CIRCULAR ECONOMY DESIGN VISIONING: EXPLORING INDUSTRIAL AND URBAN SYMBIOSIS IN SOUTH AFRICAN CITIES

by

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Thesis submitted in fulfilment of the academic requirements for the degree of Doctor of Philosophy

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Preface

The work presented in this thesis was conducted via the School of Engineering, Programme of Civil Engineering, University of KwaZulu-Natal, Durban, from 2012 to 2017, under the supervision of Professor Cristina Trois.

The body of work is the original work by the author, expect where acknowledgements and references are made to previous. The thesis has not been otherwise submitted in any form for any degree or diploma to any other higher education institution.

"Our science is of little value unless it is accompanied by social and ecological concern".

- Frijot Capra, 2014

Declaration 1 – Plagiarism

I, Kruschen Deenadayalan Govender, declare that:

1. The research presented in this thesis, except where otherwise indicated is my original research.
2. This thesis has not been submitted for any degree or examination at any other university.
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Signed:

Kruschen Deenadayalan Govender

As the candidate's Supervisor I agree to the submission of this thesis.

Signed:

Professor Cristina Trois

Declaration 2 – Publications

All of the papers listed below have been authored by myself, Kruschen Govender, with support from my supervisor Professor Cristina Trois, Linus Naik, John Filitz and Collins Mucheuki. I am responsible for conceptualising, planning and conducting the data collection and data analysis for each paper. John Filitz and Collins Mucheuki provided editorial support and assisted in data collection and analysis for paper two – presented in the form of a conference poster. Professor Cristina Trois and John Filitz provided editorial support for paper three (to be submitted). Linus Naik provided editorial support for paper 4 (to be submitted). Submission of paper four has been delayed pending patent application protocol. The list of completed, published and future publication outputs from the research:

1. Govender, K. 2011. A Mixed Methods Design to Assess Corporate Attitudes Towards Industrial Ecology; a Conceptual Framework to Advance Sustainable Waste Management. Paper published in the conference proceedings, *Sardinia 2011 Symposium, International Waste Management and Landfill Symposium*.

2. Govender, K., Filitz, J., and Mucheuki, C. 2012. Coordinating By-product Synergy Networks in South African Industries, Pilot Survey of Manufacturing Firms in the South Durban Basin, KwaZulu-Natal. Poster presented at the Industrial Ecology Gordons Research Conference 2012.

3. Govender, K., Trois, C. and Filitz, J. 2018. Primary Looping Agents: The Role of Waste Pickers in Informal Urban Symbiosis Networks. *Journal of Industrial Ecology.* (Paper to be submitted).

4. Govender K., and Naik, L. 2018. Circular Economy Design Visioning: The Internet-of-Waste Pickers. *Journal of Cleaner Production.* (Paper to be submitted).

Acknowledgements

I am greatly indebted to my supervisor, colleagues and family for supporting me throughout this journey.

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It is my privilege and pleasure to acknowledge the advice and guidance of Professor Cristina Trois, Linus Naik and John Filitz. The extensive discussions with them were extremely stimulating and will remain among the highlights of my academic career.

Thank you to *"Oom"* Sacks Stuurman and Dr Harald Witt for their mentorship and instrumental roles in my development as a scholar.

I am grateful to my younger brother, Che, for his support and counsel.

I dedicate this work to my parents, Deena and Soma.

Abstract

Cities of tomorrow will be at the coalface of the complex challenges posed by climate change, e.g. resource scarcity. Climate change adaptation strategies will include *circular economy (CE)* practices (e.g. industrial and urban symbiosis) to increase the rate of recycling technical nutrients, in turn improving the resource efficiency of cities. The study investigates *industrial and urban symbiosis* in South Africa. In doing so, exploring technology enabled (i.e. *cyber-physical-social ecosystems*) CE solutions to designing out waste in South African cities.

One of the key contributions of the research is the comprehensive synthesis and testing of an iterative problem structuring, theory building and design visioning *(problem-theory-design)* continuum to inform CE experimentation. A mixed methods design visioning approach is developed through an experiential and iterative design practice nested in a network of interdisciplinary theoretical constructs: 1) philosophical construct – *Ecological Literacy* (systems thinking), 2) techno-economic construct – *Third Industrial Revolution* (internet-of-things enabled general purpose technology platform), and *Circular Economy* (industrial and urban symbiosis), and 3) design construct – properties of *Ecodesign* derived from the dynamic renewable design of natural ecosystems. The research argues that to construct a meaningful CE transition experiment, a logical starting point is to distil key findings from a theoretically embedded case study to inform the design of a virtual experiment and simulation sketch.

Through an embedded multiple case study approach the research investigates complex resource recovery dynamics in two key waste economy sub-sectors; industrial waste management and urban informal recycling sectors in the province of KwaZulu-Natal (KZN). The case studies provide an integrated method (i.e. synthesising quantitative and qualitative knowledge) for holistic and high-resolution problem structuring. From a systems thinking perspective, key leverage points (i.e. data, information sharing and infrastructure) are identified for potential policy and technology intervention. Learnings from the case studies inform policy recommendations and CE innovation.

The findings from the industrial symbiosis (IS) case study illustrate that firms and supply chain networks recognise the environmental importance of improving industrial waste management practices, however they are locked-in to end-of-pipe solutions. Firms highlighted regulation, price sensitivity, customer pressure and top management as key drivers of pro-environmental behaviour change (e.g. waste beneficiation). The findings highlight the unrealised IS potential in the South

Durban Basin. In addition, revealing significant barriers to IS, i.e. lack of information sharing between firms and a weak regulatory environment. To increase the detection, matching and emergence of IS relationships will command the dynamic co-production of codified resource flow data; herein a big data analytics approach can be employed to construct open source platforms for interfirm information (e.g. residual resource flows) sharing and knowledge production – *an industrial commons internet.*

The urban symbiosis case study explores the informal recycling sector in KZN analysing the instrumental role of waste pickers as *primary looping agents* in recovering recyclable materials from post-consumer waste and increasing the supply of recyclable materials (e.g. cardboard, paper, plastic and metal) in the secondary resources economy. Waste pickers are an important link in recycling value chains; sorting, gathering and manually transporting recyclable materials to buy-back-centres and informal collection pick up points. The case study investigates how their efficiency can be improved to stimulate greater positive environmental impacts, create decent employment opportunities, and reduce waste management costs for municipalities.

The findings from the case study on waste pickers are extrapolated in a CE design visioning exercise. From a systems level perspective, the research culminates in the sketch of a virtual circular city experiment; a *cyber-physical social ecosystem (CPSE)* designed to increase recycling rates in cities by addressing the infrastructural needs of waste pickers. The hardware, software and social ecosystem is built out of an *internet-of-things (IoT) platform*. Firstly, the IoT enabled infrastructural system improves material recovery efficiencies (of post-consumer recyclable materials) by increasing connectivity between waste pickers and waste collectors. Increased connectivity allows for looping and aggregating material stock and flow data. Secondly, the integrated hardware and software infrastructure provides an automated, digitised and decentralised buy-back-transfer service – delivered through connected and solar-powered collection nodes strategically distributed throughout the city in a mesh network configuration. Thirdly, the digital platform aggregates big data and employs advanced analytics to generate actionable residual resource intelligence, consequently enabling evidence-based decision making by key stakeholders, e.g. government agencies, industry associations, recyclers and material reprocessors. To further the research agenda, the next step is structuring a real-world transition experiment based on the virtual circular city design experiment, defined as, *the internet-of-waste pickers (IoWP).*

Table of Contents

List of Figures

List of Tables

List of Abbreviations

CO_2	Carbon dioxide
CE	Circular economy
CPS	Cyber-physical-system
CPSE	Cyber-physical-social ecosystem
CPSS	Cyber-physical-social system
DEA	Department of Environmental Affairs
DSW	Durban Solid Waste
EPR	Extended producer responsibility
GDMA	Greater Durban Metropolitan Area
GDP	Gross domestic product
GWP	Global warming potential
IE	Industrial ecology
IS	Industrial symbiosis
IoT	Internet-of-things
IoWP	Internet-of-waste pickers
KZN	KwaZulu-Natal
LCA	Life cycle assessment
MRF	Materials recycling facility
MSWM	Municipal solid waste management
NGO	Non-governmental organisation
PRO	Producer responsibility organisation
SDB	South Durban Basin
SME	Small and medium enterprise
WISP	Western Cape Industrial Symbiosis Programme

Glossary of Terms

Circular economy design visioning – the process of designing an alternative future state (of urban and industrial systems) premised on circular economy principles.

Cyber-physical-social ecosystem – merging computing, networking and society with physical systems to create advanced and more sustainable technical capabilities – delivering shared value through a platform business model.

Data loops – undiscovered bits of information that can generate new business intelligence when aggregated, analysed and disseminated to key stakeholders. In the case of this research, *data loops* characterise material flow patterns. Looping material flow data will generate the requisite ecodesign intelligence (i.e. correct information asymmetries) to catalyse the development of closed material loops.

Internet-of-waste pickers – an internet-of-things enabled and decentralised infrastructural system for the buy-back and transfer of recyclable materials recovered from municipal waste streams in emerging economies. A demonstration of a circular economy cyber-physical-social ecosystem.

Primary looping agents – primary reclaimers of recyclable materials from urban and industrial waste streams. The primary agents in the recovery of technical nutrients and the initiation of closing material loops.

Virtual circular city experiment – a design approach to conceptualise a circular city experiment, i.e. a clearly defined circular economy practice at a city level.

Chapter 1 – Introduction

Chapter one presents a rich overview of this creative and inter-domain scholarly endeavour. In brevity, the research discourses theories and methods to design out waste (i.e. technical nutrients[1]) and improve the metabolism of South African cities. Chapter one is designed to; 1) structure and contextualise the real world complex problem, 2) delineate the research design, 3) explain the application of the interdisciplinary network of diverse theories, 4) outline the methodology, and 5) present the structure of thesis.

1.1 Problem Structuring

In South Africa approximately only 10% of the total waste generated is recycled (DEA, 2012). Waste management in rapidly urbanising and industrialising South African cities is comprised of outdated *(end-of-pipe)* treatment and disposal practices, e.g. *waste-to-landfill*. City proximate industrial clusters exhibit low levels of reuse, recovery and recycling. Furthermore, there is a paucity of comprehensive, reliable and accessible data on material flows and associated network dynamics of the formal and informal waste management systems, e.g. waste pickers. The incumbent waste management regime is fraught with systemic friction (e.g. information asymmetries) and inefficiencies (e.g. lack of adequate resource recovery infrastructure) – resulting in low material productivity. In short, there is an opportunity to improve the metabolism of South African cities.

From an economic history perspective, South Africa is locked in to a carbon intensive [2] and inefficient Secondary Industrial Revolution (20th century) general purpose technology platform;

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[1] The terms*, technical nutrients, recyclable materials, secondary resources* and *residual resources* are used interchangeably throughout this thesis.

[2] South Africa's historical development has brought with it significant costs on both society and the environment. Best represented by the carbon and water intensity of the South African economy at large. South Africa lays claim to the second most carbon intensive economy after the oil-rich Venezuela due to its high dependence on coal for electricity requirements, at 94, 7 % (UNEP 2011). In addition the country lays claim to house the "*single largest carbon dioxide emitter in the world: Sasol's coal-to-liquid plant at Secunda*" (Munnik et al., 2009). South Africa accordingly accounts for 39 % of carbon emitted of Africa each year, releasing 400 million tons of pollution into the atmosphere annually. Despite the carbon intensity of the economy and boasting per capita kilowatt usage ratios per hour similar to South Korea, over 30 %

characterised by a partially centralised communications infrastructure, highly centralised fossil fuel and nuclear energy infrastructure, and internal combustion automobile transportation on national road infrastructure (see table 2 in section 1.4.3). Similarly, waste management at a city level is locked-in to an inefficient Secondary Industrial Revolution waste management infrastructural system – a centralised, carbon intensive logistics, and information asymmetric waste-to-landfill model with limited recycling.

According to the National Waste Information Baseline Report 2012, South Africa generates 108 million tons (Mt) of waste per annum, of which 98 Mt (approximately 90%) is landfilled (DEA, 2012). Of this, 55% was general waste, 44% was unclassified waste and 1% hazardous waste. The South African government assessment report on national environmental issues, 2nd South Africa Environment Outlook (DEA, 2012), highlights the most significant challenges facing the waste management sector, including *"limited understanding of the main waste flows…and absence of a recycling infrastructure which will enable separation of waste at source and diversion of waste streams to material recovery and buy-back facilities"* (DEA, 2012).

The national government has identified the waste management sector as a critical area in need of structural redress. The incumbent waste management regime is largely characterised by inefficient modalities of collection and disposal, with limited recycling. Household waste is managed by municipalities (and/or their service providers) and commercial and industrial waste sector is predominantly managed by the private sector (GreenCape, 2016a). The *"primary mode of waste management is still landfilling and available land near areas of large waste generation is becoming scarce"*, furthermore the GHG emissions and leachate from organic waste makes the use of landfill sites less attractive (Greben and Oelofse, 2009).

It is approximated that the global waste sector contributes to approximately 3 to 4% of the global anthropogenic GHG emissions, of which waste management activities release as much as 18% of the global methane emissions (Jean et al., 2008). GHG emissions data for South Africa also reflect these trends, with the waste sector contributing to 2% of the total emissions[3] and waste management activities contributing to 12% of total methane emissions (Friedrich and Trois,

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of South Africans however do not enjoy the luxury of electricity as they are not connected to the national power grid (Marais, 2011).

[3] The GHG, which results in the greatest climate change impacts are, carbon dioxide (CO_2), methane and nitrous oxide, produced from the landfilling of municipal solid waste (MSW).

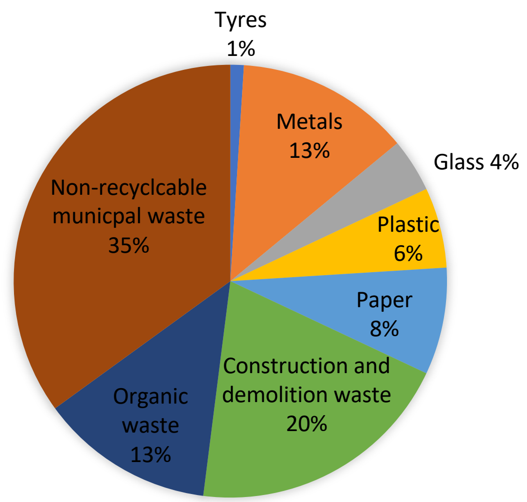
2016). In South African cities, the amount of GHG emitted due to waste management is predicted to rise in the near future.

South Africa is reliant on landfilling[4] because waste prevention, reuse, recycling and recovery are more expensive relative to the costs of disposal to landfill (GreenCape, 2016a). The artificially low price of landfilling is constraining growth in the secondary resources economy. Attributed to ineffective regulation coupled with the incumbent free market regime, which fails to provide actors with appropriate information, leading to market information asymmetries that misguidedly minimise the actual cost to landfilling.

In particular, the social and environmental lifecycle costs of production (e.g. public health and environmental impacts of landfilling) do not factor in current economic models. Ultimately, there is a lack of feedback, because the marketplace gives stakeholders the wrong information (Capra and Luisi, 2014). Globally, the externalisation of the social and environmental costs of production and consumption undermines the growth of the secondary resources economy.

[4] It is estimated that there are approximately 2000 waste handling facilities, however a significant number of these are unpermitted. There are limited compliant landfills and hazardous waste management facilities, which hinders the safe disposal of all waste streams (DEA, 2012).

Figure 1-1 South Africa general waste composition, 2011 (CSIR, 2012)



Market information asymmetries are a result of ineffective policy and regulatory design and enforcement. This has limited the growth of the waste management sector, which has an estimated turnover of approximately R15 billion per annum in South Africa. As illustrated in figure 1-1, it is estimated that approximately 65% (38 million tonnes) of classified waste (for the year 2011) is considered to be recyclable and could potentially be diverted from landfill to secondary resource markets (DEA, 2012).

According to Department of Science and Technology an additional R17 billion (per annum) worth of secondary resources could be unlocked by 2022, if 20% of industrial and 60% of domestic waste is recovered and feed into the secondary resources economy (GreenCape, 2016a). Furthermore, the feedback of recycled commodities into the economy *"has the potential to increase domestic supply and lower prices of these commodities, stimulate demand and increase overall production"* (Hartley et al., 2016).

The waste management sector currently employs approximately 29 000 people, however there is latent opportunity to expand the recycling industry and make meaningful contributions to job creation across the value chain (DEA, 2012). According to an economic study by Hartley et al. (2016), *"an increase in the share of recycled products by 18% has the potential to increase real GDP by 0.1 per cent and employ an additional 4 000 workers"*. Furthermore, under the assumption that 100 per cent of all waste is recovered and recycled, real GDP could increase by 0.5 per cent and an additional 13 661 jobs could be created.

As indicated above, South Africa has a significant opportunity to expand the valorisation of waste streams, contributing towards positive environmental, e.g. lower GHG emissions due the diversion of waste from landfill, and economic impacts, e.g. job creation and the increased supply of recycled commodities. To expand the growth of the secondary resources economy and increase the resource efficiency of South African cities, it is essential to re-think and re-design resource recovery infrastructural systems.

1.2 Background

Cities face a multiplicity of inter-connected and inter-dependent risks posed by volatile global economic, political and biosphere conditions (i.e. climate change related risks)[5]. Today, more than half the world's population now reside in cities. Although, cities occupy only around 2% of the global land area and they are responsible for producing approximately 75% of global greenhouse gas emissions (Hajer and Dassen, 2015). It is estimated that nearly 50% of the world's cities are considered to suffer from the direct impacts of climate change (UNEP, 2011a). Hence, the focus for strategic climate change mitigation and adaptation action will have to occur at a city level.

Rapid urbanisation coupled with the threat of climate change related resource constraints calls for cities to rethink their organisational structures and infrastructural systems. In the near future, cities will face mounting pressure to radically advance resource efficiency, in turn improve their overall aggregate efficiency. Due to their density, diversity and effects of agglomeration economies, cities have the inherent potential to accelerate the transition towards socially responsible and advanced eco-intelligent modalities of cleaner production. In short, it is imperative for cities to adopt a smarter and leaner approach towards the consumption of key resources, e.g. water, energy, food and raw materials.

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[5] There is widespread consensus among the international scientific community that the world's climate is being affected by anthropogenic emissions of greenhouse gases into the atmosphere, furthermore it is projected that these changes will accelerate in the future if we fail to significantly reduce greenhouse gas emissions (IPCC, 2007). Climate impacts, such as increasing temperatures, rising sea levels, changing weather patterns, and more frequent or intense droughts, floods, and storms, can pose serious challenges for rapidly urbanising cities in emerging economies.

Industrial ecology (eco-industrial) infrastructure that eradicates waste and maximises efficiencies will be critical to enable cities to reduce water, material and energy throughput, in turn improve overall aggregate efficiency. This study predicts that smart cities of the future will avoid waste generation and through ubiquitous resource recovery networks – epitomised by intelligent eco-industrial infrastructure (i.e. an immersive circular economy) built out of an emerging Third Industrial Revolution general-purpose-technology platform (see section 1.4.3).

Cities in emerging economies like South Africa face a myriad of complex, interconnected and interdependent sustainability challenges (e.g. water scarcity[6]). South Africa is the most industrialised economy in Africa and more than 60% of its population live in cities (Turok, 2012). The legacy of apartheid spatial planning continues to haunt South Africa; typified by low-density, fragmented cities resulting in harmful social, economic and environmental consequences. At a city level, South African government agencies have to meet the demands of rapid urbanisation and diverse industrial development, whilst addressing the complex challenges of socio-economic inequality and climate change.

South African cities of tomorrow will be at the coalface of the complex challenges posed by climate change. Their future resilience will be contingent on how they strategically negotiate resource constraints and recognise limits to growth. Linear and resource intensive industrial modalities of production and consumption of yesteryear (i.e. established upon a Second Industrial Revolution general purpose technology platform) will be extremely vulnerable under multi-scalar climate change related stresses; especially as local resource risks become increasingly more acute. Due to their complex socio-political, economic and diverse ecological characteristics, South African cities embody global sustainability challenges on a local scale and therefore present an attractive socio-technical laboratory to test and nurture innovative sustainability transition experiments.

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[6] With an average annual rainfall of 497mm South Africa is considered to be a dry country. South Africa is currently experiencing a severe drought, with 2015 proving to be the driest year on record (WRC 2016). The compromising state of South Africa's water supply has of recent gained prominence, in particular around issues of exhausted dilution capacity, with acid mine drainage singled out as the primary offender in this regard. Turton (2008) has argued South Africa has all but exhausted its sources of fresh water, with estimates running as high as 98 % of water resources under usage in rivers and dams which is highly polluted. This water he argues, is so polluted that *"South Africa has lost its dilution capacity"*, requiring increasingly intensive measures for the treatment and recirculation to potable standards (Turton, 2008).

South African cities are the dominant centers of economic and industrial activity, however they are not reaping the benefits of agglomeration because of shortages of energy, water, public transport and waste management infrastructure (Turok, 2012). To this end, strategic industrial port cities like Durban, eThekwini Municipality, have the inherent potential to foster primary and sustainable technology niches to drive pro-environmental change especially concerning optimising material and energy flows. In doing so, it is imperative that said technology niches incite a digital paradigm shift in infrastructural systems design in order to improve the metabolism of the city. Furthermore, if eThekwini Municipality is to retain its share of global manufacturing, taken together with addressing pressures on existing old infrastructure, rapid urbanisation and the real threat of climate change, then it needs to embrace a new economic narrative, i.e. Third Industrial Revolution (TIR).

This study posits that for South African cities to expedite the diversion of recyclable materials from landfill will require a philosophical and transdisciplinary re-conception[7] of current urban and industrial systems. To this end, it is necessary to formulate urban and industrial planning policy planning through a *circular city* design framework (e.g. urban and industrial symbiosis) (Prendeville et al., 2017). In doing so, comprehending (i.e. map, analyse and identify) the hidden web of resource flows and underscore (i.e. qualify and quantify) unrealised synergies, i.e. identifying opportunities to close material loops and divert waste from landfill.

The low level of resource recovery, reuse and recycling South Africa, evidently presents an opportunity to adopt a new urban and industrial planning perspective. Hence, this study is concerned with addressing the socio-technical transition from the incumbent centralised and information asymmetric waste-to-landfill city to an alternative decentralised, hyperconnected and eco-intelligent waste-to-resource circular city. The study proposes that a *waste-to-resource circular city model* built out of a *TIR general-purpose-technology platform* (e.g. cyber-physical-

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[7] Peter and Swilling (2011) argue that, *"what is needed is normative change that ultimately translates into wide-scale behavioural change"*. They postulate that this can be achieved by *"adopting the appropriate conceptual and theoretical frameworks for (1) decoupling (i.e. of economic growth rates from rates of resource use and associated ecological impacts), and (2) transitioning to a more sustainable, green South African economy by supporting sustainability-oriented innovations and associated investments"* (Peter et al., 2011). The decoupling perspective is critical, as it emphasizes the importance of taking into account resource constraints, materials flows and recognising waste as a resource.

social ecosystems). The TIR narrative encompasses *circular economy (i.e. circular city)* rhetoric. Herein, the research introduces the concept of *circular economy cyber-physical-social ecosystems* - to provide alternative configurations of hard and soft technologies to construct resource recovery networks with less systemic friction. To this end, the research ventures into the creative and interdisciplinary domain of recombinant innovation design visioning illustrating the process for designing circular city cyber-physical-social ecosystems. In summation, this study is critical for future proofing South African cities to adapt to the escalating impacts of climate change, namely resource scarcity.

1.3 Research Questions, Objectives and Aim

1.3.1 Research questions

- How to *design out waste* and improve the metabolism of South African cities?
- How to increase resource recovery rates in South African cities?

1.3.2 Objectives

- To construct two high-resolution case studies to explore the formal (i.e. industrial waste management) and informal waste management (i.e. urban informal recycling) sectors;
- To provide policy and technical recommendations for advancing industrial symbiosis network detection, matching and facilitation;
- To undertake a circular city technology design visioning experiment – the ideation of a cyber-physical-social system to augment the role of waste pickers in the secondary resources economy.

1.3.3 Aim

- To design circular material flows to enable more sustainable patterns of production and consumption in South Africa cities.

1.4 Theoretical Framework

Seadon (2010) postulates that waste is a direct consequence of inadequate thinking, a fundamental *"crisis of perception"*. Ultimately, a conventional reductionist approach to waste management is unsustainable, therefore necessitating a radical shift in our perceptions, thinking and our values. On this note, Seadon (2010) states, "*when waste is seen as part of a production system, the relationship of waste to other parts of the system is revealed and thus the potential for greater sustainability of the operation increases"*. Seeing, as the landfilling of waste is a systemic problem, it requires a systems-based solution.

The study adopts an interdisciplinary theoretical approach which is spawn from *"systems thinking"* or *"systemic thinking"* – *"thinking in terms of relationships, patterns, and context"* (Capra and Luisi, 2014). To elaborate on this point, Capra[8] and Luisi (2014) contend that in contemporary science there is a "new emphasis on complexity, networks and patterns of organisation," with that a new interdisciplinary science of qualities is slowly emerging. In this regard, this study is deeply rooted in Capra and Luis's synthesis and philosophical position on *sustainability* and *ecological literacy* (defined in section 1.4.1).

In this system thinking premised interdisciplinary theoretical approach, industrial ecology[9] (i.e. eco-industrial development) is espoused within the rich meta-narrative of the *Third Industrial Revolution (TIR)*. The next industrial revolution is dubbed as *The Fourth Industrial Revolution* or *Industry 4.0* in corporate and national policy arenas. *Industry 4.0* is the current buzzword in industrialised economies, but if fails to provide a holistic technical framework for application outside of manufacturing industries. Jeremy Rifkin provides a stronger argument for defining the new industrial revolution as the Third Industrial Revolution, as he tracks the concurrent evolution and convergence of core general purpose technologies, i.e. energy, communications and transport, from an economic history perspective. The overarching metanarrative of the research draws upon Jeremy Rifkin's *general purpose technology platform* framework, defined in section 1.4.3.

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[8] Frijot Capra is one of the Founding Directors of the Centre for Ecoliteracy in Berkeley, California. He is also a faculty member at Schumacher College, United Kingdom. *"He is a physicist and systems theorist and has been engaged in a systemic examination of the philosophical and social implications of contemporary science for the past 35 years"*. He is the best-selling author of The Tao of Physics (1975) and The Web of Life (1996) (Capra and Luisi, 2014).

[9] The theory of industrial ecology is succinctly defined in section 1.4.2 and unpacked in greater detail in chapter two.

The waste and residual resource debate is framed by the theory of *industrial ecology (IE)* and the umbrella concept of *circular economy (CE)* (Blomsma and Brennan, 2017). In doing so this study makes a creative theoretical contribution by coupling the TIR meta-narrative with IE and CE – with a focus on the application of a *cyber-physical-social ecosystems (CPSE)* approach to urban and industrial symbiosis. Hereto, hypothesising that the TIR general purpose technology platform will provide the infrastructural capabilities to transition towards a collaborative, networked and digital platform-based economy[10]; designed to express ecologically sustainable material and energy flow.

[10] For the purpose of this study, the term *digital platform* refers to a set of online digital configurations whose algorithms serve to organise, structure and facilitate economic and social activity.

Figure 1-2 Research narrative

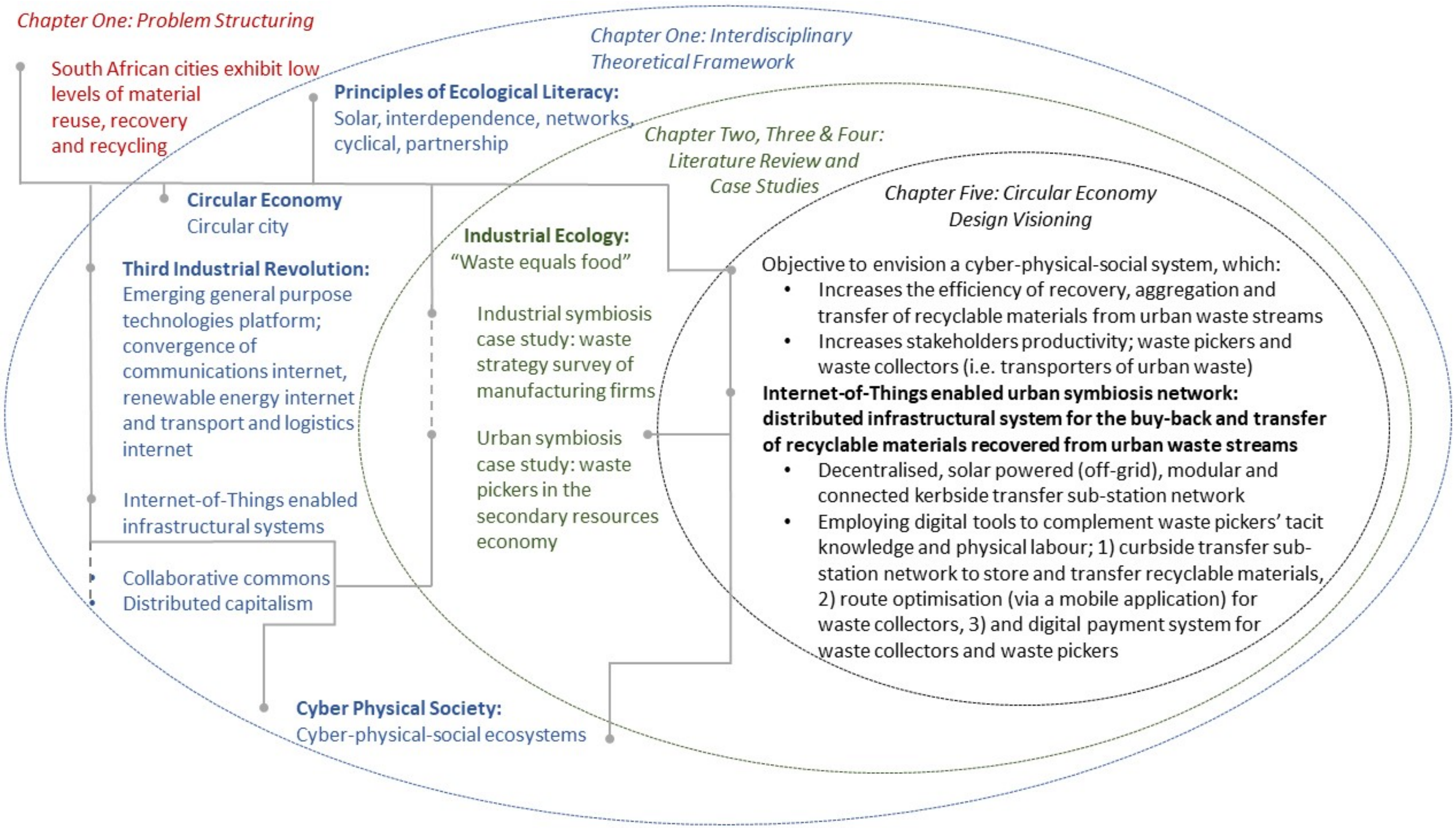

Figure 1-2 succinctly captures the logical and analytical flow[11] of this interdisciplinary research journey. In doing so portraying how the selected theoretical domains hang together and are nested to inform the conceptual framework. Herein, emerges the ideation of an *Internet-of-Things (IoT)*[12] enabled urban industrial symbiosis infrastructural system, delineated as *circular economy design visioning* in figure 1-2. In short, a key output of this research is the design of a *cyber-physical-social systems* (i.e. IoT enabled infrastructural system) model to recover recyclable materials in rapidly urbanising cities in middle-income developing countries like South Africa.

For the purpose of this research, the term IoT refers to a connected product/product-service system typically composed of a combination of multiple software and hardware components in a multilayer stack of IoT technologies (Wortmann and Flüchter, 2015). In the future, IoT technologies (e.g. sensors, actuators, wireless networks and cloud computing) will penetrate every layer of urban industrial systems. Today, in advanced industrial economies (e.g. Germany) the most prominent areas of application include, e.g. the smart manufacturing, where the implementation of intelligent production systems and connected production sites is referred to as *Industry 4.0*. In the construction arena, the concept of the smart building includes the application of embedding intelligence in thermostats, security systems, water meters and energy applications (e.g. smart grids). In the transport sector, smart transport solutions include vehicle fleet tracking, route optimisation and mobile ticketing. In healthcare, current IoT solutions address patients' surveillance and chronic disease management (Wortmann and Flüchter, 2015).

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[11] The grey connectors in Figure 1-2 depict the logical and analytical flow of this thesis.

[12] The Internet of Things (IoT) has a plethora of definitions: (1) one typology emphasizes the physical things which become connected in an IoT infrastructure; (2) while other definitions focus on Internet-related aspects (e.g., Internet protocols and network technology); and (3) a final typology focuses on semantic challenges relating to the storage, search and organization of large volumes of information (Atzori et al., 2010). For the purpose of this study the following definition by the International Telecommunication Union will be employed, which describes IoT as, *''a global infrastructure for the Information Society, enabling advanced services by interconnecting (physical and virtual) things based on, existing and evolving, interoperable information and communication technologies"*

1.4.1 Sustainability and Ecological Literacy

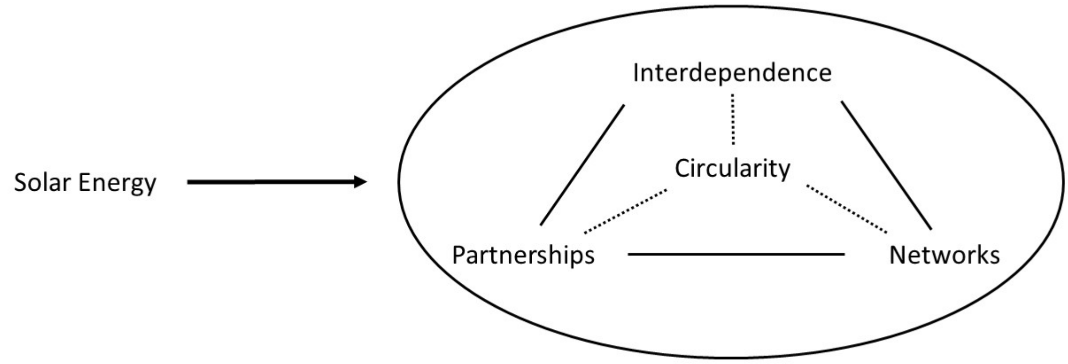
1.4.1.1 Defining sustainability

In 1987 the report of the World Commission on Environment and Development, widely referred to as the Brundtland Report, defined the concept of *"sustainable development,"* asserting, *"Humankind has the ability to achieve sustainable development – to meet the needs of the present without compromising the ability of future generations to meet their own needs"* (Capra and Luisi, 2014). However, this definition is incomplete, as it does not tell us how to construct an ecologically sustainable society. In this regard, Capra et al. (2014) argue that *"the key to an operational definition of sustainability is the realisation that we do not need to invent sustainable human communities from scratch but can model them after nature's ecosystems, which are sustainable communities of plants, animals, and microorganisms".* For the purpose of this study the following operational definition of ecological sustainability is applied, *"to design a human community in such a way that its activities do not interfere with nature's inherent ability to sustain life"* (Capra and Luisi, 2014).

1.4.1.2 Defining ecological literacy

Capra defines *ecological literacy* as the understanding and application of the basic principles of organisation that natural ecosystems have evolved to sustain the web of life (Capra, 1993, 1996; Orr, 1992 cited in Capra, 2014). In turn, he derives a set of principles of organisation based on the fundamental principles of ecology, which can be applied as guidelines to construct sustainable human communities (Capra and Luisi, 2014) (see figure 1-3).

Figure 1-3 Principles of organisation based on the principles of ecology



The first principle of pertains to the primary source of energy powering ecological cycles, *solar energy*, which has many forms; "sunlight for solar heating and photovoltaic electricity, wind and hydropower, biomass, etc." (Capra and Luisi, 2014). Solar energy and in its various forms, is the only kind of energy that is renewable and environmentally benign. Furthermore, in recent years' renewable technologies are becoming more economically efficient.

The second principle is *interdependence*[13] – *"all members of an ecological community are interconnected in a vast and intricate network of relationships"* (Capra and Luisi, 2014). Interdependence can be described as the *"mutual dependence of all life processes on one another"* and this is the fundamental nature of all ecological relationships in the web of life (Capra and Luisi, 2014). In order to understand interdependence, it is imperative to understand relationships, which requires a shift of perception, a transition toward systems thinking*; "from the parts to the whole, from objects to relationships, from quantities to qualities"* (Capra and Luisi, 2014).

The third principle is concern the basic pattern of life, which is a *network*, meaning that the relationships among members of an ecological community are primarily nonlinear, composed of multiple feedback loops. Hence, a disturbance to the system will not be limited to a single effect but is more than likely to extend out in ever-widening patterns of change (Capra and Luisi, 2014). The art of *partnership* is a governing characteristic of ecological communities. In this regard, Capra and Luisi (2014) state, *"the cyclical exchanges of energy and resources in an ecosystem*

[13]Furthermore, in unpacking the principle of *"interdependence"*, Capra and Luisi (2014) state that, *"the success of the whole community depends on the success of its individual members, while the success of each member depends on the success of the community as a whole"*.

are sustained by pervasive cooperation". As the fourth principle, partnership is one of the hallmarks of life on earth, it depicts *"the tendency to associate, establish links, live inside one another, and cooperate"* (Capra and Luisi, 2014).

A basic operating principle of natural ecosystems is that *"waste equals food"*; what is waste for one species is food for another (Capra and Luis, 2014). Thus, the fifth principle is that of *circularity*, referring to the cyclical nature of ecological processes, whereby feedback loops are conduits along which nutrients are continually recycled. The flexibility of a natural ecosystem is a consequence of its diverse and multiple feedback loops (Capra and Luis, 2014).

Five ecodesign[14] principles of organisation described above are closely interrelated and result in the manifestation of ecologically sustainable communities. In sum, ecological sustainability is an emergent property of a complex web of relationships. The following research explores the application of this ecodesign philosophical framework to direct the discourse of sustainable urban and industrial development in South Africa. Therein, employing the ecodesign framework to inform the ideation of a virtual city experiment portrayed in chapter five.

1.4.2 Industrial Ecology for Sustainable Urban and Industrial Development

The underlying ecological design principle of industrial ecology is that *waste equals food*, which is one of the key principles of ecology as demonstrated by the cyclical nature of ecological processes. Hence, all materials, products and by-products (including wastes generated) produced by urban-industrial systems must eventually provide nourishment for something new (Hawken 1993; McDonough and Braungart, 1998 cited in Capra 2014).

[14] The basic tenets of ecodesign are not new; a pioneer of this holistic design approach is a famous genius of the Renaissance, Leonardo Da Vinci. In his notebooks, he explicitly mentioned that nature's ingenuity was far superior to human design. As a designer and engineer, his body of work exhibits many examples of how he used ecological processes as inspiration for human design. Da Vinci *"worked with nature rather than trying to dominate her"*, characteristic of the spirit of the contemporary ecodesign movement (Capra and Luisi, 2014).

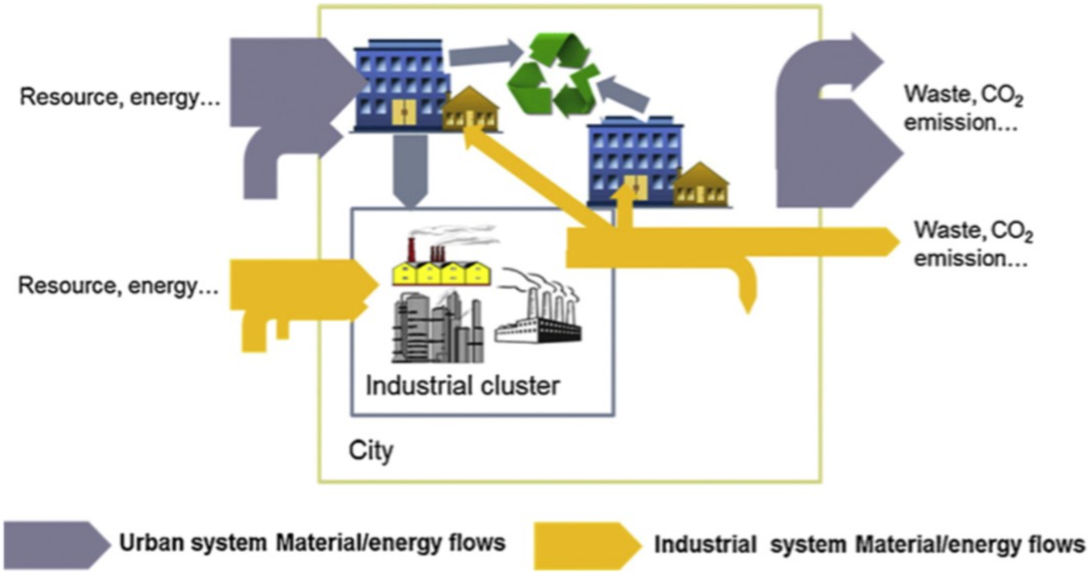
Industrial ecology[15] (IE) is a recent field of research; it emerged as an industrial engineering science. However, in recent years it has evolved into an interdisciplinary academic field, incorporating disciplines such as environmental engineering, geography, economics, agriculture, sociology and biology (Scholz, 2011). IE strives to configure urban-industrial systems inspired by the evolutionary zero-waste design of natural ecosystems – a *biomimicry* [16] approach to integrated urban and industrial design. Thus, IE is dedicated to optimising urban-industrial material and energy cycles along the supply chain; via recycling, reusing, utilising by-products, consuming less extracted primary resources and ultimately minimising waste (Scholz, 2011).

A key tenet of IE, is *industrial symbiosis (IS)*, which promotes enhanced resource efficiency through the reduction of waste generation (and associated GHG emissions) via material, energy, by-products exchange between different processes and industries (Chertow et al., 2008). As an extension, *urban symbiosis* explores potential for material and energy exchanges between in urban and industrial systems. For example, recovering recyclable materials from municipal solid waste streams and utilising this feedstock as secondary raw material inputs for nearby manufacturing industries. Conversely, capturing waste heat from industry clusters and diverting this to urban areas as an alternative form of district heating (Sun et al., 2016).

[15] Robert Frosch and Nicolas Gallopoulos coined the term *"industrial ecology"*. They adapted Robert Ayres' concept of *"industrial metabolism"* for describing *"pathways of some materials and their transformation through industry and through society"* (Frosch, 1992).

[16] *"Biomimicry"* is a chapter of ecodesign , that is *"concerned with nature-inspired designs of specific structures and processes"* (Capra and Luisi, 2014). The term *"biomimicry"* was coined by the science writer Janine Benyus; from the Greek *bios ("life")* and *mimesis ("imitation")* – means *"imitation of life"* (Benyus, 1997).

Figure 1-4 System boundary for urban and industrial symbiosis (Sun et al., 2016)



From an economic geographic perspective, urban and industrial symbiosis optimises city and regional metabolic flows through coupled infrastructural systems and emergent by-product synergy networks. Figure 1-4 depicts the system boundaries for urban and industrial symbiosis. Furthermore, from a regional metabolism perspective, urban and industrial symbiosis can generate significant life cycle environmental benefits by reducing the demand for upstream resource mining and downstream waste disposal (Sun et al., 2016). Fostering urban and industrial symbiosis networks will require holistic visioning and integrated master planning for sustainable urban and industrial development. IE master planning includes coordinating synergistic interactions between industrial and urban systems. IE provides a holistic systems perspective to analysing and re-designing integrated urban and industrial systems. Furthermore, IE advocates for a shift from linear industrial modalities of production and consumption to circular modalities inspired by the cyclical material and cascading energy modalities of natural ecosystems. Evidently, such an interdisciplinary perspective includes the pursuit of resource use optimisation, minimisation of waste and cleaner production through combinatorial technological innovation.

1.4.3 Circular Economy – Circular Cities

The circular economy model (CE) model presents an alternative material flow model, one that is cyclical (Korhonen et al., 2018). According to the Ellen Macarthur Foundation (EMF), *"a circular economy is a continuous cycle that preserves and enhances natural capital, optimises resource yields, and minimises system risks by managing finite stocks and renewable flows"* (EMF, 2016). Furthermore, it is *"restorative and regenerative by design, and aims to keep products, components and materials at their highest value at all time"* (EMF, 2016).

Figure 1-5 Circular economy model (EMF, 2016)

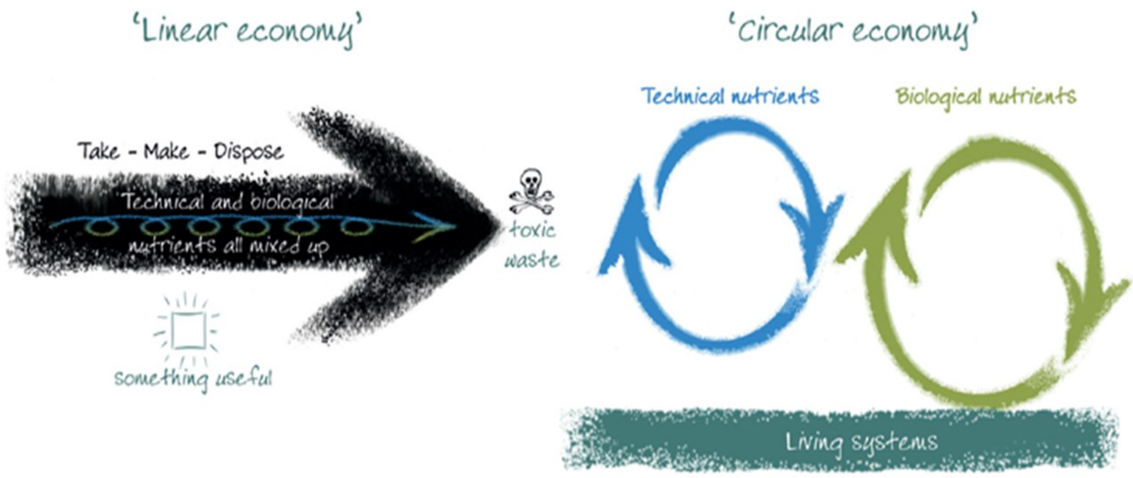


Figure 1-5 portrays the essential meaning of the CE concept. CE is currently promoted by the European Union (EU) and the governments of several leading developed economies including, Japan, China, United Kingdom, Canada, France, The Netherlands, Finland and Sweden (Korhonen et al., 2018). CE is rather unexplored in the context of promoting a sustainable development agenda in emerging economies. This thesis explores the relevance of the CE model, in framing a design discourse to address waste management in South African cities.

In the scientific community CE is a relatively new interdisciplinary concept, which originates in industrial ecology, general systems theory, and ecological economics. The CE model perceives resource flows through an industrial and urban metabolism[17] lens. Korhonen et al. define CE from the perspective of sustainable development:

> *"Circular economy is an economy constructed from societal production-consumption systems that maximizes the service produced from the linear nature-society-nature material and energy throughput flow. This is done by using cyclical materials flows, renewable energy sources and cascading-type energy flows. Successful circular economy contributes to all the three dimensions of sustainable development. Circular economy limits the throughput flow to a level that nature tolerates and utilises ecosystem cycles in economic cycles by respecting their natural reproduction rates"*. (Korhonen et al., 2018)

By extending the research done by Stahel (1994), McDonough and Braungart (2002), Bocken (2016) delineates three categories of CE design and business model *strategies: 1) "'slowing resource loops' through long-life goods and product-life extension", 2) "'closing resource loops' through recycling"*[18] *and 3) "resource efficiency or narrowing resource flows, aimed at using fewer resources per product"* (Bocken et al., 2016) (McDonough and Braungar, 2002) (Stahel, 1994). This thesis focuses on strategies to close resource loops in the context of industrialising cities in developing countries, with specific attention to typologies of industrial and urban symbiosis.

