanding of this is crucial

Have you done anything with the knowledge/experience from visiting the Marquard digester?

I am planning to install the system in my home. The truth is that although the technology seems easy enough, for it to be adopted at large scale there is a need for a mind shift. With regards to our work, efforts have increased in our Cape Town office with regards to energy from waste projects in general, but currently we have not secured any project. Our Gauteng office has, however, made better progress. For instance they have managed to secure a farm scale project where the waste will be utilised for waste generation.

In your view what is/are missing ingredients for the industry to grow and progress?

In my view the big step would be establish the biogas industry. I see municipalities playing a crucial role in achieving this e.g., through making land municipal vehicles available. Related to that, is the creation of the biogas market, which should entail converting some of the vehicle fleet that operates in the city (e.g., MyCity buses, Jammie shuttles, waste picking trucks) to operate on biogas just as it has been done elsewhere in the world. Once you have the vehicles converted you will need mechanics to maintain that fleet, so that also creates a secondary market around biogas use. And of course there is potential market creation on the supply side, e.g. biogas can come from waste treatment or transfer facilities or landfills.

So can municipalities achieve this? If so what is hindering them from doing so?

First, crucial knowledge around establishing biogas industry i.e., creating jobs and energy is missing within municipalities in South Africa. We tend to use knowledge that comes out of the United Kingdom and United States of America, but have missed important developments in the rest of Europe, especially Western Europe and Asia. Secondly, decision making at municipal level is based solely on financial viability of the projects or venture and not on the other important factors such as improvements in environmental and socio-economic impacts. The public sector does not yet understand the triple bottom line that the private sector has come to understand a lot better.

Lastly, one of the biggest stumbling blocks for municipalities to pursue these projects is has been the Municipal Financial Management Act, which is an act by parliament, that requires municipalities to undertake financially based feasibility studies for any of the projects they

wish to undertake. This is an extremely costly exercise and the national government should ideally change it. That will make pursuing waste to energy projects relatively easy.

Susan's summary of the follow-up interview: 30th June 2013: Private Sector

How much did you know about anaerobic digesters/biogas prior to your visit to the workshop?

I was introduced to the technology approximately 6-12 months prior to visiting the 2 demonstration facilities in Cape Town, the Marquard and SCAGA digesters. One of our colleagues who had visited the SCAGA project a few months before suggested that we visit the projects as part as environmental sustainability aligned with the mandate of our mandate within the organisation

Did you learn anything new from your visit?

I really learnt a lot from the visit. First, I was learnt that the system does not have to be complicated; I was envisaging a complicated system. Secondly, that technically, a small scale AD system is was not that complex to install or implement. And lastly, the cost of implementation was very attractive; it was a lot lower than we had thought making it relatively easy if we were to implement it as part of our work.

Did you do anything with the knowledge you gained through your visit?

We are considering implementing a similar system as a pilot/demonstration in the next few months. We have so far discussed amongst the colleagues the potential site for the pilot study. We had hoped that we would have the pilot up and running for the World Environment Day, this year's theme is 'Think and Save'. The biogas demonstration facility would have gone really well with this years' theme, but we won't be able to make in time for that. For now we have tentatively agreed on a location somewhere in the Northern Province as a pilot site.

Did your work entail anaerobic digesters/biogas prior to your visit to the workshop?

Although none of our current activities are directly involved in generation of energy from waste, our company takes the issues of energy efficiency and reducing carbon footprint very seriously, in line with our long term company's strategies. The pilot/demonstration facility that we are planning is to show how the company can add value to people's lives while at the same time reducing the carbon footprint. And course, we would like to show that this project

can work and use it at a platform for future planning. We are looking at implementing the technology at an even larger scale if the demonstration/pilot project is successful.

What are the plans going forward?

We believe the pilot/demonstration project is something that management would like but for now we would like to keep our activities on a low profile amongst those directly involved, only when it starts working can widely make it know.

Mary's summary of the follow-up interview: 27th March 2013: Academic

When did you visit the digester and what was your experience like?

My first visit to the Marquard biogas digester must have been 18 months ago. My experience was a positive one, I liked how it worked. That visit and the Marquard digester subsequently came up in the following forums. I worked alongside the chairman of one of industry associations I am affiliated with, the Water Institute of Southern Africa (WISA), to organise a tour of the LMH digester with fellow members, my colleagues from found the visit useful and heartening.