Seeing as cities are strategic locations to address climate change related socio-ecological challenges, the transition towards a CE will hinge upon the proliferation of the *circular city* concept. Herein, the application of industrial and urban symbiosis strategies can improve the metabolism of cities. A circular city is a city that implements CE strategies (e.g. converting production and post-consumer waste streams to resources via industrial and urban symbiosis respectively) to close resource loops in partnership with businesses and communities to realise a

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[17]Like *"industrial metabolism", "urban metabolism"* metaphorically refers to the resource consumption of cities, *"as it requires input of energy and materials to exist and grow just like a living organism, and also produces waste"* (Wolman, 1965 cited in Kalmykova, 2015)

[18] Stahel (1981) describes the recycling of materials as *"simply closing the loop between post-use waste and production"*, furthermore positing that *"recycling does not influence the speed of the flow of materials or goods through the economy"* (Stahel, 1981).

common vision of a future-proof city (Prendeville et al., 2017). A multilevel circular city strategy can foster substantial ecological and economic efficiency (i.e. eco-efficiency) gains for businesses and communities, in turn increasing the competitiveness of cities and co-located industrial clusters.

In recent years, CE has proved to be highly marketable policy rhetoric gaining global traction, especially in the EU policy arena. Due its high degree of marketability the CE model provides a useful bridge between the interdisciplinary science of industrial ecology and policy makers. In short, CE provides a communicable and convincing narrative to encourage municipalities to develop policies that engender *closed resource loop* patterns of organisation.

1.4.4 The Third Industrial Revolution: An Emerging General Purpose Technology Platform

Climate change poses an existential threat to modern civilisation, hence there is growing urgency to challenge the incumbent socio-technical regime and explore alternative narratives to organise our economy and society. In this regard, world-renowned economist and political advisor Jeremy Rifkin[19] (2011) provides a compelling counter economic narrative; he contends that throughout the history of mankind phenomenal economic transformations occurred when three core technological forces converge to create a *general-purpose technology (GPT) platform* to manage power and organise economic activity, i.e. new forms of communication converged with new forms energy and new logistics and transport systems.

Table 1-1 delineates the respective industrial revolution eras by GPT platforms (see Table 1-1). In the First Industrial Revolution, it was the steam engine, the printing press and the railroad. In the Second Industrial Revolution, it was the telephone (i.e. centralised telecommunications), electricity (i.e. centralised fossil fuel energy generation) and the automobile. Both of these GPT platforms hinged on a dirty carbon intensive energy mix (e.g. coal and oil).

[19] Jeremy Rifkin's *Third Industrial Revolution* meta-narrative and unique vision of a sustainable, post fossil fuel future has been endorsed by the European Union (EU) and the United Nations (UN). In recent years, he has served as a senior policy advisor to the EU and influential world leaders including Chancellor Angela Merkel of Germany, President François Hollande of France, and Premier Li Keqiang of China. He is also a senior lecturer at the Wharton School's Executive Education Program at the University of Pennsylvania, president of the Foundation on Economic Trends in Washington, D.C., and author of 19 books.

Table 1-1 General purpose technology platforms: energy-communications-transport/logistics matrix

Industrial Revolutions	Communications	Energy	Transport and Logistics
First (18th-19th century)	- Steam powered printing - Telegraph	- Abundant coal - Steam power	- Steam powered locomotives on national rail infrastructure
Second (19th-20th century)	- Centralised telecommunications - Telephone - Radio - Television	- Centralised electricity - Cheap oil	- Internal combustion vehicles on national road infrastructure
Third (21st century)	- The Internet - Ubiquitous computing (e.g., personal computers, smart phones) - Artificial Intelligence	- Renewable energy - Internet of Things - Decentralised generation and distribution of energy	- Internet of Things - GPS logistics - Autonomous electric vehicles - Sharing economy

The Second Industrial Revolution is expiring and that anthropogenic induced CO_2 emissions are threatening the viability of life on our planet, in turn, what we need now is a fundamentally new economic narrative that can transition us into a sustainable post-carbon economic era. In order to construct this new vision requires we require an understanding of the technological forces that expedite the profound transformations in society (Rifkin, 2014).

Rifkin posits that the merging of Communications Internet, with the fledgling Energy Internet (e.g. renewable energy powered micro-grids) and Logistics and Transport Internet (e.g. GPS logistics, autonomous plug-in electric vehicle technologies) in a seamless web of twenty-first-century smart infrastructure enabled by the Internet of Things[20] (IoT) will usher in a Third

[20]The Internet of Things (IoT) has a plethora of definitions: (1) one typology emphasizes the physical things which become connected in an IoT infrastructure; (2) while other definitions focus on Internet-related aspects (e.g., Internet protocols and network technology); and (3) a final typology focuses on semantic challenges relating to the storage, search and organization of large volumes of information (Atzori et al., 2010). For the purpose of this study the following definition by the International Telecommunication Union (ITU) will be employed, which describes IoT as, *''a global infrastructure for the Information Society, enabling advanced services by interconnecting (physical and virtual) things based on, existing and evolving, interoperable information and communication technologies''* (ITU, 2012).

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Industrial Revolution (TIR); and with it a new economic narrative for the systemic transition towards a sustainable post-carbon future (Rifkin, 2014).

In his thesis, Rifkin delineates five pillars of the TIR:

- *"shifting to a renewable energy mix;*
- *transforming the building stock around the world into micro-power plants to harvest renewable energies on-site and feeding it into a decentralised and smart renewable energy network;*
- *deploying state-of-the-art storage technologies throughout the infrastructural network (e.g. hydrogen fuel cells) to store intermittent energies;*
- *employing Internet technology to convert the power grid of every country into an energy internet; wherein millions of buildings (e.g. micro-power plants) are generating a small amount of renewable energy locally, on-site and allowed to sell surplus green electricity back to the grid; and*
- *transitioning transportation to electric plug-in and fuel cell vehicles that can buy and sell green electricity on a smart and interactive power grid"* (Rifkin, 2011).

In a world of ubiquitous computing, connectivity will play an instrumental role in the emergence of this new narrative; that is *"organised nodally, scales laterally, and favours distributed and collaborative business practices that work effectively in networks"* (Rifkin, 2011). In short, Rifkin describes a new socio-technical system that is intelligent, interactive, integrated and seamless. Furthermore, he envisions a transition from hierarchical to distributed, lateral, and collaborative structures power; a typology of *distributed capitalism*.

Rifkin, depicts a hybrid economic system, a co-evolution of market structures and the collaborative commons (Rifkin, 2014). In short, he presents an economic master plan to transition towards a sustainable post carbon era. This paradigm shift is premised on a digital GPT platform; therein intelligent, networked IoT infrastructure will manage a constant stream of big data, which can then be processed with advanced analytics to create predictive algorithms and automated systems to improve thermodynamic efficiency, increase productivity, and reduce their marginal costs across the value chain (Rifkin, 2014). Furthermore, Rifkin (2014) argues, *"when we compare the increasing expenses of maintaining an old Second Industrial Revolution communication/energy matrix of centralised telecommunications and centralised fossil fuel energy generation, whose costs are rising with each passing day, with a Third Industrial*

Revolution communication/energy matrix whose costs are dramatically shrinking, it's clear that future lies in the latter".

Rifkin (2015) contends that if the general-purpose technology (GPT) platforms of the First and Second Industrial Revolutions facilitated *the "severing and enclosing of the Earth's myriad ecological interdependencies for market exchange and personal gain"*, the IoT platform of the TIR if governed responsibly has the potential to construct a sustainable post-carbon circular economy. Furthermore, he posits that IoT is a disruptive technology in the way we organize and manage economic life, in doing so allowing mankind to creatively reintegrate itself into the *"complex choreography of the biosphere"* (Rifkin, 2014). To this end allowing us to dramatically increase productivity and aggregate efficiencies of our urban and industrial systems *"without compromising the ecological relationships that govern the planet"* (Rifkin, 2014). Utilising primary and secondary resources more efficiently and productively in a circular economy and transitions to renewable energy regime are defining features of the TIR. In addition, Rifkin (2014) highlights that in this new economic paradigm, "*we each become a node in the nervous system of the biosphere"*.

From an industrial ecology (IE) perspective and within Rifkin's TIR model, how would material and energy flows coevolve (e.g. closing material loops) with the diffusion of a new GPT platform? To this end it is supposable that via the widespread diffusion of integrated, decentralised and distributed intelligent TIR recycling infrastructural systems (e.g. IoT enabled recycling technologies), we can create a near zero waste future, i.e. a cyber-physical circular economy. In this hyperconnected future, a majority of material and renewable energy inputs and outputs are sensed, monitored and tracked with the goal of attaining an optimal pattern of consumption (considerate of ecological constraints); in turn radically improving the aggregate efficiencies of cities and regions. This study employs Rifkin's meta-narrative to frame the exploration of how residual resource flows in industrial cities and regions (in emerging economies like South Africa) can be reshaped by an emerging digital infrastructural system based GPT platform; culminating in the genesis of distributed, collaborative, hyperconnected and smart residual resource recovery networks – circular city cyber-physical-social ecosystems.

To expedite the diversion of recyclable materials from landfill and coupled with the optimisation of residual resource flows will require an interdisciplinary re-conception of current urban-industrial systems; predicated upon a systemic transition towards cleaner production technologies. The first step in overcoming the dominant and outdated linear paradigm of production and consumption is for key actors (e.g. consumers, firms and government institutions) to realise the potential of waste as a resource and in turn recognise the environmental, economic and social value of intelligent, decentralised and hyperconnected infrastructural systems espoused with the master planning framework of the Third Industrial Revolution. Furthermore, it will be necessary to enable the co-evolution of a collaborative and multilevel strategy, concurrently emanating in macro and micro socio-technical spaces – public policy arenas, firm-level top management and sustainable technology innovation niches.

How can we cultivate widespread biosphere consciousness coupled with Third Industrial Revolution strategic thinking among influential actors in the abovementioned diverse socio-technical spaces? This study posits that through collaborative and co-designed sustainable technology innovation niches (i.e. complex real world case structuring, design visioning and rapid prototyping) we can expedite the testing of sustainability transition experiments. Hence, an ancillary aim of this thesis is to employ a circular city cyber-physical-social ecosystems framework to inform the design of a new pattern of organisation; configured to improve resource recovery and recycling efficiencies in South African cities.

1.4.5 Cyber-physical-social systems

The research introduces the notion of *circular city cyber-physical-social systems*. To unpack this concept, it is imperative to define *cyber-physical systems* contextualised in a *cyber-physical society*. A *cyber-physical system (CPS)*[21] is defined as a suite of *"transformative technologies for managing interconnected systems between its physical assets and computational capabilities"* (Lee et al., 2015). In age of ubiquitous computing and sophisticated communication technologies ushering in the next industrial revolution, cyber-physical systems will transform industrial practices. Recent technological advancements have resulted in higher availability and affordability of sensors, actuators, controllers, data acquisition systems and computer network infrastructure (i.e. suite of Internet-of-Things technologies) (Lee et al., 2015). The increasing uptake of sensors and networked machines has culminated in the dynamic generation of high volume date, i.e. big data. Hence, CPS can manage big data to leverage the interconnectivity of machines to attain the goal of intelligent industrial systems.

Furthermore, in the near future cyber-physical systems will transform other aspects of economic and social life. The increased interaction between humans and cyber-physical systems *"will connect human society to form a new world – cyber-physical society"*, which Zhuge (2010) is defines as:

> *Cyber-physical society is a multi-dimensional complex space that generates and evolves diverse subspaces to contain different types of individuals interacting with, reflecting or influencing each other directly or through the natural, physical, mental, artifact, socio, and cyber subspaces. Versatile individuals and socio roles coexist harmoniously yet evolve, provide appropriate on-demand information, knowledge and services to each other, transform from one form to another, interact through super-links, and self- organize according to socio value chains. It ensures healthy and meaningful life of individuals, and maintains a reasonable rate of expansion of individuals in light of overall capacity and the material, knowledge, and service flow cycles.* (Zhuge, 2010)

As cyber-physical systems penetrate the broader economy, intelligent *cyber-physical-social ecosystems* will evolve. *Cyber-physical-social ecosystems (CPSE)* can be described as *"merging computing, networking and society with physical systems to create revolutionary science, technical capabilities and better quality of life"* (Murakami, 2012). A CPSE coordinates computational, physical and social elements of a future networked economy.

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[21] Cyber-physical systems (CPS) incorporate the suite of Internet-of-Things (IoT) technologies referred to in section 1.5 and section 1.5.1.

Figure 1-6 Cyber-physical-social systems (Murakami, 2012)

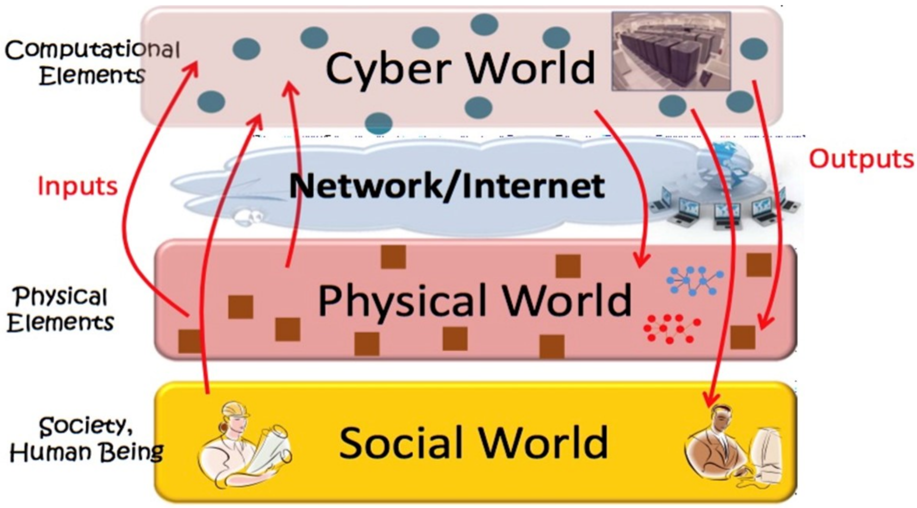


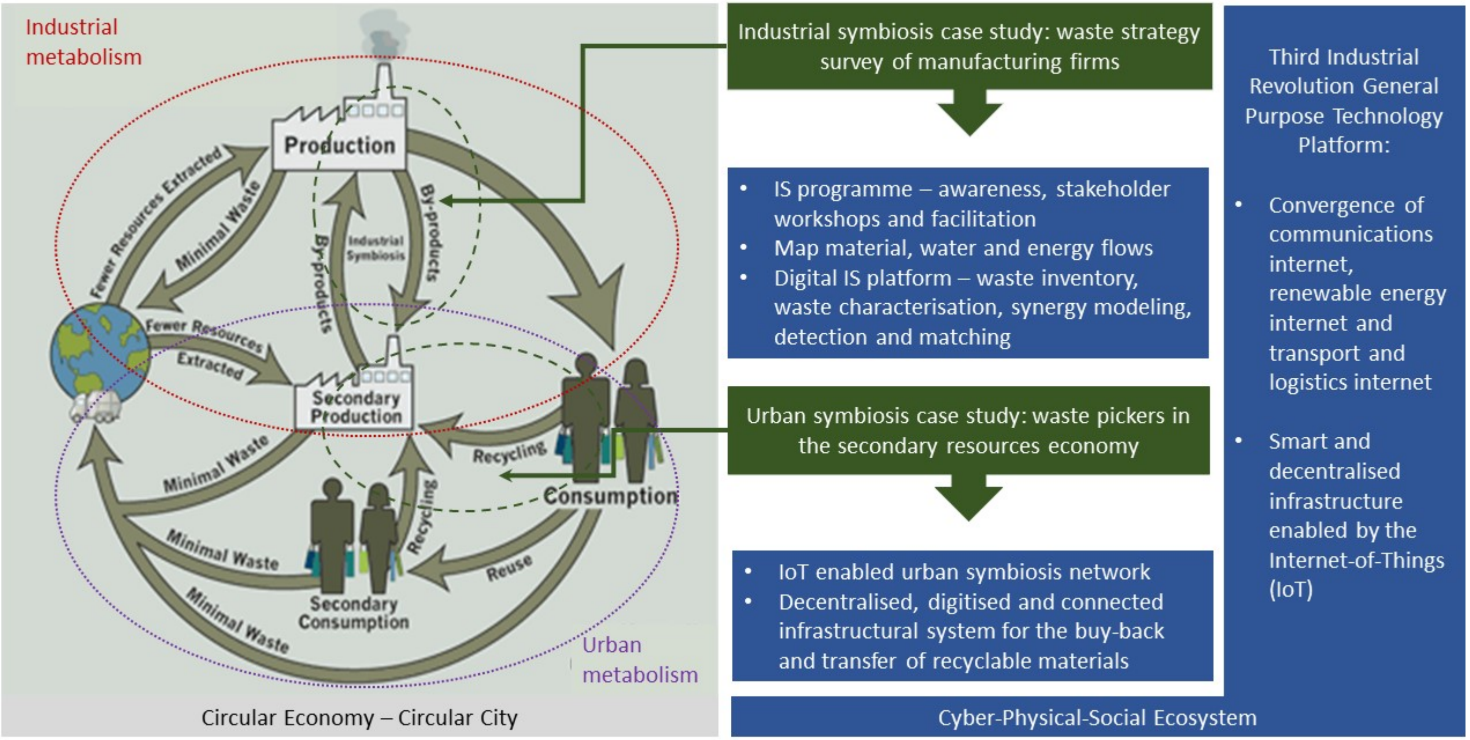
Figure 1-6 shows a simple overview of the CPSS framework. In an optimistic version of a pending new economic narrative, a cyber-physical society driven by advanced analytics, automation and embedded intelligence (i.e. ecological sustainability value-laden) will aggregate and organise resources into semantically rich forms to engender man made system to evolve towards ecologically sustainable patterns of production and consumption. In the cyber-physical society decentralised users (producer, consumers and prosumers) will be enabled to cooperate and collaborate *"to accomplish tasks and solve problems by using the network to actively promote the flows of material, energy, techniques, information, knowledge, and services in this environment"* (Zhuge, 2010).

1.5 Research Design

South Africa's major metropolitans are characterised by rapid urbanisation, infrastructure development, diverse industrial activity coupled with a burgeoning consumer base – in turn imposing increasing pressure on an outdated waste management infrastructural system. The economy as a whole is characterised by the formal and informal economies, which is highly relevant in the case waste management as there are vital linkages between the formal and informal waste management sectors. This is exemplified in the case of informally organised waste pickers' networks that physically divert large amounts of recyclable materials (e.g. cardboard, paper, glass and plastics) from urban waste streams into secondary raw material markets that supply the recycling and reprocessing sector. Thus, to grasp the complexity of designing and testing circular economy practices (e.g. urban and industrial symbiosis) for cities in a middle-income developing country like South Africa, it is imperative to gain an understanding of the dynamics of the informal and formal waste management systems.

The circular economy concept is borne from the theoretical foundation developed in the interdisciplinary field of industrial ecology (Bocken et al., 2016). Naturally, urban and industrial symbiosis are key elements of a comprehensive circular city strategy. Hence, two case studies are purposively selected to explore urban and industrial symbiosis dynamics in the context of South Africa's industrial cities. Although the case studies are located in the industrial province of KwaZulu-Natal and more specifically eThekwini Municipality, the fundamental industrial and urban dynamics (i.e. agglomeration of diverse industries, urban informal recycling networks) are characteristic of major metropolitans across the country, e.g. Cape Town and Johannesburg.

Figure 1-7 Case studies situated in an interdisciplinary theoretical framework[22]



[22] Graphic adapted from King County, WA, USA, Department of Resources and Parks

To this end, this thesis adopts an embedded multiple case study approach (Scholz and Tietje, 2002). Figure 1-7 interprets the setting of the case studies in an interdisciplinary conceptual framework and summarises their respective outputs. The respective case studies address resource recovery dynamics in two key waste management sub-systems relevant to South African cities – industrial waste management and urban informal recycling.

The following case studies were purposively selected to gain insight into designing cyber-physical circular city architectures for the secondary resources economy. The case studies are based on primary and secondary data. They provide an integrated method (i.e. synthesising quantitative and qualitative knowledge) for holistic and high-resolution problem structuring. The industrial symbiosis case study explores firms' attitudes towards waste management, providing policy and technology recommendations. The urban symbiosis case study explores the role of waste pickers in the secondary resources economy and informs the design if a virtual circular city experiment (see section 1.5.3) – IoT enabled urban industrial symbiosis infrastructural system (shown in figure 1-7 and figure 1-2).

1.5.1 Industrial symbiosis case study: waste strategy survey of manufacturing firms

Corporate attitudes of South African industries are starting to change as waste management becomes costlier due to stringent environmental regulations and fluctuations in commodity markets. However, overall, there is a paucity of reliable and comprehensive data on the waste sector in South Africa; hence, there is a need to conduct in-depth firm-level industrial studies on waste management strategies and practices. This case study posits that in order to transform the management and treatment of waste, it is imperative to incubate, nurture and advance concepts of industrial ecology at all institutional levels. In short, this case study adopts an IE perspective to explore waste management trends among firms in the South Durban Basin (SDB) industrial cluster situated in eThekwini Municipality.

1.5.1.1 Research questions, objectives and aim

a) Research questions

- What is the scope for further reusing the industrial waste generated in the SDB?
- Do firms in SDB cooperate in managing their waste? If so, how and to what degree?

b) Objective

- To identify the opportunities and barriers to detecting and facilitating industrial symbiosis (IS) networks

c) Aim

- To identify leverage points for technological intervention (i.e. virtual circular city experiments)

1.5.1.2 Methods

The study employs a mixed methods research design entailing the collection and analysis of qualitative and quantitative data to complement each other resulting in a more nuanced analysis. The mixed methods design consisted of a systematic literature review, self-administered questionnaire survey and semi-structured interviews. In addition, for purposes of data triangulation, it is necessary to conduct key informant interviews with waste service providers, industry experts and state officials at various tiers of government.

1.5.2 Urban symbiosis case study: exploring the role of waste pickers in the secondary resources economy

In South Africa, the informal recycling sector performs a large proportion of recycling in municipal solid waste management (MSWM). Some of the benefits of recycling are positive environmental effects (e.g. reduction in waste disposal and associated pollution) and economic benefits (e.g. savings on raw materials, extensive local job creation, and significant contribution to national economies). Informal, self-employed individuals who recover and sort recyclable materials from urban waste streams are termed *waste pickers*. They are instrumental actors in the informal recycling sector and the vital connection in the urban symbiosis value chain in South African cities. It is estimated that 70-90% of recyclable post-consumer packaging material is sourced by waste pickers (Godfrey, 2015). In South African cities, it is estimated that between 60 000 to 90 000 people make a living as waste pickers (Godfrey, 2015). Perceived as the poorest of the poor, waste picker communities are an extremely marginalised and exist on the fringes of mainstream economy and society.

Arguably, albeit under-reported and understated, waste pickers play an indispensable role in the recovery of recyclable materials from urban waste streams. This case study explores the urban informal recycling sector in KwaZulu-Natal (KZN) analysing the instrumental role of waste pickers as base agents in recovering materials from post-consumer (e.g. household waste) and commercial waste streams, thus increasing the supply of recyclable materials (e.g. cardboard, paper, plastic and metal) in the secondary resource economy.

1.5.2.1 Research questions, objective and aim

a) Research questions

- What is the role of waste pickers in the secondary resources economy?
- Does urban informal recycling offer a decent livelihood to waste picker communities?

b) Objective

- To gain a systemic understanding of the urban informal recycling sector

c) Aim

- To identify leverage points for technological intervention (i.e. virtual circular city experiments)

1.5.2.2 Methods

A rapid qualitative assessment (i.e. systematic literature review, key informant interviews, focus groups) of the urban informal recycling sector was undertaken. In doing so investigating the work of waste pickers, their livelihood profile, their link to the broader economy (e.g. linkages to secondary resource markets and secondary manufacturing networks), as well as the perceptions of relevant government and non-governmental organisation's of formal and informal waste management. The literature review also provides analysis of proposed and relevant government policy dialogues, like the recently proposed extended producer responsibility (EPR) proposal.

1.5.3 Design visioning – virtual circular city experimentation

The process of *design visioning* adopts the creative process of systematic scenario building, in doing so facilitating a cognitive break from the incumbent socio-technical regime. Ultimately, *"designers work to visualise 'in-the-mind' reflections on new potentialities, breaking from 'realistic' expectations that assume the continuation of past ('business as usual') trajectories"* (Ryan et al., 2016). The visualisation and modeling of alternative urban infrastructural systems are used in an iterative manner to generate discourse about more sustainable futures.

Design visioning can be defined as *"the critical human ability to conceptualise alternative realities, to imagine and to explore in the mind other sets of relationships (social, physical, technological) than those currently evident in the lived-in world"* (Ryan et al., 2016). The process is inherently transdisciplinary, engagement with key stakeholders includes co-production of knowledge (e.g. joint problem structuring) and the dissemination of visualised futures – *"workshop processes are structured to bring an ever-widening cohort of citizens to review and reflect on alternative futures and pathways"*. Virtual experiments[23] can create novel glimpses of alternative future states for stakeholders and catalyse opportunities for real physical experimentation.

The in-depth case study analyses (i.e. knowledge integration) coupled with convergence of multiple theoretical domains, provides the empirical and theoretical inputs for circular economy design visioning, in turn delineating recommendations for virtual circular city experiments (see figure 1-7). Moreover, chapter five provides a comprehensive conceptual construct of a virtual circular city experiment – an internet-of-things (IoT) enabled urban recycling infrastructural system designed to increase the productivity of waste pickers and increase the efficiency of waste collectors in the secondary resources economy.

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[23] Ryan et al (2016) introduce the idea of virtual city experimentation: *"a design approach to catalyse action in the context of rapidly emerging disruptive challenges to the fabric and life of cities. In the meaning we give to the term, the concept of virtual experimentation owes little to the contemporary association of 'virtual' with 'digital', or 'on-line'"*.

1.6 Technical and Scientific Contributions

The research makes a novel theoretical contribution through the synthesis and integration of *industrial ecology* and *circular economy* within the *Third Industrial Revolution* meta-narrative. The methodological extrapolation in this study manifests in the construct of a *circular city design visioning method*; a hybrid-transdisciplinary and creative problem solving (systems thinking and design visioning) approach, which builds upon the assertion that purposively digitally integrated actor-networks can potentially catalyse the evolution of robust residual resource synergy networks resulting in environmental, economic and social gain. In turn, the study applies the circular city design visioning approach to conceptualise a new cyber-physical-social pattern of organisation to optimise the recovery and collection of residual resources (e.g. recyclable materials) in South African cities (see chapter five).

1.7 Structure of the Thesis

This thesis is composed of six chapters. Chapter one presented above provides a detailed introduction and overview of the thesis. In chapter one, the research journey is mapped by: firstly, structuring the problem and articulating the rationale for the research; secondly, defining the meta-narrative and therein delineating the interdisciplinary theoretical framework; thirdly, presenting the research questions, objectives and aim; and fourthly explaining the methodology and introducing the case studies.

Chapter two provides a detailed literature review of industrial ecology (IE) and circular economy (CE) theory and contextualises the practice of industrial symbiosis in South Africa. In addition, chapter two synthesises relevant literature relating to the waste management sector in South Africa and presents a concise analysis of the existing national waste management policy framework.

Chapter three elucidates the industrial symbiosis (IS) case study, which investigates firms' attitudes towards waste management strategy IS. A firm level survey is conducted in the South Durban Basin (SDB), a diverse industrial cluster situated in eThekwini Municipality (KZN). The survey investigates contextual barriers and opportunities to IS. Findings inform policy development at a regional level and highlight leverage points for IS detection, matching and facilitation.

Chapter four presents the urban symbiosis case study, which explores the urban informal recycling sector analysing the instrumental role of waste pickers in recovering recyclable materials from post-consumer waste and supplying materials to the secondary resource economy. This chapter investigates how efficiency improvements targeting waste pickers can stimulate greater positive environmental impacts, create decent employment opportunities, and reduce waste management costs for municipalities. In turn, highlighting leverage points to inform the conceptualisation of alternative patterns of organising informal urban symbiosis networks. The findings inform the conceptualisation of a *virtual circular city experiment*, explored in chapter five.

Chapter five employs *a circular economy design visioning approach* to construct a virtual circular city experiment; a *cyber-physical-social ecosystem (CPSE)* designed to augment the role of waste pickers in the secondary resources economy. The *internet-of-waste pickers* is a decentralised and smart infrastructural system for the buy-back and transfer of recyclable materials recovered from municipal waste streams in emerging economies. It is an *Internet-of-Things (IoT)* enabled infrastructural system – designed to configure smart and connected informal urban symbiosis networks in South African cities. The *internet-of-waste pickers* is underpinned by ecodesign principles of organisation.

Chapter six reflects upon key findings from this critical, creative and exploratory research journey. In conclusion, how can we proceed to construct sustainable patterns of organisation within the framework of a collaborative and networked economy, i.e. CPSE expressions of ecologically sustainable resource flows? In conclusion, the final chapter proposes that future research will explore the development of an iterative *problem-theory-design-experiment continuum* to engender the leap from circular economy design visioning to the rapid prototyping and implementation of circular city experiments.

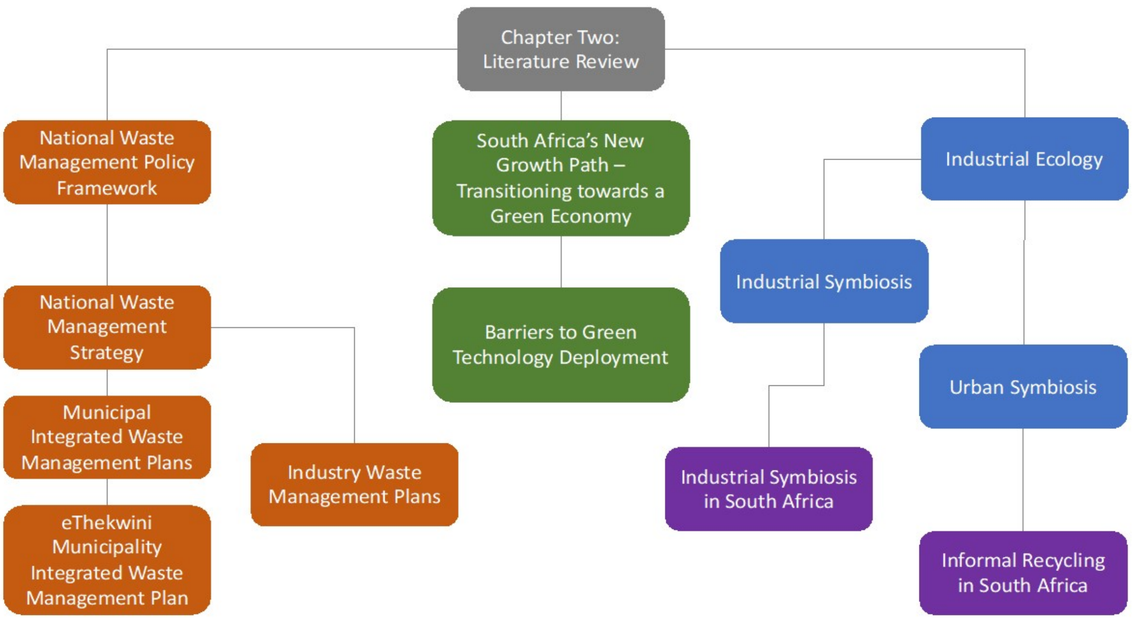
Chapter 2 – Literature Review

Chapter two provides a detailed literature review of industrial ecology (IE) and circular economy (CE) theory and contextualises the practice of industrial and urban symbiosis. In addition, chapter two synthesises relevant literature relating to the formal and informal waste management sector in South Africa and presents a concise analysis of the existing national waste management policy framework.

2.1 Introduction

Chapter two synthesises relevant literature underpinning the study. Figure 2-1 provides an overview of the main topics discussed in this chapter. It presents an overview of South Africa's green growth agenda and the state diffusing green technologies. Also, the following chapter also refers to key international sustainable development policy briefs such as the 2011 report published by the United Nations Environment Programme UNEP (2011b), outlining the need for decoupling externalisation of ecological degradation and pollution from economic growth. Furthermore, chapter two aims to provide a concise analysis of the existing waste management policy framework in South Africa as espoused by the National Waste Act (2008) and the National Waste Management Strategy (2010).

Figure 2-1 Overview of chapter two



As discoursed in chapter one, to decouple economic growth from natural resource over exploitation, South Africa urgently requires a new economic narrative. To this end, the Third Industrial Revolution (TIR) delineates a new general purpose technology platform (i.e. built out of the Internet-of-Things) and a hybrid twenty-first-century governance model (i.e. *networked collaborative commons*) for transitioning to a more sustainable development path. Regarding *designing out waste* within a TIR meta-narrative, herein industrial ecology (IE) nested in a circular economy (CE) framework provides an original policy approach. Furthermore, arguing that due its rising popularity and relevance in sustainability science, CE rhetoric presents an attractive and marketable policy vehicle to promote IE practices. Hence, this chapter explores IE theory (e.g. industrial symbiosis and urban symbiosis); constructed upon the metaphorical insight that contemporary unsustainable urban and industrial systems should observe nature and learn from the cyclic structure, cooperative and network dynamics of natural ecosystems.

2.2 Background

2.2.1 Towards Decoupling: Waste to Resource

The United Nations Environmental Programme's International Resource Panel (2011) has called for limits to growth to be recognised and strategies promoting a transition towards a decoupling of economic growth from natural resource over utilisation. Central to such an approach is ensuring economic development that *"meets the needs of the present without compromising the ability of future generations to meet their own needs"*, (WCED, 1987), through *"transcending the ecology-economy divide, internalising 'external costs' into functions of the market and economy in general"* (Mol and Jänicke, 2009). Reducing the rate of natural primary resources use in economic activity in addition to the negative impact of resource extraction is the starting point for such a strategy. *"Decoupling at its simplest is reducing the amount of resources such as water or fossil fuels used to produce economic growth and delinking economic development from environmental deterioration"* (UNEP, 2011b).

It is within such a complex socio-ecological context that possibilities for opportunities are to be realised, with critical natural resources such as water under threat. The starting point is an acknowledgement of the linkages between industrial related economic development and waste production, underscored by the limits to the extent of natural resource availability. From this vantage point, decoupling from the over-utilisation of natural resources in industrial production requires adopting innovative production strategies premised on ecological efficiency – in a bid to minimise the scale of natural resource use and waste produced. However, industrial ecology goes one step further, recognising waste not as a negative externality but rather as a latent economic potential.

According to UNEP (2011), the potential disaster looming from natural resource over-utilisation has the potential to be turned into a significant opportunity through *"a combination of physical, fiscal, institutional and technological interventions"*, which would allow for efficient, sustainable resource use. For this to be realised, however, requires the relevant natural resource, for example, water, to be seen as a binding constraint in the production cycle. Hence it is here that so-called waste arising from production related activity has the economic potential to be recycled for re-use.

This underlying rationale, recognising the limits of growth and the potential of waste as a resource within a circular production system, can be seen as the fundamental concepts of developing an industrial ecological paradigm. In this regard, UNEP (2011) depicts the long-term vision for the waste sector as *"to establish a circular global economy in which the use of materials and generation of waste are minimised, any unavoidable waste recycled or remanufactured, and any remaining waste treated in a way that cause the least damage to the environment and human health or even creating additional value by recovering energy from waste"*.

The requirement for such a transition or shift in production and consumption behaviour comes at a time of global economic crisis, with new approaches to economic decision-making seen as fundamental in ensuring sustainable and equitable development. So, to the challenge of dealing with diminishing natural resources and rapidly rising levels of waste globally and domestically motivates for a transition in industrial production and consumption philosophy. The starting point, however, requires an assessment of the scale, scope and potential of the waste market. It is imperative to understand the dynamics governing the waste recycle and transfer market in South Africa. Moreover, within the context of manufacturing industries, it is vital to assess and critically analyse demand side factors (i.e. potential for by-product exchange). Here, waste management requires a sophisticated coordination and synchronisation of policy or enforcement alongside key private sector stakeholder participation (Chalmin and Gaillochet, 2009).

In South Africa, waste management is often linked to a socio-economic context and is the responsibility of individual municipalities. Remediation for harm or loss suffered as a result of pollution is underwritten on the *polluter pays principle*, which imposes a fine or compensation for damage to the environment or to individuals that have been adversely impacted upon by a polluter, or by an employee associated with a polluter. The classification of waste and in particular hazardous waste is thus central to enforcing legislation and determining the level of compensation or cost recovery. The current polluter pays approach is regressive or can be seen as an outdated *end-of-pipe* approach in attempting to deal with the adverse impacts of waste and pollution in particular. This according to Chalmin and Gaillochet (2009) results in waste being defined at a national level through jurisprudence utilising *"an objective physical definition (a list of defined substances) with a subjective legal definition (any substance or object which the holder discards or intends or is required to discard)"*. Similarly, the measurement of pollution or limits to pollution is a value-laden political judgment which *"sets the level of externality adjustment based on remediation costs"* (Chalmin and Gaillochet, 2009). For example, through the introduction of taxes impacting on prices and emission standards impacting upon quantity, *"waste is attributed a value and externalities a price"* (Chalmin and Gaillochet, 2009). On this basis, the value of waste is determined by the recovery cost of it as a negative externality to the environment and society in general.

For a transition to a greener, more sustainable and equitable economy, however, requires upstream changes or interventions to militate against possible negative externalities impacting upon the environment and society. This requires one to reposition waste within the economy from a position of seeing waste as a threat or cost to seeing waste as an economic potential. This is not to say all waste has an inherent economic potential but rather that careful introspection within the waste sector is required to define and strategically delineate between waste and non-waste. This is determined by either the positive or negative exchange value represented in the waste recovery process. Key considerations concern whether the recovery of waste contributes to de-pollution and whether the recovery of waste is economically feasible (Chalmin and Gaillochet, 2009). More fundamentally, the utility of waste recovery needs to be determined through assessment of the extent for re-use, in addition to the threat posed to the environment and society. Defining these parameters forms the foundation of developing a waste economy, and ultimately transitioning to a greener economic development path.

This being said, the scope and economic potential of the waste economy are similarly poorly defined; due to the limited extent of credible data concerning waste within and across countries. In 2012, the market value of the formal South African waste management economy according to the South African Department of Environment Affairs (2014) was estimated at R15.3 billion per annum (0.51% of the GDP), with the scope for growth significant in both municipal and industrial waste. The recent development of a world market for secondary materials such as scrap ferrous, non-ferrous metals and paper is indicative of this potential, with secondary material flows between wealthy countries and emerging economies driven by demand/shortages for such resources in emerging economies such as China, India and Turkey (Chalmin and Gaillochet, 2009).

The key starting point, however, requires an adequate assessment and understanding of production and consumption patterns (i.e. urban and industrial metabolism) at a city level. It must be noted that in general, waste estimates and amounts of industrial waste, in particular, are difficult to assess, the primary reason being *"incomplete, heterogeneous and uncertain available data"*, South Africa is no exception (Chalmin and Gaillochet, 2009).

Towards this, as a starting consideration, the first case study (chapter three) adopts an *industrial metabolism* perspective, thereby investigating firms' attitudes towards waste management and industrial symbiosis. Whereas, the second case study (chapter four) adopts an *urban metabolism* perspective, thereby exploring the role of waste pickers in the secondary resource economy and informal urban symbiosis patterns. Therefore, this study adopts a circular economy (industrial ecology) strategic lens, recognising waste not as a negative externality, but rather as a latent economic potential.

2.2.2 South Africa's New Growth Path – Transitioning towards a Green Economy

The South African government's support for the transitioning towards a green economy as outlined in the New Growth Path (NGP)[24], is premised on the fact that not only is it a response to growing concerns about climate change, but that it also represents a key growth strategy proposing to create 300 000 green jobs by 2020 (Economic Development Department, 2011 #504). Especially the green economy strategy is underpinned by a need for a qualitative change in the South African economy, especially concerning carbon intensity of energy production and also the wasteful consumption of critical resources (e.g. water).

[24] The South African government adopted the New Growth Path (NGP) as the framework for economic development and is considered the primary driver of the country's job creation strategy.

Table 2-1 South African government departments responsible for facilitating green growth (Academy of Science of South Africa, 2014)

Government Department	Responsibility
Presidency (advisory powers only)	National Planning Commission
Economic Development Department – has direct control over the Industrial Development Corporation and the Development Bank of Southern Africa	New Growth Path (NGP) and green economy
Department of Trade and Industry (DTI) – has to rely on other departments to implement measures aimed at green industries	Support for green growth
National Treasury	Environmental fiscal reform; green taxes and subsidies which support both green industries and the greening of the economy as a whole
Department of Environmental Affairs and Tourism (DEAT)	Responsible for the protection and restoration of ecosystems and the setting of environmental standards, e.g. for pollution or emissions
Department of Energy (DEA)	Responsible for issues relating to fossil fuels and renewable energy
Department of Water Affairs (DWA)	Responsible for issues relating to water
Department of Science and Technology	Responsible for technology policy and R&D

There is a proliferation of policies and strategies across various national government departments concerning supporting green growth and diffusing green technologies. Table 2-1 highlights the responsibilities of the important South African government departments tasked with facilitating green economy projects in different areas (e.g. water, energy and waste management).

The Department of Trade and Industry's (DTI) Industrial Policy Action Plan (IPAP) is tasked as the central tool in the NGP which will lead to job creation through downstream innovation and beneficiation, with green industries comprising a key component of this strategy. The release of IPAP 2 in 2010 was followed by the Green Economy Summit, an initiative led by the Economic Development Department (Teddlie and Yu) with the publication of the Green Jobs and Industries for South Africa initiative known as Green-JISA. The potential for the growth of green industries is briefly mentioned in the most recent IPAP (2016/17 – 2018/19), with a focus on increasing the proportion of local content in renewable energy technology value chains (e.g. local manufacturing of wind turbine blades and photo-voltaic cells, modules and panels). In short, the South African government is slowly recognising the importance of transitioning towards low-carbon practices and creating an enabling environment to foster the creation of green jobs.

The 2010 Green Economy Summit argues the waste management sector accounts for 90 000 jobs in the recovery, reusing and recycling. Findings from a study commissioned by the Department of Trade and Industry (DTI) on the potential of recycling in South Africa have illustrated that based on production levels and population estimates, *"the recycling industry could at full capacity, sustain 190 000 jobs opportunities"* (of which 90% would be unskilled jobs, largely in waste collection) (IDC, 2011). The Industrial Development Corporation's Green Jobs report (2011) illustrates that by 2025 the formal jobs in the waste management sector could double from, 8000 to 16 000 jobs, associated with the construction, operations, maintenance and manufacturing concerning waste stream beneficiation.

The waste management sector thus has immediate and significant growth potential. An important factor underpinning the potential of waste recycling resides in the phenomenon of increasing urbanisation; by 2025, it is estimated that 70% of South Africans will reside in towns and cities. The development and realisation of the waste recycling sector potential, however, will be presented with challenges concerning infrastructure bottlenecks surrounding limited landfill space and adequate service provision (Peter and Swilling, 2011).

The starting point, however, is assessing the potential for waste streams beneficiation at a city and regional level. Recycling trends in South Africa have steadily been on the increase in recent years. This as a result of increasing requirements for legislative compliance, in addition to significant economic opportunities manifesting in the recycling sector with the arrival of standard recycling and material reprocessing technology (Oelofse and Strydom, 2010).

Table 2-2 Producer responsibility organisations and management of respective recyclable materials (GreenCape, 2016a)

Producer Responsibility Organisation	Material	Generated (tonnes)	Diverted from landfill (tonnes)	Still available for recycling (tonnes)	Still available for recycling (percentage)
Paper Recycling Association of South Africa	Paper	2 200 000	1 100 000	1 100 000	50%
Plastics SA	Umbrella organisation for plastics	1 400 000	315 000	1 085 000	77.5%
The Glass Recycling Company (TGRC)	Glass	845 663	338 265	507 398	54.32%
e-Waste Association of South Africa (eWASA) South African e-Waste Alliance (SAEWA)	e-Waste	322 000	45 000	277 000	86.03%
Metal Recyclers' Association of South Africa	Scrap metal	3 121 000	2 497 000	624 000	20%
Recycling and Economic Development Initiative of South Africa (REDISA)	Tyres	270 000	109 906	160 094	40.71%

In comparison to other emerging economies, South Africa has a fairly well-developed recycling industry with the primary recycling activities centred around paper and cardboard, metal cans, glass and tyre waste streams. However, there is still the opportunity for radical improvement and optimisation of residual resource recovery networks. Packaging SA[25], a voluntary industry organisation, argues that recycling and reuse in South Africa have significant scope for further growth, with approximately 1.5 million tonnes of packaging and paper waste going to landfill annually (PACKINGSA, 2015). Table 2-2 elucidates the potential to increase the recovery of recyclable materials from post-consumer waste streams and the consequential recycling, reprocessing and utilisation of secondary materials in South African industries.

[25]Packaging SA has recently replaced The Packaging Council of South Africa (PACSA), a voluntary body funded in 1984, representing converters, raw material suppliers, customers and major recyclers.

2.2.3 Barriers to Green Technology Deployment in South Africa

The deployment of advanced waste management technologies (i.e. green technologies) is necessary to enable the transition towards sustainable waste management regimes in South Africa. Ultimately, the deployment of new technologies hinges upon the transfer of socio-technically appropriate technologies incubated within a robust National System of Innovation (NSI?). From an innovation perspective, it is argued that South Africa has the potential to lean towards a *"developer role"*, rather than just an *"implementer role"* (Diab, 2015). However, there are significant barriers hindering the both the implementation and development of green technologies in South Africa, specifically:

- *Institutional challenges* – pertains to the lack of a coherent and cohesive policy framework to support indigenous green technology innovation/technology transfer and green economy project development. *"There is rather a proliferation of policies, sometimes with conflicting goals and in some cases a lack of policy certainty"* (Academy of Science of South Africa, 2014).

- *Government bureaucracy* – a lack of political will, complex and protracted government processes are in some cases delaying and even preventing the investment and implementation of green technology projects (Academy of Science of South Africa, 2014).

- *Skills shortages* – lack of relevant technical skills inhibits the development of green technology projects and is also an impediment to sustainable innovation. Furthermore, project developers have referred to the frustration experienced in dealing with local government officials, who lack the adequate skills to support green technology projects (Academy of Science of South Africa, 2014).

- *Intellectual property rights* and the associated high costs of obtaining advanced green technologies is recognised as a significant barrier to technology transfer[26]. Generally, developing countries can't afford the high costs of obtaining advanced technologies from multinational companies.

- *Financial barriers* – although some efforts have made by the South African government to address funding (e.g. the Green Fund), the supply does not match the demand for innovation and project development funding. Furthermore, green technologies require *"high R&D investments initially and continued funding to ensure the commercialisation and scale up of these technologies"* (Academy of Science of South Africa, 2014 #505).

- *Market information asymmetries* – In South Africa, lack of awareness and market information asymmetries hinders the development and deployment of appropriate technologies. Greater awareness of market needs will assist in focusing innovation efforts. Furthermore, there is a need for greater awareness among consumers and other key stakeholders regarding the public benefits (e.g. environmental and social) of supporting the adoption of green technologies.

The lack of a diverse and healthy national innovation ecosystem is one of the key reasons that green technology transfer mechanisms fail in developing countries, so too is the case in South Africa. Consequently, due the barriers listed above South Africa has an unimpressive rate of green technology transfer. *"One of the main market mechanisms designed to transfer technology is the Clean Development Mechanism of the Kyoto Protocol, and yet South Africa's involvement in the scheme has been dismal, in contrast to other developing nations such as China"* (Academy of Science of South Africa, 2014).