Why did you visit the digester?

I am personally interested in anaerobic digestion both from research point of view but also practically as a potential business venture. My interest is around nutrient recovery, especially from the agricultural perspective. Also related is the ability of the technology to remove pathogens from either waste water. My interest is really around closing energy and material cycle, but I should stress that I am more interested in nutrient recovery. I view AD as some form of a waste bio-refinery that is crucial for eco-system type of economy.

Since you are already doing research in the field, did you learn anything new from your visit?

Yes and No. Yes, I learned about a few non-technical lessons. For one, I was pleasantly surprised that the system isn't as complicated as I had thought, and although I had seen the AGAMA unit on their website, I had never seen it at work. I also got to learn about the processes around permissions, community acceptance and how it was made to work. No, in that I know a lot about AD technology, as I research in the field of bio-refineries.

And so what did you do with the knowledge that you gained for the visit

I spread the word. As mentioned earlier, after my first visit, I co-organised for a tour of LMH digester with my colleagues at WISA to. E&PSE research leader (the author of this thesis) was an invited speaker on biogas technology and LMH digester in general, following the tour of the digester.

What in your view are the hurdles that are preventing this seemingly uncomplicated technology from being widely disseminated?

There seemingly no incentives to explore the technology on a larger scale. From what I have heard, costs of implementing these systems is too high, this is especially true for households systems. Also, there is a sense within utility sectors and municipalities in general, that the interventions will not be profitable, so there is a sense of reluctance to invest on big scale projects

Any views on how these issues can be addressed going forward

My views, informed by recent readings, are that biotechnology technology will only really pick up when the investment in IT (Information Systems) goes down. Science is also way too rigid, so, ways of making it easy for people to work with is crucial for technology to take root in society. I think the legal framework that governs waste water (municipal services) are fine, but their interpretation remain problematic. Overall, there is a need for more practical examples, that demonstrate how one can play with the system.

APPENDIX C4.2 Guiding questions for semi-structured interview with workshop attendees:

Guiding questions for semi-structured interview with pilot projects' visitors:

1. What do you think your role is within the BIS? What kind of activities does your job entail?
2. How long have you been in the industry? Have your activities changed over the years? If so, in what way?
3. Of the seven types of processes or activities discussed at the workshop which ones do you consider to be enablers and/or barriers to you effectively playing your part within the BIS?

4. Have your activities increased or declined in the past few months to a year, or since the Boigas Innovators Workshop?
5. Did you interact with any other workshop attendees after the workshop? If so who was it?
6. Did your interactions lead to any outcome that contributes towards the fulfilment of one or several of the seven system functions??
7. Any general comments about workshop and the biogas industry?

Examples of interviews summaries:

Sample interview summaries from workshop attendees from various sectors viz. NGO, private sector, technology development agency and research & academia

Stanley's summary of the follow-up interview: 27th June 2013: NGO

Tell me about your involvement in the industry, what are some of the activities that you or your organisation do?

Biogas technology was on my radar prior to the workshop, I viewed the technology as a potentially good addition to one of our educational courses at WESSA. Also, others had already shared insights with me about it. And of course, as we got more and more interested in sustainability, I began doing my own research. I have also been told of working biogas digesters in Namibia, both at household and at institution levels. Later on, I became aware of the AGAMA system that had been installed at UCT and other parts of Cape Town.

Overall, I see my exposure to the technology as a result of cumulative impact from various sources. Although I do not have that much technical expertise, as a member of Peak Oil Association and participant in the Transition Town movement and energy caucus as well as working for WESSA, I consider these bodies great platforms for discussing/sharing what we know about the technology as our contribution to the development of the industry. My disappointment has been that waste in our country is generally externalised. What is really needed in my view is to combat the state of mind that embraces dependency and instead exploit opportunities such as biogas technology to address several societal problems.

Do you perhaps remember around what time (in years) you started having interest/being involved in the bioenergy/biogas industry?

It has been several years, over 3 years or so

What you have been up to in relation to the biogas since you visited the digester or attended the workshop?

I have added a bioenergy/biogas component to our training modules for the Leadership course on Sustainability this year. We have also been working with Zero Organics to Landfills, a composting company that is also toying with small scale anaerobic digesters, of approximately 200 litres. I feel their approach is based on sound engineering and we would like to mimic their system. Due to the relatively small amount of biogas they produce, they are currently burning it off on a bunsen burner to heat water as they are off the electricity grid. I paid them a visit for the first time last year.

We are planning to build a drum sized biogas system, and are hoping to use the biogas on a retrofitted LP gas burner for demonstration purposes, specifically for the students who take part in the Leadership course on Sustainability. One of the things I would like to learn is retrofitting of the current LPG burner in a relatively easy manner to operate on biogas. And of course, I see biogas technology working well/complementing the concept of Green Shacks and sustainable housing design.

Have your activities increased/declined in the next few months/year?

The activities around biogas have increased, so much that we are planning to build our own drum biodigester similar to the one constructed by Zero to Landfill. The students have learnt about biogas and they are also taking up the challenge to build biogas digesters. Also, E&PSE Research Group at ChemEng UCT came earlier in the year to give input in the bioenergy module, sharing their experience on operating a digester and generally about the status of the biogas system in the country.

About the workshop, one of the objectives was to begin to discuss issues that will improve the dissemination of the biogas technology. To what extent do you feel this was achieved at the workshop?

It was good to know and meet other industry players, which is good for information sharing. It was also good to meet people pushing the same agenda, e.g., other NGOs. There were also useful discussions in the workshop which led to more insights around policy, the issues of green jobs as well as eco schools. The discussions also highlighted some of challenges like

bad demonstration projects owing to lack of understanding of the technology then impacting on the credibility of what should be a growing industry.

Any general comments about workshop and biogas industry in general?

For the technology to be successful in the country, several industries would need to come on-board. Those industries include: sanitation, plumbing, electricity etc. although some know about the technology most are not aware of it and there is little in terms of policy to encourage awareness and uptake unfortunately. One way of solving this could be through an 'Energy Literacy course' which is both accredited and funded that officials who are involved in the sector can and should attend.

It will be useful also to look at ways in which biogas can be used, e.g. biogas cleaning. I am also noting that there is an increased media coverage about bioenergy in general and that can only be good for biogas technology and a useful alternative to the commercial and often destructive biofuels industry. Like solar and wind biogas offers decentralized power supply options which could challenge the traditional tightly controlled and centralised model. In this way it can contribute to the unfolding of democracy by distributing energy production and benefits amongst more actors across society.

Our role is of knowledge dissemination, but also we also make use of various platforms to advocate for the technology.

Have you since interacted with anyone who attended the workshop? If so with who and what kind of interaction is it?

With AGAMA who have provided a lot more technical guidance and supplied us with a predrilled burner as well as the plans for making them yourself.

Interestingly I was approached, after a short energy presentation I gave to a multi-sectoral civil society grouping, by someone from the Gauteng wastepickers association who is keen on having organics separated at landfills to provide feedstock for biodigestors. He will contact me about getting your details.

Seba's summary of the follow-up interview: 27th June 2013; Academic

Tell me about your involvement in the industry, what are some of the activities that you or organisation do?

I have been working in the waste water treatment sector for quite some time from a research perspective, mainly focused on aerobic treatment and adsorption. I have only started working on anaerobic digestion & biogas related research about 2 years ago. There are quite a number of activities that I am involved in. One of the research focus area is around improving the bio-degradation of recalcitrant waste streams to improve biogas production and methane yields.

One of the waste streams that we are focusing on is molasses waste water. We have been able to identify the sequence/configuration for treating molasses waste water. We employ photo degradation followed by anaerobic digestion (AD) in a sequence that best fits the type of waste water we are treating. In some instances, photo degradation process comes first followed by AD, in some instances; the reverse is a preferred configuration. Other waste streams that we work with are dyes, pharmaceuticals, and streams that have high phenolics concentration such as abattoir waste. With regard to the size of AD reactors, currently the biggest size we are employing is approximately 4 litres.

Do you perhaps remember around what time (in years) you started having interest/being involved in the bioenergy/biogas industry?

We started working doing research in biogas about 2 years ago.

Are involved in the same activities you were involved in when you first got involved in this industry/innovation system?

Yes the activities are largely the same, with a lot more activity and more emphasis now on process integration.

What you have been up to in relation to the biogas since you attended the workshop?

I have continued with my research activities, which have increased. We currently have an equipment budget of R8 million and planning on installing a system similar to the one installed outside the UCT residence in the near future. We are also in a process of purchasing a solar simulator for the Advanced Photo-degradation that precedes or follows the AD process. We are also looking at collaborating with colleagues from Kenya and Nigeria on bio-methane potential of water hyacinth.