A logical starting point to enhance the deployment of green technologies is to engender greater policy coherence and coordination among state departments – in turn enabling local authorities to expedite the transparent development and implementation (i.e. void of corruption) of green technology projects. Also, it is posited that the Department of Science and Technology (Ferri et al.) should take the lead as custodian, overseeing the development of appropriate human capital and coordination of financial and technical support (Diab, 2015). Furthermore, extensive local investment in research and development and the subsequent incubation of technology niches is a prerequisite for a meaningful green technology push and, by implication, a transition towards a green economy.

2.3 South Africa's National Waste Policy Framework

The internationally recognised waste hierarchy (see figure 2-2) forms the conceptual basis of the National Waste Management Strategy (NWMS). The first step is avoidance or reduction, where waste cannot be avoided it should be recovered, reused, recycled and treated, with the disposal of waste as a last resort. Implementation of the waste hierarchy requires upstream as well as downstream innovation in production and manufacturing processes promoting the 3Rs concept also known as cradle-to-cradle waste management.

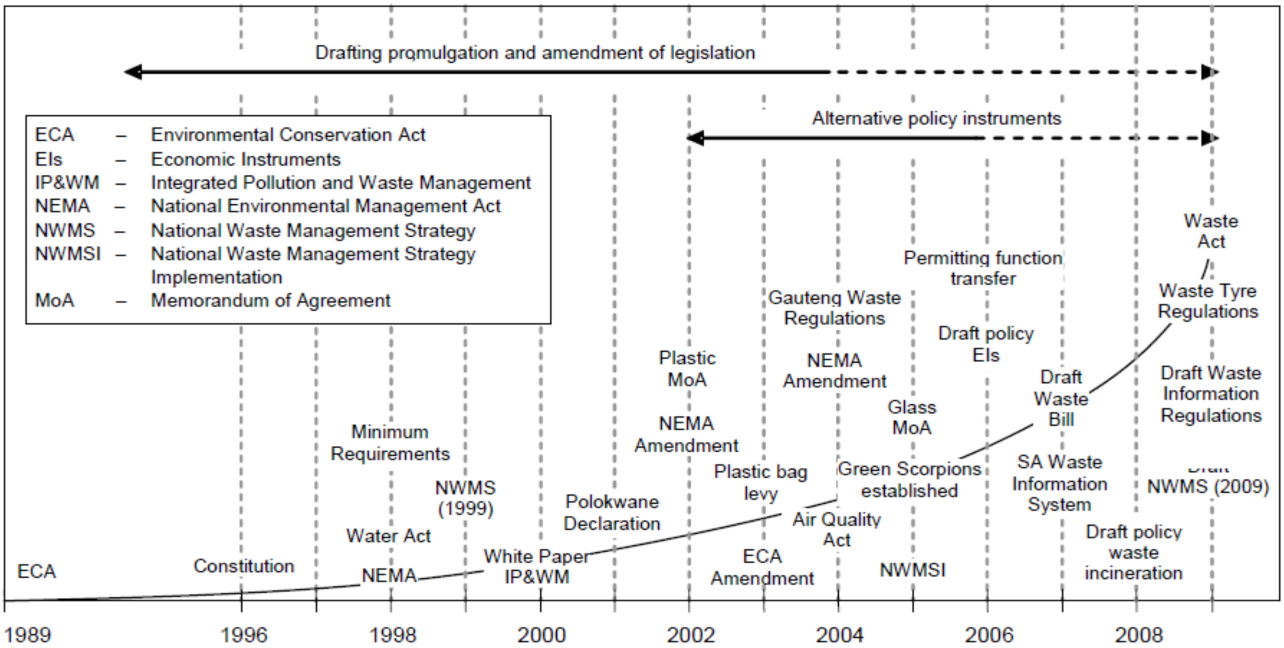
Figure 2-2 Waste management hierarchy (eThekwini Municipality, 2016a)

Implementation of the NWMS is underpinned by a system of norms and standards, on one hand, creating a *"common national platform for waste management activities to be undertaken by both public and private sectors"*, whilst simultaneously allowing for the development of provincial and municipal norms and standards as long as they do not conflict with national standards (Olver et al., 2009).

The NWMS is underwritten by the polluter pays principle, which makes provisions for remediation of contamination of land to protect human health and the environment. The NWMS can be seen as the culmination of a policy maturation recognising the limits to pollution, as a result of the promulgation of the National Environmental Management Act: Waste Act (No. 59 of 2008) (hereafter Waste Act) driving this process.

The graphic below illustrates the process of environmental and waste legislation development in South Africa:

Figure 2-3 History of pollution and interventions in South Africa (1989-2009) (Oelofse and Strydom, 2010)



2.3.1 Legislative Implementation through Waste Classification

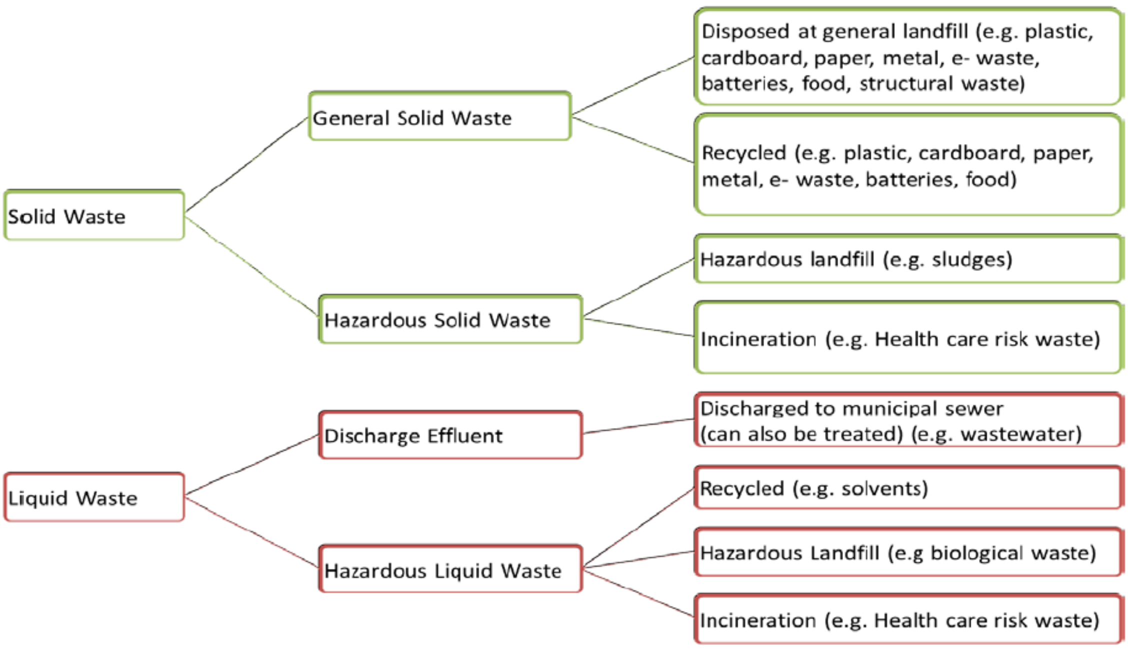
Implementing a national holistic waste management programme has, however, been fraught with challenges. According to Oelofse and Godfrey (2008), the problems stem from the difficulty until recent in defining waste, mainly due to the lack of a specific legislative instrument mandated for the effective management of waste. Waste was either defined as unwanted nature under the Environmental Conservation Act 1989, with the second definition of waste regarding pollution potential under the National Water Act 1998. This, however, has been remedied with the promulgation of the Waste Act. Under the Waste Act, the classification of waste in South Africa is categorised according to the basis of potential risk the waste poses to human health and the environment.

The waste is further classified into two sub-groupings namely; general waste and hazardous and industrial waste (see table 2-3 below). Figure 2-4 provides further detail, by delineating the differences between solid and liquid waste.

Table 2-3 Waste classification

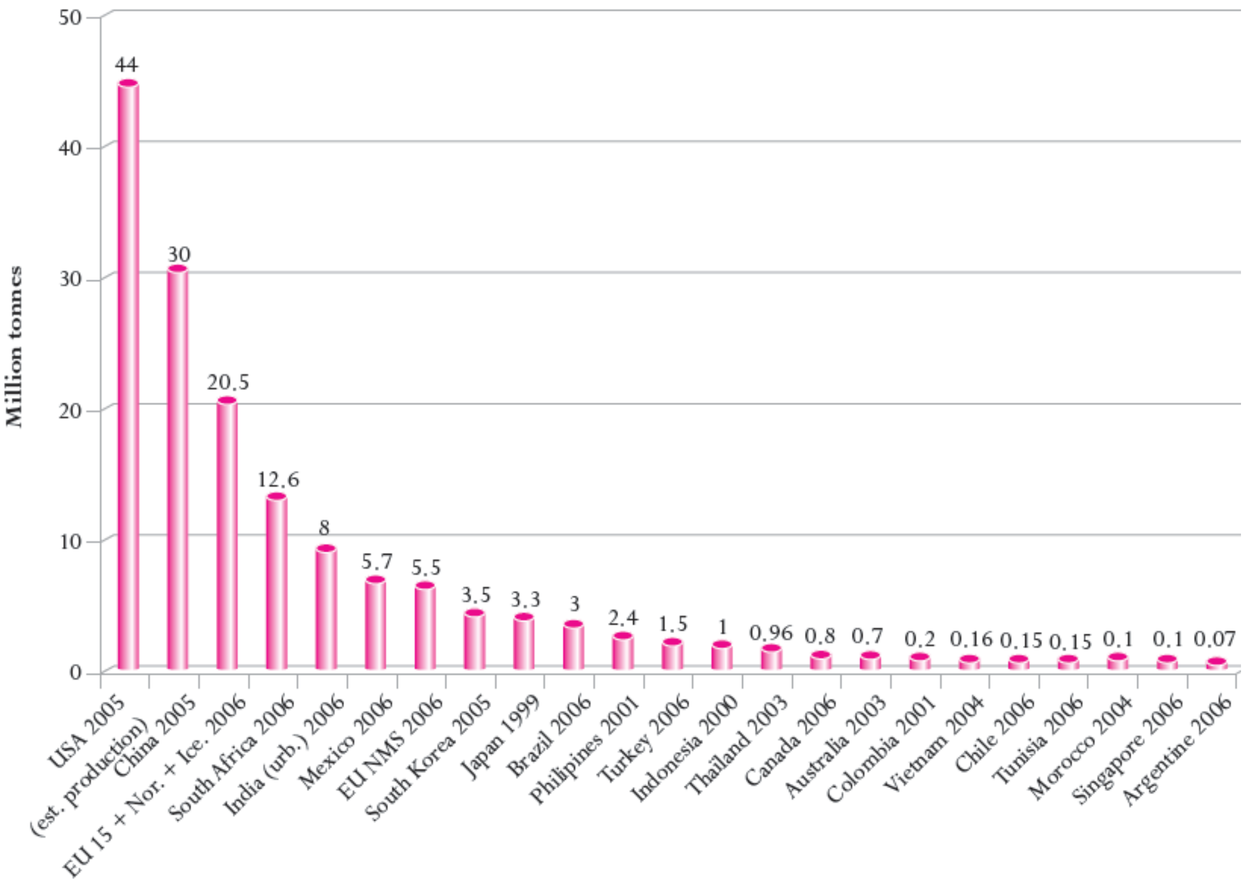
General Waste	Hazardous and Industrial Waste
• Domestic waste • Construction and demolition waste • Business waste • Inert waste	• Health care waste • E-waste • Batteries • Fluorescent lamps • Oil • Sewage sludge • Effluent • Carbon emissions

Figure 2-4 Typical solid and liquid waste streams (DEA, 2011 #2)



Currently, however, South Africa is facing the challenge of dealing with increased volumes of hazardous and industrial wastes, with a limited extent of recyclability of these wastes within the context of current infrastructure constraints and the underdevelopment of the waste economy. As figure 2-5 illustrates South Africa ranks fourth behind the USA, China and the EU (including Norway and Iceland) regarding the production of hazardous manufacturing waste. Furthermore, treatment facilities of these wastes are limited to few treatment facilities in the country, with waste streams from the healthcare risk waste, used oil, sewage sludge, batteries, e-waste, pesticide waste and power station waste in particular problematic (Peter and Swilling, 2011).

Figure 2-5 Hazardous manufacturing waste in selected countries (Chalmin and Gaillochet, 2009)



2.3.2 Municipalities and the Integrated Waste Management Plan

Every municipality in South Africa is required to have an Integrated Waste Management Plan (IWMP) that includes the 3R approach. However, at a practical level, there is limited capacity for implementing this approach countrywide. Even though the eThekwini (KZN) and Cape Town municipalities have made significant progress, little has been done to syndicate these learnings in other municipalities (Peter and Swilling, 2011). Furthermore, unlike the water, energy, transport and agriculture sectors which are governed by their ministries/government departments, waste falls under Environmental Affairs directorate where an under-resourced sub-directorate is responsible for the entire sector.

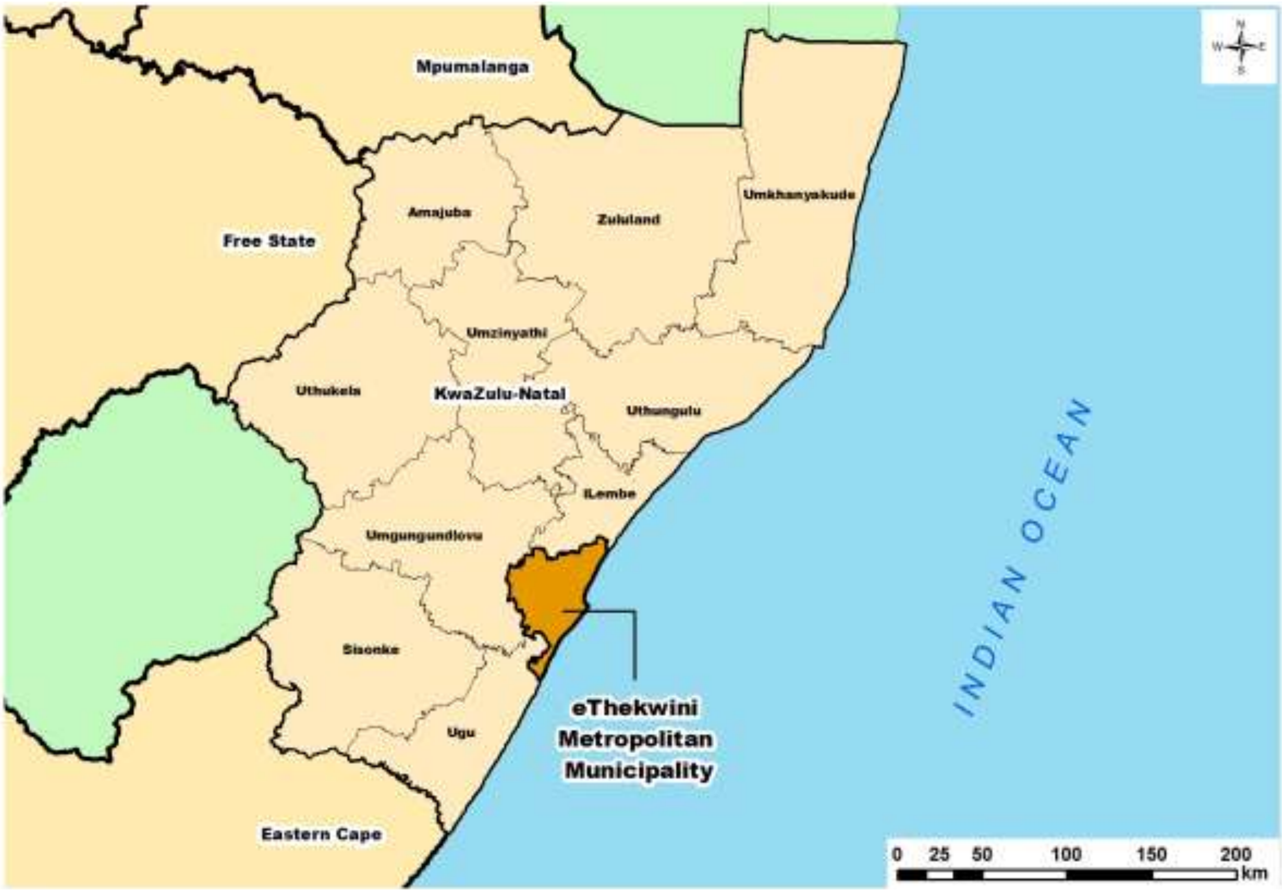
2.3.3 eThekwini Integrated Waste Management Plan

2.3.3.1 Background information

eThekwini Municipality is situated on the east coast of South Africa, covering an area of 2297 square kilometres. It is located in the southern extent of the Province of KwaZulu-Natal (see figure 2-6), with a population of approximately 3.5 million people. The municipality is comprised of 45% rural, 30% peri-urban and 25% urban areas (eThekwini Municipality, 2016a). The main city in the municipality is Durban; it is a regional industrial hub with the largest and busiest shipping terminal in sub-Saharan Africa. The municipality ranks as the second largest economic centre and the second most significant industrial region in the country (eThekwini Municipality, 2016b). The economy is based on a large and diverse manufacturing sector (e.g. paper and pulp products, chemicals and petrochemicals, automotive components, clothing and textiles, and food and beverage production). Despite its existing industrial capacity and potential for economic growth, social transformation is slow exemplified by high levels of inequality[27] and unemployment – approximately 25% of the population not economically active.

[27] From a national perspective, the Gini coefficient for eThekwini ranked second with Nelson Mandela Bay while Johannesburg was the highest during 2014. The Gini coefficient is a summary statistic of income inequality (eThekwini Municipality, 2016b).

Figure 2-6 Locality map of eThekwini Metropolitan Municipality(eThekwini Municipality, 2016a)



2.3.3.2 eThekwini Integrated Waste Management Plan 2016-2021

The eThekwini Integrated Waste Management Plan 2016-2021 (EIWMP) sets out priorities for improving waste management services and established targets for the collection, minimisation, reuse and recycling of waste.

The EIWMP is underpinned by the following legislative and policy frameworks (eThekwini Municipality, 2016a):

- The Constitution of South Africa; Chapter 2; Environment Article 24[28].
- The National Environmental Management: Waste Act (Act No 69 of 2008).
- The eThekwini Municipality Integrated Development Plan 2015-2016
- The National Waste Management Strategy.

The EIWMP highlights seven critical areas where a so-called gap or constraints exist (eThekwini Municipality, 2016a):

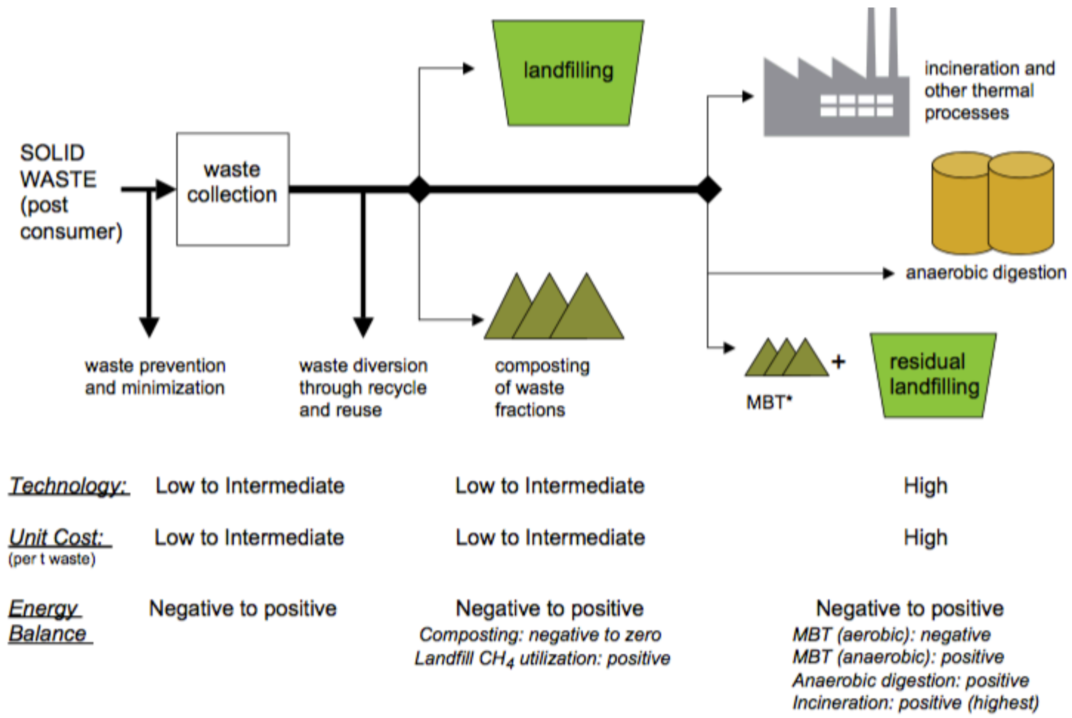
1. Waste Generation and Waste Collection;
2. Recycling and Re-Use;
3. Waste Treatment and Disposal;
4. Maintenance and Improvement of Waste Management Facilities;
5. Public Awareness and Education;
6. Management Systems, Human Resources and Finance;
7. Legislation, Compliance, Monitoring and Enforcement.

Taking into consideration stricter national environmental regulations, increasing waste transportation and disposal costs, it is essential for the municipality to minimise landfilling of waste by increasing recycling and reuse. Therefore, the ultimate goal of the EIWMP is to gradually transition towards an advanced integrated waste management system. There is a broad range of mature technologies to mitigate GHG emissions from waste and increase the recovery and utilisation of secondary material resources. However, variable feedstock and high input costs are barriers to pursuing high technology strategies for municipalities in emerging economies like South Africa.

[28]Environment Article 24, in the South African constitution states: "*Everyone has the right –(a) to an environment that is not harmful to their health or wellbeing; and (b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that—(i) prevent pollution and ecological degradation; (ii) promote conservation; and (iii) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development*".

Figure 2-7 depicts the technology gradient for urban waste management with low to high-technology options:

Figure 2-7 Technology gradient for waste management: major low- to high-technology options applicable to large-scale urban waste management (IPCC, 2007)



2.3.3.3 Waste characterisation

The quantification of general waste is based on the monthly datasets that are sourced from Durban Solid Waste (DSW) – the Cleansing and Solid Waste Management Unit of eThekwini Municipality. This contains monthly waste quantities over a period of 3 years which are 2013, 2014 and 2015. Sanitary landfilling is the incumbent waste management technology employed by DSW to dispose of non-hazardous waste. DSW operates four landfill sites; Bisasar Road, Buffelsdraai, Mariannhill and Lovu (see figure 2-8). Waste quantities are recorded by weighbridge facilities when delivery trucks enter the site (eThekwini Municipality, 2016a).. Furthermore, DSW also operates *"two small scale landfills that only accept garden refuse, builders' rubble and cover material"* (eThekwini Municipality, 2016a).

Figure 2-8 Map of transfer stations and landfills in eThekwini Municipality (eThekwini Municipality, 2016a)

Table 2-4 Characterisation of waste landfilled in eThekwini Municipality (eThekwini Municipality, 2016a)

Waste Category	Characterisation
DSW	Domestic, commercial and industrial waste (non-hazardous) that is collected by DSW, including subcontractors
General Solid Waste	Domestic, commercial and industrial waste (non-hazardous) that is collected by private contractors
Garden Refuse	Discarded plant/tree trimmings, grass cuttings, tree branches and trunks
Builders' Rubble	Discarded non-hazardous material that originated from building or demolishing projects. Includes fragmented concrete, broken bricks and blocks
Mixed Loads	Refers to loads of waste that have mixtures of general solid waste, garden refuse, builders' rubble
Sand and Cover Material	Excavated earth that can be used for cover material for the landfill cell
Tyres	Discarded vehicle tyres
Light Type Refuse	Includes items such as plastic, polystyrene, insulation material and foam. Refuse that can be windblown easily
Other	Business waste
Purchase Cover Material	Cover material that has been purchased by DSW for utilisation at the landfill
Recyclables	Refers to loads of sorted recyclable material

Table 2-4 characterises the waste landfilled in eThekwini Municipality. DSW also operates seven transfer stations, where municipal solid waste (MSW) is aggregated, compacted and load onto long haul vehicles for disposal to landfill. Also, DSW operates 14 garden refuse transfer stations (see figure 2-8) – utilised by the public to dispose of garden refuse as well as certain domestic waste. Most of the garden refuse transfer stations have *"private recycling drop off stations that accept paper/cardboards, plastic, glass bottles, steel and used oil"* (eThekwini Municipality, 2016a)

Table 2-5 eThekwini Municipality landfill quantities 2013-2015 (eThekwini Municipality, 2016a)

Combined landfill waste quantities (tonnes)	2013	2014	2015
Total	1 444 283	1 340 583	1 272 452

According to the most recent EIWMP, from 2013 to 2015 the municipality experienced a marginal decrease in landfill quantities (see table 2-5). This could be attributed to an incremental improvement in resource recovery and recycling rates over this period. Nevertheless, it is estimated that only 21% of household and commercial waste was recycled during this period (eThekwini Municipality, 2016a). Furthermore, population growth coupled with improved living standards, economic growth coupled with industrial expansion, will result in an increased household, commercial and industrial waste volumes being generated in the coming years (eThekwini Municipality, 2016a). Hence, more widespread and sophisticated waste avoidance and minimisation measures will be needed to reduce further the amount of waste being landfilled and increase the diversion of recyclable materials to secondary material markets.

2.3.3.4 Waste collection

a) Household waste collection

In formal residential areas, DSW provides a once per week collection service, and this includes a weekly kerbside collection by DSW owned and operated waste collection vehicle. DSW supplies black plastic bags to households, waste is placed in these bags and positioned on the kerb once a week for collection. In select few residential areas orange (i.e. for cardboard, paper and plastic) and clear plastic (i.e. for glass bottles and tin cans) bags are supplied by DSW for the collection of recyclable materials. The orange and clear bags are collected by privately operated waste collection and transport operators for delivery to recycling facilities (eThekwini Municipality, 2016a).

In low income, high density and underdeveloped urban settlements (i.e. townships[29]) DSW employs private contractors, known as Community Based Contractors (CBCs)[30], for the collection of household waste. CBC's are preferred suppliers due to their local knowledge and ability to navigate areas with limited road access (eThekwini Municipality, 2016a).

In rural areas waste collection is facilitated by DSW or CBC's. In these communities, limited road access means that DSW/CBC's utilise tractors or smaller vehicles for waste collection. However, in some cases these communities may not receive waste removal bags; hence boxes or plastic shopping bags serve as substitute receptacles for household waste (eThekwini Municipality, 2016a).

b) Commercial waste collection

Commercial areas include business districts and suburban commercial areas (e.g. shops and offices). Waste produced in commercial areas is collected either DSW or private waste management service provider (eThekwini Municipality, 2016a). The frequency of collection is a minimum of once per week but can be more frequent in the case of contractual arrangement between a business and a private waste management service provider.

c) Industrial waste collection

Industries are provided with waste management services either by DSW or private waste management service providers. Seeing as DSW only collects general solid waste, specialist private waste management service providers are required for the collection and management of

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[29] *"The term 'township' has no formal definition but is commonly understood to refer to the underdeveloped, usually (but not only) urban, residential areas that during Apartheid were reserved for non-whites (Africans, Coloureds and Indians) who lived near or worked in areas that were designated 'white only' (under the Black Communities Development Act (Section 33) and Proclamation R293 of 1962, Proclamation R154 of 1983 and GN R1886 of 1990 in Trust Areas, National Home lands and Independent States)"* (Pernegger and Godehart, 2007). In the post-apartheid era, townships have been under serviced by municipalities; hence widespread protest action demanding access to basic services (e.g. access to clean water, sanitation and waste management) continue today.

[30] To date DSW has utilised 366 CBC's via tender processes to assist with household waste collection in townships (eThekwini Municipality, 2016a).

hazardous waste streams, i.e. treatment and disposal in appropriately licensed privately owned and operated hazardous landfill sites.

2.3.3.5 Recycling activities

In eThekwini Municipality recycling is practiced by DSW, private companies and local entrepreneurs. *"The level of recycling initiatives range from small scale street collection to large business enterprises that have collection, storage and processing facilities"* (eThekwini Municipality, 2016a). Also, The Education and Waste Minimisation Department has implemented many community-based recycling projects and facilitated the development of buy-back centres[31], school recycling programmes and drop off centres (eThekwini Municipality, 2016a).

DSW's main recycling project is the orange bag kerbside collection system (eThekwini Municipality, 2016a). Orange waste bags are supplied by DSW to households in select formal residential areas for the recycling of cardboard, paper and plastic. The collection of the orange bags run parallel on the day that the household's general waste (i.e. black bags) is removed. The municipality outsources this service to private waste collection companies.

DSW most recent recycling programme is the implementation of a kerbside collection system for glass bottles and cans from households via the utilisation of allocated clear bags. This programme is in the initiation phase. *"Many of the garden transfer stations have drop off centres which are equipped to accept paper, cardboard, glass bottles, plastics, metal and used oil"* (eThekwini Municipality, 2016a). Materials received at the drop off centres are supplied by individuals and households *"that utilise their own resources to transport recyclable material to these collection points"* (eThekwini Municipality, 2016a).

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[31]. The role of buy-back centres in providing basic infrastructure to the informal urban recycling sector (i.e. waste pickers) is explored in chapter four and five.

2.3.4 Industry Waste Management Plans (IndWMP)

eThekwini Municipality is a hub of diverse industrial activities, with the manufacturing sector, accounts for approximately 20% of the municipality's Gross Domestic Product (GDP) (eThekwini Municipality, 2016a). Major manufacturing industries are located within eThekwini Municipality include, automobile and component sector, pulp and paper, chemicals and petrochemicals and food and beverages. Some of these industries produce hazardous solid and liquid waste that needs to be disposed of safely and in accordance with The Waste Act, which outlines the framework for Industrial Waste Management Plans (IndWMP).

IndWMPs are a co-regulatory instrument within the waste management sector and are either mandatory or voluntary depending on the nature of the waste produced as per Part 7 of the Waste Management Act, section 28 to section 34. The IndWMP can be seen as an attempt to mandate industry on how industry will address waste management issues within specific guidelines and time frames. Key considerations in determining whether an IndWMP is mandatory or voluntary include:

- The actual and potential environmental and health impacts of the waste being generated.
- The consumption of sensitive natural resources in the production process.
- The potential for the IndWMP to mitigate these impacts while achieving waste avoidance and minimisation.

To date it is mandatory for the following industries to prepare their IndWMP, under consultation with the Department of Environmental Affairs (eThekwini Municipality, 2016a):

a) Tyres industries to manage waste tyres;
b) Paper and Packaging industries to manage packaging and paper waste;
c) Lighting industry to manage mercury containing lamps, e.g. CFLs;
d) Pesticide industry to manage residual pesticides and pesticide containers[32].

[32] Agriculture and interlinked upstream (e.g. pesticide manufacturing) and downstream (e.g. sugar refining) industries constitute key value chains in eThekwini Municipality. According to 2011 census, data crop farming accounts for around 50% of agricultural activities, which is followed by livestock farming that accounts for 23% of agricultural activities (eThekwini Municipality, 2016a). The major crop grown is sugarcane, in turn, sugar production is an important export commodity that contributes to the

2.3.5 Compliance and Enforcement

Enforcement by way of the *polluter pays principle* under section 28 of the National Environmental Management Act 1998 (NEMA) makes provisions for remedial action to be taken against perpetrators. Also, South Africa is signatory to some international agreements that relate to the issue of waste management and international legislative enforcement summarised in table 2-7 below:

Table 2-6 South African affiliation – international conventions on waste (UN, 2002)

Basel Convention 1989	• Controls and limits the movement of hazardous wastes across national borders on the basis of informed consent and provides stringent tracking requirements.
Montreal Protocol 1989	• Provides for the progressive phasing out of gaseous emissions found to deplete the ozone layer. The NEMA: Air Quality Act and the National Framework for Air Quality Management provide an additional regulatory framework with respect to this protocol.
Rotterdam Convention 1998	• Controls the cross-border movement of hazardous chemicals by defining a procedure for informed consent which includes standards for labelling and documentation.
Polokwane Declaration 2001	• Prioritisation of Waste Management. • Implementation of the NWMS.
Johannesburg Plan of Implementation 2002	• Prevent and minimise waste and maximise reuse, recycling and use of environmentally friendly alternative materials, with the participation of government authorities and all stakeholders. • Advance Agenda 21 to the sound management of chemicals and hazardous waste for sustainable development.
Stockholm Convention 2004	• Provides measures for limiting Persistent Organic Pollutants (POPs) - a category of harmful chemical compounds that accumulate in the food chain and damage the integrity of ecological systems.
Various Maritime Conventions	• Several maritime conventions deal with disposal of waste at sea, with varying levels of international ratification.

Reform and compliance, however, cannot be a stand-alone policy process, but rather requires a sophisticated synchronisation of environmental governance, impact analyses and technological innovation. The need for environmental governance is especially pertinent where economic activity *"places heavy demands on the environment"*, such as "*the raw material industries, and equally so of energy, transport, building and agriculture"* (Jänicke and Jörgens, 2009). Without due consideration given to the sustainability of the environment, persistent ecological problems will arise, often complex in nature and vast in scale, requiring specialised and costly intervention to mitigate ecological crisis. In the absence of a coordinated response to ecological governance,

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regional economy.

the state is often faced with the financial and ecological costs as a result of private sector actors absconding from responsibility, due in part either to weak state precedent or governance. For example, soil or ground water contamination, or ozone depletion associated with heavy carbon orientated industry. Taking this into consideration, there is thus a critical need for ecological governance by way of synchronisation of policy premised on socio-ecological sustainability through a bargaining and building process with relevant stakeholders (Jänicke and Jörgens, 2009).

Steps toward enforcement of the Waste Act currently rely on requesting industry to submit Industry Waste Management Plans (IndWMPs) as per section 28 to section 34 however, failing to make this a universal mandatory policy commitment. It is within such a context that the onus for ecological governance enforcement at present, and the realisation of a green economy through legislative or policy interventions alone, will fail to materialise. On this basis, the potential and value of industrial ecology resides in linking growth potential through ecologically sustainable development practices driven by public-private partnerships, with a particular emphasis on the role of firm behaviour. This can be motivated on the premise of economic relevance of an effective waste management strategy. For example in 2004, "*the Environmental Goods and Services (EGS) sector in South Africa was valued at between R14, 5 billion and R23, 2 billion (US$ 3-4 billion or 1%-1,6% of GDP)"*, of which the waste management sector accounted for 80% of this activity (Peter and Swilling, 2011).

However, this is not to discount the fact that various state inter-departmental mandates do exist in a bid to move industry towards compliance with the Waste Act. At a national level, the Department of Trade and Industry (DTI) through its Cleaner Production Strategy (CPS) (2004) and the establishment of the National Cleaner Production Centre (NCPC) forms an important component in the realisation of the NWMS. Here, the Minister of Environmental Affairs through consultation with the Minister of Trade and Industry determine the percentage of recycled material in manufactured products. This can be seen as a regulatory intervention enforcing the Extended Producer Responsibility principle (EPR), requiring producers to take responsibility *"for aspects of a product's management beyond the point of sale"* (Peter and Swilling, 2011). Currently, most of the EPR agreements in South Africa are voluntary initiatives, with mandatory initiatives implemented through government regulation, for example in tyre recycling as well as the mandatory tax imposed on plastic bags.

Further initiatives include the launch of the Industrial Energy Efficiency Improvement Project (IEEIP). The IEEIP is a collaborative initiative between the South African government (led by the Department of Trade and Industry and the Department of Energy), the United Nations

Industrial Development Organization (UNIDO), the Swiss Secretariat for Economic Affairs and the UK Department for International Development aims to assist industry in moving towards a more sustainable growth path. The principal implementation partners are UNIDO and the NCPC, with the programme hosted by the Council for Scientific and Industrial Research (CSIR). In light of the national electricity crisis, the current predisposition however in NCPC function, is towards energy efficiency and energy conservation.

In a bid to transitioning towards a more sustainable economic development path, it is contended that there is a need to develop an expanded perspective of industrial policy based on a more holistic approach to improve the environmental performance of firms. Hence, industrial ecology (IE) is proposed as an interdisciplinary approach to industrial policy making in South Africa.

2.4 Resource Efficiency through Industrial Ecology

According to the *"Porter Hypothesis"*, stricter environmental regulations introduced by the state will catalyse the uptake of cleaner production technologies improving the environmental performance of firms; in turn making production processes more efficient thereby enhancing competitiveness (Porter and Van der Linde, 1995). An auxiliary challenge is to fundamentally embed and sustain pro-active environmental thinking at a top management level.

Industry-state collaboration is key to transition to a greener economy, in turn, a principal driver is the strategic orientation of the private sector, in particular at an inter and intra firm level. To this end, the IE paradigm promotes resource efficiency; providing a conceptual framework for firms to design and pilot innovative strategies to pursue more sustainable business scenarios, by exploring the positive environmental externalities that can accrue in industrial clusters using industrial symbiosis (Chertow et al., 2008).

IE is a relatively new interdisciplinary field of academic study emerging as an important set of concepts from the theory and practice of sustainable development. In short, this paradigm proposes that industrial systems should operate like natural ecosystems in which, *"the consumption of energy and materials is optimised and effluents of one process...serve as the raw material for another process"* (Frosch and Gallopoulos, 1989). The main ontological commitment of IE is founded on the metaphorical insight that unsustainable industrial systems should observe nature and learn from the structure and dynamics of natural ecosystems.

In the second edition of their textbook Graedel and Allenby (2003) refine their definition of industrial ecology, inspired by biological ecology, in which they say (Hermansen, 2006):

> *"A working definition of Biological Ecology (BE) is the study of the distribution and abundance of organisms and their interaction with the physical world. Along the same lines, IE can be defined as follows: Industrial ecology is the study of technological organisms, their use of resources, their potential environmental impacts, and how their interactions with the natural world could be restructured to enable global sustainability".*

The overarching thesis is that if production and consumption methods and trends in human designed systems could be re-engineered to emulate the synergetic efficiencies of natural systems then greater sustainability would arise. In essence seeking to transform current industrial processes from linear to closed loop systems based on the principles of ecology; whereby the wastes and by-products created within one system are utilised as energy or raw materials for another system (Nanas and Bellestri, 2011). Hence, *"raw material and fuel costs on the input side and waste and emission management and control costs on the output side can be reduced while new market opportunities can emerge for products with less impacts"* (Korhonen et al., 2004).

Table 2-7 Fundamental principles of industrial ecology

	Principles of Industrial Ecology (Roberts, 2004)
1.	Promote opportunities to establish genuine partnerships and engagement with communities and government in developing a more responsive attitude to sustainable industry practices
2.	Locate industries strategically to optimise the capture and concentration of by-products, waste material flows and energy surplus for use by other industries
3.	Co-locate industries that will benefit economically from the trade or exchange of waste and by-products
4.	Capture and create opportunities to add value by applying waste and energy recovery practices in industrial systems
5.	Provide a catalyst to create synergies and an environment for fostering technological advancement in cleaner production,
6.	waste management and sustainable industry development
7.	Provide appropriate 'smart infrastructure', to ensure the growth of eco-industries that support sustainable industry practices to maintain high levels of innovation as the basis of their competitive edge
8.	Support industry policies and incentives to encourage innovation, collaboration and commercialisation of new and improved product developments using materials, water and energy surplus to production
9.	Demonstrate commitment to the benefit of industries that have strong, sustainable development

The fundamental principles of IE are listed in table 2-7 (Roberts, 2004). IE involves the design of industrial processes and products from the dual perspectives of product competitiveness and environmental interaction (Pongracz, 2006). The conceptual framework provided by IE can be useful to firms seeking to improve their resource productivity and in turn their competitiveness. The systems perspective that IE promotes can cultivate a particular type of strategic corporate thinking that may lead to innovations that improve efficiency, lower costs, and raise the value created by production processes up and down the supply chain (Esty and Porter, 1998).

Korhonen argues that strategic thinking is the imperative antecedent to achieving real success in practice because ultimately IE principles must be embedded in the business strategy and decision-making structures at a firm level. Also, *"the systems and network philosophy of IE can be coupled with inter-organisational management studies to complement the more traditional intra-organisational environmental management"* (Korhonen et al., 2004). IE, presents a conceptual framework for environmental analysis and decision making, promoting technological innovation, developing a preventive stance toward environmental problems, and highlighting the vital role of firms in realising environmental goals (Graedel and Allenby 1995).

Since IE has been largely unexplored in management and policy studies; there is an opportunity to investigate this topic through the trans-disciplinary lens of mixed-methods research. As a systems-oriented approach, IE concentrates on groups of firms and their stakeholders and how they interact to achieve more sustainable outcomes. Therefore, *"stakeholder management theory"* is an important path to pursue in linking corporate environmental management theory to IE (Korhonen et al., 2004). Furthermore, environmental management issues have extended the narrow scope of traditional stakeholder theory in that more stakeholders need to be taken into account (Madsen and Ulhoi, 2001). Korhonen et al. (2004) conclude that "*stakeholders should include not only the standard members – the owner, the employees and the authorities – but also neighbours and non-governmental organisations concerned with environmental issues such as waste and pollution"*.

2.4.1 Industrial Ecology and Sustainable Waste Management

The traditional reductionist approach towards waste is fundamentally unsustainable as it lacks flexibility and long term thinking (Seadon, 2010). A transition to a sustainable society requires a critical systems approach towards waste management, especially at an intra- and inter-organisational level. In this regard, *"waste management has many of the characteristics reminiscent of a living system, an example of a complex adaptive system"* (Seadon, 2010). A systems-oriented vision, constructed on the principle that industrial design and manufacturing processes are to be considered in partnership with the environment, is what sustainable waste management needs to grow into (Pongracz, 2006). Seadon (2010) posits that *"a sustainable waste* *management system incorporates feedback loops, is focused on processes, embodies adaptability and diverts waste from disposal"*.

Therefore, IE as a systems-oriented approach to industry-environment interactions to aid in evaluating and minimising environmental impacts provides an ideal scientific canopy to frame Waste Management Theory (WMT) (Pongracz, 2006). WMT offers procedural models to achieve the goals of waste minimisation, and resources use optimisation under the IE paradigm. In this regard, Pongracz (2006) argues that WMT will be instrumental in *"optimising resources use from virgin material to finished material, to component, to product, to obsolete product, to disposal and, eventually, re-integration into the material cycle"*.

2.4.2 Industrial Symbiosis and Agglomeration Economies

Two the main aspects of IE are waste minimisation and the conversion of by-products into reusable products or resources. *"By-product exchanges may enhance a firm's resource efficiency by taking advantage of the intrinsic economic value of 'wastes', and are key in transitioning from linear to circular material and energy flows in industrial systems, a fundamental goal of industrial ecology"* (Chertow et al., 2008). Therefore, the co-location and integration of firms which can use or reprocess the waste of other industries in the same locality are critical to the manifestation of IE (Roberts, 2004). Industrial symbiosis (IS) (see figure 4) is a core component of the IE process and essentially endorses the engagement of traditionally separate industries in cooperative approaches for managing resource flows that improve their overall environmental performance. *"Taking as its starting point a vision of industry organised along the model of an ecosystem, industrial symbiosis draws on the concept of symbiotic biological relationships where unrelated organisms can find mutual benefit through the exchange of resources, typically wastes"* (Chertow et al., 2008).

Table 2-8 summarises the main economic, social and environmental benefits which are networks can present to stakeholders:

Table 2-8 Economic, environmental and social benefits of industrial symbiosis networks (O'Carroll et al., 2014)

Economic benefits	Environmental benefits	Social benefits
Increase profits	Reduce CO2 emissions	Job creation
Increase sales	Divert material from landfill	Create opportunities for knowledge transfer and learning
Reduce waste disposal costs	Reduce use of virgin resources	
Create enterprise development opportunities	Reduce hazardous waste disposal	
Reduce raw material costs	Reduce production of pollution	
Creates inward investment opportunities	Increased energy efficiency Increased innovative waste management practice	

Within the theoretical framework of IE, IS focuses on the flow of resources through clusters of geographically proximate businesses and the positive externalities that accrue from geographic concentration are known as *"agglomeration economies"* (Chertow et al., 2008). Chertow et al. (2008) advocate extending the argument concerning agglomeration economies to encompass the positive environmental externalities that potentially can accrue in industrial clusters by means of industrial symbiosis; *"by broadening agglomeration economies to include environmental advantages explicitly, it is hoped to raise the awareness of the need for environmental sustainability within regional development contexts"*. In sum, by applying industrial symbiosis to enhance the concept of agglomeration economies, it will theoretically mitigate the impact of negative agglomeration externalities while increasing production efficiency.

Firms can participate in different types of collaborative arrangements that can lead to industrial symbiosis. Chertow et al. (2008) state that to compare industrial symbiosis with related concepts in economic geography, three primary means for resource sharing have been delineated:

- Utility/infrastructure sharing—the pooled use and management of commonly used resources such as energy, water, and wastewater. The provision of public utilities and shared access to infrastructure underpin the rationale for business clustering and positive Marshallian-type agglomeration externalities (Chertow et al., 2008). Via utility sharing firms can reduce input costs and also ensure the provision of fundamental resources (e.g.

water and energy). Two international examples of utility-sharing initiatives with public and private benefits include: *"1) the collective use of a geothermal exchange system in the Phillips Eco-Enterprise Center in Minneapolis, Minnesota, which improved energy efficiency by 35% in its office building facility (Krause and Brinkema, 2003 cited in Chertow et al., 2008), and 2) the provision of water, steam, and compressed air by an oil refinery to more than ten neighbouring chemical companies on Pulau Aayer Merbau in the Jurong Island petrochemical complex in Singapore"* (PCS, 2007 cited in Chertow et al., 2008).

- By-product reuse/exchange— the exchange of firm-specific materials between two or more parties for use as substitutes for commercial products or raw materials. By-product exchange is constrained by geographic proximity, when economically viable it can result in financial and environmental benefits. *"Using by-products as raw material substitutes can lower input costs and reduce overall materials and energy requirements as a result of increased cycling. Selling wastes rather than paying to dispose of them brings additional revenues to firms, decreases waste management costs, and most often reduces the environmental impact of these materials"* (Desrochers, 2002; Ehrenfeld and Gertler, 1997; Lowe et al., 1995; Mirata, 2004; Schwarz and Steininger, 1997, cited in Chertow et al., 2008). International examples of by-product exchanges include the use of steel slag for cement production (Forward and Mangan, 1999 cited in Chertow et al., 2008), and the recovery and reuse of animal by-products as an alternative fuel source in the UK (National Industrial Symbiosis Programme, 2006, cited in Chertow et al., 2008).

- Joint provision of services—meeting common needs across firms for ancillary activities such as fire suppression, transportation, and food provision. Providing services collectively are characteristic of agglomeration economies. *"Material and energy intensity may be reduced through joint provision as individual firms do not have to own ancillary infrastructure and equipment when using a common external provider, and resource productivity may increase as those providers, whose core business is precisely that of the ancillary activity, are presumed to use resources more efficiently"* (Chertow et al., 2008). One example of joint service provision with positive environmental impact is evident in the Rotterdam harbour and industrial complex; where an external supplier is currently providing compressed air to 14 companies in the complex, and preliminary results show savings of 20% in both costs and energy, as well as reductions in carbon dioxide (Baas and Boons, 2004, cited in Chertow et al., 2008).

2.4.3 Industrial Symbiosis in South Africa

From an IE life-cycle perspective, South Africa still finds itself in the birth and growth life-cycle phases, with some informal and formal networks, and mostly in the regional efficiency stage. Regional learning has occurred due to; integrated waste exchange using an internet based exchange platform, the establishment of waste minimisation clubs and the increase of cleaner production initiatives (Brent et al., 2008). Furthermore, Brent et al. (2008) assert that the public and private sectors have in the past adopted only the tools that are used regarding the dematerialisation and decarbonisation focus of industrial ecology, namely life-cycle assessment (LCA) and material flow analysis (MFA).

To advance IE in the context of South Africa progress regarding institutionalising the field can be made via industrial symbiosis strategies at local and regional levels. In this regard, the concept of international eco-industrial parks (EIPs) is envisaged in the planning of South African industrial development zones (IDZs); however, the ideal has yet to manifest in practice. There are various barriers to the formation and management of an industrial ecosystem are shown in table 2-9:

Table 2-9 Barriers to industrial symbiosis

	Barriers to forming by-product synergy networks (Brent et al., 2009)
1.	Company concerns about propriety or confidential information
2.	Negotiating balance of payments
3.	Reluctance on the part of business to be involved in inflexible contractual commitments that do not relate directly to their core activity;
4.	Supervision and operation of co-treatment facilities
5.	Complexity managing the wastes produced by the companies

Brent et al. (2008) highlight that an additional barrier in the context of South Africa is *that "there is no legislative support for industrial symbiosis; specifically, there is no clear guidance as to the responsibilities of the parties associated with the waste streams"*. More importantly, they stipulate that more emphasis should be on the development of mechanisms that encourage firms to manage waste streams effectively while the necessary freedom to develop new and profitable uses for by-products.

It is argued that South Africa's industries present abundant opportunities to explore the design and application of different types of industrial symbiosis networks (i.e. by product exchange) through the facilitation of Public, private partnerships (PPPs) and working with key institutions such as the South African National Cleaner Production Centre (NCPC)[33]. PPPs become a contractual relationship between a local authority and private companies that commit all parties to providing an environmental service (i.e. wastewater treatment). Furthermore, the National Waste Management Strategy Implementation Project presents the foundation to construct innovative PPPs project informed by IE design principles (DEAT, 2005). Public, private industrial symbiosis partnerships should be considered as a key tool as part of a contextualised strategy toolbox designed to nurture a transition towards sustainable modalities of production and consumption in South Africa.

2.4.4 Case Study: Western Cape Industrial Symbiosis Programme

The Western Cape Industrial Symbiosis Programme (WISP) is a *"free facilitation service which use an industrial symbiosis (IS) approach to enhance business profitability and sustainability"* (GreenCape, 2016b). There are two models to organising IS exchanges and networks. The first is an *"eco-industrial park"*, where a cluster of co-located companies exchange by-products. The second model is a *"network of companies"* that is not restricted by geographical proximity, often spread over a city region (Agarwal and Strachan, 2006). WISP is a demonstration of the second model, as it facilitates IS relationships with a network of companies located in the City of Cape Town and the hinterland, i.e. surrounding region of the Western Cape.

WISP is the first subsidised IS facilitation service of its kind in South Africa. It is funded by the Western Cape Provincial Government and the British High Commission's Prosperity Fund. WISP is delivered through the Western Cape Provincial Government's strategic green economy programme, GreenCape. Furthermore, WISP works in collaboration with other key stakeholders, namely the City of Cape Town, the National Cleaner Production Centre (NCPC) and International Synergies Limited (United Kingdom based not-for-profit IS facilitation organisation).

[33] To date the NCPC together with UNIDO has assisted 153 industrial plants; R1.54 billion saved in energy costs; 5,700 jobs created/preserved (Department of Industry, 2016 #503).

Since its inception in 2013, more than 200 companies across industrial sectors have joined the network. Furthermore, over 1000 underutilised resources were identified (GreenCape, 2016b). WISP works closely with trade associations, manufacturers, industry clusters and government agencies to identify and develop IS opportunities. To date, WISP has achieved the following social, environmental and economic benefits (see table 2-10) from facilitating synergies[34] (WISP, 2017):

Table 2-10 Economic, environmental and social benefits of WISP

Economic	Environmental	Social
• R18.23 million additional revenue; • R15.40 million cost savings; R640 000 private investments	• 5449 tonnes waste diverted from landfill • 46,700 tonnes CO_2 fossil GHG savings	• 25 temp jobs created, 20 direct permanent jobs in members, 85 indirect and induced jobs created in the economy (based on direct jobs created and additional revenue generated).

Although WISP has succeeded in creating awareness among local industries about the benefits of IS and facilitating certain synergies, they have also encountered various barriers and challenges, including (O'Carroll et al., 2014):

- *"Complex regulatory framework, especially around the reuse/recycling of waste materials;*
- *High cost of transport and logistics services;*
- *Poor appetite for the use of secondary and alternative materials;*
- *Challenging and lengthy enterprise development process;*
- *Poor appetite for additional capital investments;*
- *Lack of large scale solutions for waste composite materials, organics, textiles and wood".*

[34] *"A synergy is described as the transaction or movement of materials between participating companies enabled by the active facilitation of WISP"* (O'Carroll et al., 2014).

Table 2-11 Summary of WISP synergies implemented from 2013-2014 (O'Carroll et al., 2014)

	Synergy Description	Benefits	Once-off/Continuous
1	Label manufacturer's wood pallets returned to various suppliers for reuse	Landfill diversion	Continuous
2	New logistics service provider selected by plastic injection molding company through increased networking opportunities	Cost savings	Continuous
3	Pharmaceutical company and consulting company collaborate to increase the efficiency of waste management in a manner that benefits eight companies	Landfill diversion Additional sales Cost savings Additional investment	Continuous
4	Wood pallets exchanged between waste management company and wood pallet refurbisher	Landfill diversion Additional sales Cost savings	Once-off
5	Wood pallet refurbisher internally investing due to increased networking opportunities	Additional investment	Once-off
6	Plastic pallets exchanged between a wood pallet refurbisher and a plastic pallet refurbisher	Landfill diversion Additional sales Cost savings	Once-off
7	Broken fishing nets exchanged between a marine fishing company and the City of Cape Town	Landfill diversion	Once-off
8	Replacement of LED Lights at a foundry by an energy efficient lighting company - following a relationship facilitated at a WISP workshop.	Additional sales Cost savings Energy savings	Once-off
9	X-ray film and litho fixer exchanged between a Label Manufacturer and a metal recovery company	Additional sales Cost savings	Once-off
10	Increased low-density polyethylene (LDPE) recycling by label manufacturer and waste management company	Landfill diversion Cost savings	Once-off

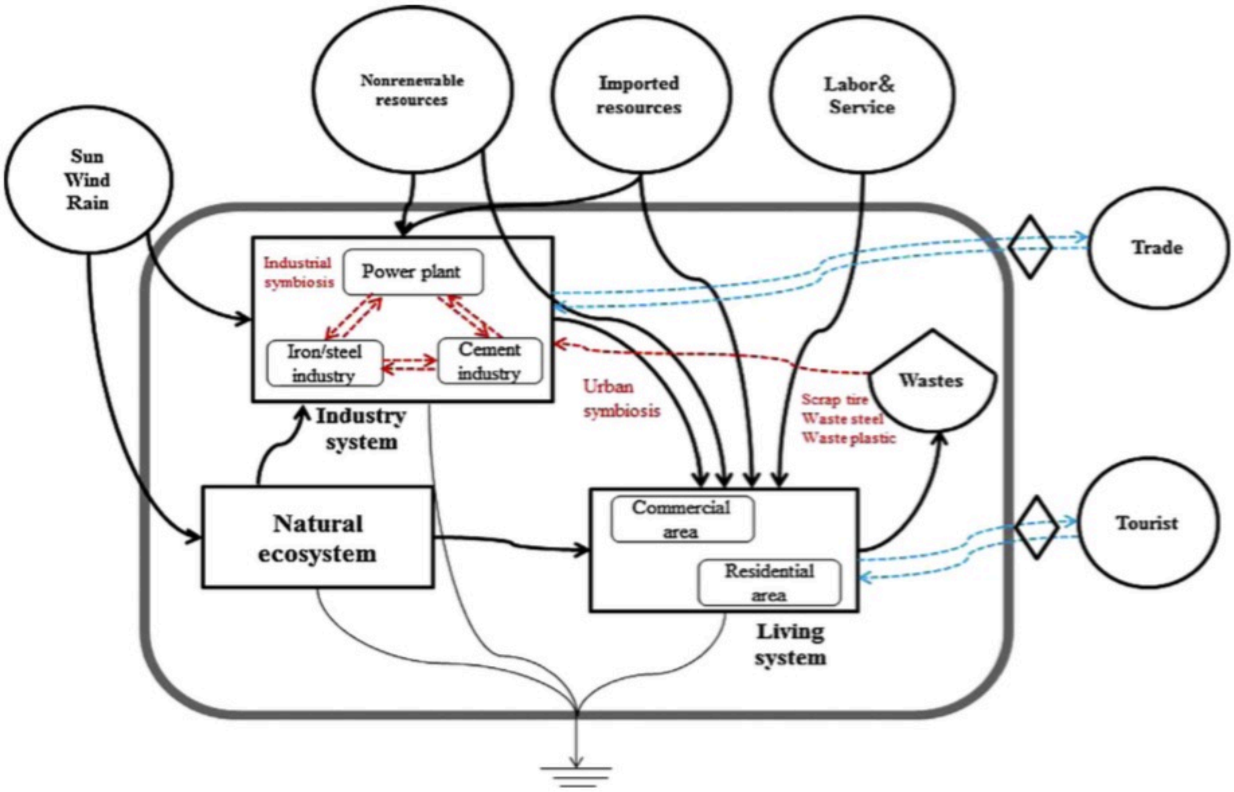
Table 2-11 provides an example of the types of static synergies facilitated by WISP. This can be described as IE-retrofit strategy to prevailing unsustainable urban-industrial systems. This approach is rather limited regarding the actual potential to accrue environmental and economic benefits, seeing as it is effectively an end-of-pipe strategy. While this is a useful starting point, it is imperative that in short to medium term this approach be complemented by an eco-industrial park strategy to yield higher and longer lasting eco-efficiency benefits. Hence, there is an opportunity for WISP to expand its role by migrating towards inculcating IE strategic thinking and disseminating IE planning methodologies (e.g. input-output analysis, material flow assessment, life cycle assessment and the purposeful design of by-product synergy networks) among stakeholders invested in designing future industrial parks in South Africa.

2.4.5 Urban Symbiosis

IE is an emerging systems-oriented approach of industry-environment interactions, which holds considerable potential to achieving greater levels of material and energy resource use efficiency. In turn, industrial symbiosis (IS) is a sub-field of IE; principally concerned with the cooperative management of resource flows through networks of firms as a means of approaching ecologically sustainable industrial activity. Urban symbiosis is described as an extension for industrial symbiosis and can be defined as *"the use of byproducts (waste) from cities (or urban areas) as alternative raw materials or energy sources for industrial operations"* (Van Berkel et al., 2009). In South African cities, urban symbiosis organically occurs through the operation of the informal urban recycling sector, which sources and supplies approximately 70-90% of recyclable packaging material (e.g. paper, cardboard, plastic) to the secondary resources economy. These materials are recirculated in co-located industries, i.e. material reprocessors and recyclers.

Like industrial symbiosis, urban symbiosis is based on the *"synergistic opportunity arising from the geographic proximity through the transfer of physical resources (waste materials) for environmental and economic benefit"* (Geng et al., 2010). More specifically, urban symbiosis is an opportunity arising from the geographic proximity of urban areas and industrial hinterlands and refers to the exchange of the physical waste resources (i.e. by-products from production and consumption) between urban and industrial systems (Geng et al., 2010). For example, employing municipal solid waste as feedstock for industrial applications (e.g. refuse derived fuel, reprocessing recyclable materials), and meanwhile, applying industries as providers for living resources (e.g. waste heat and hot water) (Geng et al., 2010).

Figure 2-9 Emergy flow diagram of urban and industrial symbiosis (Sun et al., 2016)



From a geographic perspective, urban and industrial symbiosis design seeks to optimise city region metabolic networks through synergistic resources and infrastructures allocation. Figure 2-9[35] provides a simple characterisation of the input and output emergy[36] flows throughout a virtual city and a constructed urban and industrial symbiosis framework; portraying the adjacency and critical interconnectivity of urban and industrial symbiosis networks. UIS is premised on strategic and purposively coordinated interaction between industrial and urban sub-systems (Dong et al., 2013). Coordinating urban and industrial symbiosis provides an integrated material flow design

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[35] In the illustration, the urban ecosystem is divided into three subsystems: natural ecosystem, living system, and industry system. *"Emergy flows are categorised into renewable resource, nonrenewable resource, import resource and wastes"* (Sun et al., 2016).

[36] Emergy is defined as "*the sum of available energy of one kind previously required directly and indirectly through input pathways to make a product or service" (Odum, 1996 cited in Sun, 2016). 'Transformity, which represents unit emergy value (UEV), is an indirect measure of the activity of the environment, either directly or indirectly, has been required to manufacture a given product"* (Brown and Ulgiati, 1997 cited in Sun, 2016).

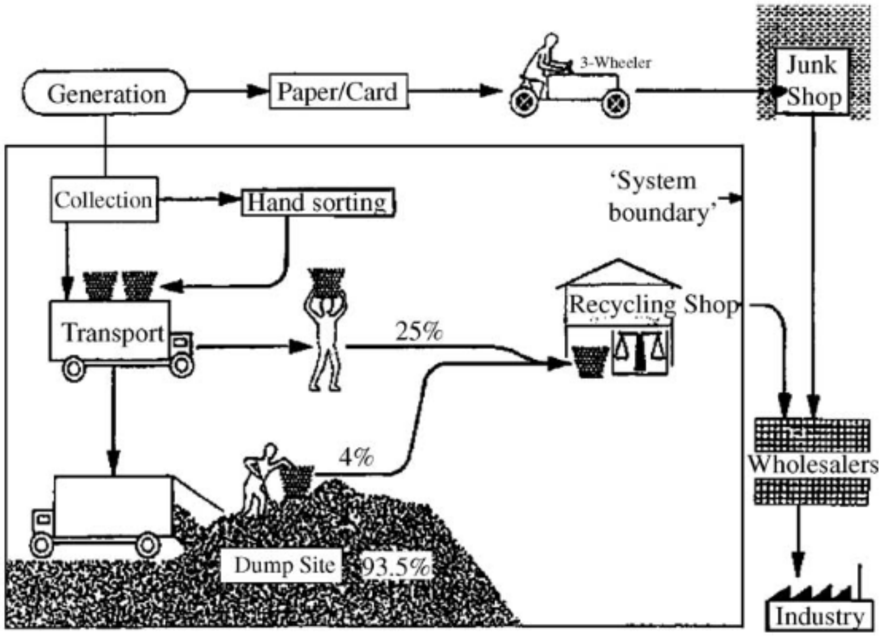
approach to address the environmental challenges of rapid urbanisation and promote regional eco-industrial development in emerging economies. This study argues that in a diverse port city like Durban, with a critical clustering of intensive industries and a thriving urban informal recycling sector, there is inherent opportunity to experiment with holistic urban and industrial symbiosis design – to re-engineer existing outdated urban and industrial systems and to engineer smart circular economy infrastructure.

2.5 The Informal Recycling Sector

Recent studies have documented how the informal recycling sector plays a crucial role in promoting a sustainable production and consumption in cities in developing countries. Firstly, the informal recycling sector represents a vital survival strategy for millions of individuals worldwide. It contributes to sustaining the livelihoods of disadvantaged and marginalised groups in society by generating employment and income (Gerdes and Gunsilius, 2010, Schenck and Blaauw, 2011). The act of reclaiming recyclable materials provides an avenue for income generation and contributes to poverty alleviation in cities in emerging market economies. Secondly, waste pickers contribute to environmental sustainability by diverting a substantial quantity of recyclable materials from landfills to the secondary resource markets. Leading to a decline in waste disposal and reduces the number of virgin materials required for production. The recovery of recyclable materials decreases the total emission of greenhouse gas, reducing a city's carbon footprint (Scheinberg et al., 2010).

Thirdly, the existence of the informal recycling sector reduces solid waste management (SWM) costs for cities in developing countries. According to UN-Habitat, informal waste management accounts for more than 50 % of the total waste collection in some developing countries (UN-HABITAT, 2010). Essential waste management services provided by waste pickers done at no cost to municipal authorities. The informal recycling sector essentially subsidises the formal waste management sector, especially in cities with small public service budgets. According to Wilson et al. (2006) in most developing countries with formal municipal solid waste management (MSWM) there are four main categories of informal waste recycling that can be identified listed below (see figure 2-10): itinerant waste buyers; street waste reclaiming; municipal waste collection crew; recovering recyclable materials from landfill sites/illegal dumps.

Figure 2-10 Example flow chart of an informal recycling system, showing four types of informal recycling (Wilson et al., 2006)



Recovering recyclable materials requires limited skills, quickly learned on site, unlike other sectors, which require specific qualifications. Informal recycling is characterised by mostly free entry, low capital investment and on-job training (Masocha, 2006). However, waste collection systems often deny the informal recycling sector access to waste as a resource (Gerdes and Gunsilius, 2010). For example, landfills controlled by municipalities, often restrict waste pickers' access to work on site. A study was undertaken in six cities in low and middle-income countries (Cairo, Cluj, Lima, Lusaka, Pune, and Quezon) found that recycling rates of over 20 % can be credited to the informal sector alone (Scheinberg et al., 2011). Table 2-12 shows the reported rates contributed by the informal sector as a percentage of the total waste generated in the six cities listed above.

Table 2-12 Recycling rates contributed by different groups, 2006 (Wilson et al., 2009)

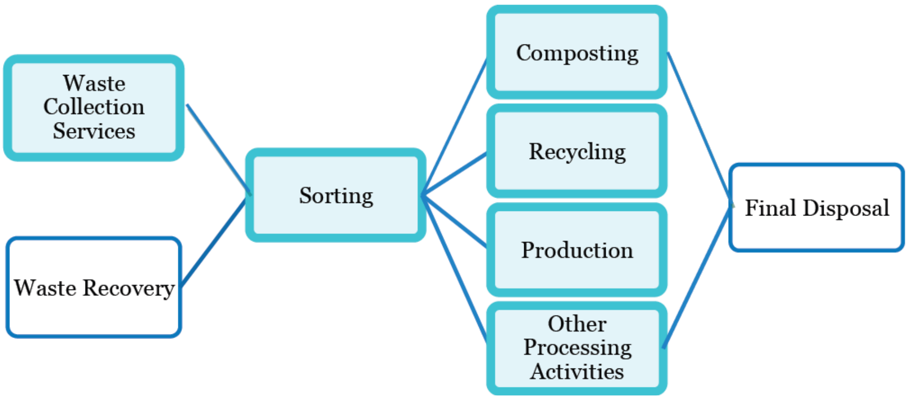
2006 recycling rates contributed by different groups (% of total waste generated)

City	Country	Informal sector					Totals		
		Informal service providers	IWBs	Street pickers	Dump pickers	Other	Informal sector	Formal sector	Total
Cairo	Egypt	74.3	0.0	0.0	0.0	0.0	74.3	10.6	84.9
Cluj	Romania	0.0	0.2	3.0	4.4	0.0	7.6	4.6	12.1
Lima	Peru	2.2	8.4	9.3	1.9	9.3	31.1	0.3	31.5
Lusaka	Zambia	0.0	0.0	23.1	9.4	0.0	32.5	3.9	36.4
Pune	India	7.8	8.3	0.0	2.4	5.8	24.3	0.0	24.3
Quezon	Philippines	0.0	16.4	3.6	1.8	0.9	22.8	2.5	25.2

Source: Data calculated from Tables 24, 29 and 37 in WASTE and Skat, 2007.
Notes: Informal service providers collect mixed waste; 'Other' may include local variations on the other categories, as well as e.g. pickers at transfer stations or other waste facilities.

In cities such as Moshi, Quezon City, Delhi, and Bengaluru, the informal sector is responsible for 50 to 100 % of all ongoing waste activities (UN-HABITAT, 2010). In Cairo (Egypt) approximately 40,000 *"Zabaleen" waste pickers sort, process, and sell recyclables, and have created "what is arguably one of the world's most efficient and sustainable resource-recovery and waste-recycling systems"* (Fahmi and Sutton, 2010). Zabaleen waste pickers and the Kattameya Centre for Integrated Waste Management and Recycling (Cairo) transform waste into new products; for example, they make new construction materials from melting plastic and mixing it with sand to make bricks and sheeting. They do not recover waste from landfills, but they do provide household services. The Zabaleen value chain highlighted in figure 2-11 below:

Figure 2-11 Value Chain for Zabaleen in Cairo, Egypt (Source: Spring, 2011)



There has been a recent trend in such countries as China, Vietnam, Egypt, and Nicaragua to use small transfer stations to facilitate low-cost primary collection systems with the use of handcarts, tricycles, and small trucks (UN-HABITAT, 2010). Such an approach enables micro-privatisation and labour-intensive source separation and collection executed by micro and small enterprises, community-based organisations (CBOs), and non-governmental organisations (NGOs). Municipalities' role is then only to monitor the collection, and transfer its resources to create more efficient operation, transfer and disposal services (UN-HABITAT, 2010).

In a study done on twenty cities around the world, UN-Habitat concluded that municipalities cannot ignore or prevent waste pickers from collecting, reselling, or recycling materials, and collaboration can aid in developing more efficient waste management systems (UN-HABITAT, 2010). Further analysis of international best practices and public policies toward informal waste recycling will be discussed in section 2.5.5.

2.5.1 Socioeconomic profile of waste pickers

Most studies report that the vast majority of waste pickers are disadvantaged and vulnerable populations such as rural migrants, immigrants, and members of religious minorities (Medina, 2005). In India, the Harijans is a cast of untouchables that deal with waste collection and recycling. The Zabaleen informal recyclers in Cairo, Egypt belong to a Christian minority. Stories of waste pickers from around the world reveal that waste pickers come from many diverse ethnic backgrounds and are typically a marginalised and poverty-stricken community (Samson, 2009). Some come from generations of waste pickers and entered the profession similar to previous generations because they knew it was a good way to make a living, others are the first in their family to partake in this kind of work (Samson, 2009). Many had a low level of education and entered the informal waste sector because they had few options. However, others have high levels of formal education but are unable to find employment and prefer waste reclaiming than other options to earn income. Due to their daily interaction with waste, waste pickers are usually associated with disease, dirt, and are perceived as a problem, and even as criminals by society (Medina, 2005).

2.5.1.1 Gender

Gender plays a major role in the informal waste management sector (Muller and Scheinberg, 2003), though there is conflicting evidence about the gendered nature of informal recycling in low- and middle-income countries. Empirical case studies indicate a range of different situations concerning the gender composition of informal waste pickers (Samson, 2010a). In a recent study on waste pickers in Pretoria, Schenck and Blaauw (2011) report that 97 % of respondents were male. Similarly, echoing the findings in Benson and Vanqa-Mgijima (2010) and McLean (2000) in Cape Town and Durban respectively. While many of these studies focused on street waste pickers, Samson (2008) and Chvatal (2010) argue that a larger proportion of female waste pickers in South Africa are likely to be located at the landfill sites. This, the authors claim, is due to the physical requirements of operating a street trolley, and that the landfill site offers a higher degree of security. However, it is important to note that the gender dimensions of the informal recycling sector are context specific.

The literature on waste pickers seems to reveal a general pattern of gendered division of labour. The gendered division of labour is clear primarily regarding the kind of materials collected and the role of men and women in the value chain. De Kock (1986) found that men focused primarily on materials generating higher revenue. The finding supported by Tevera (1993), who observes that men have higher incomes than women, as men collect materials of higher value. The study by Mitchell (2008) reveals that female waste pickers make significantly less than their male counterparts. Her findings suggest that while men and woman work, on average, the same amount of time, men still earn 39 % more. Mitchell explains this pattern by looking at the position of women and men within the value chain, as well as the type of materials collected. Men tend to specialise in collecting electronic equipment and household appliances, while women are more likely to collect glass, carton, paper and styrofoam (Mitchell, 2008).

Muller and Scheinberg (2003) explain the gender division of labour by pointing at specific societal conditions. First, in some societies, the gender rights only permit women to access to low-value waste materials, often at the least profitable locations. Second, women spend less time collecting waste than men, as they normally have additional domestic duties to fulfil. The combination of cultural perceptions and expectations of what is appropriate work for women is a means of excluding women from obtaining more profitable work (Muller and Scheinberg, 2003).

The existing literature on informal waste management and waste pickers accentuates the role played by women in recycling activities. This does not relate solely to the role of female waste pickers in the value chain but also to the significant spill-over effects of female participation in the labour market. As Medina (2005) concludes, the informal recycling sector provides women with the means of earning an income. By participating in income generating activities, women can achieve greater independence from male-headed authorities. Moreover, considering the role and responsibility of women in the household, the income generated by female waste pickers can play a major role in sustaining and improving the livelihoods of the most d urban communities.

2.5.1.2 Health and safety

There are many occupational health and safety issues associated with the manual handling of waste and lack of personal protective equipment. Waste pickers in the informal recycling sector are very vulnerable to infections, diseases and sometimes poisoning from hazardous wastes discarded at landfill sites.

Table 2-13 Risk causing factors related to solid waste: origin and examples (Wilson et al., 2006)

Origin of risk factor	Examples of source of risk
Composition of waste	Toxic, allergenic and infectious components including gases, dust, leachate, sharps, broken glass
Nature of organic decomposing waste	Gaseous emissions, bio aerosols, dust, leachate, and fin particles sizes; and their change in ability to cause a toxic, allergenic or infectious health response
Handling of waste	Working in traffic, shovelling, lifting, equipment vibrations, accidents
Processing of waste	Odour, noise, vibration, accidents, air and water emissions, residuals, explosions, fire
Disposal of waste	Odour, noise, vibration, stability of waste piles, air and water emissions, explosions, fires

Consistent exposure to toxic gaseous emissions at poorly managed landfill sites may cause serious long-term respiratory problems. In Cairo, one in four children born in waste picker communities dies before reaching their first year (Medina, 2005). Table 2-13 illustrates risk factors from the handling of solid waste.

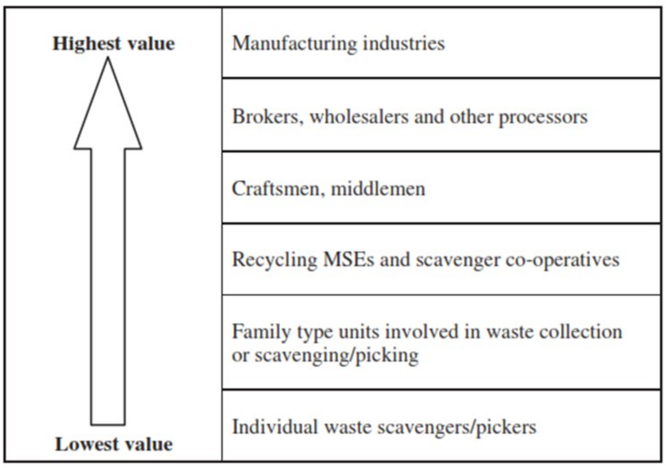
2.5.1.3 Economic and social

Informal recycling systems are critical for rapidly growing cities in emerging economies. From a macroeconomic perspective, emerging economies are well adapted to foster the growth of the informal recycling sector, with capital limitations countered by the surplus supply of unskilled labour. The transition from informal to formal waste management and recycling systems in the developed economies is near completed. The informal waste recycling systems subsidise the formal waste recycling system through cost reduction for the formal waste management sector, as informal waste pickers reduce both the quantity of waste for collection, in addition to the sorting of waste; resulting in less money and time spent on collection, transportation, treatment and disposal (e.g. landfilling).

On this basis, the organisation of the waste recycling sector has important consequences for both the waste pickers and to the formal waste management sector. The less organised the informal recycling sector, the less chance of maximising economic potential both for waste pickers and the potential value derived from secondary raw materials. Furthermore, poor organisation facilitates exploitation of waste pickers by so-called intermediary waste handlers. "*A chain of intermediate dealers often exists between the scavengers and end-users. This chain may contain primary and secondary dealers, recycling SMEs, junk shops, intermediate processors, brokers and wholesalers, and may include both formal and informal sector activities"* (Wilson et al., 2006).

As illustrated in figure 2-12, the recycling chain takes the form of a hierarchy. *"The higher a secondary raw material is traded, the greater the added value it possesses"* (Wilson et al., 2006). In most cases waste pickers tend to occupy, and are restricted to, the base of the secondary materials trade hierarchy and this reduces their potential income.

Figure 2-12 Hierarchy of informal sector recycling (Wilson et al., 2006)



Highly marginalised informal urban settlements are near waste sites, as this is where the majority of waste pickers live. In this context, a household is an important unit of analysis due to family organised activities common in dump scavenging (landfill waste reclaiming). This often requires women, children and the elderly to participate in waste collecting activities in a hazardous environment; exacerbating the vulnerability of already extremely disadvantaged households.

2.5.2 Waste pickers in South Africa

South Africa's urbanisation rate (annual) of change for the period of 2015-2020 is estimated to be 1.33%, and its urban population constituted 65.8% of its total population (CIA, 2017). Nearly two-thirds of the working population live in urban areas, 57% in formal urban areas, and 8% in informal urban areas (Budlender, 2011). Cities are expanding more quickly than municipal mechanisms can adapt. With large movements of people entering the city, this is often a catalyst for the formation or persistence of the informal sector, such as informal recycling and recovery. With this phenomenon compounded in South Africa by the legacy of segregation left by the apartheid system. The difficulty of obtaining formal employment elsewhere because of a noted decrease in demand for low-skilled jobs in South Africa explains in-part the informal sector's presence in the South African economy (Blaauw and Pretorius, 2007, Lymboussis, 2011). Herein, the urban informal recycling sector provides low-skilled and labour intensive income-generating opportunities with low barriers to entry.

There is a large informal waste recycling sector in the major cities in South Africa, but there is very little official data and reporting of how this complex sector operates, what its linkages are to the formal recycling industry, and how government policy can improve the livelihoods of waste pickers and in turn improve their productivity, income and alleviate negative health impacts. Although no official data exists, the number of waste pickers in South Africa is conservatively estimated between 60 000 to 90 000 (DST, 2013). These waste pickers have found a way of making a living, and this makes a large contribution to improving the resource efficiency and environmental performance of cities (Schenck and Blaauw, 2011). As depicted in figure 2-13 waste pickers are the base agents in bridging the waste management service and secondary resources value chain. In South Africa, they are responsible for recovering approximately 80-90% of paper and packaging post-consumer waste which is diverted from landfill and recycled (Godfrey, 2016).

Figure 2-13 Simplified paper and packaging waste value chain in South Africa (Godfrey, 2016)

Research suggests that there is a steady improvement in recycling rates in South Africa over the past 20 years. However, it is still far from what it should be to significantly reduce the diversion of recyclable materials to landfill on a daily basis (Oelofse and Strydom, 2010). According to the Council for Scientific and Industrial Research, *"every year at least R17.0b worth of valuable secondary resources are lost to the SA economy as waste, disposed of to landfill"* (Godfrey, 2015). In short, existing formal waste management systems are under-equipped to fully exploit significant volumes of potentially recyclable materials to feed the growing South African recyclate market. Waste pickers in South Africa already play a major role in supporting formal waste management systems in the recovery of recyclable materials from urban waste streams, moreover in the case of recovering materials from landfill sites and kerbsides.

Recycling also seems to be a priority area for job creation as articulated by the Department of Trade and Industry (DTI) in their 2010–13 Industrial Policy Action Plan (IPAP). Future policy action should seek to realise to what degree coordinated government departments can best collaborate with the informal sector, private sector and NGO sector to increase the efficiency and productivity of waste pickers to improve materials recovery rates, in turn, improve their livelihoods and working conditions. Currently, as dictated by the Department of Environmental Affairs (DEA) municipalities are to phase out salvaging at landfill sites, marginalising the role of waste pickers. Government's policy outlook is premised on the assumption that there will be a rapid shift in consumer behaviour to waste separation at source. Arguably in short to medium term shifts in consumer behaviour are unlikely to occur on a requisite mass scale to support government's policy position. Pro-environmental citizenship is a young, niche and emerging concept in South Africa and limited post-consumer separation at source and recycling has occurred. Recycling statistics suggest an average growth rate of 23.7% over the past few years in the percentage of recyclables recovered and reprocessed (Oelofse and Strydom, 2010). However, Oelfose and Strydom (2010) argue, *"this progress is not the direct result of implementing waste legislation, which prior to 2008 focused on the control of waste disposal at landfill and did not require waste separation at source or recycling"*. Oelofse and Strydom (2010) posit *that "any post-consumer recovery which has taken place has largely been supported by a large informal recycling sector which is dependent upon the income stream associated with informal collection"*.

Recyclables are recovered by waste pickers at all stages of disposal – from streets, landfills, open dumps, municipal trucks, or by itinerant buyers. A study conducted examining waste pickers in three provinces shows vastly different experiences of waste pickers in varying provinces. In KwaZulu-Natal, New England Road landfill site in Pietermaritzburg (at the time of the study), the municipality had tried to prevent waste pickers from entering the landfill site, with devastating effects on their income. In the Free State, Metsimaholo municipality allows waste pickers to work on the site, but only if they sell their materials to a company run by two local professionals running a black economic empowerment company, monopolising the market, which has led to a reduction in income for waste pickers. In Gauteng, Emfuleni municipality has tried to take a more progressive approach assisting waste pickers to transport their goods to the market (Samson, 2008).

South Africa's waste pickers are starting to organise into a united front with the formation of the South African Waste Picker Association (SAWPA). SAWPA formed in 2009 at the first National Waste Picker Meeting which took place in Gauteng organised by the environmental justice NGO, GroundWork (Samson, 2009). SAWPA is operating in seven provinces and is reported to have approximately 20,000 members (Khuzwayo, 2011). The waste picker movement is still in its early stages, and many waste pickers are yet to be inducted. One of the key challenges identified by SAWPA is *"to resist privatisation of our resources, both at the landfill site and upstream, and to ensure our right to work and to resist exclusion from the landfill sites where we derive our livelihoods"* (Samson, 2009). SAWPA represents an important platform to grow and advocate for the rights and position of waste pickers in the South African waste economy.

2.5.2.1 South Africa's waste management policy framework in relation to the informal recycling sector

Legislation concerning waste management is young in South Africa, with the majority of environmental legislation passed beginning in 1998, as shown in Figure 6 (Oelofse and Strydom, 2010). To date, waste pickers have been for the most part neglected and marginalised in South African legislation. Several scholars have examined contemporary waste management legislation in South Africa and how it relates to waste pickers and recycling (Hallowes and Munnik, 2008, Langenhoven and Dyssel, 2007, Ralfe, 2007, Zoya, 2008, Benjamin, 2007). These studies reveal a fairly inconsistent and incoherent legislation. The lack of clear national legislation has created a policy vacuum, and the municipalities have the opportunity to develop their approaches.

The National Environmental Management Act, 107 of 1998 (NEMA) endorses recycling as an important component of waste strategies, however, does not acknowledge the role of waste pickers operating within the current system. In the National Waste Management Strategy of 1999 (NWMS), and in the White Paper on Integrated Pollution and Waste Management for South Africa of 2000, both acknowledge the existence of waste pickers, however stating that reclaiming will be controlled by 2003 which has not yet occurred (Samson, 2008). The White Paper indicates that reclaiming poses risks and is dangerous. However, there is no strategy on how to improve working conditions or how to integrate the informal recycling sector.

The Polokwane Declaration that emerged out of the first national waste summit in 2001 commits the government, business and communities to reducing waste and disposal by 50% and 25% respectively by 2012, and to achieve zero waste by 2022 (Samson, 2008). These targets were not legislated and had become an area of contention within the South African waste sector (Oelofse and Strydom, 2010). The latest National Environmental Management, Waste Act No. 59 of 2008 promotes the reduction, re-use and recycling of waste. After lobbying from GroundWork and other civil society organisations, a clause was added that makes some allowance for recovering recyclable materials: Section 51 (1), *"a waste management license must specify if applicable, the conditions in terms of which salvaging of waste may be undertaken"* (Government of the Republic of South Africa, 2009).

However, while waste pickers have been acknowledged, again there is no clear strategy as to how to incorporate them into formal waste management systems. There is a certain level of ambiguity in interpreting the National Waste Management Strategy (2011) in accordance with the Waste

Act 2008, specifically related to the status and integration of waste pickers into municipal waste management systems (MSWM). As mentioned previously, on a municipal level, the Department of Environmental Affairs Draft of the Municipal Waste Sector Plan issued in 2011 calls for a *"phasing out of salvaging at landfills"* (DEA, 2011a). The plan calls for a movement toward waste separation at source and collaboration with the recycling industry to establish more buy-back and drop-off centres, kerbside collection of recyclable material, and establishment of materials recovery facilities for sorting of source separated recyclables (DEA, 2011a). However, the plan also notes that *"the activities of scavengers can have a great impact on the economy and waste management if the scavengers are properly organised, enlightened and provided with the necessary economic and institutional support"* (DEA, 2011a). There is no clear strategy on how to move forward to this long-term goal.

When it comes to policy implementation, the Minimum Requirements for Disposal of Waste by Landfill (implemented in 1998 and amended in 2006) allow landfill managers of individual sites to decide whether or not to permit salvaging onsite. However, those managers that choose to allow salvaging have to indemnify the department from any responsibility, creating a disincentive to make efforts to legitimise waste pickers (Samson, 2008). Despite the possibilities created from the Minimum Requirements, the Gauteng Provincial Waste Management Policy of 2006 does not mention reclaiming, and the KwaZulu-Natal Prevention and Management of Waste Bill of 2007 seek to prohibit reclaiming (Samson, 2008). These movements do not bode well for the status of waste pickers.

All national legislation leaves significant scope for municipalities to develop their policies and approaches to waste management (Samson, 2010a). As mentioned previously, Samson's (2010) research on three separate municipalities (Msunduzi, Metsimaholo, Emfuleni) demonstrates three distinct approaches to waste pickers: exclusion of waste pickers from landfills; forced subordination to private companies; and benevolent patriarchy of which waste pickers are tolerated on terms defined by the municipality. This demonstrates that there is no uniform approach to waste pickers and their position within the waste economy to date, and there is room to develop norms and development strategies for municipalities' incorporation of waste pickers into the formal waste management systems.

Currently, no informal waste pickers are allowed on the eThekwini municipality's landfill sites. In the 1990s there were an estimated 350 waste pickers working onsite, over a seven to ten year period they were phased out, and fences and security were enforced (CSIR, 2011). The municipality worked with the recycling industry to formalise picking at the landfill, and now there are only four registered recyclers collecting from the site. Each of these recyclers has workers that are allowed onsite, are provided with personal protective equipment at an identified sorting area with a specific time frame and are paid based on what volumes they collect (CSIR, 2011). This significantly limits waste pickers' access to potentially valuable goods to sustain their livelihoods. Furthermore, eThekwini's current municipal waste management strategy does not account for the role of the informal recycling sector, in short presenting no strategic plan for consolidating the role of waste pickers in the secondary resources economy.

2.5.3 Role of the private sector in informal recycling

Regarding privatised waste collection, there are many sources of potential conflict with formal waste collection and the informal sector (Gerdes and Gunsilius, 2010). Competition may arise as the formal sector involved in recycling activities has an interest in collecting the largest possible amount of waste and could try to prevent the informal sector from diverting large quantities of waste from the waste stream. In a bid to explore the *"trigger to recycling in developing countries"*, Oelofse and Strydom (2010) suggest that financial incentives are the primary drivers for recycling from an industry point of view while environmental awareness supported by convenience are factors influencing post-consumer household recycling behaviour.

However, if convergent interests and common interests are identified there is also a potential for formal enterprises and the informal sector to complement each other and in the process, strengthen the position of waste pickers. For example, a private contract with the municipality could include a quota for recycling collected waste, where the informal sector can separate materials at its recycling facilities (Gerdes and Gunsilius, 2010). If the informal sector can organise and establish a regular business relationship with industries involved in recycling and production, this would increase their income opportunities substantially. Waste recycling in South Africa is largely industry driven. The recycling industry – paper, glass, plastic, and metal *"have had several drivers including financial, competition in the market, energy saving, water consumption and environmental responsibility"* (Oelofse and Strydom, 2010).

2.5.4 Role of NGOs in improving the livelihoods of waste pickers

NGOs can provide vital links between the informal and formal sectors, and have played a major role in fostering grass roots developments in the waste system (Gerdes and Gunsilius, 2010). In Egypt, the Association for the Protection of the Environment (APE) began working with informal waste pickers in the 1980s. As a result of their projects recycling enterprises have formed and are currently fully self-sustaining, creating jobs for the informal waste sector. In India, women's activist associations led to the formation of co-operatives (KKPKP) and greater recognition of waste pickers. In Brazil, the Catholic Church (and its NGOs) was the first to support waste picker organisations and organise forums to gather a collective voice to advocate their interests and be recognised by the government as professionals. NGOs can provide technical expertise, financial support, and advisory services to waste pickers (Gerdes and Gunsilius, 2010).

Table 2-14 is taken from a study of six cities where local partners (NGOs) have good relations with waste pickers and local authorities. These partners are active in advocating for the rights and recognition of waste pickers in the informal recycling and recovery sector.

Table 2-14 Cities and local partners in relation to waste pickers (Scheinberg et al., 2011)

City	City partner	Type of organisation
Cairo, Egypt	CID Consulting	Private consultant with NGO daughter, specialised in social development, public relations, education and advocacy
Cluj-Napoca, Romania	Green Partners	Small private consultancy specialised in economics, carbon financing, solid waste
Lima, Peru	IPES	NGO institute with strong economic and technical focus on entrepreneurship
Lusaka, Zambia	Riverine Associates	Small private consultancy focused on solid waste, sustainability, governance
Pune, India	KKPKP	Union of waste pickers representing 10 000 waste pickers in the informal sector, primarily women
Quezon City (Manila), Philippines	Solid Waste Association of the Philippines (SWAPP)	National solid waste association, municipal and private sector members, deep formal sector knowledge and connections

In South Africa, a leading NGO working in the field of environmental justice is GroundWork, a *"non-profit environmental justice service and development organisation working primarily in South Africa but increasingly in Southern Africa"* (Groundwork, 2012). GroundWork has established a Waste Campaign and has been working with waste pickers for the last three years. With SAWPA, it is fighting for the recognition of waste pickers by the government and advocating for waste pickers to be a part of decision-making in municipal waste management systems. GroundWork is a key stakeholder and will be integral in the process of strategic planning and transforming the informal recycling sector. Other important NGOs working in the field of environmental justice and waste management include Asiye eTafuleni, WESSA, WWF, and Earthlife Africa.

2.5.5 Public policies towards integrating waste pickers

The relationship between formal and informal waste management has been subject to extensive debate. The debate revolves around whether or not it is appropriate to attempt to formalise the informal recycling sector, and if so, how can the integration of waste pickers be accomplished? It is evident that a new alternative framework for integrated waste management needs to be designed based on the strengths of, and the interaction between, both the existing formal and informal waste sectors. Waste pickers must no longer be regarded as the problem, but rather as a fundamental part of the solution to creating circular economy models at a city level, i.e. circular city concept. As cases in Brazil and Indian have demonstrated, waste pickers can be successfully integrated into the formal municipal waste structure. Medina (2005) argues that this can only be achieved by opposing the conventional approaches to waste collection and recycling, to focus on models *"that create jobs, that protect the environment, that promote community participation, that encourage and support the entrepreneurial spirit in the community, and that consider the contribution that informal refuse collectors and waste pickers can make"*.

One example of a conceptual model of urban recycling is referred to as *"modernised mixtures"* (Scheinberg et al., 2011). This model refers *to "socio-technical complexes of infrastructures, institutions, and payment systems which combine large-scale centralised, high-technological, low citizen-consumer participation models, with small-scale, decentralised, less technologically advanced and more participative models"* (Scheinberg et al., 2011). The idea is that the mixing of elements from different approaches will offer socio-technical infrastructure adapted and appropriated to the given context. Moreover, it aims to upgrade and modernise the solid waste management system by taking advantage of the different characteristics (efficiency, effectiveness and experience) of informal and formal operations.

Research shows that in many cases the cost-efficiency of waste pickers has outperformed the formal waste management sector (Scheinberg et al., 2011). While the primary function of the formal recycling sector is service provision, such as collection and disposal of materials, it has failed to achieve high recycling rates, which leads to higher operational costs. The informal recycling sector, on the other hand, focuses primarily on recovering materials and adding value to them through collection, separation and transportation. While informal activities such as reclaiming on the street and the landfill take place outside of formal channels, unlicensed and untaxed, waste pickers significantly contribute to national economies (Gerdes and Gunsilius, 2010).

The notion of integrated solid waste systems is still facing significant opposition. Perhaps the greatest challenge is the lack of recognition of the role played by waste pickers in the economy of waste. The informal recycling sector continues to be undermined by authorities and legislation in countries around the world (Medina, 2005). The perception of the informal waste management sector as a whole needs to be changed to advance the incorporation of waste pickers into the formal economy and actualise green economy policy rhetoric (Sembiring and Nitivattananon, 2010).

The following case studies demonstrate approaches to incorporating the informal recycling sector into formal systems has different implications for how waste pickers relate to the state and the state's residents, how MSWM is transformed as a result of formal integration and how waste pickers generate their livelihoods (Samson, 2009). The examples of Brazil and India reveal unique, context-specific initiatives. These city-level mini case studies demonstrate that implementing a successful waste management strategy relies on building upon the strengths of individual cities, to improve and support the indigenous processes that are already in place (UN-HABITAT, 2010). There are key lessons to be learned for South Africa moving forward to create sustainable and, low-skilled and labour intensive jobs, in turn foster circular economy development at a city level.

2.5.5.1 Mini case study Brazil: successful grass roots mobilisation

Brazil has a long history of social activism in civil society. The Brazilian Constitution (Art. 30, clause V) stipulates that municipalities are responsible for MSWM, and the role of the federal government for the establishment of environmental and territorial guidelines (Dias, 2011). The first organisations of waste pickers were formed in the 1980s resulting from work carried out by the Catholic Church and its affiliated NGOs. Belo Horizonte was among the first cities anywhere in the world to recognise the informal recycling sector and build a policy for inclusion of informal recycling in their waste strategy (UN-HABITAT, 2010). The Waste Pickers' Association (Asmara) was founded in 1990 and fought for their right to work collecting recyclables and allocate space for sorting waste. The City Government entered into a social accord with Asmare that provided incentive for its growth and contributed to its local and national visibility (Gerdes and Gunsilius, 2010). The municipality provides the association of catadores (waste pickers) with a monthly subsidy coming from the social welfare budget. It also provides, amongst other things, recycling containers, a warehouse where catadores can sort materials, trucks for collection, and environmental education (Samson, 2009). This has led to higher productivity and recognition of the value of waste pickers. In Belo Horizonte, Asmare has now extended to include door-to-door collection in some parts of the city covering 80,000 people.

In 1998 Brazil with the help of UNICEF launched a national forum called Waste & Citizenship with the aims of preventing child labour at dumps, developing sanitary landfills, and promoting partnerships between municipalities and waste pickers (Gerdes and Gunsilius, 2010). The effect of the forums inspired other groups of waste pickers to organise and create a basis for social activism. The grassroots movement that began in Belo Horizonte spread and led to inclusion on a national level.

In 2001 waste picking was included as a profession in the Brazilian Occupation Classification, entitling them to a minimum wage in their negotiations with municipalities, and giving them official recognition (UN-HABITAT, 2010). During this time the National Movement of Catadores (MNCR) was founded, promoting collective as opposed to individual advancement (Samson, 2009). In 2007 the government introduced the Basic Sanitation Bill which established national guidelines for sanitation practices, allowing for the hiring of waste reclaiming cooperatives directly by municipal authorities to perform recycling operations. The Presidential Decree 5940/06 issued a 'Solid Waste Selective Collection' was established in all federal public buildings. As a result, waste material generated would be offered directly to waste picker associations to strengthen the position of waste pickers and allow for greater income generation (Dias, 2010). This policy was instituted officially in 2010 and recognises the vital service waste picker cooperatives provide (Dias, 2011).