Have your activities increased/declined in the next few months/year?

Activities have increased significantly since I started working on biogas research. When I joined the institution I only had one part time Masters student. Currently, I have 15 post-graduate students working in different aspects of our research, 10 of whom are full time. Some focus on t photo-degradation, whilst others are focus on improving the biogas production and methane yields. We have been collaborating with Talbot&Talbot on our AD work on molasses waste water for the past 2 years.

Have you interacted with anyone who attended the workshop?

I haven't yet been in touch with anyone I met at the workshop. One thing that was useful is the site visit to the LMH digester, which converts food waste into biogas. We are currently looking at installing a similar system and therefore may need to contact some of the people we met at the workshop. We are looking at collaborating on research and with government entities that are involved in similar research.

What in your view is an obstacle that your work addresses and any general comments about biogas industry in general?

My concern is that African policies and bioenergy agenda are formulated and based respectively, on wrong data. There is a need to generate context (site specific) specific data for us to better inform policy. For instance, even from a scientific point of view, aspects like C:N ration are waste stream specific and can vary widely.

If we were to host another one of these workshops, whom do you think we should invite? And what should the focus be?

The attendance was very representative of the stake holders. Perhaps more microbiologists and civil engineers could spice the discussion.

Thandi's summary of the follow-up interview: 23rd April 2013: Academic

Tell me about your involvement in the industry, what are some of the activities that you or organisation do

I work for the Technology Innovation Agency (TIA). My department's focus is on the industrial bio-technology sector, and waste to energy has been one of our central areas. Our involvement in the industry/sector is largely from the investment side of things. Some of our activities include assisting entrepreneurs develop their innovative ideas, piloting ideas and assisting with business start-up in the sector. We also help innovators or new start-up

companies with non-financial support tools. One way of achieving that is by commissioning/conducting studies that help identify hurdles to entering the market.

Overall, we as TIA mobilise resources to finance initiatives for various purposes. First, with the aim of removing/sharing risk by financially supporting pilot projects. We also help conduct studies which seek to understand how a technology can be taken into mainstream market. We also feel that we play an important role in the development of an industry through hosting of workshops that create awareness about various bioenergy technologies.

To some extent we see ourselves also providing guidance to the sector through the advocacy of proven technologies

Are involved in the same activities you were involved in when you first got involved in this industry/innovation system?

So waste to energy and biogas in particular have pretty much been on our radar since the workshop, although there is a slight shift in our broader strategic focus.

Have your activities increased/declined in the next few months/year?

It's a bit of a tricky question, in a way yes because of the interactions that I have made in the past year. However, the department has shifted its focus from the specific bio-energy in the past few years, a broader strategic focus is on bio-remediation. However, I still use the same platform to pursue waste to energy projects, and indeed I see my activities growing in the next year on both avenues in the past year.

What stood out for you during the workshop? If we were to host another one of these workshops, whom do you think we should invite? And what can we do to improve on it?

The workshop helped raise awareness of biogas activities in the country, so in that way I found it most useful. I thought the 'framework' that is used in the PhD (of the thesis) author taking part in as an attempt to understand the slow diffusion of biogas technology in the South Africa has been helpful in identifying where the hurdles may be. I have been able what I shared that which I learnt workshop with some of the people I work with.

If we were to host another one of these workshops, whom do you think we should invite? And what can we do to improve on it?

If a similar workshop is organised I it will be useful to invite more private players, I would personally like to hear about hands-on experience from the companies that are working in the

biogas industry. In fact, what I would like to see is these companies compiling a list of barriers and hurdles that they have experienced in setting up their various problems.

Have you since interacted with anyone who attended the workshop?

Yes, through the workshop, I was able to make a few contacts. These are the contacts that we would otherwise not have made had we not attended a workshop. It was through that workshop that I was able to invite 3 of the workshop participants. The three were from UCT (E&PSE), SANEDI and from an independent project development company (entrepreneur) to a Southern African ICS-UNIDO regional workshop on bio-energy from agricultural wastes and algae held in Centurion in July 2012. All the 3 participants were able to attend and gave input in the form of presentations at a 3 day workshop.

I have also been in touch with SABIA's president and his colleagues. Overall I want to remain informed and possibly work out how I can contribute towards the shaping up of the industry. I have also been involved with more knowledge dissemination activities related to the energy from waste in recent times. I have managed to establish contacts with colleagues within the City of Cape Town innovation hub and would like to exchange ideas with the UCT E&PSE Research Group and a project developer on an industrial biogas project.