Another example of a municipal system integrating catadores is found in the municipality of Diadema. This is the first city where waste pickers are paid by the municipality for removing recyclable materials from the waste stream (Samson, 2009). The municipality recognised that catadores save the city significant costs by diverting materials that would otherwise need to be landfilled. The waste pickers are authorised to conduct door-to-door collection and separate out recyclables, and sixty locations have been designated where residents can take their recyclables (Samson, 2009). The initiative has successfully increased the income of the catadores; in addition to selling recyclables, the catadores now also receive payments from the municipality for the service that they provide; secondly, the groups obtain higher prices for their materials by selling directly to industry and cutting out the middleman (Dias and Alves, 2008).

Waste pickers collect five times the tonnage that municipalities do, at a lower cost and with fewer emissions than the municipalities. The Brazilian Development Bank has invested $250 million to support waste picker projects (PACSA, 2011). The private sector is also involved in improving the position of waste pickers in Brazil. In 1992 Cempre was established by seven large corporations, which has grown into 35 corporations, supported by larger brand owners, retail chains and packaging companies. Cempre currently supports 660 co-operatives and offers consultancy to municipalities. It acts as a facilitator for waste picker co-operatives and municipalities to increase recycling rates. Waste prices are published on its website, regulating the industry and increasing the incomes earned by waste pickers. The Cempre model has been exported to such countries as Uruguay, Mexico, Colombia, and Thailand (PACSA, 2011).

Brazilian society is generally supportive and accepting of waste pickers. Brazil is an example of grassroots mobilisation leading to their recognition on a federal and municipal level. The inclusion of catadores in formal municipal solid waste systems has had benefits for both the municipalities and waste pickers, as demonstrated by the examples cited above. Currently, the National Movement of Recyclable Waste Collectors represents more than 800,000 waste collectors in the country.

2.5.5.2 Mini case study India: trade union-led integration of waste pickers into formal waste management

The informal waste management sector plays an essential part of India’s waste collection and recycling structures. Research estimates that about 1% of India’s urban population is active in informal recycling (Gerdes and Gunsilius, 2010). Due to the predominant number of women involved in waste reclaiming, women’s organisations were the first to draw attention to waste pickers and their interests. Delhi alone has more than 100,000 waste pickers, and the average quantity of waste collected by one waste picker is 10-15 kg per day. Studies show that 27 % of Delhi's waste management is undertaken by informal waste pickers, saving the local government approximately US$13,700 daily (UN-HABITAT, 2010). If the waste pickers were to disappear, the city would have to compensate for their loss and pay its contractors to collect and dispose of an additional 1,800 tons of waste every day (UN-HABITAT, 2010). Similar tendencies can also be found in other parts of the country.

The local Kagad Kach Patra Kashtakari Panchayat (KKPKP) trade union in Pune has played an important role to facilitate the integration of waste pickers into the official waste management structures. In 1993, KKPKP was formed as a registered trade union to represent the collective identity and interest of waste pickers. Trade unions represent worker organisations, and so the decision was made to register KKPKP as a trade union to establish waste pickers are workers (Chikarmane and Narayan, 2005).

In 1990 the Project for the Empowerment of Waste pickers began, which among other activities issued identity cards to waste pickers and promoted door-to-door waste collection and source segregation (Gerdes and Gunsilius, 2010). The identification cards authorised waste pickers to collect and recycle waste materials to legitimise their work. The Pune Municipal and Pimpri Chinchwad Municipal Corporations became the first municipalities in the country to officially register (through the KKPKP) to endorse identity cards of waste pickers and recognise their contribution to MSWM (Chikarmane and Narayan, 2005).

Research quantified the amount of money that waste pickers save the municipalities in transport costs and how much income they contributed to the local economy, health costs borne by waste pickers, and also established the importance of waste pickers' impact on the environment (Samson, 2009). Based on this research KKPKP argued that the financial benefits accrued to municipalities warranted compensation, and emphasised the health costs waste pickers bear while contributing to MSWM, working in abominable conditions (Chikarmane and Narayan, 2005). In 2002-2003, the Pune Municipal Corporation agreed to create a Scheme for Medical Insurance for all registered waste pickers' in the city (Samson, 2009). In addition the KKPKP argued for the inclusion of children of waste pickers in the Pre-Matric Scholarships to Children of those engaged in Unclean Occupations (Chikarmane and Narayan, 2005). Waste pickers then lobbied for the responsibility for door-to-door collection and won. Now they receive support from the municipality but the KKPKP is independently controlled by its members (Samson, 2009). Participating in doorstep collection increases waste pickers' access to recyclables, improves their working conditions and earnings, and transforms their occupation from *"scavenging"* to service provision (Chikarmane and Narayan, 2005). The trade union has shifted waste pickers from individuals to a collective identity, led to a change in consciousness for the self-image from *"non-worker"* to a valued *"productive worker"* changed public perception of waste pickers, and finally a change in material conditions (increased income, medical insurance, increased access to education) (Chikarmane and Narayan, 2005). As of 2009, KKPKP had 8,000 members.

KKPKP expanded and joined with a group of seven other organisations around the country to form a network called Solid Waste Collection and Handling (SwaCH) co-operative which formally came into existence in 2007, integrating waste pickers into the MSWM system outside of a contracting framework (Samson, 2009). A pilot project was implemented in 2005 and enabled 1,500 waste pickers to become service providers through door-to-door collection of waste (SwaCH, 2012). The project demonstrates that residents are willing to pay for collection services; providers are more accountable when paid directly by users; and collection by waste pickers has increased the recovery of recyclables with a low-cost, labour-intensive, and less polluting alternative to the collection of waste with motorised vehicles (Samson, 2009). The municipal government of Pune (located in the state of Maharashtra) save some US$200,000 a year due to waste picker operations (Sharholy et al., 2008). Currently, 1,900 SWaCH members service 300,000 households in Pune City (SwaCH, 2012).

In recent years, the Indian government has succeeded in promoting an inclusive waste management policy for the informal sector. Waste pickers have achieved considerable recognition in national and municipal legislation, and parts of the informal recycling sector have successfully been integrated into formal structures. Although the conditions of informal waste management vary greatly from region to region and between cities, the overall trajectory reveals that the rights and conditions of Indian waste pickers have improved over the last decade.

Regarding national policy, the Indian government refused until recently to acknowledge the contributions of the informal recycling sector. In September 2000, the Ministry of Environment and Forests issued the country's first Municipal Solid Waste (Management and Handling) Rules 2000 under the Environmental Protection Act, 1986. The legislation is a mandatory blueprint for action and compels urban local authorities with populations over 20,000 to improve the waste management system (Patel, 2002). The Rules stipulate that legal procedures for collection, transportation, segregation and disposal must be put in place. Cities are required to establish adequate waste treatment and disposal facilities, as well as imposing specific standards for waste management (Scheinberg and Mol, 2010). Despite the importance of informal waste management in the recycling chain, the sector was not mentioned in the legislation. As a result, the legislative framework of the Municipal Solid Waste Rules failed to integrate waste pickers into the solid waste management structures (Gerdes and Gunsilius, 2010).

The legal status of waste pickers, however, changed with the adoption of the National Environment Policy in 2006. It is the first national policy document to recognise the existence of informal recycling. The legislation gives *"legal recognition to and strengthen the informal sector* *systems of collection and recycling of various materials. In particular, "to enhance their access to institutional finance and relevant technologies"* (Indian Ministry of Environment and Forests, 2006). The aim of the policy was primarily to strengthen the capacity of regional and local bodies for undertaking adequate measures regarding waste management (Gerdes and Gunsilius, 2010). In the National Action Plan for Climate Change, 2009, the government emphasises on the role of waste pickers in the national strategy on the issue of climate change (http://wiego.org/).

While the national government has been slow to implement comprehensive waste policy reforms, the most progressive moves have been in local and regional legislation as seen in the case of Pune above. Equally important achievements have been made in Ahmedabad, Gujarat, where the Self-Employed Women's Association (SEWA) has established cooperatives for female informal workers. Waste pickers constitute a significant proportion of the organisation's members. In coordination with the municipal government, SEWA has improved access, rights and conditions for its members working in the informal waste sector. As a result, waste pickers are now perceived as an integral part of the municipal waste management structure (Patel, 2002).

The recent developments in India have illustrated how informal waste management activities can be integrated into municipal waste management systems. Although the working conditions for the average Indian waste picker remain precarious, the inclusive and empowering processes in cities such as Pune and Ahmedabad show the potential gains of inter-sectoral cooperation and integration.

2.5.5.3 WIEGO Case study, Tshwane (adapted from Samson, 2010a)

The position of waste pickers in Tshwane represents a unique case study in South Africa. The Greater Pretoria Metropolitan Council attempted to regularise relations with waste pickers and improve their working conditions (Samson, 2010a). In 2000, the Council received funds from DEA for a project to help waste pickers form co-operatives and sell materials collectively to buy-back centres also built with DEA funding. However, the project collapsed, and the municipality currently accepts waste pickers on landfill sites but does not work with them to integrate them into the formal recycling economy.

The first phase of the project focused on making new products out of recycled materials, hiring waste pickers working on landfills to make handbags out of plastic bags. This project was unsustainable due to high production costs, and the quality of the plastic bags recovered was not usable for the project. So, the project was shut down, to focus on different initiatives that were thought to be more sustainable for a longer period. This left workers unemployed without compensation.

The second phase of the project focused on building buy-back centres. A company X received the tender to execute this project and build the buy-back centres. This company was also in charge of organizing and training waste pickers to form a cooperative. However, allegedly no cooperative was formed. Company X had a vested interest in regularising the reclaiming of recyclable materials at the landfill sites, leading to a conflict of interest. It was also unclear to waste pickers the distinction between Company X and the municipality. There was no proper organisation or support among waste pickers and waste pickers were not able to successfully run the buy-back centres, and effectively the project left the waste pickers under the control of a large company, reducing their income. The project went through several hands from the waste pickers themselves, to the municipality then to another Company Y. In 2009-2010 the project came to an end with the municipality realising that companies X and Y were exploiting the management contract for their own benefit.

While the attempts to build buy-back centres controlled by waste picker cooperatives failed, lessons can be learned from the process. The first phase shows that for recycling, re-production projects to be financially viable, projects cannot rely solely on the sale of new products produced by recyclable materials. The financial model did not account for the fact that waste pickers need to be compensated for removing recyclables from the waste stream.

Lessons from the second phase related *to "building the capacity of democratic, waste picker-controlled cooperatives that act effectively in waste pickers' best interests"* (Samson, 2010a). Large companies that received the tender had a vested interest in controlling waste pickers on the landfill site to gain profit from the project themselves supporting their business initiatives and had no experience in building worker cooperatives. Therefore, the buy-back centres failed due to lack of support and organisation of waste pickers on the part of the municipality.

Although these projects failed, in 2009 waste pickers formed a city-wide network of all committees from the different landfill sites to form the Tshwane Network. The Network has taken on markets with the goal to have buyers: increase prices, regulate prices at all of the landfills and stop playing the landfills off of each other. The Network shares information on prices and tries to negotiate prices directly with the buyers as a collective. Through forming the Network, waste pickers began to recognise the value of their work and its link to the greater economy. This has in turn given the waste pickers greater bargaining power to negotiate their earnings from materials collected and sorted at the landfill.

Inspired by the network, a co-operative was formed on the Ondestepoort landfill called Yebo Rekopane Recycling (Yes, We All Work Together Recycling), which aims to buy and sell material and then purchase a bailing machine, truck, and shelter to increase their productivity. One of the biggest challenges of the network is formal recognition from the municipality. Although the municipality accepts waste pickers working on the landfill, this has never been formalised into written policy. This means that the waste pickers are vulnerable to changes on how the city relates to them and leaves an unclear notion of what their position and rights are as workers on the landfill site.

2.5.5.4 Key lessons learned

Brazil demonstrates the power of a grassroots movement to uplift waste pickers to a status of formal employment. The KKPKP's initiatives in India reveal the effectiveness of trade unions to build a collective voice and go from informal workers to formal service provider collaborating with municipalities. Each country is unique, and programs and interventions must be context specific. Table 2-15 provides a summary of the key lessons learned from both international and local efforts to integrate the informal recycling and recovery sector into the formal economy that can be used and applied in South Africa.

Table 2-15 Key lessons learned from mini-case studies

Case study	Key Lessons
Brazil	1. Grassroots mobilisation (supported by NGOs) led to official recognition of waste pickers as a profession by the national government. 2. Waste & Citizenship forums promote partnerships between municipalities and waste pickers. 3. Door-to-door collection of waste by waste pickers reduces costs for MSWM.
India	1. Identity cards are given to waste pickers to authorise waste pickers to work officially. 2. Trade union (KKPKP) facilitation of integration of waste pickers into official waste management structures. 3. Municipal compensation: health insurance, education improves the lives of waste pickers and their families making them more productive in their work. 4. Service fees paid directly by households to a service provider (waste pickers) allocated to a block. The service provider has the right to valorise the recyclables and organic waste, improving income of waste pickers and diverting waste from the waste stream.
Tshwane City, South Africa	1. Need for sustainable financial models when designing recycling projects. 2. Need for capacity building, and organisation of waste pickers. 3. Formalised relations between cooperatives and networks with the municipality are needed to give waste pickers' more autonomy to organise and develop their enterprise.

2.6 Research Gap

There is the potential for science and engineering to transform cities, but contingent upon the local social, political and economic landscape. In South Africa policy rhetoric is fixated on extractive and inefficient economic growth, centralised infrastructure development and short-term job creation with little attention paid to the true efficacy of creating ecologically sustainable cities. Although the policy landscape in South Africa is littered with green economy rhetoric, there is marginal practical application, e.g. limited procurement of renewable energy from a small cluster of independent renewable energy power producers. In short, there is a lack of a precise transdisciplinary narrative on how to manage a transition towards more ecologically sustainable and socially equitable modalities of organising social and economic life in our cities.

In South Africa, there is seemingly a lack of urgency to future proof cities in light of forecast climate change related resource constraints. Increasing resource conservation, optimising aggregate efficiency, shifting towards renewable energy and closing material loops are the fundamental design drivers for a future proofed (i.e. ecological literate) city. At a strategic management level, there is lack of evidence to suggest that local authorities comprehend the significance of how a new *emerging general purpose technology (GPT) platform*, i.e. Third Industrial Revolution, is the antecedent to a sociotechnical transition towards an economic model premised on ecological design principles. Hence, there is room to explore how the emerging GPT platform can transform urban and industrial systems. Herein, the circular economy (CE) model is a useful approach to optimise the flow of technical nutrients in cities. In South Africa, CE strategic thinking and industrial ecology practice is narrow, merely espoused in dispersed and anecdotal industrial symbiosis exchanges (e.g. Western Cape Industrial Symbiosis Programme).

Furthermore, in South African cities there is an inadequate technical understanding of the role of waste pickers in the secondary resources economy. In the context of eThekwini Municipality, this is highlighted by no mention of waste pickers in the municipality's most recent integrated waste management plan. The literature highlights the proliferation of *soft approaches (e.g. waste picker cooperatives)* to address the needs of waste pickers across cities in the global south. Strategies and practices to date have focussed on organising waste pickers within traditional political and economic models. In sum, there is an opportunity reposition the *waste picker narrative* through a highly interdisciplinary and *technology-enabled approach*.

2.7 Conclusion

In the age of the Anthropocene, resource management is imperative, especially at a city level where resource depletion is compounded by rapid urbanisation. Herein, from an urban metabolism perspective, initiating the transition to a *circular city*, is a critical first step. Adopting circular economy strategies towards de-coupling and waste minimisation has relevance in rapidly urbanising South African cities. However, quantifying the scope and potential of the secondary resources economy is difficult due to the lack of detailed data on secondary resource stocks and flows. Overall, there is a paucity of reliable and comprehensive data on material flows in South African[37] cities and industrial hinterlands.

Industrial symbiosis (IS) can be an instrumental approach to prevent the creation of industrial waste, by supporting the utilisation of by-products (e.g. material exchange) and the recycling of waste through inter-firm cooperation and public-private partnerships. To this end, chapter three investigates firms' attitudes towards IS in the South Durban Basin (industrial cluster) in eThekwini Municipality, a strategic port industrial city. Also, highlighting leverage points to be addressed in terms engendering more eco-efficient patterns of organising industrial systems.

Urban symbiosis as an extension of IS concerned with synergistic material and energy exchanges between adjacent urban and industrial clusters to improve the aggregate efficiencies of city regions and foster circular economy models. In this light, chapter four explores the instrumental role of waste pickers in recovering recyclable materials from urban waste streams – secondary resources which in turn supply adjacent recycling and reprocessing industries. In turn, highlighting leverage points to inform the conceptualisation of alternative patterns of organising informal urban symbiosis networks.

Chapter 3 – Industrial Symbiosis Case Study

Chapter three elucidates the industrial symbiosis (IS) case study, which investigates firms' attitudes towards waste management strategy IS. A firm level survey is conducted in the South Durban Basin (SDB), a diverse industrial cluster situated in eThekwini Municipality (KZN). The survey investigates contextual barriers and opportunities to IS. Findings inform policy development at a regional level and highlight leverage points for IS detection, matching and facilitation.

3.1 Introduction

To further circular economy (CE) transitions (e.g. industrial symbiosis), requires a robust dialogue and dynamic connectivity between firms and relevant stakeholders (e.g. waste management service providers and municipalities). The transfer of firm level and industry level information pertaining to industrial metabolism is at the core of such an approach. The scope for developing a CE will require an innovative approach to frame industrial ecology solutions. Industrial symbiosis (IS) presents collective solutions to common issues (e.g. waste management) through cooperative management of resources and by-product exchanges for firms in geographic proximity (Chertow et al., 2008). Chertow et al. (2008) contend *that "from policy and planning perspectives, industrial symbiosis is a useful contribution to agglomeration insofar as it can highlight opportunities for combining environmental with economic benefits in regional economic development strategies"*.

The following chapter investigates the potential for organising IS networks among manufacturing firms in eThekwini Municipality, located in the industrial province of KwaZulu-Natal (KZN). The case study is framed in an economic context, providing a snapshot of national, regional and local economic dynamics. Furthermore, highlighting the significance of the manufacturing sector as part of the port city's diverse industrial ecosystem. eThekwini Municipality's manufacturing sector is embedded in global value chains, in turn vulnerable to a multiplicity of exogenous economic forces, e.g. commodity price oscillation and uncertain global financial markets. Furthermore, as a major metropolitan in a fluctuating emerging market economy, it is exposed to a diversity of local economic (e.g. critical skills shortages), political (e.g. poor governance), social (e.g. rapid urbanisation) and environmental (e.g. water scarcity) challenges. The manufacturing sector provides vital downstream and upstream linkages, in turn is a hub of strategic economic activity and job creation. Hence, the research locus is the South Durban Basin – the major industrial cluster situated in eThekwini Municipality.

3.2 Background

In last decade, the South African economy experienced low growth, fluctuating around two per cent. This was a result of the global economic recession coupled with a risk laden domestic political environment (e.g. characterised by widespread corruption scandals and associated fiscal mismanagement) and critical primary resource constraints (e.g. water scarcity as a result of severe drought and a national energy supply crisis). Similar to national trends the regional economy of KwaZulu-Natal (KZN) also experienced sluggish growth since 2008 (TIPS, 2016).

Of the nine provinces, Gauteng, KZN and the Western Cape contribute over 60% to the country's value added, herein manufacturing is a vital sector. According to Statistics South Africa (STATSSA), *"the manufacturing sector continues to occupy a significant share of the South Africa economy, despite its relative importance declining from 19 percent in 1993 to about 17 percent in 2012 in real terms"* (STATSSA, 2017). Moreover, manufacturing is the dominant sector in KZN.

3.2.1 Regional economic profile of KwaZulu-Natal

KwaZulu-Natal (KZN) is an important agricultural and manufacturing (e.g. light and heavy industries) region in South Africa. Situated in eThekwini Municipality, it houses the largest and busiest shipping terminal in Sub-Saharan Africa. However, the region is still marred by the socio-economic structural inequities of apartheid spatial planning, with approximately half the population living in impoverished former *homeland*[38] (semi-rural and rural) regions, compared to the national average of 30% (TIPS, 2016). These areas have limited employment opportunities and severe infrastructure backlogs, as a result KZN exhibits high unemployment[39], low household

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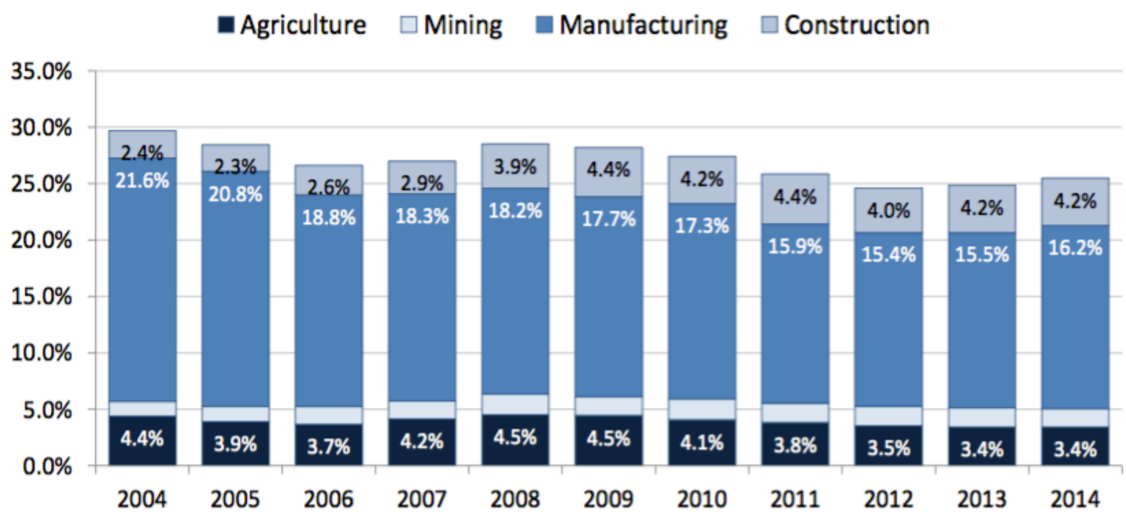
[38] During the apartheid regime, the former *homeland* regions were purposively underdeveloped. These areas were reserved for the indigenous African population and typically excluded evidence of valuable natural resources (i.e. mineral resources), and were largely deprived of infrastructure and basic government services.

[39] In 2015 only 38% of the working-age population was employed. The national average was approximately over 40%, while the international norm is around 60% (TIPS, 2016).

incomes[40] and poor delivery of municipal services (e.g. water and sanitation, waste management).

KZN has 10, 9 million residents, accounting for 20% of South Africa's population. In 2014 (latest data available) it contributed just 16% of national GDP. According to the Trade and Industrial Policy Strategies (TIPS), *"the real economy (represented here by agriculture, mining, manufacturing and construction) made up 25% of KwaZulu-Natal's output"* (TIPS, 2016). Manufacturing composed 16.2% of the provincial economy, followed by agriculture at 3.4%, construction at 4.2%, and mining at 2% (TIPS, 2016) (see figure 3-2). From a national economy perspective, *"KZN contributed 22% of national manufacturing, 25% of national agriculture, 19% of national construction, but only 3% of national mining"* (TIPS, 2016).

Figure 3-1 Share of real economy sectors in KZN (TIPS, 2016 #508)



Job creation is a national priority. Manufacturing is a key sector in this regard and makes a significant contribution to the regional economy as illustrated in figure 3-1. In 2015, KZN accounted for 20% of national manufacturing employment. *"The top five manufacturing industries in the province, in terms of employment, were clothing, textiles and footwear; food and beverages; basic iron and steel and metal products; chemicals and plastic; and paper and publishing"* (TIPS, 2016). KZN's most prominent employment generating manufacturing

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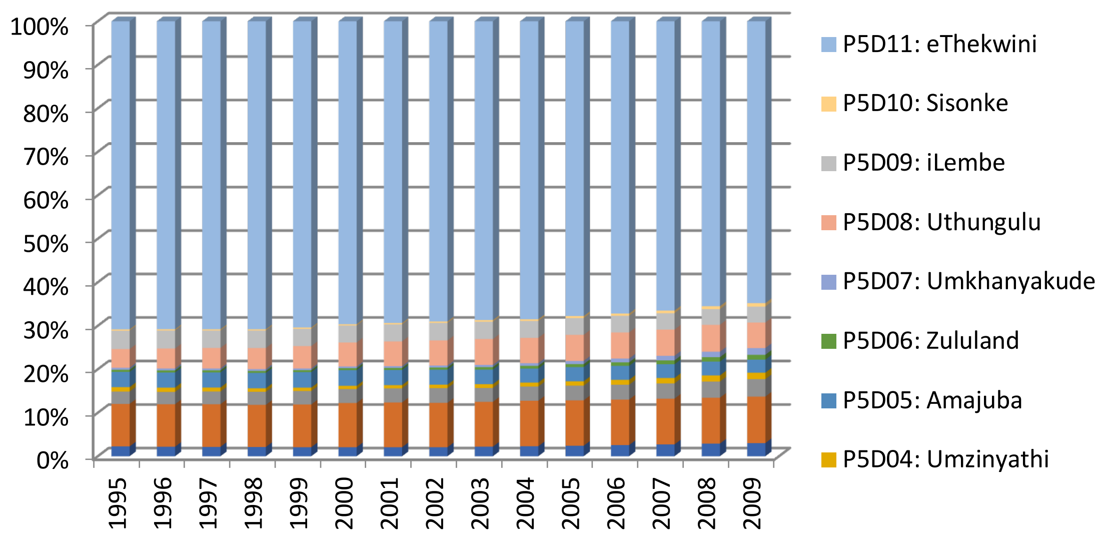
[40] *"The 2015 General Household Survey found that the median household income was R2 600 a month, compared to R3 260 nationally. In the former homeland regions, it was R2 160 a month, while it was R3 010 in the rest of the province"* (TIPS, 2016).

industry is clothing, textiles and footwear – accounting for 41% of provincial manufacturing jobs. Although, in 2015 the main growth in manufacturing jobs came from food and beverages cluster.

3.2.2 eThekwini Municipality

eThekwini Municipality forms the logical locus for this study by virtue of its diverse manufacturing base and sheer scale in significance to provincial GDP (as illustrated in figure 3-2).

Figure 3-2 eThekwini's share of Provincial GDP (Source: Quantec data)



eThekwini Municipality is the third largest city in the country. It is considered one of the oldest and most significant municipal industrial zones second to Gauteng and boasts a significantly diversified and modernised economy. Understanding the character and potential of real and latent opportunities within this economy forms the basis for manufacturing sector analysis. The eThekwini Industrial Spatial Strategy (EISS) aims to provide the entry point in attempting to bridge the current knowledge gap on eThekwini's industrial base by attempting to present a spatial map facilitating management of existing and future industrial development zones in the city.

The municipality has a diverse manufacturing sector, as portrayed in figure 3-4 and 3-5. With prominent chemicals and plastics, automotive, clothing, footwear and textiles sectors. The diverse manufacturing activities presents opportunities for uncovering industrial symbiosis networks, making eThekwini Municipality is an attractive circular economy case study.

Figure 3-3 eThekwini's manufacturing sector contribution (EISS, 2009)

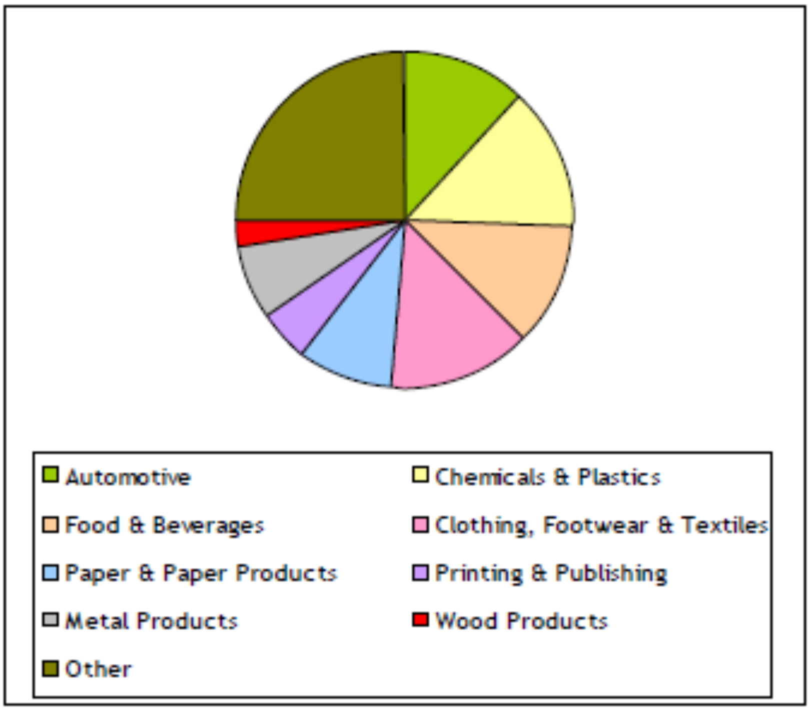


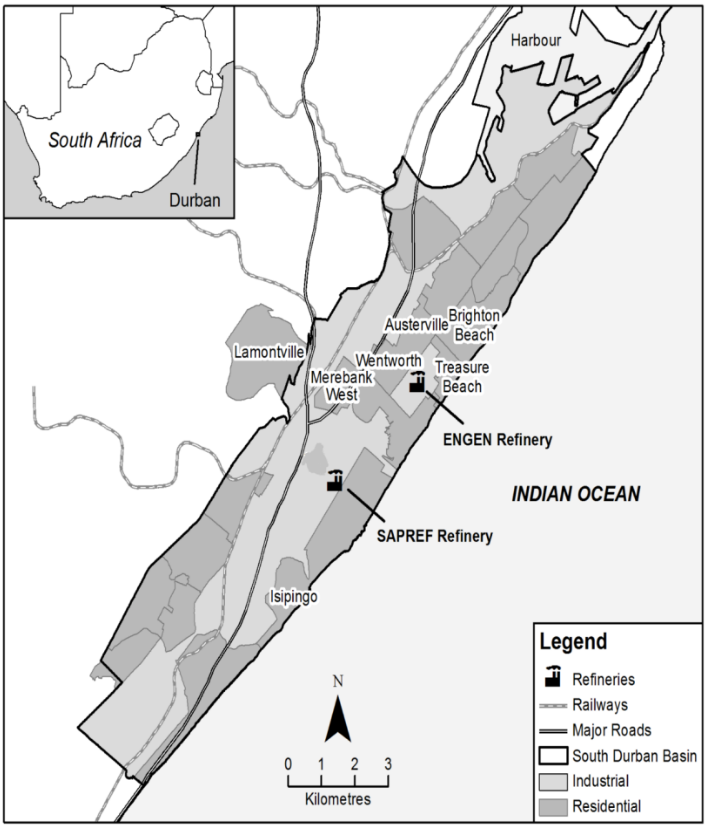
Figure 3-4 eThekwini's manufacturing contribution by sector (Source: EISS, 2009)

Sector	R (billion)	% of total
Automotive	5.2	12.0
Chemicals & Plastics	6.0	14.0
Food & Beverages	5.0	11.5
Clothing, Footwear & Textiles	6.0	14.0
Paper & Paper Products	3.9	9.0
Printing & Publishing	2.2	5.0
Metal Products	3.0	7.0
Wood Products	1.0	2.0
Other	11.0	25.5
TOTAL	43.2	100.0

3.2.3 Research locus: South Durban Basin

The rationale for focusing on the South Durban Basin (SDB) within Durban concerns the fact that it is the largest manufacturing and industrial zone within the city and is estimated to contribute some 30% of Durban's GDP (van Alstine, 2007).

Figure 3-5 Map of South Durban Basin, eThekwini Municipality, South Africa



The development of SDB has its origin in apartheid spatial planning, with the site identified in the 1950s for industrial development in addition to serving as a residential node housing African, Coloured and Indian communities (van Alstine, 2007). As a result, today the SDB is home to approximately 300 000 people, with majority of the population from black communities, living alongside four crude oil refineries, two of which are the largest crude oil refineries in South Africa – refining approximately 60% of the country's petroleum (see figure 3-5).

Pollution in the SDB remains a serious environmental and public health concern; threatening resident communities constitutionally protected right to a clean and healthy environment. These low-income communities are to a disproportionate extent exposed to a hazardous environment and carbon dioxide pollution. However, the SDB is also demarcated as a strategic site for South Africa's economic growth, particularly in the value added manufacturing sectors such as chemicals, plastics, metalworking, and the motor industry (Barnett and Scott, 2007).

It is within this context that issues of industrial pollution and understanding the parameters shaping waste management and the realisation of the full potential of the secondary resources economy in the SDB are juxtaposed against broad-based, inclusive and sustainable socio-economic development for all.

3.2.4 Rationale of the research

To promote sustainable development in South Africa, urban and industrial development should be formulated within an industrial ecology (IE) approach nested in a broader circular economy (CE) framework. To this end the IE paradigm promotes urban and industrial resource efficiency; providing a conceptual framework for firms to design and pilot innovative strategies to pursue more sustainable business scenarios by exploring the positive environmental externalities that can accrue in industrial clusters by means of industrial symbiosis (Chertow et al., 2008).

Future IE systems (e.g. industrial symbiosis networks) will be built out of the emerging general purpose technology platform (e.g. cyber-physical systems architecture) depicted in Rifkin's *Third Industrial Revolution* thesis (described in chapter one). Herein, the potential value of technology enabled IS resides in generating actionable resource flow intelligence (i.e. mapping resource flows and modeling synergies), reducing transaction costs for stakeholders (e.g. firms) enabling self orginsation.

Industry-state collaboration is key to transition to a more sustainable CE, in turn a principal driver is the cooperation among key industries (e.g. manufacturing), in particular at an inter-firm level. Although firms and supply chain networks may recognise the importance of environmental performance and improving waste management systems, the critical issue is how to induce strategic long-term CE activities (e.g. industrial symbiosis)? In a study, addressing inter and intra organisational challenges to IE, findings indicated that while technical solutions to improve waste management systems can be developed, the difficulty resides in the organisational issues connected to introducing IE (Dahl et al., 2001). Taking this under consideration and in the context of industrial development in South Africa, it is critical to investigate the underlying organisational dynamics (e.g. barriers, opportunities and leverage points) influencing the cultivation of industrial symbiosis networks in the major industrial cities.

3.3 Research Questions, Objective and Aim

The case study was guided by following key research questions and sub-questions were probed through the implementation of a mixed methods research design:

3.3.1 Research questions

- What is the scope for further reusing the industrial waste generated in the SDB?
- Do firms in SDB cooperate in managing their waste? If so, how and to what degree?

3.3.2 Objective

- To identify the opportunities and barriers to detecting and facilitating industrial symbiosis (IS) networks

3.3.3 Aim

- To identify leverage points for technological intervention, i.e., virtual circular city experimentation

3.4 Methodology

The study was conducted using a mixed methods research design entailing the collection and analysis of qualitative and quantitative data; to complement each other resulting in a more nuanced analysis. The mixed methods design consisted of a questionnaire survey and semi-structured interviews. In addition, for purposes of data triangulation, key informant interviews were conducted with waste service providers, industry experts and state officials at various tiers of government.

3.4.1 Sample design

The questionnaire survey is a follow-up to Greater Durban Metropolitan Area (GDMA) firm survey, which was important for an understanding of local manufacturing performance. However, the initial GDMA firm level survey did not specifically explore the complexities of waste management in the SDB. The present survey thus targeted a cross section of manufacturing industries within the SDB, sampled in the GDMA survey. However, this study has an explicit focus on firm-level waste management strategy and practice.

The rationale for identifying a cross section of firms is to explore possibilities for industrial symbiosis at an inter sector level, as well as within sectors. The survey has an explicit focus on waste management and sustainability issues; with a designated focus on investigating corporate attitudes towards IE as a conceptual framework to advance sustainable waste management. Top management (directors and senior managers) are responsible for setting corporate strategy, hence their views are important in assessing a firm's environmental management strategic orientation and waste management practices (Wang and Li, 2010). Table 3-1 presents the description of the standard industrial classification codes of the firms that were in the sample.

Table 3-1 Standard Industrial Classification (SIC) codes for firms in the sample (Source: STATSSA)

SIC Code	Description
2	Mining and Quarrying
301-306	Food, Beverages and Tobacco
311-317	Textiles, Clothing and Leather goods
321-326	Wood, Paper, Publishing and Printing
331-338	Petroleum products, Chemicals, Rubber and Plastic
351-359	Metals, Metal Products, Machinery and Equipment
391-392	Furniture and other manufacturing
371-376	Radio, TV, Instruments, Watches and Clocks

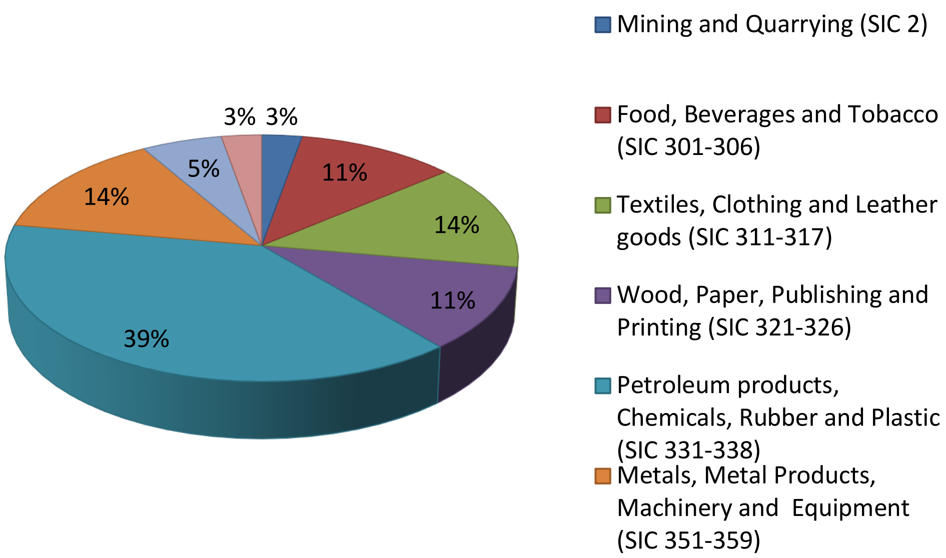
The initial sampling strategy was informed by a purposive quota sampling approach. The objective was to compile a representative sample of firms categorised by industrial sector as defined by the Standard Industrial Classification (SIC) codes (see table 3-1). The quota sample was based on the manufacturing sector contribution to eThekwini's GDP; from which ratios based on manufacturing sector contribution determined the number of firms to be included in the sample (see table 3-2).

Table 3-2 Sector contribution to eThekwini's GDP and intended and actual sample

Industrial Sector (SIC)	% Contribution to eThekwini's GDP	Intended number of firms in the sample	Actual number of firms in the sample
301-306	12%	5	4
311-317	15%	6	5
321-326	8%	3	4
331-338	15%	6	14
351-359	21%	8	5
391-392	2%	1	2
Other	27%	11	2
Total	100%	40	36

After the intended number of firms per manufacturing sector was ascertained, a total of 54 relevant medium to large manufacturing firms were identified from the GDMA list. From this list, 40 were successfully contacted and invited to participate in the study, of which 17 agreed to participate in the study. Based on the poor response from firms in the GDMA sample a convenience sampling rationale was employed to supplement the sample. Industrial database searches were carried out and firms falling in the SDB (outside of the GDMA list) were contacted and invited to participate in the study; including firms from the Durban Automotive Cluster, Durban Clothing and Textiles cluster and the Durban Chemicals Cluster. From the requests that were sent out, a significant number of firms in the petroleum, chemicals, rubber and plastic sector (39% of sample) were more receptive and willing to participate in the study, than any other industrial sector. The overall sample for the study was comprised of 17 firms from the initial GDMA list and 19 respective firms that were purposively and conveniently sampled.

Figure 3-6 Sample breakdown by industrial sector



The survey purposively targeted top management (including Safety, Health, Environmental and Quality managers) of medium and large-sized manufacturing firms in SDB. Firms that were included in the sample were contacted via telephone and email concerning the objective for the study.

3.4.2 Research instrument

The survey questionnaire[41] was designed by adapting concepts from international (peer-reviewed) waste management and industrial ecology studies. The result was a composite tool that consisted of ordinal scales, closed questions and open-ended questions. The questionnaire comprised of five main sections: 1) general business information, 2) waste management, 3) industrial symbiosis.

[41] See Appendix A for firm level questionnaire.

3.4.3 Data collection protocol

Data collection was done by way of an interviewer administering the questionnaire in addition to a note-taker documenting qualitative responses. This approach minimised the common problem of missing information. The questionnaires were administered to top management in the firms that had been identified. In addition, semi-structured interviews were conducted with key informants representing different stakeholders; civil society, industry associations, waste sector experts, waste management service providers and local government.

3.5 Limitations

Although the study elicited interesting findings from the analysis, the uneven distribution of firms by sector made it difficult for meaningful sectoral comparisons to be made. However, this can be attributed to a geographical and spatial dynamics. Social desirability bias is another limitation – managers who were interviewed may have been portraying a positive attitude of their firm's practices.

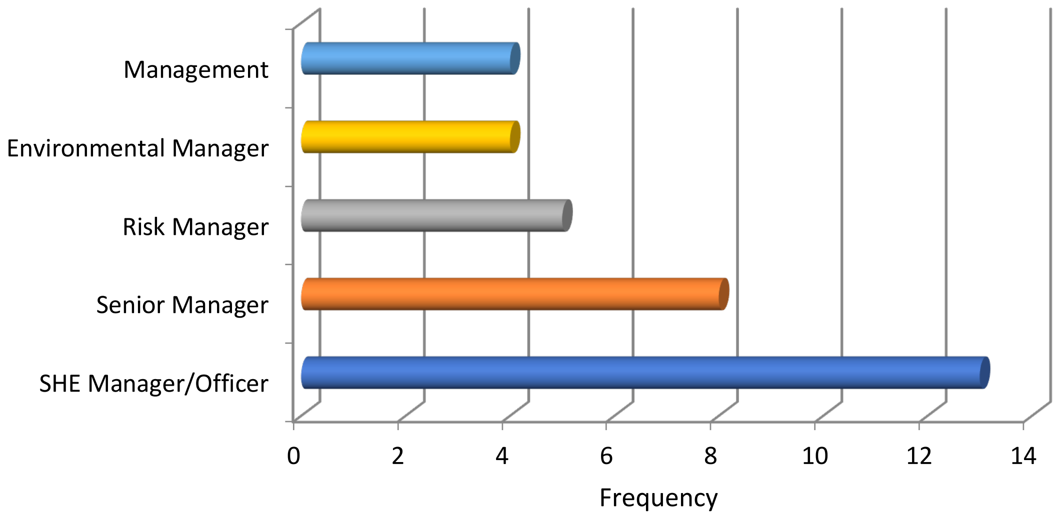
3.6 Findings

This section presents the preliminary findings arranged into four themes: 1) firm profile, 2) waste management, 3) industrial symbiosis, and 4) corporate environmentalism.

3.6.1 Firm profile

3.6.1.1 Respondent's position

Figure 3-7 Respondent's position



As shown in figure 3-7, safety health and environment (SHE) managers/officers constituted about 36% of the respondents, followed by senior managers (22%), risk managers (14%), environmental managers (11%) and management (11%). The number of respondents who are SHE managers/officers is high because of the nature of the study. Most of the information regarding waste management and the environment could best be provided by the SHE manager. 47% of the respondents were in the age category 40-49, while only 8% of the respondents were under the age of 30. The respondents in terms of gender were constituted of 58% male and 42% female.

3.6.1.2 Firm history

The year when production started at current location of firms varied from 1949 to 2011. However, seven of the firms started their production on the current location between 1960 and 1969, six firms started between 1990 and 1999, another six firm's started production between 2000 and 2009. Only one firm started production on its current location in the last 3 years.

3.6.1.3 Employment

In terms of permanent employees (see table 3-3), 36.1% of the firms have employees in the 100-249 category, 27.8% in the 250+ category, 19.4% in the 50-99 category and 8.3% for the two categories, 10-19 and 20-49.

Table 3-3 Permanent employees

Permanent employees	Percentage
10-19	8.3%
20-49	8.3%
50-99	19.4%
100-249	36.1%
250+	27.8%

For part-time/contract employees (see table 3-4), 27.8% of the firms had employees in the age category 20-49, 22.2% in the 0-5 category, 13.9% in the 250+ category, 11.1% for the 10-19, 50-99 and the 100-249 categories.

Table 3-4 Part-time employees

Part-time employees	Percentage
0-5	22.2%
10-19	11.1%
20-49	27.8%
50-99	11.1%
100-249	11.1%
250+	13.9%

3.6.1.4 Market

All the firms that participated in the study produce for the local market with 24 of the firms also producing for the overseas markets (see table 3-5).

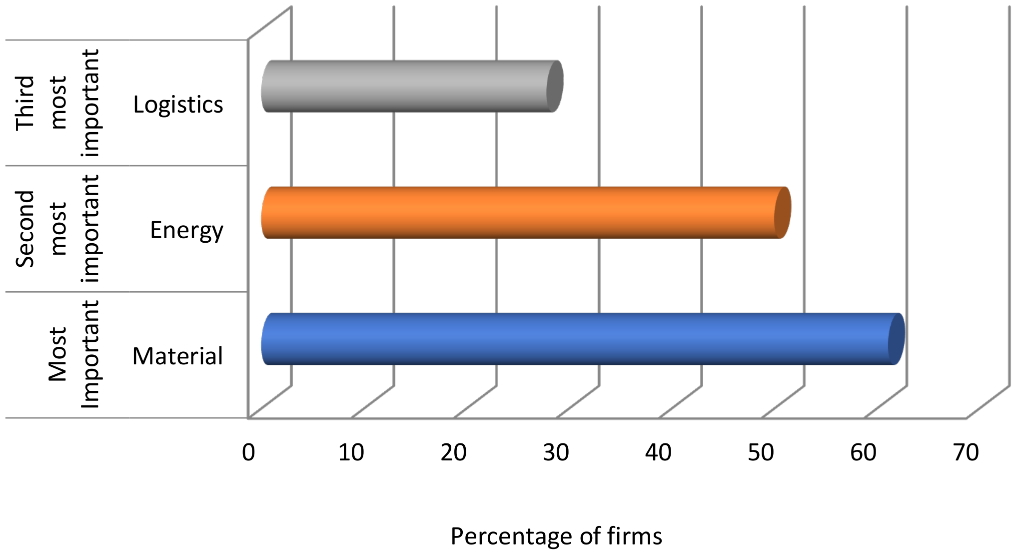
Table 3-5 Production and market breakdown

General Breakdown of Markets	Frequency
Local	36
Overseas	24

3.6.1.5 Factor inputs

In ranking factor inputs (see figure 3-8), the three most significant inputs that firms highlighted were: firstly *materials* (which was identified by 22 firms), the second most important was *energy* (18 firms), and thirdly *logistics* (10 firms).

Figure 3-8 Key factor inputs



3.6.2 Waste management

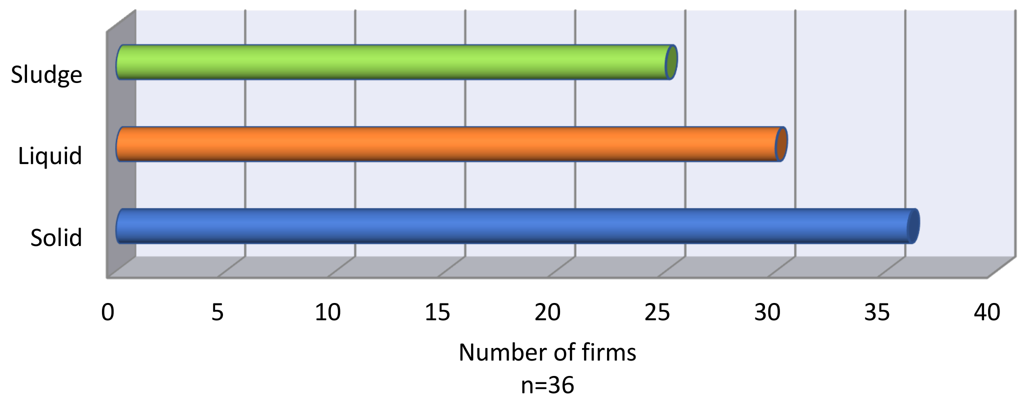
3.6.2.1 Waste stream

Table 3-6 Waste type

Waste Type	Frequency
Chemical waste	23
Metallic waste	26
Healthcare and biological waste	15
Discarded Equipment	30
Animal and Vegetable waste	13
Mixed Ordinary Waste	35
Common Sludge	16
Mineral waste	20

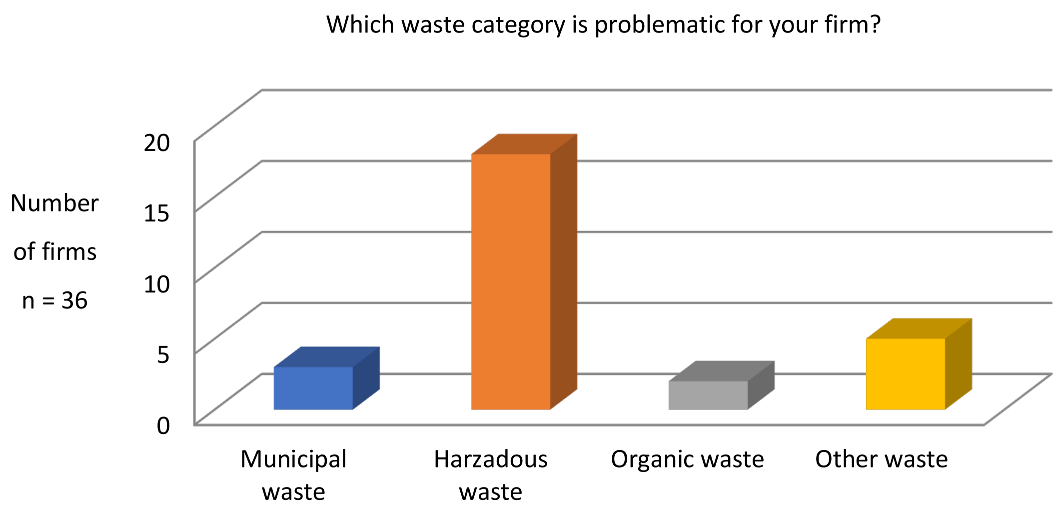
Of the 36 firms, 35 produce mixed and ordinary waste, 26 produce metallic waste and 23 firms produce chemical waste (see table 3-6). Almost 92% of the firms have a person responsible for waste management with 83% having the required permits/licenses for waste management.

Figure 3-9 Physical form of waste



All the firms interviewed reported that they produce solid waste, 83% of the firms have liquid waste and 69% produce sludge. In terms of the nature of the waste, 81% of the firms produce hazardous waste. 69% of the firms indicated that they have procedures in place to deal with hazardous waste. Waste separation is a value adding process and most firms have adopted it, 89% of the firms in the survey indicated that they separate their waste at source with 69% of the firms indicating that their waste requires special treatment. 50% of the firms in the study highlighted that they pre-treat their waste. Waste management is usually done off-site with 94% of firms reporting that their waste is managed off-site. 69% have waste management on-site. Regarding the re-use of waste, 72% of the firms said that their waste could be re-used in production on-site. With the increasing importance of reporting on waste data, 64% of the firms keep records of their waste. A large number (92%) of firms employ a waste contractor to manage their waste. Waste management has been problematic for some firms, 61% of the firms complained that the fees for waste collection are a burden to their organizations. Firms are taking responsibility for environmental preservation; 86% have their safe disposal certificates in place and 83% of the firms have signed operational agreements with transporters of hazardous waste. 61% of the firms have a signed operational agreement with their respective waste contractors for the collection of waste when full. Others (55%) have an agreement to collect on a set frequency (e.g. weekly, daily).

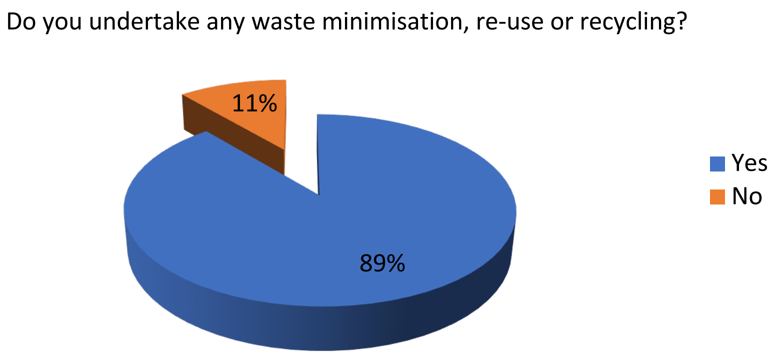
Figure 3-10 Problematic waste category



Hazardous waste was identified by 50% of the firms as problematic (see figure 3-10). This is mostly due to the high costs that are associated with transporting, treating and disposing of hazardous waste.

3.6.2.2 Waste recovery, recycling and re-use

Figure 3-11 Waste re-use, recycling and minimisation



75% of the firms have carried out a waste audit in the past 3 years. 89% of the firms undertake waste minimisation, reuse and recycling initiatives (see figure 3-11). 50% reported that the waste they produce can be recycled, 82% highlighted that their waste could be re-used by other firms off-site. In terms of waste recovery, 49% of firms have waste that is recoverable. 75% of the firms have formal waste management training in place, this is indicative of how waste management issues are becoming more important.

Table 3-7 Indicators of environmental management

Indicator	Number of Firms
Best Available Technology	30
Onsite Recycling	22
Treatment of waste/by-products	22
Environmental Policy	29
Company Industry Waste	18
Global Reporting Initiative	14
Recycling Fund	10
Local Waste Market	26

The most prominent type of waste management is landfill, moreover a majority of firms stated that they were using the best available waste management technology (see table 3-7). Almost all the firms (94%) reported that they send their waste to landfill sites (see table 3-8). 92% engage in recycling activities as a way of managing their waste. Some of the waste is re-used off-site; this was reported by 53% of the firms in the study.

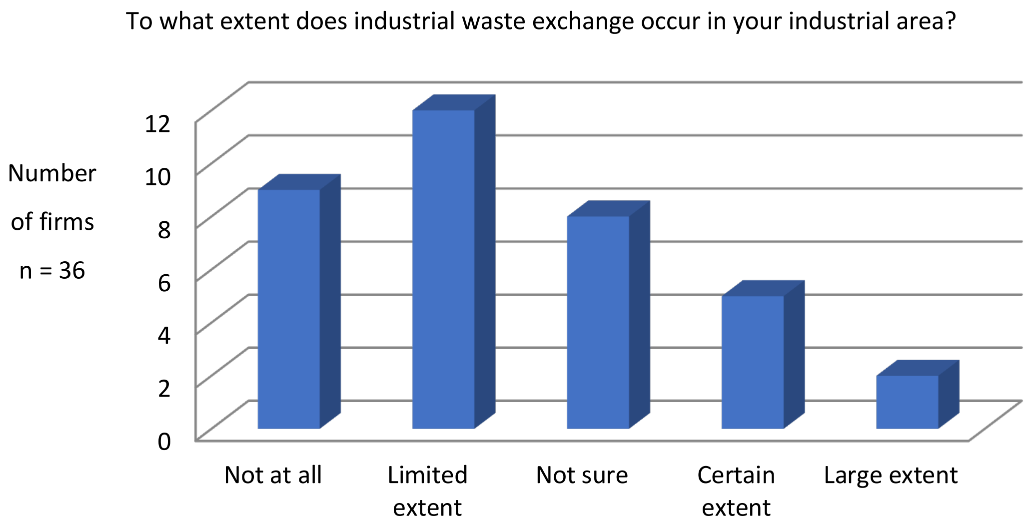
Table 3-8 Waste management

Waste Management Type	Number of Firms
Landfill	34
Land recovery	5
Thermal with energy recovery	3
Thermal without energy recovery	1
Transfer station treatment	7
Recycling	33
Composting	4
Re-used off-site	19

3.6.3 Industrial symbiosis

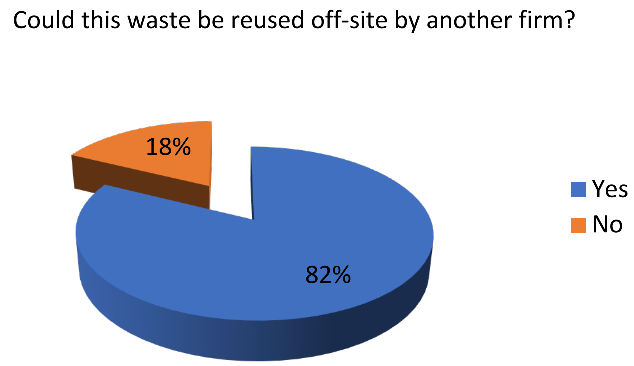
IE and IS are under explored among manufacturing firms in the SDB sample. Findings illustrate that firms' exhibit limited explicit knowledge and awareness of IE and IS concepts and tools. When asked to what extent waste exchange occurs in their industrial area, 33% of the firms concurred that it is happening to a limited extent, whereas 25% noted that it does not occur at all (see figure 3-12). However, 47% of firms stated that they would be able to use waste/by-product of another firm as an input material for its own processes, under conditions that it meets certain quality requirements. In turn, 36% of firms stated that there is economic potential for waste/by-product exchange in their industrial area. Furthermore, 42% of the firms claimed to have resources that could be offered to other firms.

Figure 3-12 Waste Exchange



It is interesting to note that a majority of firms declared that some of their waste streams had the potential to be reused off-site by another firm in a different production process (see figure 3-13).

Figure 3-13 Waste Re-use



In addition, 35 firms (97%) were interested in joining a cooperation system between firms which could potentially result in saving costs related to waste management, input materials and unused capacities. The potential for industrial symbiosis in SDB is inherent, with 97% of the firms highlighting that they would be interested in joining a system of industrial symbiosis. However, there are various institutional, cultural (corporate) and physical barriers to realising industrial symbiotic relationships between firms.

The main barriers to IS as reported by the firms are listed below:

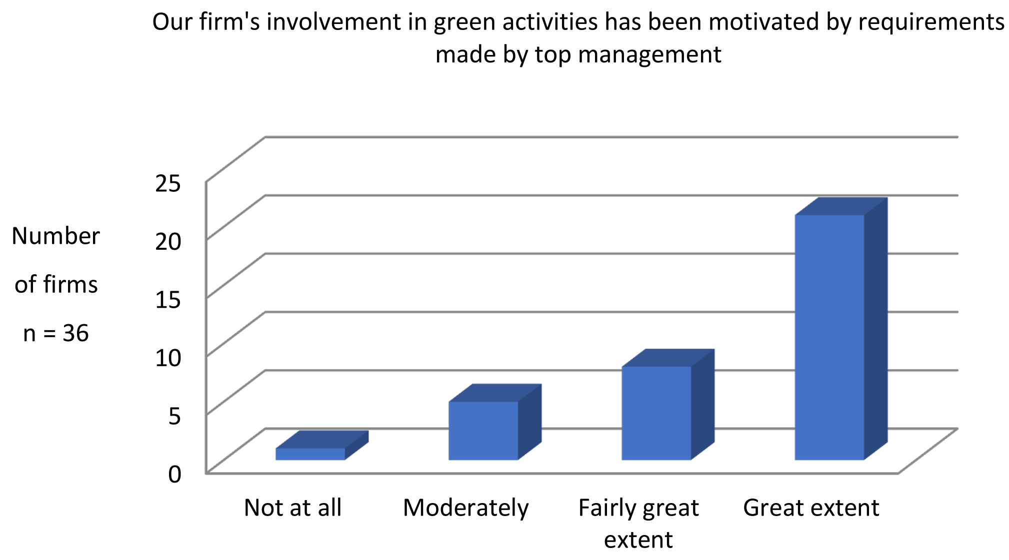
- Restrictive regulatory environment/by-product exchange based on the lack of clarity regarding waste classification
- Lack of information sharing platform between firms and industrial clusters regarding waste generation and management
- End of pipe-treatment of waste is the common management disposition rather than strategic upstream innovation premised on resource efficiency
- Intra-firm constraints: lack of awareness, lack of expertise, lack of leadership, lack of time, lack of interest, cost of technology
- Inter-firm constraints: lack of trust, highly specific manufacturing processes, identifying firms to use by-product/waste as a resource, risk associated with waste trading, sometimes volumes of by-product/waste are too low (require economies of scale)
- Limited IS potential due to poor industrial planning, unsophisticated and inadequate infrastructure

3.6.4 Customer pressure and top management

Firms highlighted customer pressure and top management as key drivers of green activities. At a firm level, top management commitment is one of the decisive drivers for success in balancing economic and environmental performance (Yen and Yen, 2011). Top management's strategic disposition and commitment is a critical antecedent to systemically integrating environmental concerns into product and industrial process design; in turn promoting sustainable waste management practices.

Customer pressure was identified as another key driver of environmental performance; this was more relevant for firms engaged in exporting to EU markets and/or integrated into global value chains (e.g. South African automotive component manufacturers). Firms belonging to multinational corporations formulate their environmental policy based on the lead of the parent company.

Figure 3-14 Firm's green activities motivated by top management

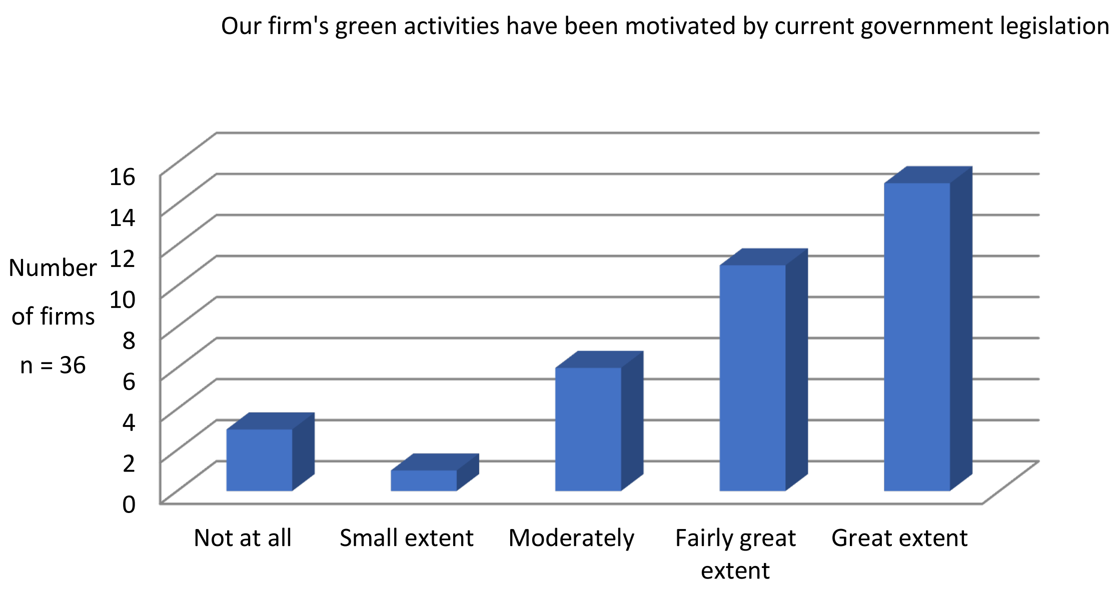


A majority of firms agreed that role of top management is critical in driving environmental and green activities (see figure 3-14). Thus, highlighting the assertion that top management's pro-environmental strategic disposition is a critical antecedent to integrating environmental concerns into product and process design.

3.6.5 Regulatory environment

Government legislation was seen as a key factor encouraging compliance and pro-environmental behaviour by 67% of firms in the survey, as illustrated in figure 3-15.

Figure 3-15 Firms' green activities motivated by government legislation



3.7 Discussion

3.7.1 The Waste Act

The implementation of the National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008) has been met with scepticism due to the lack of clarity regarding the classification and management of waste and by-products. Multiple respondents surveyed argued that the Waste Act is overburdened with policy content, which results in ambiguous definitions pertaining to the classification of waste. This in turn results in instilling uncertainty in the secondary resources economy, specifically around potential reuse of waste and by-products. For example, certain firms have expressed reservation regarding the requirement for an application of a Waste Management License required for on-site waste management, where potential for the reuse of waste streams could potentially be realised as an input in secondary production processes off site. This is evident in cement production, with reference to the use of fly-ash, which under the Waste Act has been re-classified as waste. The issue of waste classification has been noted and is currently under review. The issues regarding the classification of waste and by-product according to industry have arisen due to the lack of meaningful consultation and communication between government and industry.

3.7.2 Enforcement

Reservation was similarly expressed concerning the poor level of municipal and national law enforcement regarding waste management. Certain firms argued that until rigorous and uniform waste management enforcement occurs across industries, there remains little incentive for firms to move beyond legal compliance and exhibit a pro-environmental strategic approach towards their core business. More fundamentally it was argued, until government sets the example of what is considered "good practice" in waste minimization, waste reduction and reuse, the targets set out by the Waste Act will be unattainable.

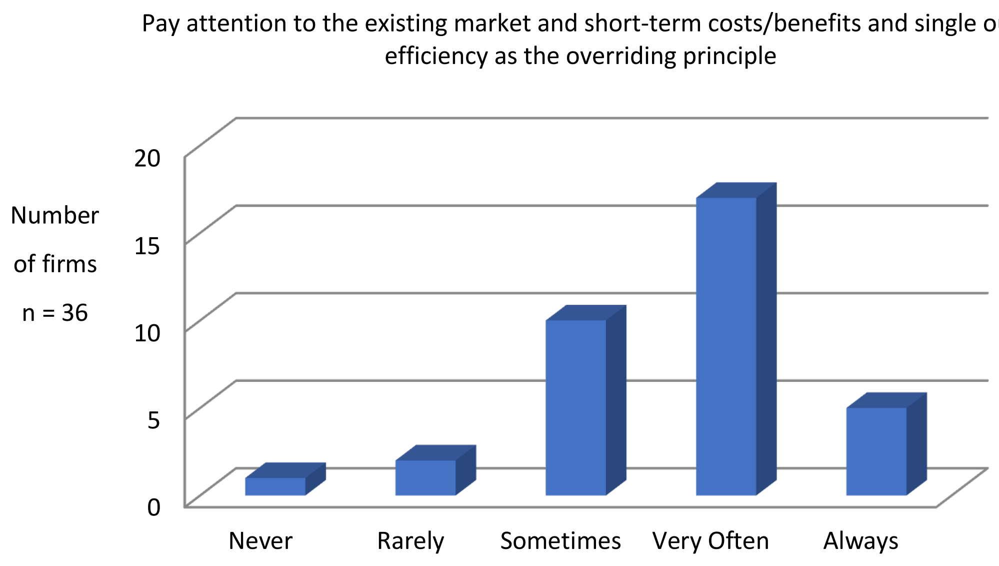
Furthermore, the current *polluter pays* approach inherent in the Waste Act facilitates a culture of retrogressive compliance, as firms particularly in the petro-chemicals sector are willing to pay monthly penalties regarding toxic effluent discharge should they arise, rather than adopting pro-active policy positions. This is compounded by poor legal enforcement of the Waste Act at a municipal, regional and national level, and essentially results in impeding upon the realisation of a dynamic secondary resources economy. According to a leading researcher involved in waste water treatment, government incapacities regarding adequately trained staff in waste management and oversight are a large part of the problem. A further shortcoming concerns the lack of inter-departmental cooperation in government, significantly hampering the implementation of universal cleaner production systems.

What is required is for government to lead the way, in addition to partnering with industry to realise the full potential of the secondary resources economy. A starting point could be the enforcement of waste separation at source by municipalities. Further considerations such as introducing incentives for pro-environmental behaviour have the potential of shifting firms beyond mere compliance. However, this being said, the findings also suggest that firms belonging to a multinational parent company, or firms who are integrated into a global supply and value chain exhibit a significant degree of pro-environmental behaviour regarding waste management. Perhaps the greatest driver of change concerns the realisation that implementing an effective waste management strategy affects the bottom line; with a leading expert on firm-level waste management intervention stating that potential gains of between 2-7% can be achieved through the effective implementation of a waste management strategy.

3.7.3 Price, resource efficiency and environmental performance

Due to the recent escalation in electricity tariffs a majority of firms sampled in this study, have or are, currently in the process implementing effective demand-side strategies to reduce energy consumption. The acute escalation in a fundamental input such as energy has brought about increased awareness amongst firms and in particular top management in regard to resource efficiency. However, more can be achieved by increasing awareness of the salient interplay between resource productivity, competitiveness and sustainability. Firm behaviour in this context with reference to energy price sensitivity provides tangible evidence that pro-environmental firm behaviour can inadvertently be driven by market and/or state facilitated economic interventions. From the survey, a majority of firms stated that their environmental strategic approach was guided by the existing market and short term costs/benefits (see figure 3-16).

Figure 3-16 Firm's environmental behaviour motivated by markets and short term cost/benefits



3.7.4 Waste management services sector

A further key finding concerns the significant potential of the waste services sector. The current status quo comprises of a monopoly of a few waste service providers which dominate the waste services economy in Durban. A significant number of firms across economic sectors indicated that service provision was poor and inadequate, specifically regarding the lack of multiple and suitable hazardous waste landfills. Firms expressed reservation that hazardous waste had to be transported to Johannesburg's Holfontein site. The recent closure of Bulbul waste landfill site in South Durban has resulted in congestion at the remaining Shongweni waste landfill site controlled by Enviroserv. The non-incineration policy in KwaZulu-Natal has also come under criticism.

Market inefficiencies present opportunities that have the potential to be realised. However, waste entrepreneurs argue that the inability in accessing dedicated state funds (IDC green jobs fund); continue to curtail the development of the secondary resources economy to its full potential. This being said however, there is a significant potential for the development of waste sorting and processing facilities in the region.

Waste service providers have not taken a pro-active approach concerning facilitating by-product exchange. Nor have waste service providers been driving cleaner production technologies, this as a result of increasing waste streams and waste management being core business interest. A general trend of increasing costs associated with waste management due to increasing pressure on existing landfills, compounded by rising transportation costs was elicited from the findings. The increase in cost of waste management can have both positive and negative outcomes. For example, a leading waste services expert stated that rising costs would result in decreasing legal compliance. However, a chemicals firm surveyed stated that due to the economic recession of 2008, new avenues of waste reuse are being interrogated, opening up opportunities for further research and development.

Lastly, it was noted that security of supply of waste streams are essential for securing a waste stream for reuse. Here co-location of waste generators alongside waste re-processors is essential. This at the current conjecture is a significant impediment to the realisation of the secondary resources economy due to the failure of waste separation at source. Further factors such as firm location and level of social capital between firms in a given location have a significant amount of bearing on the matter. It was noted that it is extremely difficult to have an integrated waste services solution for an industrial complex comprising of multiple firms due to high levels of risk, a lack of trust, as well as divergent character industry, resulting in individual firm-level waste management solutions.

3.7.5 Material flow intelligence, education and awareness

The inaccessibility of education and information sharing regarding the secondary resources economy has been identified as one of the significant barriers in the secondary resources economy. Firms stated that there is a fundamental lack of communication between government and industry, as well as between and industry concerning available clean development mechanisms and internationally benchmarked best practice manufacturing. Firms expressed the desire for waste information sharing within industrial locations such as South Durban and beyond; more specifically the mapping and characterisation of waste streams, identifying generators and users to model potential by-product synergy networks. A typology of *open access industrial symbiosis intelligence*, collated, co-produced and shared on a *digital platform*.

Towards this, the establishment of a dedicated open access IS digital platform has the potential to shed greater clarity on legislation, best practice and benchmarking trends regarding waste management. In particular, information and knowledge sharing by large scale manufacturing firms within specific economic sectors regarding waste management have significant potential to set industry benchmarks for small and medium manufacturing firms to follow. This will have a cumulatively positive effect on the economic sector as a whole.

However, government must lead the way in this regard, by adequately incentivising cleaner production initiatives to shift the paradigm from mere compliance into a pro-active and innovative environmental management paradigm. Here the National Cleaner Production Centre (NCPC) has a central role to play; by building and fostering stronger networks with provincial and municipal government. In addition, there is a need for the NCPC to broaden it’s the mandate beyond focusing primarily on energy conservation to all facets of cleaner production. More fundamentally, however, this requires building capacity within all spheres of government regarding the relevance and potential of cleaner production.

Industries however have to be receptive for adopting pro-environmental policy positions, as the implementation of a new corporate ethos concerning waste management and waste reuse must essentially permeate from the boardroom to the factory floor. It was interesting to note that multinational parent or holding companies of firms surveyed were in many instances the agent of change towards a pro-environmental policy position. On the whole however, the survey revealed a serious dearth of professionally qualified environmental managers. On this basis, this study proposes the need for industry benchmarking and exposure of forums on international best practice regarding environmental and waste management. This can be facilitated by a dedicated guild or existing business forum.

3.8 Conclusion

The case study explores the opportunity to organise industrial symbiosis networks in the South Durban Basin (SDB) in eThekwini Municipality. The attitudes of firms towards waste management strategy is assessed through a firm-level survey. The key findings are triangulated with insights from the literature. In sum, the findings highlight the latent opportunity to improve industrial waste management practices in the SDB by applying industrial ecology tools and concepts, such as industrial symbiosis (IS).

The key findings from this case study include:

- Waste management survey of manufacturing firms in the SDB; eliciting key insights on firms' waste management strategies
- Identifying challenges associated with existing industrial waste management, recovery and recycling practices
- Identifying barriers and opportunities for organising IS networks
- Identifying *information sharing and knowledge production* (i.e. data collection and co-production of actionable resource flow intelligence) as one key leverage point

In line with the literature, this study suggests that IS networks in eThekwini Municipality can be traditionally organised through a local government funded coordination body. Currently in South Africa IS programmes are deliver at a regional level, e.g., the Western Cape Industrial Symbiosis (WISP). Although, WISP has achieved some success through its traditional top-down approach, the organisation of by-product synergy networks has been slow due to the analogue and static nature of its coordination activations. Hence to ensure faster and leaner identification and organisation of by-product synergy networks, an IS coordination programme should be devolved to a city level and framed within a broader circular economy approach – *circular city strategy*. A circular city strategy will allow for the integrated and co-evolutionary framing of urban symbiosis and industrial symbiosis patterns of organisation.

The transition to a *smart closed loop city*, hinges upon the broader mobilisation of *cyber-physical systems* (i.e. suite of internet-of-things of technologies), to track, monitor and analyse industrial and urban metabolism (material and energy flow data) in a more efficient and effective manner. Thereby correcting information asymmetries and connecting stakeholders and residual resources through digital a platform. Information pertaining to all facets of economic activity associated with industrial production and urban consumption, especially the conventionally disconnected aspects of industrial production such as cost externalisation through various waste streams, serves as the starting point. The onus however, remains on the state to develop the capacity (i.e. constructing a digital platform to generate actionable actionable resource flow intelligence) to define, quantify and unlock the economic potential of the secondary resources economy linked to the efficient management of natural resources and beneficiation of waste produced within the broader urban-industrial ecosystem.

The relevance of focusing on a firm level thus resides in reconfiguring the existing information asymmetry concerning proprietary waste management knowledge to one of an open access material flow intelligence-collaborative common, recognising the potential of waste as a resource through adopting an industrial ecological approach in firm-level strategic thinking. Hence, the research posits, that a traditional top-down coordination approach should be complimented with a technology enabled approach (i.e. digital platform) to effectively promote IS knowledge dissemination (i.e. international best practice and actionable resource flow intelligence) and create the space for self-organising collaborative and cooperative inter-firm networks to emerge. The objective of the platform is to collect and analyse material flow data, synthesise tacit local industry knowledge (e.g. material flow and process engineering knowledge) with international best practice to formulate rich and contextualised IS semantics. The platform will connect participating firms, waste management service providers and the municipality. To address the obstacle of propriety material stock and flow data, stakeholder participation (i.e. firms and private waste management service providers) may have to be incentivised, either through economic instruments (e.g. subsidies for closing material loops) or regulatory instruments (e.g. stricter internalisation of environmental costs associated with the disposal of industrial waste). The design and build of the abovementioned digital platform can be framed as a *virtual circular city experiment* espoused within a broader CE strategy.

The case study was presented to the KwaZulu-Natal Department of Economic Development and Tourism (KZN-DEDT), highlighting the opportunity for industrial symbiosis and the barriers and opportunities to inter-firm cooperation (i.e. by-product exchange). The research provided a strategic policy output by informing the development of the regional KZN Industrial Symbiosis

Programme (KISP). KISP is currently delivered through a collaboration with the Western Cape Industrial Symbiosis Programme and the Council for Scientific and Industrial Research (CSIR).

Chapter 4 – Urban Symbiosis Case Study

Chapter four presents the urban symbiosis case study, which explores the urban informal recycling sector analysing the instrumental role of waste pickers in recovering recyclable materials from post-consumer waste and supplying materials to the secondary resource economy. This chapter investigates how efficiency improvements targeting waste pickers can stimulate greater positive environmental impacts, create decent employment opportunities, and reduce waste management costs for municipalities. The findings inform the conceptualisation of a *virtual circular city experiment*, explored in chapter five.

4.1 Introduction

Rapid urbanisation is presenting massive challenges for municipal authorities in emerging economies, for example inadequate basic service delivery and infrastructure (UN, 2017). The Sustainable Development Goal 11, calls for *"better urban planning and management are needed to make the world's urban spaces more inclusive, safe, resilient and sustainable"* (UN, 2017). Herein, organising solid waste systems is one of the key challenges of the 21st century, and one of the major responsibilities of local governments around the world (UN-HABITAT, 2010). In short, *"the safe removal and management of solid waste represents one of the most vital urban environmental services"* (UN, 2017).

In low and middle-income countries, the informal recycling sector (e.g. waste pickers) is largely responsible for recovering recyclable materials from in municipal solid waste streams. One of the major planning challenges posed to municipal solid waste management (MSWM) authorities in South Africa is how to integrate the informal recycling and the formal waste management sector. To advance a robust circular economy agenda in cities in middle-income developing countries, it is imperative to conduct further applied research to fully understand the value of the informal recycling sector and the critical role of waste pickers therein. For the purposes of this case study, the term *"waste pickers"* is defined as people that *"through their labour are recycling items cast aside by others, and are also revivifying dead commodities and recycling the value inherent within them"* (Samson, 2010b). Waste pickers provide a low cost and labour-intensive solution to the weakest link in the product value chain, i.e. recovering recyclable materials after final disposal by consumers. Waste picker communities will have a critical role to play in transitioning towards a future-proof circular city model.

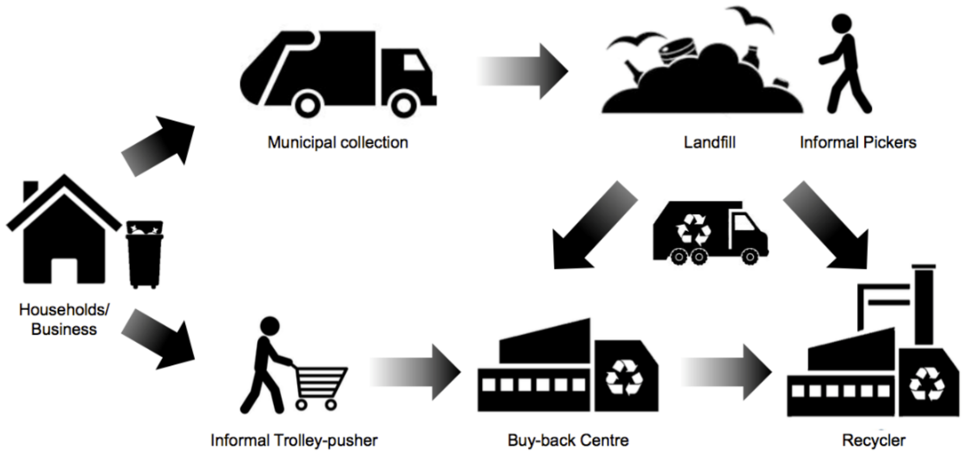
In South Africa, it is estimated that 70-90% of recyclable post-consumer packaging is recovered by informal waste picker networks (Godfrey, 2015). As South African municipalities strive to implement more sustainable and modernised waste management systems, very little is known about the status of waste pickers in cities (Samson, 2008). A recent study by Godfrey et al. estimates that waste pickers have *"saved South African municipalities between R309.2 – R748.8 million in landfill airspace (in 2014), at little to no cost, by diverting recyclables away from landfill, at ± 16-24 tonnes/picker/annum"* (Godfrey et al., 2016). From industrial ecology perspective, as discussed in chapter three, waste pickers are considered to be *primary looping agents acting in informal urban symbiosis networks* in cooperation with waste collectors and intermediaries (e.g. buy-back centres), in doing so closing material loops by diverting dry recyclable materials from urban and commercial waste streams to secondary material markets (e.g. plastic, paper and metal reprocessing industries).

Chapter four examines the position of waste pickers in the secondary resources economy of recycling in a small town and major metropolitan context in the province of KwaZulu-Natal (KZN). Through a rapid qualitative assessment, the case study investigates the daily occupation of waste pickers, their livelihood profile, their link to the broader economy, as well as the perceptions of relevant government and non-governmental organisations. From the key findings, *leverage points* are identified, for the purpose of envisioning technology enabled solutions (i.e. cyber-physical-social-systems) to augment the role of waste pickers in cultivating robust circular economy patterns at a city level in South Africa.

4.2 Background

Millions of waste pickers in developing and developed countries depend on recovering recyclable materials from urban waste streams for their livelihoods (Blaauw and Pretorius, 2007). Albeit under-reported and under-stated, waste pickers play an indispensable role in the recovery of recyclable post-consumer waste. There is an emerging opportunity to augment their position within the secondary resources economy as greater attention is directed towards developing institutional mechanisms in the transition to a circular economy. Hence, this case study is premised on the notion that waste pickers are primary looping agents in recovering recyclable materials from urban post-consumer waste streams and increasing the supply of recyclates in the secondary resources economy.

Figure 4-1 Resource recovery and recycling value chain (Godfrey, 2016)



Informal economies exist all over the world, and are often unorganised, unregistered activities that are not necessarily illegal but are unregulated (Rogerson, 2007); as can be observed with waste pickers who are a part of this sector. The notion of *"informal recycling"* refers to the multiple recycling activities conducted by unregistered, unregulated small businesses, groups or individuals not recognised by the formal waste management authorities as being a part of waste management system (Scheinberg et al., 2011). Stigma attached to the informal recycling sector overall, particularly with waste pickers who are associated with the refuse they deal with, makes it difficult to secure decent livelihoods (Samson, 2009).

A United Nations (UN) study conservatively estimates that the informal sector is responsible for recovering approximately 35% of recycled materials in cities in low and middle-income countries, making a huge contribution to municipal waste management (UN-HABITAT, 2010). The majority of informal recycling in developing countries does not represent an activity whose underlying purpose is related to ecological advances or a service of removal, but rather is an economic activity, involving the recovery and sorting of materials, upgrading, adding value and trading them back to the formal industrial sector – an act of recycling (Scheinberg and Mol, 2010). Studies indicate that in developing economies it is often counterproductive financially to establish new formal waste recycling systems without integrating informal systems that are already in existence (Wilson et al., 2006).

Lessons learned from countries around the world, such as Brazil and India, demonstrate that integrating the thousands of marginalised waste pickers' work has the potential to enhance their position within the secondary resources economy both as individuals and collectives (e.g. co-operatives). South African government agencies define decent work as: *"opportunities for women and men to obtain decent and productive work in conditions of freedom, equity, security and human dignity"* (DEDT, 2011). The global shift towards mitigating against climate change and the associated growth of the environmental goods and services sector presents an opportunity to create decent jobs for waste pickers by improving working conditions and enhancing efficiency and productivity for the informal recycling sector as a whole.

Despite the health and social problems linked to informal recycling, it provides important economic benefits for marginalised individuals and social groups (Nzeadibe, 2009). As informal recycling activities are set to continue for the foreseeable future, a focus should be placed on mitigating the environmental and health impact generated by them. Furthermore, building on waste pickers' practices and tacit experience while working to improve efficiency and the living and working conditions, as opposed to forbidding and stigmatising their activities. There is potential for mutual benefits to be gained between formal and informal waste management systems if support is given to the informal recycling sector to increase the efficiency of waste pickers (Medina, 2005).

There is an opportunity for local governments to build on existing informal recycling systems, to increase recycling rates and subvert the landfilling of inherently useful materials. Some of the major benefits of recycling are positive environmental effects (e.g. reduce reliance on waste disposal, reduce pollution associated with disposal) and economic benefits (e.g. savings on raw materials, extensive local job creation, contribution to national economies) (UN-HABITAT, 2010). Formal sector recycling sector costs around €30 per ton, while informal activities range from less than €2 per ton for dump recycling to a high of €31 for transfer station extraction (Scheinberg et al., 2011). Listed below are suggested strategies and tactics for municipal governments adapted from lessons learned from international best practices (Gerdes and Gunsilius, 2010):

- *"Create a clear legal and policy framework for informal recycling sector integration*
- *Constitute boards or forums with equal representation of waste pickers, traders and government officials*
- *Register all waste pickers and itinerant buyers and find ways to provide contributory social security*
- *Recognise and provide incentives for the informal recycling sector through excise, tax and other concessions*
- *Favour informal waste organisations in the contracting process*

  - *Reserve waste collection and small-scale processing for small and medium informal waste collection enterprises*
  - *Reserve land in development plans for decentralized processing of organic wastes*
  - *Reserve space for recycling sheds, material recovery facilities, storage of recyclables, intermediate processing*
- *Provide technical support services in upgrading technology and industrial processes"*

4.2.1 Integrating waste pickers in South Africa

The National Waste Management Strategy (NWMS) released in 2011 by the Department of Environmental Affairs (DEA) states that one of the goals for waste management is to increase the contribution of the secondary resource economy (inclusive of the informal recycling sector) to the green economy:

> *The objectives of this goal are to stimulate job creation and broaden participation by SMEs and marginalised communities in the waste sector. These objectives include creating decent work through formalising the role of waste pickers and expanding the role of SMEs and cooperatives in waste management. New jobs will also be created by investing in recycling infrastructure to facilitate re-use, recycling and recovery (DEA, 2011b).*

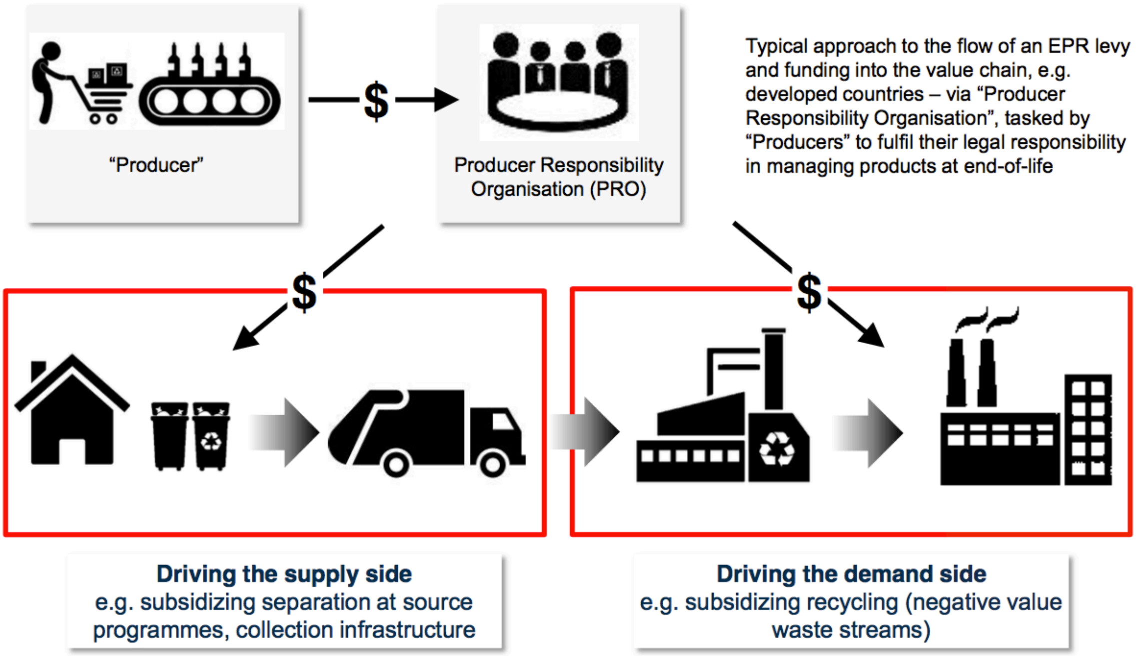
However, recent evidence suggests that the cooperative and small and medium enterprises (SMEs) model for the formal organisation of waste picker networks has been ineffective in the context of South African municipalities (Godfrey et al., 2015). In this regard, the research estimated *"91.8% failure rate of waste and recycling co- operatives, the fourth highest rate amongst the 18 identified economic sectors"* (DTI, 2011). Waste picker co-operatives face a plethora of challenges, *"including lack of infrastructure, weak capability, and limited access to recyclables and markets, often resulting in co-operative members returning to informal picking"* (Godfrey et al., 2016). Furthermore, waste picker cooperatives are not integrated into MSWM systems and operate on the periphery (Godfrey, 2015). Due to the low level of skills of its member, the evolution of resilient recycling cooperatives necessitates long term support (e.g. incubation) from municipalities and the private sector (e.g. private waste management service providers and reprocessing industries) (Godfrey, 2015).

At a provincial level, KwaZulu-Natal Department of Environment and Tourism (KZN DEDT) has acknowledged the need to transform the province's economy to a green economy (DEDT, 2011). *"Waste management in urban centres and in rural areas is an area of need…waste collection and recycling present opportunities for income generation, inclusive of small scale electricity generation"* (DEDT, 2011). While this discusses the importance of addressing the waste sector, it does not take into account the position of waste pickers in the secondary resources economy, nor does it outline strategies to move towards integration of waste pickers in the formal economy. In its report entitled, *"Unlocking the KwaZulu-Natal Green Economy"*, little attention is paid to the informal recycling sector and its potential to generate *"green jobs"* for the reported thousands of waste pickers operating in KZN. Similarly, at a municipal level, there is little attention paid to the informal recycling sector. The eThekwini Municipal Integrated Waste Management Plan (2016-2021) does not deliver a strategic plan for the integration of waste pickers in MSWM systems.

4.2.1.1 Extended producer responsibility

Extended producer responsibility (EPR) is a policy tool employed in advanced economies to shift the responsibility of managing recyclable materials from government agencies (e.g. municipalities) to producers. In traditional EPR model, producer responsibility organisations (Bacudio et al.) undertake partial/full financial and operational responsibilities. According to the Organisation for Economic Co-operation and Development (OECD), EPR is defined as *"an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle"* (OECD, 2001 cited in Godfrey, 2016).

Figure 4-2 Producer responsibility organisation (Bacudio et al.) scheme (Godfrey, 2016)



In the case of South Africa, *"the Department of Environmental Affairs (DEA) has gazetted its intent to call for EPR in paper and packaging; waste electrical and electronic equipment (WEEE); and lighting – it already has EPR in place for waste tyres – through the development and implementation of Industry Waste Management Plans (IndWMP)"* (Godfrey et al., 2016). When designing EPR programmes for middle-income developing countries, like South Africa, it is imperative to consider the informal recycling sector and the role of waste pickers – still a largely marginalised community.

A PRO has the potential to compromise the role that the informal sector plays by formalising source separation and resource recovery activities, which are currently assumed by waste picker communities. Hence, poorly designed EPR schemes can negatively impact upon the livelihoods of thousands of informal waste pickers in South Africa. To date the informal recycling sector has not yet been sufficiently consulted in the design and implementation of EPR and the development of a circular economy in South Africa (Godfrey, 2016).

According to a recent study by Godfrey (2016), in terms of integration models, four scenarios emerged:

i. *"the informal sector is utilised in its current format, as a largely marginalised and unregulated community, recovering value at little to no cost to the value chain;*

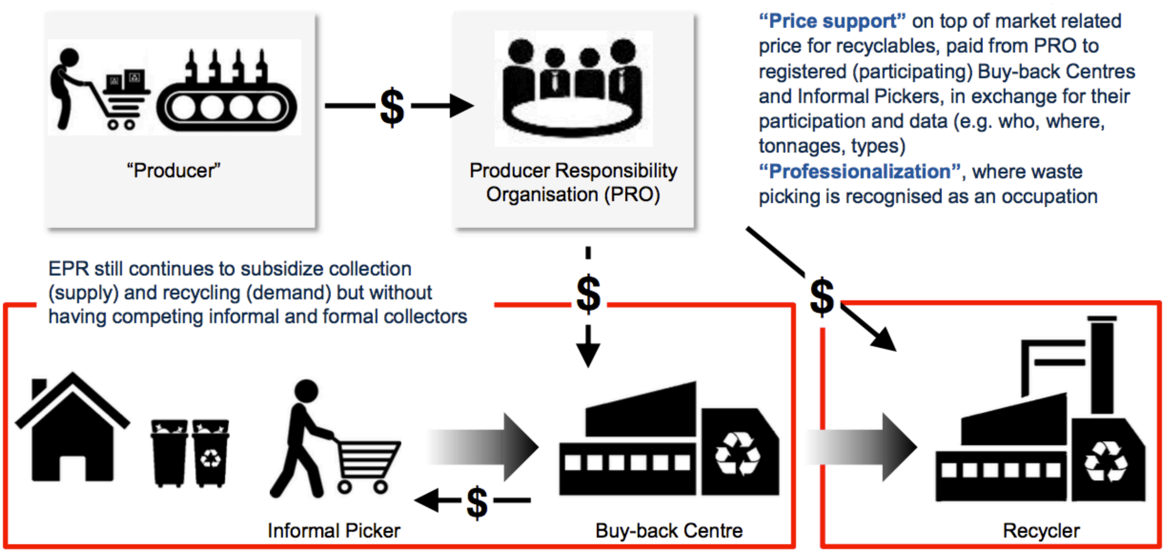
ii. *the informal sector is integrated into recycling programmes, with some level of control (regulation) and monitoring, and with increased support from business and industry*

iii. *government and business drive to formalise the informal sector through the establishment of co-operatives and SMEs;*

iv. *the formal waste and recycling sector drive a labour-intensive process, based on an employment model of absorbing the informal sector".* (Godfrey, 2016)

With regard to integrating the informal recycling sector a model emerging in Eastern Europe, is *price support*, where waste pickers continue to operate as individuals, but are eligible for access to increased income by belonging to an EPR scheme managed by a PRO (Godfrey, 2016).

Figure 4-3 Integration of waste pickers into EPR schemes (Godfrey, 2016)



4.3 Research Questions, Objectives and Aim

4.3.1 Research questions

- What is the role of waste pickers in the contemporary secondary resources economy?
- How to improve the efficiency and improve the livelihoods of waste pickers?

4.3.2 Objectives

- To gain a systemic understanding of the urban informal recycling sector
- To get a snapshot of the economic contribution of waste pickers to the secondary resource economy

4.3.3 Aim

- To envision the role of waste pickers in transitioning towards a future-proof circular economy
    - To identify leverage points for technological intervention, i.e., virtual circular city experimentation

4.4 Methodology

The case study adopts a mixed methods research approach employing quantitative and qualitative data to construct a snapshot of waste pickers livelihoods and contribution towards the secondary resources economy. A rapid quantitative assessment is conducted using the latest recycling data as reported by the packaging industries and national government agencies. The data is triangulated to provide an economic and environmental assessment of the approximated impact of the informal recycling sector in South Africa. To gain an understanding of recycling trends at a municipal level a proxy variable, gross domestic product (GDP), is extrapolated in relation national industry recycling datasets. This is discussed in more detail in section 4.6.1.