Any general comments about workshop and biogas industry in general? Also, what in your view what are current hurdles addressed by your current activities and any comments about biogas industry in general?

The workshop was good, I liked a mix of the attendees, representatives from the municipalities, some private companies, SANEDI etc. I think provincial government can play an instrumental role in taking this industry to another level, and that needs to be deliberated and discussed by responsible entities, still it would be useful for the industry move from current levels to real implementation

George's summary of the follow-up interview: 31st May 2013: Private sector

Tell me about your involvement in the industry, what are some of the activities that you or organisation take part in?

Just before the workshop I was involved in three bioenergy projects, all of which were based within municipalities. These projects didn't move beyond the concept phase due to several

issues. Waste to energy in the municipal context is very tricky and this is due to the institutional hurdles, particularly the MFMA, a municipal supply chain procurement act. Moreover, lack of political cohesion within municipalities hinders these projects from getting off the ground. I actually started working in the bioenergy sector/industry as early as 2005. Initially my interest was in biodiesel production from both waste oil and oil crops. Later on, I worked on a thermal conversion of waste to energy project with Eskom whilst working for the city from 2007 to August 2011.

I also worked on a project that looked at harvesting of biogas from landfills. I later on picked interest in both anaerobic and aerobic fermentation of organic waste, with the former being for energy production whilst the latter was for manure production. On that line of work, my team and I commissioned a study to the University of Cape Town to conduct a bio-methane potential of various feedstock around the country. Lastly I was also to some extent involved in research in the area of Refuse Derived Fuels (RDFs). So to sum up my activities in the sector, I have been involved in various roles: as a civil worker, I was part of a team that mobilised resources that were used to conduct R&D and pilot projects. In the later years I have worked in the industry as an entrepreneur.

Are involved in the same activities you were involved in when you first got involved in this industry/innovation system?

Somewhat yes, but currently as an entrepreneur

What you have been up to in relation to the biogas since you visited the digester or attended the workshop?

I worked for a government agency called 'The Innovation Hub' where I was able to put bioenergy high on the agenda of the programmes and initiatives that should be considered and supported

Have your activities increased/declined in the next few months/year?

My activities have declined in the past few months; one of the major reasons can be attributed to the new renewable energy generation programme, REIPPP. According to me this programme only recognises renewable energy as electricity. But I am currently working on some other projects and I am optimistic that the activities will increase in the next few months and years. I have however shifted my focus from energy being the main product of interest via AD for biogas production. I have made a conscious decision to take

municipalities out of my projects endeavours. Instead my focus is applying AD as a waste management and sanitation solution and to have energy as a by-product not the main product and hence the driver of my activities

About the workshop, one of the objectives was to begin to discuss issues that will improve the dissemination of the biogas technology. To what extent do you feel this was achieved at the workshop?

The workshop was useful in that it was able to bring like-minded individuals under the same roof, both from the private and public sectors. My feeling is that we were essentially singing about the issues that we know very well and have been spoken about several times in the past.

What in your view what are current hurdles addressed by your current activities and any comments about biogas industry in general?

In South Africa, the challenge is that a paradigm shift is needed on 2 levels. One the one hand there needs to be an understanding and acknowledgement that energy is not equal to electricity. It should be realised that bioenergy affects transport sector through biofuels, thermal energy sector, steam generation and LPG generation etc. Also various sectors are instrumental in making bioenergy a reality. Among these sectors are: sanitation, agriculture, forestry, and municipal solid waste, commercial and industrial waste. Therefore changes should involve an acknowledgement the role of bioenergy can play in each of the sectors mentioned above. After all, they are the primary markets for bioenergy; all the sectors have to take part. And secondly, the legal framework is required that needs to recognise ways of procuring energy, in particular thermal energy, which I feel has been undermined up to this point.

Have you since interacted with anyone who attended the workshop?

I was able to make connections at the workshop that led to participation in regional bioenergy workshop that will otherwise not be possible. I am also in touch with the representative from TIA. TIA has been a very good connection for me, therefore I have found it useful

Any general comments about workshop and biogas industry in general?

In general, I have told a whole lot of people who knew very little about the technology or nothing at all about the potential that the technology holds. Especially in my recent

University of Cape Town