The rapid qualitative assessment of waste pickers presented in this study applies a conceptual and methodological framework based on the *sustainable livelihood approach*. The concept of sustainable livelihoods is an attempt to expand the traditional framework for poverty alleviation. More attention is now being paid to the processes which affect people's ability to make a living in a sustainable manner. Recyclable materials in this context are not only a commodity but represent a source of livelihoods for the millions of waste pickers around the world. Poor people move in and out of relative poverty as they respond to available opportunities, shocks and stresses, socio-economic and environmental, which they experience (Robert, 1995). For example, the economic crises in 1997 and 2008 both resulted in increased numbers of people joining the informal recycling and recovery sector (Sembiring and Nitivattananon, 2010). Waste pickers are one such example of individuals, households and in some cases, communities reacting to changing circumstances, pressures both external and internal to use their collection of assets and capabilities as their livelihood systems.

A sustainable livelihood is one that is defined as:

> *"…a livelihood is sustainable which can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation; and which contributes net benefits to other livelihoods at the local and global level and in the short and long term"* (Chambers et al., 1991).

In terms of informal recycling, this conceptual framework highlights the fact that while economic growth and development might be important to reduce poverty, the relationship between the two is dependent on whether the poor are capable of taking advantage of economic opportunities; accessing and participating formally in the secondary resources economy. Waste pickers need to be at the centre of the process of integration, as *primary looping agents* they have tacit knowledge about material stocks and flows. Input and participation from waste pickers themselves becomes essential in designing future policies and practices (Krantz, 2001). Finally, the sustainable livelihood approach looks at asset profiles of waste pickers in terms of access to capital: human, social (relationships with dealers, the government); physical (living and working conditions); and financial. The sustainable livelihood approach offers an important tool to assess the way in which waste pickers maintain and enhance their livelihoods.

A rapid qualitative assessment of the informal recycling sector in KwaZulu-Natal (KZN) was undertaken. The sample consisted of two municipal landfill sites (interviews conducted with landfill waste pickers) and one middle-income suburb (interviews conducted with street waste pickers). The research sites were purposively sampled to provide a basis for comparative analysis between two waste sites; one with a co-operative established onsite (Mooi River landfill in Mpofana Local Municipality), and one where waste pickers are operating individually (New England Road landfill in Msunduzi Local Municipality). The key contextual factors considered when selecting these sites include waste pickers': access to the landfill site; access to equipment for handling waste; recognition from authorities; and formation of co-operatives.

Qualitative research methods were used because this study focused on hard to quantify variables, including experiences, motivations, perceptions, interactions and processes. In-depth interviews[42] were conducted with 25 waste pickers. The sample was selected with an attempt to interview an equal number of men and women, but due to the population found on each site, this was not possible; in Mooi River there were predominantly women working on site. No other characteristics were taken into account when selecting the sample. An interview guide was developed and focused on understanding the nature of waste pickers work, livelihood profile, and the link to the broader economy. Semi-structured interviews were conducted with key informants representing relevant government, non-governmental organisations and key private sector actors (see table 4-1 and 4-2 below).

Table 4-1 Waste pickers interviewed

	Male	Female
Mooi River landfill, Mpofana Local Municipality	2	8
New England landfill, Msunduzi Local Municipality	5	5
eThekwini Metropolitan Municipality, Durban (Glenwood)	5	0
Subtotal	12	13
Total	25	

[42] See Appendix B for waste picker questionnaire.

Table 4-2 List of organisations represented by key informants interviewed

Mpofana Local Municipality
Msunduzi Local Municipality
South African Waste Picker Association (SAWPA)
Groundwork
Durban Solid Waste (DSW)
Central Waste
Private waste collectors/transporters x 2 (anonymous)

Interviews were conducted in isiZulu and English and averaged one hour in length. Interviews were digitally recorded and transcribed and translated into English. Participants all offered their informed consent (written) prior to interviews, and participant confidentiality was ensured to keep all participants anonymous. Pseudonyms are used in this report to protect respondents identifies. Respondents (waste pickers) were offered protective gloves and eyewear as an incentive to participate in the study.

The data was coded according to key concepts and themes to create a coding framework to make comparisons and organise the data. Participants' responses were labelled and translated into themes that were identified and then synthesised to carry out a thematic analysis. In addition, an in-depth literature review was conducted to complement and contextualise the findings of the study.

4.5 Limitations

One of the main challenges confronted during the study was the nature of the informal sector. As limited research, has been done on the informal recycling sector, few links have been established, and the research team found it difficult to gain trust of waste pickers, notably waste pickers who are foreign nationals. Time constraints were faced trying to conduct interviews; many waste pickers were unwilling to give up time in their working day to participate in the study. Location constraints were also faced at landfill sites and on the street. The majority of interviews were conducted on the landfill site amidst trucks, compactors, and other distractions making it difficult to conduct interviews.

The sample size is limited to two landfill sites (Mpofana Local Municipality and Msunduzi Local Municipality) and one urban area (eThekwini Municipality), which imposes limitations on the sample size. Thus, to support the primary research, extensive secondary research was conducted to triangulate the primary data and allow for informed extrapolations about waste pickers in South Africa.

In regard to the quantitative assessment, there is limited data on the contribution of waste pickers to the secondary resources economy. Hence, based on the literature and available datasets (e.g. national recycling trends) assumptions have to be made in order to construct a model depicting the economic and environmental contribution of the informal recycling sector. Furthermore, a proxy indicator, gross domestic product (GDP), is applied to infer recycling trends at a municipal scale. The integration of proxy indicators and assumptions embeds inherent uncertainty in the quantitative assessment.

4.6 Findings

4.6.1 Rapid quantitative assessment

The rapid quantitative assessment provides a snapshot of the environmental and economic impact the informal recycling sector in South Africa, with a focus on the most popular recyclable fractions among waste pickers, i.e. post-consumer paper (including cardboard) and plastics. The quantitative assessment is underpinned by a monetary, mass flow and CO_2eq[43] (global warming potential) metrics. The secondary data is collated and aggregated as reported by industry associations (i.e. PROs). Municipal authorities traditionally have very weak data regarding recycling trends and the operations of informal recycling networks in areas under their jurisdiction. Chapter two provided an assessment of eThekwini Municipality's recent integrated waste management plan, underscoring the lack of reliable data regarding urban recycling trends and the contribution of waste pickers to the secondary resources economy.

4.6.1.1 Economic impact

Figure 4-4 and 4-5 illustrate the potential market value of recyclable plastic and paper in South Africa. Approximately 1 1179 000 tonnes of plastic material fractions are available for recovery from urban and industrial waste streams, with an estimated market value of ZAR 3,6 billion. In regard to paper, there is approximately 557 000 tonnes available for recovery, with an estimated market value of ZAR 400 million. Waste pickers are estimated to source at least 70-90% of recycled packaging waste (Godfrey, 2015). Under the conservative assumption, i.e. 70%, then through their source separation, aggregation, human-powered transportation and transfer services,

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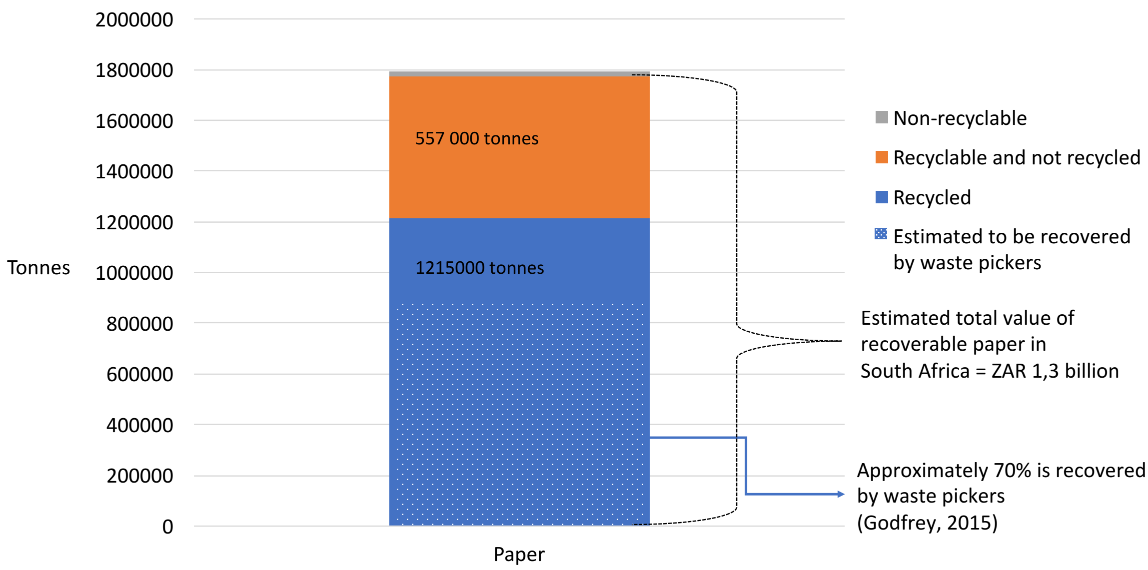
[43] CO_2eq is the globally accepted measurement for describing global warming potential (GWP). GWP was developed to allow comparisons of the global impacts of different greenhouse gases, e.g. carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The US EPA (2017) states, *"it is a measure of how much energy the emissions of 1 tonne of a gas will absorb over a given period of time, relative to the emissions of 1 ton of CO_2"*, furthermore, "*GWPs provide a common unit of measurement, which allows analysts to add up emissions estimates of different gases (e.g., to compile a national GHG inventory), and allows policymakers to compare emissions reduction opportunities across sectors and gases"*.

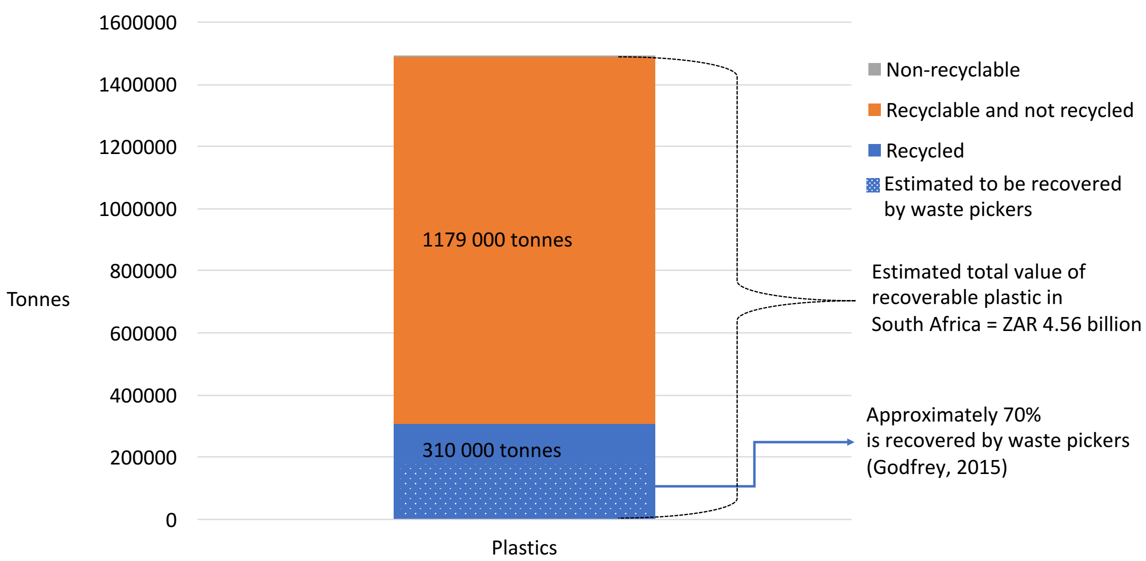
waste pickers create ZAR 630 million (850 500 tonnes) worth of recycled paper and ZAR 672 million (825 300 tonnes) worth of recycled plastics.

Figure 4-4 Paper recycling profile in South Africa



*Source: Data adapted from Paper Recycling Association dataset of South Africa (PRASA, 2015) cited in Waste Economy 2017 Market Intelligence Report (GreenCape, 2017), https://www.green-cape.co.za/assets/Uploads/GreenCape-Waste-MIR-2017-electronic-FINAL-v2.pdf

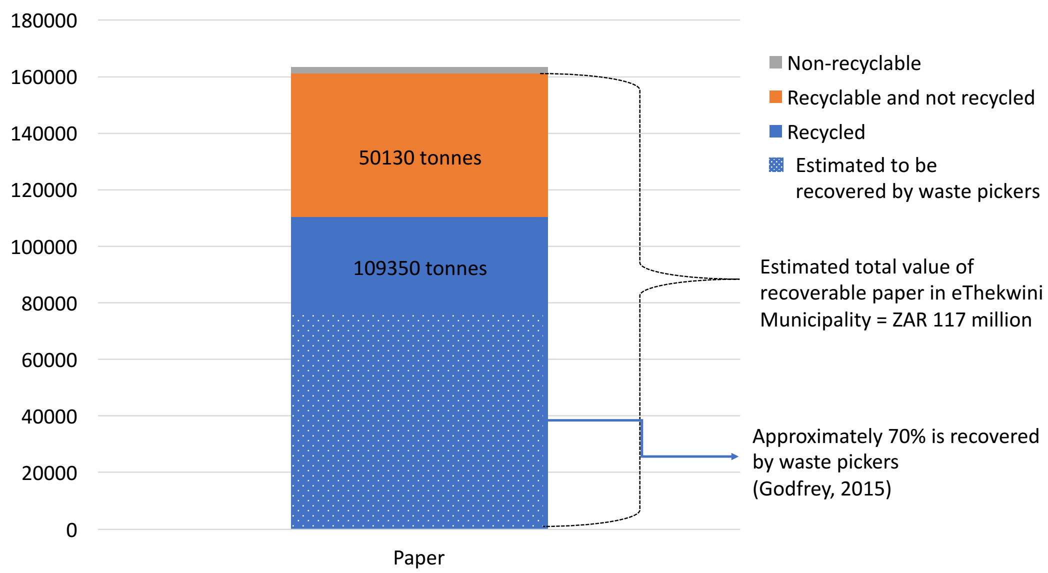
Figure 4-5 Plastic recycling profile in South Africa



*Source: Data adapted from Plastics Industry Associations datasets cited in Waste Economy 2017 Market Intelligence Report (GreenCape, 2017), https://www.green-cape.co.za/assets/Uploads/GreenCape-Waste-MIR-2017-electronic-FINAL-v2.pdf

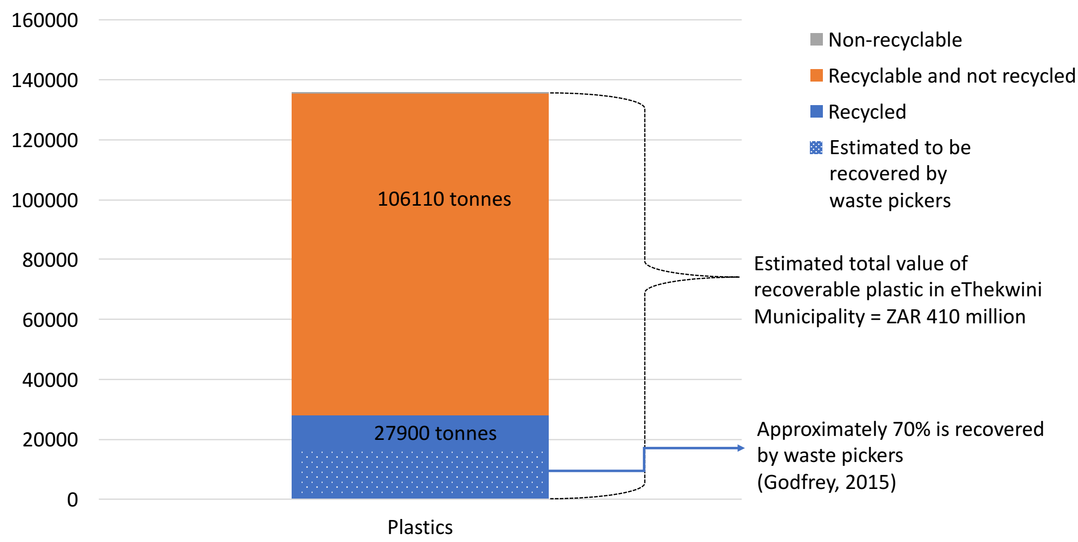
Due to the lack of reliable local government data on recycling trends in the municipality, gross domestic product (GDP) is adopted as a proxy variable in relation to national recycling trends (as reported by industry associations) to approximate plastic and paper recycling mass flows. The municipality's GDP compromises 57,1% of the regional GDP (KwaZulu-Natal) and 9,1% of nationally (eThekwini Municipality, 2016b). The ratio of eThekwini Municipality GDP to national GDP is extrapolated to approximate plastic and paper recycling trends at a municipal scale. Figure 4-6 and 4-7 depict the plastics and paper recycling market in eThekwini Municipality.

Figure 4-6 Paper recycling profile of eThekwini Municipality using GDP as a proxy variable



*Source: Proxy data adapted from Paper Recycling Association dataset of South Africa (PRASA, 2015) cited in Waste Economy 2017 Market Intelligence Report (GreenCape, 2017), https://www.green-cape.co.za/assets/Uploads/GreenCape-Waste-MIR-2017-electronic-FINAL-v2.pdf

Figure 4-7 Plastics recycling profile (proxy) of eThekwini Municipality



*Source: Proxy data adapted from Plastics Industry Associations of South Africa (PRASA, 2015) cited in Waste Economy 2017 Market Intelligence Report (GreenCape, 2017), https://www.green-cape.co.za/assets/Uploads/GreenCape-Waste-MIR-2017-electronic-FINAL-v2.pdf

There is an opportunity to improve paper recycling in eThekwini Municipality by approximately 50 130 tonnes, i.e. 31% of recyclable of paper that is not recovered. In terms of plastics, there is an opportunity to improve recycling by approximately 106110 tonnes, i.e. 79% of recyclable plastics that is not recovered. Furthermore, there is an opportunity to improve the efficiency of the existing proportion of recyclable materials estimated to be recovered by waste pickers in the municipality, i.e. 76 545 tonnes of paper and 19 530 tonnes of plastics (approximations derived from figures 4-6 and 4-7). Currently, waste pickers work under challenging conditions without access to adequate infrastructure and equipment. Also, there is an opportunity to increase the efficiency of waste collection from informal kerbside collection points and traditional buy-back-centres.

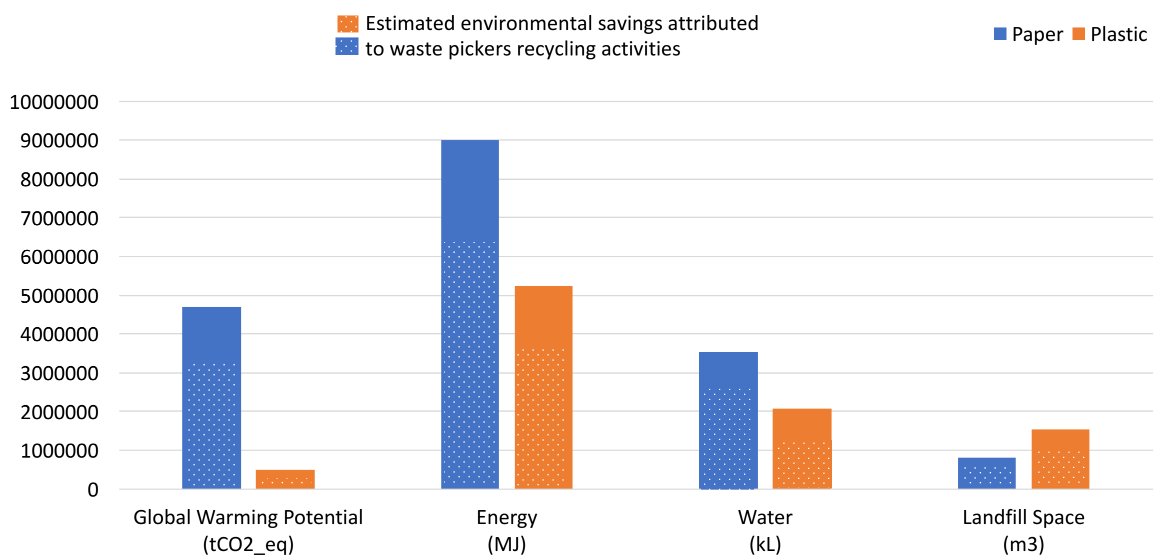
4.6.1.2 Environmental impact

Waste pickers as primary looping agents are responsible for the most fundamental activity in the recycling value chain, which is separation at source, processing, aggregation, manual transportation and transfer of materials into the formal logistics and processing phase. By diverting waste from landfill, we can attribute approximate environmental savings to this primary resource recovery activity assuming that the recovered materials are recycled and re-looped into manufacturing cycles. If we apply the above-mentioned assumption, that waste pickers are responsible for 70% of reclaimed paper and plastic, then they are proportionally responsible for the attributed environmental savings. Figure 4-8 depicts the environmental savings of paper and plastic recycling activities in South Africa, in turn highlighting the likely contribution of waste pickers. The United States Environmental Protection Agency (US EPA) Waste Reduction Model (WARM) was utilised to calculate the environmental savings. WARM adopts a life cycle analysis (LCA) approach to construct emissions estimates from waste management practices.

WARM is a scenario based LCA tool. It compares the overall environmental savings between two scenarios. In this instance, the baseline scenario is disposal in a permitted landfill, while the alternative is recycling. WARM used a cradle to grave approach for all material and energy inputs in the supply chain. The result shows the environmental savings on the current recycling performance of paper and plastic in South Africa. According to the Godfrey (2015), waste pickers are directly and indirectly responsible for sourcing 70% - 90% of this material, and therefore their impact at the conservative level of 70% is also highlighted in Figure 4-8.

According to WARM (version 14 (released in March 2016), from a national perspective (in South Africa) and in terms of diverting paper from landfill, waste pickers are potentially responsible for avoiding 3 290 877 t CO_2_eq emissions (GWP) in total. If we assume that there are 90 000 active waste pickers country wide, then each waste picker is responsible for avoiding 36.56 t CO_2_eq (GWP) emissions due to the diversion of paper from landfill. Similarly, for the diversion of plastics from landfill, waste pickers are potentially responsible for avoiding 357 953 t CO_2_eq (GWP) emissions in total, at 3.97 t CO_2_eq (GWP) emissions per waste picker. These are conservative estimates, and it is likely that the environmental savings accrued by waste picker recycling activities is higher, especially under the scenario where it is assumed that 90% of recycled packaging material is source by waste pickers (Godfrey et al., 2016).

Figure 4-8 Environmental savings from paper and plastic recycling in South Africa



*Source: Environmental savings calculated using the United States Environmental Protection Agency (US EPA) Waste Reduction Model – Version 14, https://www.epa.gov/warm/versions-waste-reduction-model-warm#WARM Tool V14

4.6.2 Rapid qualitative assessment

Municipal solid waste is generated by residential and commercial actors, then it is sorted, aggregated, transferred and collected by various actors in the recycling value chain: waste pickers, municipal workers, private waste collectors and intermediaries. From there, materials are processed and treated in a variety of manners by re-processors. Street waste pickers sort, process, aggregate and re-sell materials to private sector *intermediaries* (middlemen), namely; buy-back centres, waste collectors and scrap yards. Prices are fixed by the intermediaries and fluctuate based on demand-driven forces. Prices are then marked up by and intermediaries re-sell the materials to re-processors in various industries (e.g. Nampak, Mondi, Sappi).

Apart from its traditional function a landfill site also acts as a recovery site for post-consumer recyclable materials; where discarded materials from the formal economy are recovered by waste pickers, a space where the informal recycling sectors forges critical linkages with the formal secondary resource economy. Hence, the other stream of informal recycling starts with waste transported directly to the landfill site, where waste pickers onsite: a) sort, process and re-sell materials acting in their individual capacity; b) sort, process and re-sell materials as part of co-operatives with equipment (e.g. balers); c) re-use materials for themselves, families, or communities; or, d) sort, re-use and re-produce new goods (e.g. crafts, building materials). Some materials are reported to be collected by municipal workers as well which are then sold to intermediaries re-looping into the formal secondary resources economy.

The key findings based on waste picker and key informant interviews. Presented below are brief profiles of the two landfill sites (in KZN) chosen for the study. The third site (i.e. kerbside source separation by street waste pickers) is a middle-income urban area, Glenwood in eThekwini Municipality. A brief profile on eThekwini Municipality is omitted in chapter three as a detailed overview of waste management trends in the municipality is provided in chapter two, see section 2.3.3.

Some basic facts about New England Road Landfill (Msunduzi Local Municipality, KwaZulu-Natal):

- The Msunduzi Municipality has a population of approximately 618,536. With a high unemployment rate, 33%, and low economic growth rate 1.12% (2001-2011) (STATSSA, 2017). Pietermaritzburg, the capital city of KwaZulu-Natal (KZN), is located in Msunduzi Municipality.
- The landfill was created in 1956. It is located next to the Msunduzi River directly across from Sobantu, Pietermaritzburg's oldest African township. According to the landfill manager, approximately 300 to 400 tons of waste is brought in per day. The figures from the weighbridge records are deemed unreliable to determine how many tons are brought in and out of the landfill.
- Due to a lack of funds, external audits have found a number of problems such as the collapse of the leachate collection system; problems with gas capture and flaring system; inadequate cover material; insufficient machinery and vehicles; inadequate monitoring of air quality; and breaks in the fence and burglary (Samson, 2008).
- There is a tender that circulated for a contractor to establish a Materials Recovery Facility (MRF) at the entrance of the landfill to manage the influx of waste and promote recycling initiatives.
- Currently waste pickers are legally not allowed to salvage on the landfill, however they are *tolerated*. There are a reported 300-800 waste pickers on site per day.

Some basic facts about the Mooi River Landfill (Mpofana Local Municipality, KZN)

- The population of Mpofana Local Municipality is 38 103. With a high rate of unemployment, 23.9%, and a low economic growth rate, 0.34%. The main industry in the area is agriculture, with a diverse range of agricultural products being produced. Estimated that only 48% of the population have access to municipal solid waste management services (STATSSA, 2017).
- The landfill is located an African township[44]. A five-year rehabilitation programme is currently in process to expand the area of operation at the landfill.
- There are a reported 50-100 waste pickers on site per day.

[44] The term *township* in the context of South Africa, is referred to *"the underdeveloped, usually (but not only) urban, residential areas that during Apartheid were reserved for non-white (Africans, Coloureds and Indians) who lived near or worked in areas designated 'white only'"* (Pernegger and Godehart, 2007).

- A co-operative called the Mooi River Waste pickers was formed in 2005. The co-operative was issued a permit from the municipality to give waste pickers access to work onsite forming part of an outreach initiative, according to the landfill manager.

4.6.2.1 Socioeconomic profile of waste pickers

The waste pickers interviewed range in age from eighteen years old to their late fifties. Of the twenty-five who participated, thirteen (52%) were black females, and twelve were (48%) black males. All of the respondents were born in South Africa; several were migrants from rural areas and other provinces (Gauteng and the Eastern Cape). As noted in previous studies, waste picking is an occupation that migrants from rural areas are able to enter fairly easily (Hayami et al., 2006, Schenck and Blaauw, 2011). There were a number of foreign nationals working on the landfill sites, and there is a high prevalence of foreigners among street waste pickers, but none were interviewed in this study.

The majority of waste pickers (44%) are between the ages of 30-39, and 32% were over the age of 50. Only one respondent was below the age of 20. The age of street waste pickers was generally younger than those who work on the landfill. The significant proportion of older people working at the landfill could be due to the fact that employment opportunities for people above 40 years of age are scarce, especially if they have never worked in the formal economy, as found in a previous study on waste pickers in South Africa (Schenck and Blaauw, 2011). From observation, the majority of waste pickers on landfill sites were in their mid to late 30s. The data reveals the majorities of respondents (60%) have gone to high school but have not matriculated. There is a wide range of education levels from no formal schooling, to completed tertiary education. One respondent has completed a diploma in accounting, but is working as a waste picker to pay off his debts in order to obtain his certificate. Others have never received a formal education. This reveals the diverse background of waste pickers.

Three of the respondents were married, the rest reported to be single. All of the waste pickers working on the landfill sites collect and sell recyclable materials to support themselves and their families. However, most of the street waste pickers reported to be disconnected from their families, living on their own, or living on the streets. On the landfill sites, 58% of waste pickers are head of household, living with approximately four to five people. The respondents support four dependents on average, primarily their children and relatives living in their household. Three of the street waste pickers live on their own without shelter, residing on the street closest to waste collection points to maximize their earnings. This suggests that waste pickers working on the landfill earn a more stable income enabling them to support their dependents.

Respondents were asked what their employment status was. Twelve respondents (48%) reported to be *employed* on the landfill sites. Six waste pickers (24%) reported to be *self-employed*, and seven (28%) reported to be *unemployed*. The majority of waste pickers reporting unemployment are working on the street collecting recyclables. This is an interesting finding, indicating that recycling is considered a job, particularly on landfill sites. The majority of respondents reporting to be employed form part of the co-operative in Mooi River giving waste pickers a sense of responsibility and accountability to the co-operative as a form of employment. The establishment of the co-operative has changed waste pickers' self-image of an unemployed person to that of a productive worker. Respondents work on average five days per week and eight hours per day.

Only a few of the respondents reported having had previous employment. After being retrenched, these respondents heard via word of mouth that there were opportunities to make a living working on a landfill or on the streets recycling waste. Two respondents came to New England Road landfill looking for work after coming out of jail. They came to work at the landfill primarily to be involved in recycling to prevent themselves from engaging in illegal activities. The remainder of participants had no previous work experience and entered the waste sector through word of mouth from friends, neighbours, and families.

> *"I've found most of them [waste pickers] are females and heads of household, and can't find formal employment; out of desperation they are here just to maintain their households. We've got young men here purely because they can't find work or because they find this is an easy job for them because the waste comes to them as a free resource".*
>
> \- New England Road landfill manager

Table 4-3 Socioeconomic profile of waste pickers

Age range	18-59 years' old
Gender	52% Female
Education	60% high school (incomplete)
Household composition	58% head of household, average 4-5 people per household
Average days/hours per week	5 days per week /8 hours per day
Mean income	Female ZAR 1414
	Male ZAR 1894

The income earned by landfill and street waste pickers ranged from ZAR 1000 per month to ZAR 3,600 per month. The mean income for male waste pickers was ZAR 1894 per month. The mean income of female waste pickers in the sample was ZAR 1414 per month. This is well below the national minimum wage, ZAR 3500 per month (R20 per hour/40-hour work week)[45]. The amount of money earned per month was reported to vary according to price fluctuations, most often dictated by the *middleman*, e.g. buy-back centres such as Central Waste, Reclamation, and other materials recovery facilities. Prices per kilogram (kg) for materials sold reported from respondents were: PET plastic (ZAR 2 per kg); HD plastic (ZAR 1.55 per kg); colour plastic (ZAR 1.30 per kg); paper and cardboard (ZAR 0.55 – ZAR 1 per kg).

The earnings reported in this study are notably higher than other studies. Benson and Vanqa-Mgijima reported waste pickers in Cape Town earn ZAR 60 to ZAR 70 per day (Benson and Vanqa-Mgijima, 2010). A previous study done in Durban reported street waste picker earnings ranging from ZAR 30 to ZAR 60 per day, however it was noticed, and is corroborated in this study that landfill workers earn more per day (McLean, 2000). This differential could be attributed to the greater access to a wider range of recyclables, or access to transport to sell collected goods for waste pickers based on a landfill site.

[45] Source: http://nationalminimumwage.co.za/

The majority of respondents report no outside income other than that earned from recycling. One respondent runs a tuck-shop in the Mooi River area. Several waste pickers receive child support grants, and members of their household receive an old age pension, which supplements household income. The KZN representative of SAWPA stated that there is a huge opportunity to increase waste pickers' income, based on technical advice and expertise, as well as learning from international experiences. The majority of waste pickers are people who were unable to find a job, and recycling is recognised as a viable form of employment to support themselves and their families.

4.6.2.2 Gender

All of the street waste pickers were male. From observation, more women were found working at the landfill sites, which, consistent with previous studies, could be due to physical constraints, trolleys are too heavy and women are too vulnerable on the street (Chvatal, 2010, Samson, 2008 #3). There appears to be a gendered division of labour. The female street waste pickers observed were seen only handling cardboard. Often it was reported that women collect cardboard, soft plastic and other recyclables that are light in weight due to physical and resource constraints (acquiring trolleys, transport, etc.). Men are noted to collect steel, metal, and copper which is much heavier and more difficult to handle.

An income differential was noted between male and female waste pickers, with female waste pickers earning less than males. This could be due to the fact that women do not collect heavier materials such as metal, and therefore earn less than men who are able to reclaim these materials. Metal, copper and steel, for example are worth more value per kilogram than plastics and cardboard. However, these figures should be used with caution, as the sample is small and not representative of a general population.

Being a woman makes one particularly vulnerable, especially in such working conditions. On the other hand, one respondent commented that being a woman could be an advantage, as women do not often engage in high-risk taking behaviour: While there seems to be a gendered division of labour, and women are more vulnerable than men working on landfill sites, there is a general feeling that the working conditions are not fit for women or men.

4.6.2.3 Health and safety issues

The conditions on the landfill site pose major health and safety risks to the waste pickers on a daily basis. The majority of participants do not possess adequate safety equipment to protect themselves, therefore increasing their exposure to health risks. There are no sanitary facilities (e.g. toilets, changing rooms) and limited access to water.

> *"This place is not safe at all. They throw all kinds of dirt here, dead dogs and waste from hospitals. So, it is not safe at all."*
>
> - Female waste picker, Mooi River landfill

Health problems waste pickers reported experiencing since handling and working with waste ranged from chemical exposure to car accidents. Some respondents have existing health conditions, and the environment of the landfill is not conducive to maintaining a healthy lifestyle. Respondents reported health problems such as tuberculosis, respiratory problems, headaches, needle pricks, car accident injuries, chemical exposure (burns) and food poisoning. Needle pricks were reported frequently. Almost half of the respondents reported finding dead animals at the landfill site. This is testament to the dangers of working on the landfill site and is particularly dangerous as dead animals are often carriers of disease.

> *"There are many dangers and risks. We get cut by bottles, spilled on by chemicals, we even eat food that could be poisonous, and so it's very dangerous".*
>
> - Male street waste picker, Glenwood, Durban

The majority of waste pickers do not own safety equipment to protect them while working. Many use clothes, or plastic bags found on site to cover their bodies, and scarves to cover their mouths. A few waste pickers own gumboots and gloves that they wear to work. Not only are there health risks associated with the physical handling of the waste. There are also frequent reports of injuries as a result of car and truck accidents. With hundreds of people onsite and no coordination between municipal workers and waste pickers, there have been instances of people going in front of compactors to prevent it from compacting waste which is vital to their income, endangering themselves in the process (this was observed at the New England Road landfill site). In addition, the lack of ordered pathways leads to accidents, with a high influx of waste pickers' onsite.

All waste pickers highlighted the need to improve their health and safety conditions in order to allow them to increase their productivity with improved working conditions. Health and safety is one of the key issues to be highlighted in elevating recycling to be able to be classified as *decent work*.

4.6.2.4 Economic and social issues

Many of the waste pickers at the landfill site in Mooi River have entered the field of informal recycling recently, whereas those in Pietermaritzburg have been working for as long as seven years in the sector. The average time spent working in the informal recycling sector among respondents is two and a half years. The majority of waste pickers walk to work ranging from two hours to 10 minutes. A few respondents take taxis to work. A typical day for landfill waste pickers begins at home, doing household chores, caring for children, and then traveling to work. One waste picker describes his work day as the following:

> *"I take 10 minutes from home to get here and we start at 8:30 a.m., but now its 8:00 a.m. because now its summer and we can walk. So, when I get here I start by cleaning, then I prepare the sacks to collect the waste, then I start collecting plastic from 8:30 a.m. to 1:00 p.m. collecting plastic, and then after that I collect plastic bottles and then when I am done, then from 2:00 p.m. to 4:30 p.m. I am working on the glass bottles".*
>
> \- Male waste picker, Mooi River landfill

Respondents interviewed in Mooi River are all part of a co-operative, Mpofana Waste pickers and work together to collect and sell recyclables. The co-operative currently has a membership fluctuating between ten and fifteen waste pickers. Each person is designated a task whether that is collecting a certain type of recyclable or working with the equipment. Collectively the co-operative recovers, sorts, and sells approximately 15 tons of plastic and paper and 10 tons of glass per month, earning on average ZAR 10 000 per month. Each member of the co-operative receives a salary of ZAR 50 per day.

The founder of the co-operative is in charge of organising transportation and selling recyclables. The co-operative only deals with plastic, paper, and glass due to reported conflicts onsite with other individual waste pickers collecting metals. Their biggest client is Central Waste, which they deliver to on a weekly basis. The co-operative is an example of a successful initiative to give waste pickers a stable income, and a collective voice which has increased their productivity. Once formed they were able to lobby Central Waste, their prime client, to donate a bailer for their use, increasing the co-operatives productivity, thereby increasing the materials supplied to Central Waste itself. Members of the co-operative contend that with more equipment, access to transport, and tighter security measures they would be able to recover double the number of recyclables than at present. The co-operative is currently in the process of creating a business model to lobby for more funding to support their work.

Figure 4-9 Waste picker profile - male

Waste picker profile: Sizwe*

Sizwe grew up in Mooi River, in a peri-urban area called Phumlasi, in close proximity to the landfill site which he currently works. Sizwe is in his late 20s. He studied at Mangosuthu University of Technology in Durban, where he completed a diploma in accounting. Due to outstanding fees, he has been unable to collect his certificate and therefore cannot apply for employment in his field. He has since been unemployed and relies on waste recycling for a livelihood. Sizwe refers to waste recycling as a full-time job, and is able to support his two children, as well as his parents who are unemployed. His aim is to work at the landfill until he is able to pay his debts and obtain his certificate. He earns R300 a week from waste recycling. His role involves collecting cardboard, plastic, soft plastics and glass bottles.

Sizwe is proud to be a waste picker not only because he can support his family, but he says he also saves the environment by recovering recyclable materials. He envisions waste pickers progressing very far as long as they can get the help that they need from the government. He suggests that the government should support them by providing equipment and creating the necessary infrastructure. In addition, he stated that government should also provide training workshops to educate waste pickers about recycling activities. Sizwe has become very passionate about what he does and hopes to start his own recycling business one day, contributing to the initiative of job creation, green economy development and working towards saving the environment.

*Pseudonym

At the New England Road landfill site, a typical working day is different, as each waste picker works individually to collect recyclables. In most cases waste pickers look for whatever they can find, and then put their findings aside, sort the materials, put them into a sack or trolley, and find middlemen on the premises to trade with. As noted in previous studies, waste pickers' work is on a *first come first serve basis*, whoever touches the waste first, owns it (McLean, 2000). Many waste pickers wait at the entrance of the landfill for trucks to arrive. When a truck is spotted, workers will run to touch it first, climb on the truck and ride it inside in the hopes of recycling the goods being brought in. Earnings of waste pickers at the New England landfill site fluctuate per day/per month, whereas Mooi River waste pickers receive a stable salary from the waste picker co-operative per day. In Pietermaritzburg, trucks are available at the landfill to rent onsite to transport recyclables to buy-back centres for between ZAR 100 and ZAR 120 per load.

Figure 4-10 Waste picker profile - female

Waste picker profile: Thandi*

Thandi is the mother of six children, living in Sinathing in Pietermaritzburg. She is a single parent and doesn't receive any government support (e.g. child support grant), except for remittances, which is usually sent to her by her son who has recently found employment. With only a primary school education she was unable obtain a formal job and has been unemployed for years. She heard about recycling from a friend as a source of income that could help her support her children. She joined the waste pickers at the New England Road landfill site and has been working there for five years. This work has provided financial support for her family. She can now support her children and send them to school.

Thandi conceals the fact that she is a waste picker from her neighbours due to the stigma attached to this kind of work, and the hurtful remarks they would make. She is also very concerned about her health in relation to the conditions of the landfill. Despite the health risks she will not stop working at the landfill because she has found a source of income for her family – this has provided her with a sort of employment that she can rely on. She earns approximately R1000 a month. The benefits are highly visible and she also admits that this job has provided her with knowledge about recycling and what to do with waste. Thandi strongly recommends that the government create initiatives that would assist in their medical needs, like regular check-ups to ensure that they are still in good health because they are working in unsafe conditions in which their health is compromised.

*Pseudonym

As previous studies have noted, recycling initiatives are largely industry-driven and what waste pickers collect is influenced by a variety of factors that are related to the broader political economy (Hallowes and Munnik, 2008). If there is a demand for products, then waste pickers will prioritize gathering them. Currently the respondents reported collecting: plastic (hard and soft) bottles, PET, cardboard, glass bottles, tin, copper, metal, aluminium, office paper, and newspaper.

Waste pickers also re-use materials found such as clothes, computers, and radios either for themselves or their families and communities. One respondent collects wood to make tables for his community. Another respondent collects bricks, wire and planks to sell to poor people, to give them building materials for housing structures. In addition, discarded foodstuffs are consumed when found by waste pickers: In New England Road landfill site, there are many tensions on site with municipal workers. Several respondents reported having had materials taken away from them by municipal workers who then sell the recyclables themselves to supplement their own income.

Street waste pickers operate under entirely different conditions. Their work starts around 4 a.m., in a selected area of the city, collecting recyclables before the municipal, kerbside collection crew from DSW come to collect the waste. Their work is highly unstable, and they face challenges from municipal workers and residents preventing their collection of recyclables. Furthermore, street waste pickers reported that they spend a lot of time manually transporting materials to buy-back-centres or waiting on the kerbside for private waste collector to purchase their materials. An interview with a private waste collector, highlighted that weighing materials and interacting with waste pickers by the kerbside is a very time-consuming activity, further impeded by traffic flows in busy urban areas. In addition, waste pickers are reported to purposively wet materials (e.g. cardboard) to increase the mass and thereby attract a higher price. In doing so they compromise the integrity of materials. This leads to protracted bargaining between street waste pickers and kerbside waste collectors as they offer a lower price for compromised materials. As depicted in figure 4-11 and 4-12, street waste pickers manually recover materials from municipal solid waste streams and transport materials with trolleys or by carrying loads baled materials.

Figure 4-11 Typical scene of a street waste picker transporting recyclable materials to a buy-back-centre in Johannesburg, South Africa

Figure 4-12 Typical scene of a street waste picker recovering recyclable materials generated by households in an affluent suburb in Durban, South Africa

Their materials are prone to weathering during the manual transportation and transfer (i.e. exchange of materials for cash with private collectors and buy-back-centres) phases of the value chain, for example as illustrated in figure 4-13, rainy conditions can compromise the integrity of paper and cardboard. In the scene captured below, street waste pickers can sometimes wait for hours (in inclement weather) for private waste collectors to arrive and purchase their materials. According to the literature, private waste collectors are reported to exploit waste pickers through volatile and unfair prices for recyclable materials, furthermore they are accused of misusing scales when weighing recyclable materials at informal kerbside collection points (Mkhize et al., 2014). Previous studies on waste pickers infer that waste pickers will sell their materials at the collection point in their closest proximity due to the logistical challenges of manually transporting baled materials long distances in urban environments (Ralfe, 2007 cited in Mkhize, 2014).

Figure 4-13 Street waste pickers in Glenwood (Durban) selling cardboard to a private collector through an informal kerbside collection scheme

The goods collected and sold by the waste pickers are sold at fixed prices as determined by the intermediary which they are sold to. Landfill waste pickers at both sites reported Central Waste as the most frequented buy-back centre to sell their goods. Central Waste appears to have a stronghold on the recycling industry in the area. When interviewed, one of the co-owners of Central Waste was unwilling to share financial reports but did comment that generally goods are bought from waste pickers, and then resold to industries with a 30% mark-up rate on the materials.

Central Waste was established in 1992. It currently employs 60 to 70 people, and receives waste from approximately 100 waste pickers per month. Central Waste then sorts and compacts the waste and serves as an agent for industries such as: Mondi, Nampak, and Sappi. Central Waste is also responsible for the kerbside recycling programme in Pietermaritzburg, which serves 16 neighbourhoods. Through this program, thousands of tons of recyclables are brought in each month. The programme was started by Mondi, an international paper and packaging group with a paper mill in Durban, partnering with Msunduzi municipality in 2009. Central Waste was contracted to collect, sort, process and re-sell all recyclables. Central Waste reports that the programme may not be sustainable due to the cost of running it, and the inadequate space at their facilities to process all materials brought in.

In eThekwini municipality, the Deputy Head of Strategic and New Development of Durban Solid Waste (DSW) described the value chain of recyclables with waste pickers at the bottom, forming the base of the industry. DSW estimates that 80-90 per cent of waste sold to registered buy-back centres is supplied waste pickers (Rogan, 2012). The DSW representative reported that there is a high demand for recyclables, and it has now become a highly competitive industry. DSW put in place a kerbside, recycling programme called the orange bag initiative. When the programme began, municipal workers found that most of the recyclables were taken by street waste pickers before the collection truck arrived. Tensions arose between street waste pickers and municipal workers. Currently DSW tolerates the activities of street waste pickers and does not interact with them on a formal level. DSW has started some initiatives in townships contracting entrepreneurs to collect waste from houses, which has been a success. DSW recognises that it is necessary to unify and organise waste pickers and educate them about recycling as well as build their capacity to become entrepreneurs, but does not engage with them at any level.

While some waste pickers reported feeling exploited by buy-back centres, there is a prevailing interdependence. Waste pickers feel as though they are not receiving fair compensation for the materials they supply to buy-back centres and private waste collectors. The Central Waste (buy-back-centre) representative acknowledged waste pickers as vital:

> *"I think they [waste pickers] are vital, I think they are very, very important. Two reasons: it's not an easy job, believe me, I know it's extremely difficult, and it's a form of collection of recyclables, [there is] no other way at this stage where you can collect recyclables".*
>
> \- Central Waste representative

Another important theme that emerged was the public's perception of waste pickers, as noted by the President of SAWPA.

> *"We also talk about social issues like changing people's attitudes about waste and waste picking, because when you are doing this kind of work, people also treat you like waste".*
>
> \- President of SAWPA

Repeated problems with the police and landfill security interfere with waste pickers' work, which is dependent on access to the landfill on a regular basis. While landfill workers appear to be tolerated onsite to do their work, street waste pickers are still facing major barriers to collecting recyclables:

"Sometimes we ask if we see them [residents], for like uncooked food and clothes, some will be very nice and give [it to] us, but some white people can say all kinds of things. They can be mean".

- Street waste picker, Glenwood

"Like maybe, I get something in the waste that I collect and then the police will see that and ask me where I got it. If I don't remember the place they will take that thing away from me".

- Street waste picker, Glenwood

A lack of formal recognition makes it difficult to conduct recycling activities, particularly on the street. Interruptions from residents and authorities cause a drastic drop in income for waste pickers.

4.6.2.5 Attitudes toward informal and formal recycling

"The formal waste recycling in South Africa exists because of informal waste recycling in South Africa, if there were no waste pickers on landfill sites or on the street, we wouldn't have a formal recycling as we have in South Africa".

- Waste Campaign Manager, GroundWork

The Waste Campaign Manager from the NGO GroundWork reports that waste pickers are an integral part of MSWM, and their role in the recycling sector forms an important contribution to recycling rates in South Africa. As seen in the previous section there are tensions between the formal and informal recycling sectors. While both municipal managers of the landfill sites acknowledged the importance of waste recycling, they both viewed waste pickers as a liability to their sites.

"It's very difficult for the municipality to get directly involved with the waste pickers simply because the permit does not allow them to be around. So as much as we understand their plight, it's dubious for us to engage with them because then we start to create expectations".

- New England Road landfill manager

This highlights the vague legislation around the position of waste pickers, and the fact that they are considered illegal on the landfill sites yet are "tolerated". This leaves very little bargaining power for waste pickers to secure a stable income through their work. While the manager at the landfill site in Pietermaritzburg tolerates waste pickers, he did emphasise the importance of their livelihoods for the greater aim of a circular economy:

> *"I think it's [informal waste recycling is] a huge contribution towards mitigating against climate change and so on, you know the benefits are definitely there. I mean recycling is not rocket science, we just need to get it going".*
>
> - New England Road landfill manager

The landfill manager commented on future plans for a materials recovery facility (MRF) to be established in the near future at the entrance of the landfill site. This facility would generate employment for approximately 60 to 100 people. However, no clear strategies emerged on how to incorporate the remaining hundreds of waste pickers that operate onsite. On the other hand, at the Mooi River landfill site, progress has been made in establishing a permit allowing Mpofana Waste pickers to operate on the premises. The landfill manager in Mooi River recognises the Mpofana Recyclers as a business, and the potential they have to grow and generate employment and income. According to the head of the co-operative a shelter and more equipment was promised to them from the municipality, but has yet to be delivered. The co-operative has faced major challenges with theft and burglary due to poor security measures at the landfill site, with no assistance from the municipality. When asked how recycling waste benefits themselves and their communities, the majority of respondents replied that it enables them to support their families, namely feed and educate their children.

The waste pickers were asked at the end of every interview what the government could do to improve their lives, one respondent replied:

> *"Since our job provides employment and environmental protection, the municipality should be integrated with us. The perception about waste pickers must change and be made professional. We must also be able to deal directly with the manufacturers".*
>
> - Head of Mpofana Waste pickers, Mooi River landfill

Waste pickers were asked how the government could improve their lives and working conditions. The following common responses were extracted from the transcripts. According to respondents, local government should provide technical support in the following areas:

- Shelter to process waste and protect dry recyclable materials from inclement weather
- Legal access to landfill and waste management sites
- Provision of safety equipment and work apparel
- On-site (at landfills) material processing equipment (e.g. compactors, waste balers)
- Develop a system to sell recyclable materials without a middleman (e.g. buy-back-centres) and save time spent transporting materials to buy-back centres or waiting on the kerbside for waste collectors
- Provision of sanitary facilities (e.g. toilets, changing rooms) at landfills

With the above equipment and facilities, it is believed by the majority of waste pickers that their productivity would increase, which would not only increase their own incomes and improve their working and living conditions but would also benefit the municipality in reducing the amount of waste being disposed, and reduce costs to the MSWM.

> *"The informal recycling sector provides sustainable jobs. It just needs support from the local government. Waste pickers love their job and they rely on waste picking for survival, the only thing [that needs to change] is the conditions they work under".*
>
> \- President of SAWPA

SAWPA was active during the United Nations Climate Change Conference (COP 17) in December 2011 and has started to present themselves as a unified body advocating for the recognition and rights of waste pickers around the country.

4.7 Discussion

The critical role of waste pickers in a transitional circular economy model has yet to be articulated in the context of cities in middle-income developing country, like South Africa. Waste pickers face a plethora of challenges, to name a few: 1) stigmatisation by the public, 2) exploitation by intermediaries (e.g. buy-back-centres and private waste collectors), 3) limited access to materials, 4) harassment by police and municipal workers, 5) health and safety concerns and 6) lack of adequate recycling infrastructure. Also, the paucity of reliable data on the informal recycling sector, stifles evidence based policy making.

Gaps in material flow data generation and analytics, knowledge sharing, co-ordination and cooperative practice persist in the informal and formal waste management sectors. The most significant *gap* is in a cohesive, systemic approach to comprehending and quantifying the contribution of waste pickers to city level resource efficiency and climate change mitigation. Furthermore, there should be official recognition and quantification of the economic contribution of waste pickers. This is an area that is highlighted for further research in the South African context, as there have yet to be reliable statistics available to quantify the economic and environmental contributions of waste pickers.

The main advantage of the informal recycling sector is that material recovery networks are already in place, and these *informal urban symbiosis networks* are designed to adapt, be flexible, and respond to demand-driven forces. Informal urban symbiosis networks have evolved despite unfavourable circumstances. However, the failure of waste picker cooperatives and recycling SMEs in recent years, necessitates stronger financial, management and technical support (especially in the start-up phase) to ensure medium to long-term survival.

With the pending onset of national extended producer responsibility (EPR) schemes, it is necessary to consider the role of waste pickers in an evolving recycling ecosystem – where producer responsibility organisations (PROs) will have operational and financial influence over national source separation programmes (Godfrey, 2016). Also, there is a call to phase out waste picking from landfill sites, however this is a long-term objective. Hence, in the short to medium-term, it is necessary to implement measures to formal accommodate waste pickers on landfill sites.

As municipalities are in charge of solid waste management, they need strategically consider the role of informal recycling. New models would take the form of hybrid public-private collaborative networks; including municipalities, PROs, NGOs, waste picker cooperatives, and technology suppliers. With the implementation of EPR schemes, PROs will be instrumental in coordinating and subsidising the recycling value chain – source separation, collection and reprocessing. To maintain a steady supply of recyclates PROs will have to harness the effective source separation and collection activities of *informal urban symbiosis networks*.

NGOs have been proven to be important players in the process of integrating the informal recycling sector, acting as advocates and intermediaries, as seen in the case of Brazil and India (Gerdes and Gunsilius, 2010). Technology suppliers will be needed to develop and supply contextualised urban recycling infrastructural systems to augment the role waste pickers in the transition towards a sustainable circular economy.

Recognising that the integration of the informal sector in MSWM is a controversial issue for stakeholders in South Africa. Framed within a circular economy (and embedded industrial ecology framework, this study contends that a portfolio of transition experiments[46] should aim to build the capacity of waste pickers and optimise their service in the recycling supply chain. Capacity building has the potential to result in significant increases in materials managed through the recycling economy (Hickman et al., 2009). To compete in the secondary resources economy, waste pickers need to become reliable service providers (Gerdes and Gunsilius, 2010).

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[46] In the duration of these transition experiments, waste and citizen forums (similar to those in Brazil) would be set up to facilitate a dialogue between stakeholders (e.g. local government, waste pickers, NGOs, private companies). This would open a space to create norms, development standards, and discuss challenges going forward.

The following main themes underpinning the integration of waste picker recycling networks were distilled from the primary (e.g. interviews and observation) and secondary research (e.g. systematic literature review) conducted in this case study (see table 4-4):

Table 4-4 Key issue underpinning the integration of waste pickers

Legislation	• formal recognition of waste pickers as a profession • clear national legislation and municipal by-laws to integrate waste pickers into MSWM systems • inclusion and consultation of waste pickers in designing EPR mechanisms
Organisation	• strengthening NGOs and waste picker cooperatives to establish a collective voice to engage with government and private sector • symbiotic relationship between waste picker communities and PROs
Recycling infrastructural systems	• there is a need for "waste picker-centred" recycling infrastructural systems • to increase their efficiency and augment their role in the secondary resources economy
Regulation of secondary resources economy	• impose stricter rules on intermediary recycling centres, "middlemen", e.g. buy-back centres • ensure fair compensation for waste pickers
Health and safety	• address the working conditions and health and safety of waste pickers, especially on landfill sites
Data generation and analytics	• quantifying the informal recycling market is a pre-condition to designing effective strategies to integrate waste pickers • generate reliable economic, material flow and environmental metrics

4.8 Conclusion

In the context of cities in developing countries, the secondary resources economy is entirely dependent on the informal recycling sector for the supply of recyclates, i.e. *informal urban symbiosis networks*. Hence, waste pickers should be viewed as *primary looping agents* of change in the transition towards a circular economy. Furthermore, in an age of ubiquitous computing how can we utilise a technology-enabled approach to explore more efficient patterns of organisation? Therefore, it is recommended that future research explores *distributed, quasi-integrated and cyber-physical-social models of organisation* (i.e. human centred, decentralised, partially integrated and connected) designed to protect and augment the role of waste pickers in the transition towards a circular economy. Ultimately, the goal is to improve the metabolism of cities by harnessing the potential of *technology enabled* informal urban symbiosis networks – in turn, creating sustainable employment opportunities, and reducing waste management costs for municipalities.

The rapid quantitative assessment, highlighted the potential economic and environmental contribution of waste pickers in South Africa. Due to the lack of specific and reliable time series datasets on the informal recycling sector, the analysis was premised upon assumptions as presented in the literature. The integration of proxy indicators and assumptions embeds inherent uncertainty in the quantitative assessment. In summation, there is a paucity of accurate datasets on the contribution of the informal recycling sector and the inherent role of waste pickers in the South Africa's waste management sector. To support evidence based policy making, it is imperative to generate and aggregate reliable data on waste picker networks and related material flows.

The research also revealed that waste pickers receive nominal prices for their materials and informal waste management service provision. A key feature of improving waste picker livelihoods hinges on augmenting their position in the value chain and securing better wages. To this end, negating the function of traditional and inefficient *brick and mortar* intermediaries, i.e. buy-back-centres, has the potential to increase the price waste pickers receive for their materials. There is an opportunity design smart recycling infrastructural systems that negate the role of traditional intermediaries, create safer working conditions and provide auxiliary services. Taking this into account and through a system thinking lens, two key leverage points suitable for technology enabled interventions are identified, namely *infrastructure* and *data*.

Firstly, integrating waste pickers hinges upon designing user-centred recycling infrastructural systems, while leveraging the different strengths of informal (e.g. manual labour and tacit knowledge) and formal (e.g. logistics and linkages to reprocessing industries) recycling networks. This study proposes that separation at source and transitioning away from centralised landfilling resource recovery can be driven by waste picker-centred, information-centric and decentralised recycling infrastructural systems, which negate traditional intermediaries (e.g. buy-back-centres) by automating and digitising third party functions.

Secondly, there is a need to bridge the knowledge gap, by generating and disseminating reliable and real-time big data analytics about material flows and actors (e.g. waste pickers, waste collectors, buy-back-centres and private waste management service providers) bridging the service and value chain in the secondary resources economy. As mentioned previously, reliable data analytics has the potential to empower waste picker communities, by providing quantifiable metrics to support their demands for better working conditions and fair compensation. Herein, lies the opportunity to design an *internet of-things (IoT) enabled recycling infrastructural system* to foster the aggregation and analysis of relevant big data; tracking the real time flow of recyclable materials and the activities of waste pickers and waste collectors. Furthermore, enhancing efficiency by digitising and automating the primary interaction (i.e. material exchange) between waste pickers and waste collectors. A *Third Industrial Revolution (TIR)* inspired infrastructural systems model of this typology (e.g. decentralised, distributed and connected), has the potential to leverage the strengths of actors in informal and formal recycling networks, while enhancing aggregate efficiency.

In sum, chapter four highlights the critical role of waste pickers in increasing resource efficiency and improving the metabolism of cities in developing countries. Through mixed methods this case study provides a snapshot of waste pickers' livelihoods and contextualises the informal recycling sector in the province of KwaZulu-Natal. The leverage points, i.e. *infrastructure* and *data*, which are distilled from the findings are extrapolated in the design of a virtual experiment in chapter five. Chapter five provides a sketch of a technology enabled *virtual circular city experiment (i.e. cyber-physical-social ecosystem)* to increase the efficiency of material recovery in cities in developing countries, which possess existing informal recycling networks. In doing so, the next chapter conveys the design framework to construct a theoretically and empirically informed circular economy transition experiment; intended to augment the position of waste pickers in the recycling value chain and create stronger linkages between the informal and formal recycling sectors in the transition towards a circular city.

Chapter 5 – Circular Economy Design Visioning

Chapter five employs a circular economy design visioning approach to construct a virtual circular city experiment; a *cyber-physical-social ecosystem (CPSE)* designed to augment the role of waste pickers in the secondary resources economy. The *internet-of-waste pickers* is a decentralised and smart infrastructural system for the buy-back and transfer of recyclable materials recovered from municipal waste streams in emerging economies. It is an *Internet-of-Things (IoT)* enabled infrastructural system – designed to configure smart and connected informal urban symbiosis networks in South African cities. The *internet-of-waste pickers* is underpinned by ecodesign principles of organisation.

5.1 Introduction

In South Africa, recycling value chains are fraught with systemic inefficiencies and characterised by an unequal distribution of revenue, favouring downstream actors in formal recycling and reprocessing networks. Informal urban symbiosis[47] networks, i.e. the informal recycling sector, performs a large proportion of recycling in municipal solid waste management systems. Some of the benefits of informal recycling are positive environmental effects (e.g. reduction in emissions associated with landfill disposal) and economic benefits (e.g. savings on virgin materials through the recirculation of secondary materials and local job creation). As discussed in the previous chapter, the secondary resources economy is dependent upon the unregulated services provided by waste pickers; they manually recover recyclable materials from post-consumer waste and in doing so increase the supply of recyclates (e.g. paper, plastics, glass, metal and e-waste).

Albeit under-reported and under-stated in the formal waste management sector, waste pickers play an indispensable role in the recovery of post-consumer recyclable materials. They are a marginalised and vulnerable urban group, carving out a survivalist existence on the periphery of the formal economy. Despite limited access to infrastructure and equipment (e.g. protective gear, balers, compactors and carts/trolleys), waste pickers provide indispensable manual sorting and inter-modal collection services. Integrating and empowering the thousands of marginalised reclaimers work in South African cities has the potential to improve urban metabolism. In

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[47] Urban symbiosis refers to purposively designing urban infrastructural systems to aggregate and utilise by-products (e.g. municipal solid waste) from urban areas as alternative sources of raw materials for surrounding industries (Van Berkel et al., 2009).

particular, there is an opportunity increase the recovery of recyclable paper and plastics from post-consumer waste streams by up to 20-30% and 70-79% respectively (see chapter four, section 4.6.1.1).

The study posits that augmenting the role of waste pickers in technology enabled urban symbiosis networks can be highly effectual in optimising recycling rates and promoting circular city transitions in South Africa. To this end, chapter five undertakes a circular economy design visioning exercise. In doing so, sketching an innovative virtual circular city experiment; an integration and convergence of various emerging and established technologies (i.e. recombinant innovation); prototyping an internet-of-things (IoT) enabled urban recycling infrastructural system.

5.2 Framing a Virtual Circular City Experiment

5.2.1 Conceptual framework

The proposed virtual circular city experiment is an interdisciplinary and emergent abstraction from the case study analysis (in chapter four) embedded in a network of theories, namely *Third Industrial Revolution (TIR), Industrial Ecology (IE) and Circular Economy (CE)* (see chapter one, section 1.5.2 – 1.5.4). The interconnected theories respectively exhibit systems thinking attributes, furthermore demonstrating varying degrees of eco-centric values, i.e. deep ecological ethics.

The *Third Industrial Revolution (TIR)* metanarrative provides a broader conceptual landscape (i.e. new economic narrative) to frame the experiment – delineating the suite of *internet-of-things technologies (IoT)* underpinning an emerging *general purpose technology platform (GPT)*. In a future of ubiquitous computing and connectivity, the new economic narrative will be defined by the convergence of a digital communication, energy and transport internet. To this end, providing an exploration of the novel structure, i.e. *cyber-physical-social systems*, of socio-technical systems in the new economic narrative. In the near future, the digital world of bits and the physical world of atoms will be ubiquitously meshed reducing the marginal costs of production. To improve urban metabolism[48], it is imperative to address the inherent information asymmetries in

[48] Urban metabolism is defined as, "the sum of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy and elimination of waste" (Kennedy et al., 2007).

prevailing urban-industrial material flows. By *"seeing invisible bits that overlay the physical world",* it is possible to generate ubiquitous urban-industrial material flow data (Kelly, 2016). Cyber-physical systems can be deployed to discover the *invisible material flow bits*, in turn leveraging this information to configure new patterns of organisation which yield higher efficiencies for cities. In this regard, the following chapter strives to imagine the evolution of waste pickers in an IoT enabled urban recycling infrastructural system nested in a decentralised and digital platform organisational (non-profit) model.

Industrial ecology (e.g. urban symbiosis) and *circular economy* provide interdisciplinary and multilevel (e.g. firm, industry, city and regional) understanding about strategic resource management. *"Understanding the city as an ecosystem, and by better understanding the material and energy flows within the city, it will be possible to generate new ideas about how to create a sustainable urban future by fostering urban symbiosis"* (Iveroth, 2014). In the case of South African cities, waste picker networks have strong forward linkages to the reprocessing industry, through the steady supply of recyclable materials recovered from urban waste streams. Therefore, this study frames the role of waste pickers as primary looping agents within through an *urban symbiosis network* and *circular city* lens, to allow for the conceptualisation of policy informing transition experiments nurtured in strategic niches (Geels and Schot, 2007). Strategic niches of this typology, i.e. cyber-physical-social systems, are designed to challenge the incumbent regime and catalyse new policy discourse premised on fostering greater digitalisation, decentralisation, efficiency, transparency and equity.

Figure 5-1 Framing a virtual circular city experiment – ***the internet-of-waste pickers***

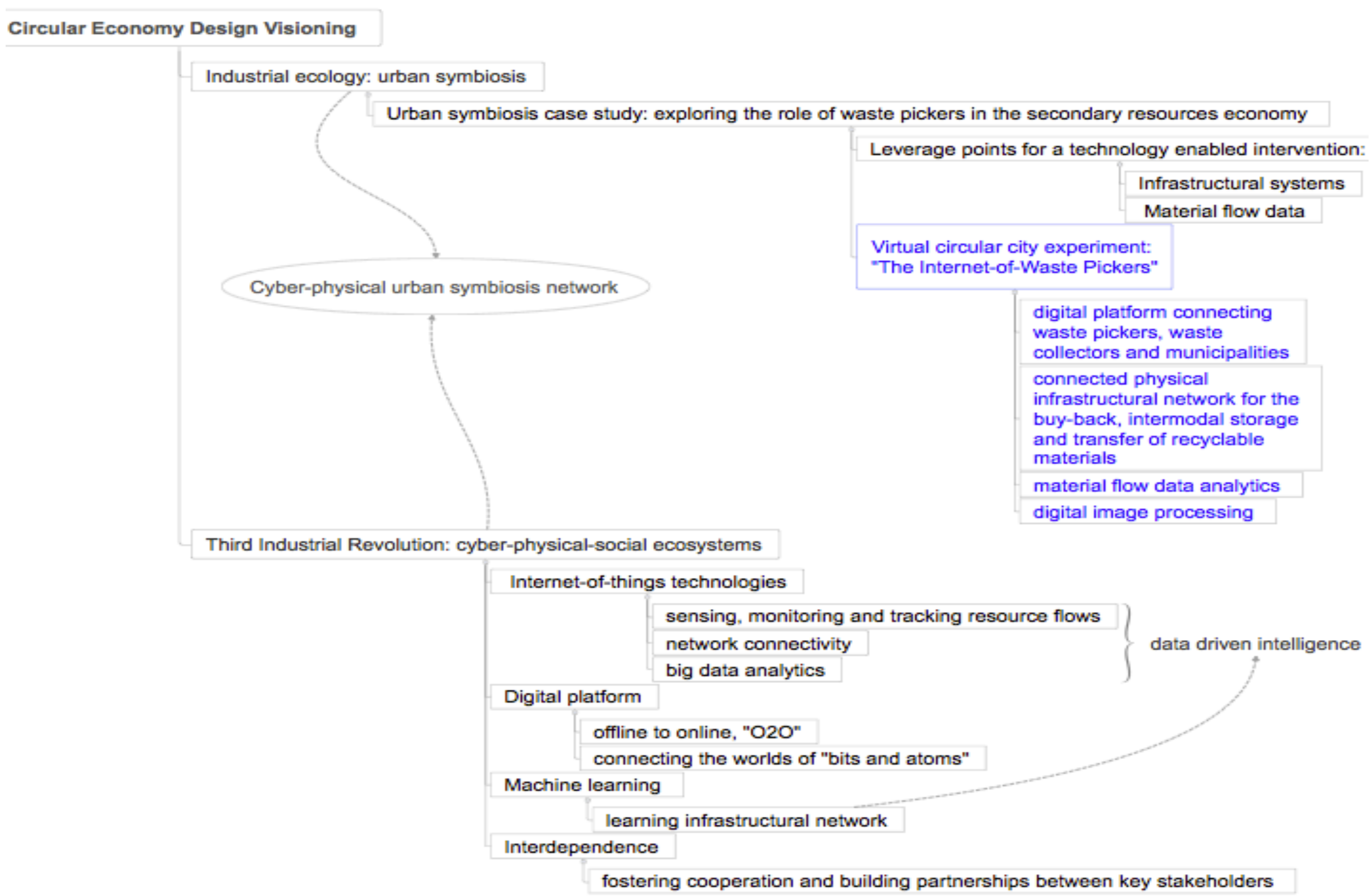


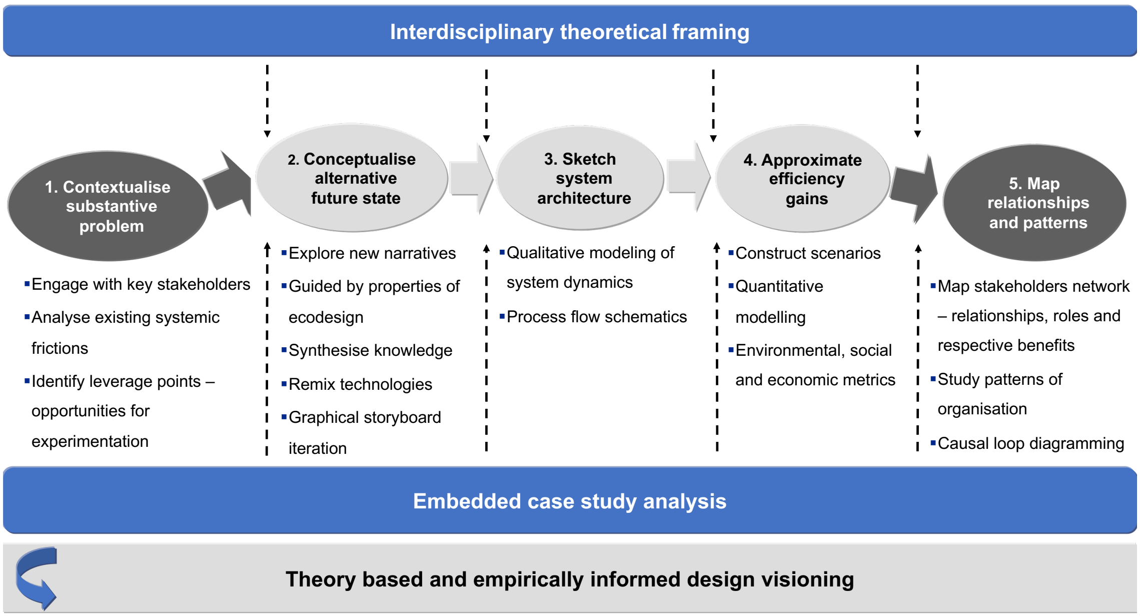
Figure 5-1 above illustrates the initial mind mapping process, culminating in a detailed sketch of a virtual circular city experiment, which is described in greater detail later on this in chapter. The blue coding depicts the novel design case. The black coding depicts theories and case study analysis informing the design case. This process allowed the designer to understand the influences of the various theoretical domains and respective disciplines. Furthermore, highlighting the application of key findings from the case study analysis in the design process.

5.2.2 Design Methodology

The *ecological literacy* approach, presents a holistic philosophical (systems thinking) framework to situate this explorative and interdisciplinary study (see chapter one, section 1.5.1). The entire study is underlined by the a systems thinking perspective, i.e. *"thinking in terms of connectedness relationships, patterns and context"* (Capra and Luisi, 2014). Systems thinking is applied in the problem structuring phase of the case study, to identify systemic frictions and subsequent leverage points in the incumbent recycling regime in the context of South Africa. The leverage points distilled from chapter four, *infrastructure* and *data*, inform the conceptualisation of a *virtual circular city experiment*. With this at the forefront of the design thinking process, the experiment explores the application of digital instruments to complement the physical labour of informal waste picker networks and improve the efficiency of waste collectors, in turn embed intelligence in recycling value chains. A new pattern of organisation is explored, i.e. configuration of relationships in a cyber-physical urban symbiosis network, which seeks to optimises efficiency and fairness. Furthermore, from a systems thinking perspective, there is conceptual shift from studying *"objects to relationships"* (Capra and Luisi, 2014). Hereto, from a sustainable innovation and design standpoint, special attention is paid to harnessing communications technologies to establish stronger and more equitable relationships between key stakeholders, i.e. waste pickers, waste collectors, material reprocessors, industry associations and municipalities.

As mentioned in chapter one, design visioning is defined as the creative process of systems level scenario building to envision circular economy transitions via the structuration of virtual circular city transition experiments as an essential starting point. A virtual circular city experiment is moulded from an amalgamation of new and existing technologies and ecodesign imagination. The general-purpose technology platform (built out of the internet-of-things) as delineated in the Third Industrial Revolution (TIR) metanarrative, is used a guiding technology infrastructural framework to inform circular economy design visioning discourse. Furthermore, the design visioning process is framed by ecological literacy discourse, which proposes an *ecodesign thinking* construct for conceptualising alternative and more sustainable patterns of production and consumption. Five properties of ecodesign are recommended to inform *"new patterns of organisation"*, namely, 1) interdependence, 2) partnership, 3) networks, 4) solar energy and 5) circularity (Capra and Luisi, 2014). The guiding ecodesign framework is underpinned by the assertion that to avert the existential threat posed my human induced climate change, modern society needs to fundamentally redesign patterns of social and economic organisation premised on the five ecodesign properties. For the purpose of this study, the aforementioned ecodesign framework is utilised to govern the following circular economy design visioning exercise.

Figure 5-2 Circular economy design visioning – constructing a virtual circular city experiment



The circular economy design visioning method (see figure 5-2) builds upon the interdisciplinary theoretical framing (i.e. metanarrative structuring) and meta-problem structuring explicated in the previous chapters. The first step in the circular economy design visioning process involves harnessing the case study findings, i.e., identification of leverage points to inform the design of a virtual experiment. The second step involves the conceptual iteration of integrated technologies scenarios corresponding to the five ecodesign properties. Herein, synthesising interdisciplinary knowledge to inform the creative work of ideating and expressing an alternative technological future. In doing so, content creation and theory building involves utilising an iterative graphical storyboard method. The third step comprises the exploration of the system dynamics through process flow schematics. The fourth step covers modelling the environmental, social and economic efficiency gains of the proposed technological intervention. Step five involves sketching a qualitative model of organisation, this includes mapping the relevant stakeholders; understanding their relationships, roles and respective benefits. The methodology described above is employed to develop a circular economy design vision to increase the efficiency and productivity of informal recycling networks in recovering recyclable materials within the context of South African cities.

5.3 Circular Economy Design Visioning

5.3.1 Contextualise substantive problem

The study proposes an alternative technology enabled version of existing informal urban symbiosis networks, i.e. informal recycling sector, operating in South African cities. The aforementioned networks are heavily reliant on the resource recovery activities of waste pickers; depicted as *primary looping agents* for the purpose of this study. In South Africa, it is estimated that waste pickers supply 70-90% of recyclable packaging waste to the secondary resources economy with strong forward linkages to reprocessing industries (Godfrey et al., 2016). In doing so waste pickers provide an indispensable and subsidised waste management service to municipalities in most middle-income developing countries. However, they are marginalised community, facing a plethora of challenges:

- barriers to accessing material rich sites, e.g. landfills, commercial estates and affluent suburban neighbourhoods,
- harassment from police and municipal workers,
- stigmatisation from the general public,
- unsafe working conditions,
- exploitation from middlemen, i.e. intermediaries like buy-back-centres and waste collectors,
- paucity of reliable data on the economic and environmental contributions of waste pickers,
- lack of equipment, e.g. trolleys/carts, balers, compactors and protective gear,
- and manually transporting materials long distances to access intermediaries and designated collection points.

Based on the application of a systems thinking approach to a high-resolution case study on waste pickers (see chapter four), two key leverage points are identified for further exploration; data (i.e. information asymmetries) and infrastructure (i.e. infrastructural systems). The study contends that if we generate and mobilise reliable data and user centred infrastructure it is possible to increase the efficiency of waste pickers, resulting in greater positive environmental impacts, decent employment opportunities, and reduction in waste management costs for municipal governments. Furthermore, the study argues that by focussing on the abovementioned leverage points we can create stronger linkages between the informal recycling sector and downstream industries that convert and utilise recyclates into secondary raw materials.

The centralised and capital intensive infrastructural approach to enable material recovery has been the introduction of material recycling facilities (MRFs) on or near landfill sites. Ideally, MRFs should provide safer and healthier working conditions for waste pickers. At Marianhill landfill site in Durban, a sophisticated MRF was constructed, however was rendered economically unviable due to the low volume of material recovery (Mkhize et al., 2014). The municipality outsourced the development of the project to a large private waste management firm, Re-ethical Engineering. Typically, governance models for capital intensive infrastructure projects of this typology exclude marginalised stakeholders like waste picker communities. In sum, there is an opportunity to explore decentralised, distributed and collaborative urban infrastructural solutions to improve the efficiency of recovering recyclable materials from municipal solid waste streams.

5.3.2 Conceptualise alternative future state – the internet-of-waste pickers

5.3.2.1 Definition of the internet-of-waste pickers

The *internet-of-waste pickers* is a decentralised and smart infrastructural system for the buy-back and transfer of recyclable materials recovered from municipal waste streams in emerging economies. It is an *Internet-of-Things (IoT)* enabled infrastructural system – designed to configure smart and connected informal urban symbiosis networks in South African cities. The internet-of-waste pickers is underpinned by ecodesign principles of organisation. It is a demonstration of a *cyber-physical urban symbiosis network;* through an *offline-to-online (O2O)* strategy allowing users (e.g. waste pickers and waste collectors) to participate in a *peer-to-peer digital market place* while increasing the efficiency of exchanging physical goods, i.e. recyclable materials. The *digital platform* employs tools to complement and supplement waste pickers' tacit knowledge, informal peer-to-peer networks and physical labour.

The *cyber-physical-social*[49] *ecosystem* integrates software, hardware and social elements; 1) kerbside buy-back-transfer substation network to store and transfer recyclable materials, 2) route optimisation (via a mobile application) for waste collectors, 3) digital payment system for waste collectors and waste pickers, 4) and the provision of basic financial services (e.g. savings account) to waste pickers via a financial intermediary. The physical infrastructure is comprised of a mesh network of decentralised, connected, modular and solar powered (off-grid) kerbside buy-back-transfer substations. The *buy-back-transfer substation* is a solar powered, smart, automated and connected infrastructural node embedded in a decentralised cyber-physical-social ecosystem. It is a smart city application designed to optimise waste management systems in cities in developing countries by automating and digitising the buy-back and transfer of recyclable materials.

The whole system is enabled by IoT technologies; including embedded sensors (to measure load frequencies in real time and collect valuable longitudinal data on materials and actor networks) at buy-back-transfer substations and is connected to a cloud computing platform. The buy-back-transfer substation incorporates, a smart vertical-baler, conveyor, and storage compartment (e.g. 1-2 tonnes). The user interface has an intuitive touchscreen interface which loads waste pickers recycling rebate onto a chipped PVC card after materials have been analysed and accepted. Recyclable materials (e.g. cardboard, paper and plastics) are deposited into an aperture where they are weighed, characterised and baled with like kind material. Data about the materials is collected in at various points through embedded sensors and is collated and analysed in real time via a cloud computing platform. The baled materials are stored until they are collected by a waste collector, i.e. a transport service provider who collects material from buy-back-transfer substations and transports it to a material recycling/reprocessing facility.

Waste collectors access information about material loads and location via a mobile application. Allowing them to optimise routes (on demand) based on how much material is available at substations strategically distributed around the city. Waste collectors receive a matrix barcode (e.g. QR code) login to retrieve a load for collection from a buy-back-transfer substation, previously purchased online via the mobile application payment system. Also, the transaction costs for waste collectors are reduced, for example fuel costs are reduced through route optimisation as location and characterisation of aggregated materials are mapped and analysed in real time via the cloud computing platform. In turn, transport emissions are reduced. Waste

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[49] The term *cyber-physical-social ecosystem* and *cyber-physical urban symbiosis network* are used interchangeably as the latter is an abstraction of the former.

collectors save time as they do not have to physical exchange cash for materials supplied by waste pickers either at informal kerbside collection points or buy-back-centres.

The system optimises the recovery of recyclable materials by adding a layer of automation and digitisation to the existing material buy-back-network. In doing so augmenting the role of waste pickers in the secondary resources economy; increasing their efficiency (i.e. reduce transport time), access to transparent value chains, and providing basic auxiliary financial services (i.e. cashless payment solutions and basic banking services). Furthermore, the system increases the efficiency of waste collectors through route optimisation and cashless payment via a mobile application. In the internet-waste-pickers infrastructural network, buy-back-transfer substations aggregate and store materials for waste collectors. Beneficiaries, e.g. municipalities, waste management firms and industry associations, profit from increased efficiencies in material recovery and access to actionable intelligence generated by the cyber-physical-social ecosystem.

Figure 5-3 Circular economy design visioning storyboard – internet-of-waste pickers

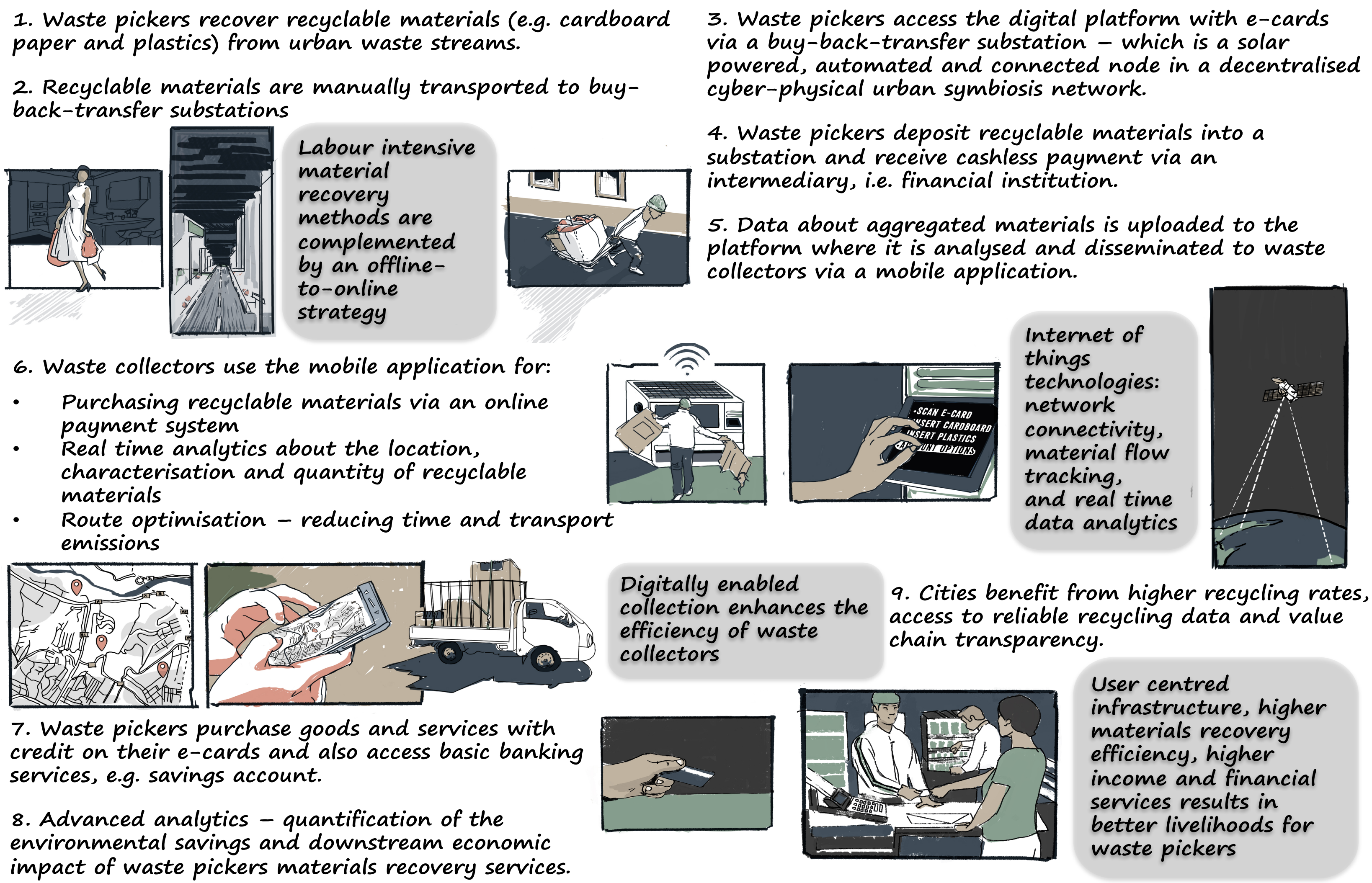


Figure 5-3 illustrates the design visioning storyboard, in doing, so providing a succinct graphical overview of the key elements of the cyber-physical-social infrastructural system. Also, figure 5-3 provides a synopsis of the design narrative, in short explaining how the system functions. The graphical storyboard interface is instrumental for remixing and iterating the core components of the system. Table 5-1 explicates the use of the properties of ecodesign, and respective property characterisation in the first generation of the internet-of-waste pickers system architecture. The proposed sustainable technology design is underpinned by deep ecological ethics, with the goal of increasing the ecological sustainability of urban-industrial material flows (i.e. diverting recyclable post-consumer packaging materials from landfill) and income equity in recycling value chain in the context of emerging market economies.

Table 5-1 Ecodesign matrix – internet-of-waste pickers

Properties	Characterisation
Solar	The buy-back-transfer substations are distributed nodes in the cyber-physical-social network and are powered by solar energy. The hardware nodes are decentralised and modular, powered by a smart off-grid rooftop solar PV system.
Networks	The internet-of-waste pickers is a cyber-physical-social ecosystem, premised upon the self-organising property of informal recycling networks, i.e. waste picker communities. The efficiency of the existing (offline) network is augmented by adding a layer of advanced information and communications (online) technologies, thereby embedding actionable material flow intelligence in the network, i.e. offline to online strategy.
Partnerships	The organisational model depends on strategic partnerships and augmented cooperation between user groups (e.g. waste pickers, waste collectors) and beneficiaries/regulators (e.g. municipalities and industry associations).
Interdependence	Waste collectors are dependent on waste pickers to provide a consistent supply of recyclable materials, conversely waste pickers are reliant on waste collectors to serve as linkages to secondary resource markets. The internet-of-waste-pickers reduces transaction costs (e.g. time and energy) for both parties and increases buy-back-transfer and collection efficiency through automation and digitisation.
Circularity	The internet-of-waste pickers is designed to increase the efficiency of recovering recyclable materials from municipal solid waste streams, also to create stronger and transparent linkages between waste pickers and secondary resource markets. The system is designed to promote transitions toward circular economy practices at a city level.

5.3.2.2 Aim and objectives

The proposed *cyber-physical urban symbiosis network* applies digital instruments to complement physical labour and reduce systemic friction in prevailing *offline* informal recycling networks, concomitantly embedding intelligence to increase recycling efficiencies in South African cities. The first generation of the proposed innovation is designed to enhance the recovery of paper and cardboard in commercial, urban and industrial settings. The overall aim of the system is to improve urban metabolism in major metropolitans in South Africa, with application across middle income developing countries (e.g. Brazil and India). The main objectives of the virtual circular city experiment are:

- To increase the efficiency of recovering, sorting, aggregating and transferring recyclable materials from municipal waste streams to secondary material markets
- To increase key stakeholders' efficiency; waste pickers and waste collectors (i.e. transporters of urban waste)
- To improve transparency in recycling value chains, ensuring that primary looping agents (e.g. waste pickers), receive a fair price for their materials and service provision
- To provide waste pickers with customised financial services; cashless payment and a savings account

5.3.3 Sketch system architecture

The following process flow diagrams illustrate the fundamental system operations. Figure 5-4 provides an overview of the cyber-physical system architecture, mapping data and material flows. Herein, figures 5-5 and 5-6 map data flow models for the primary users; waste pickers and waste collectors respectively.

Figure 5-4 Cyber-physical system architecture – internet-of-waste pickers

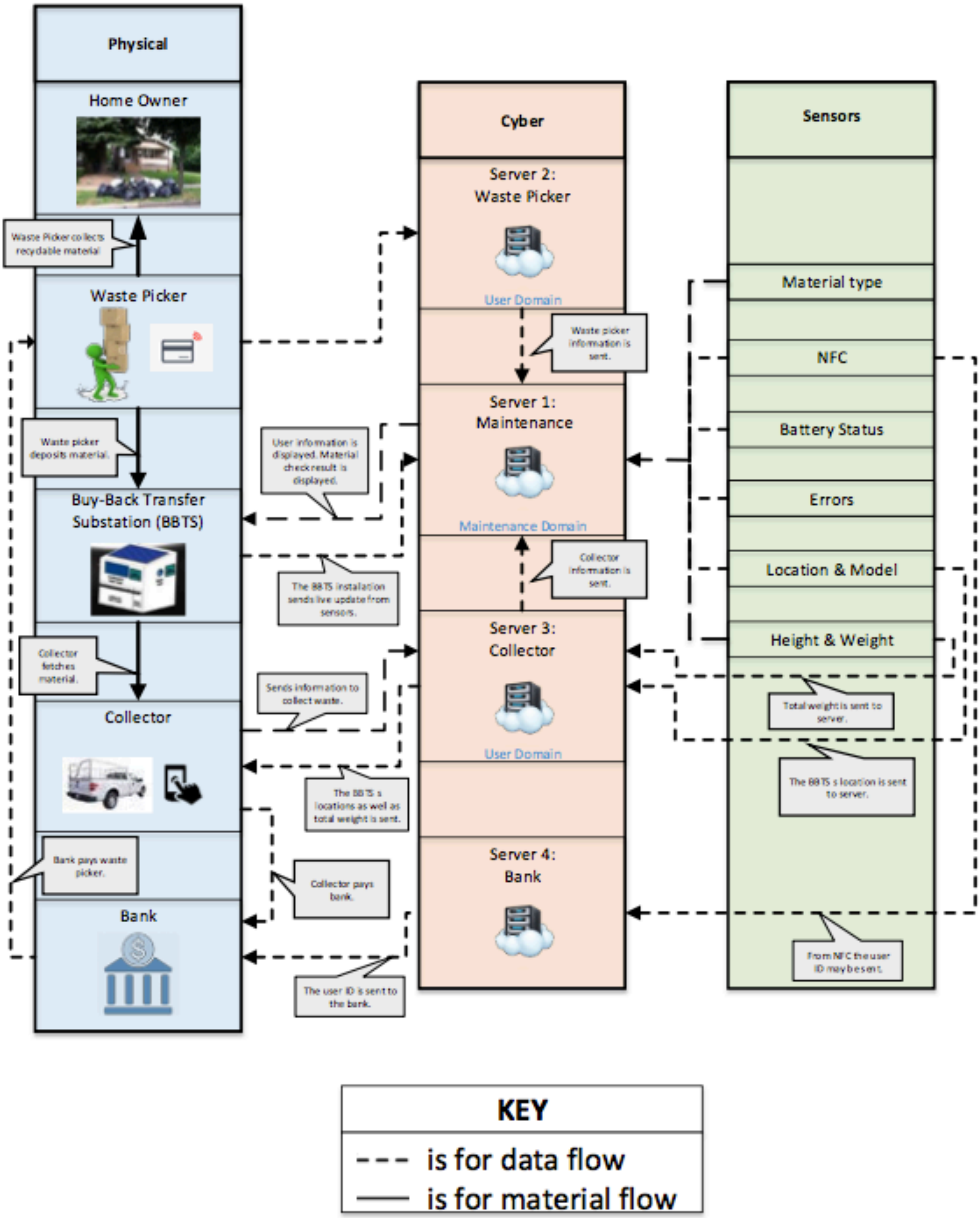


Figure 5-5 Data flow model for waste pickers

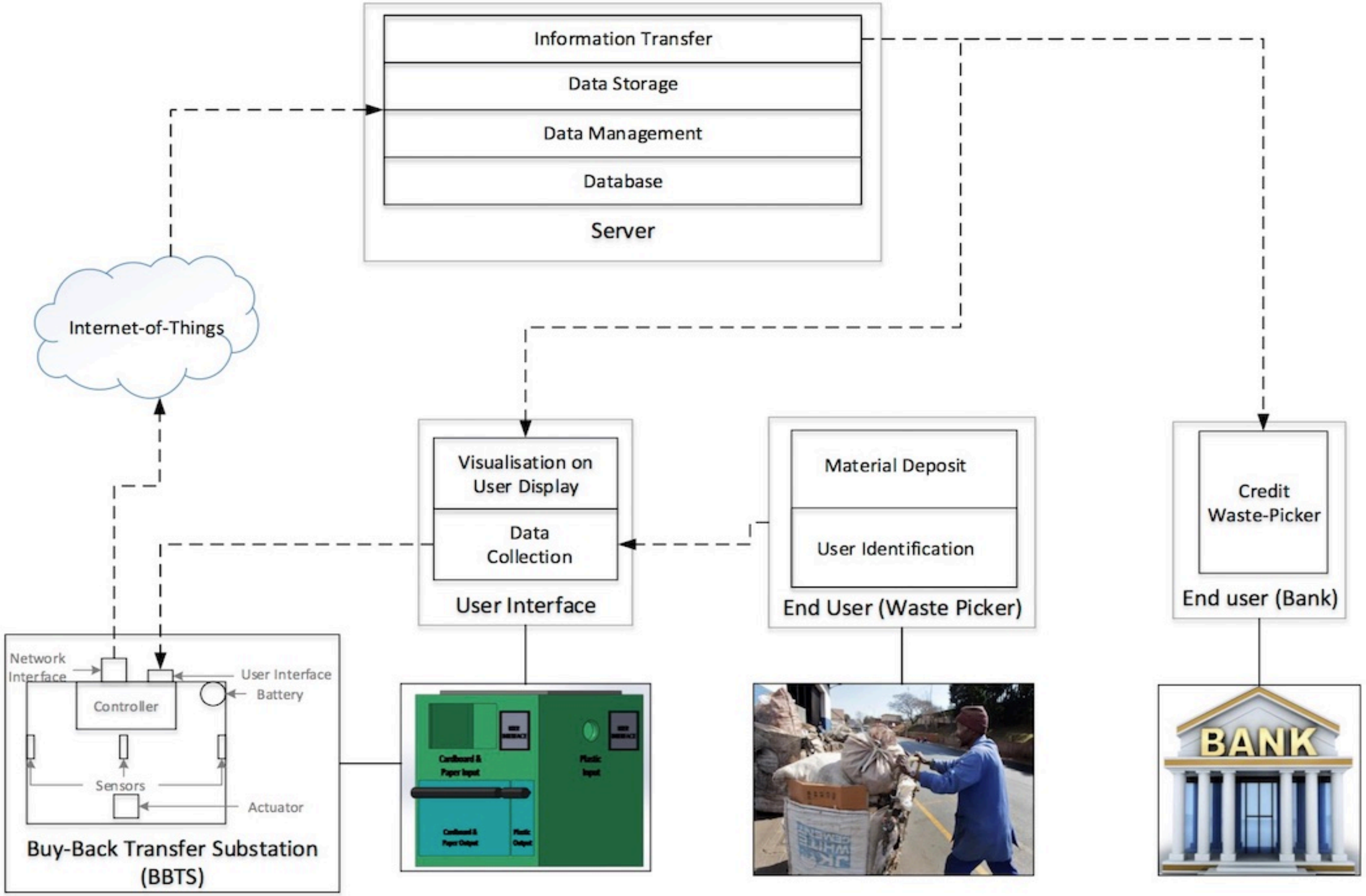
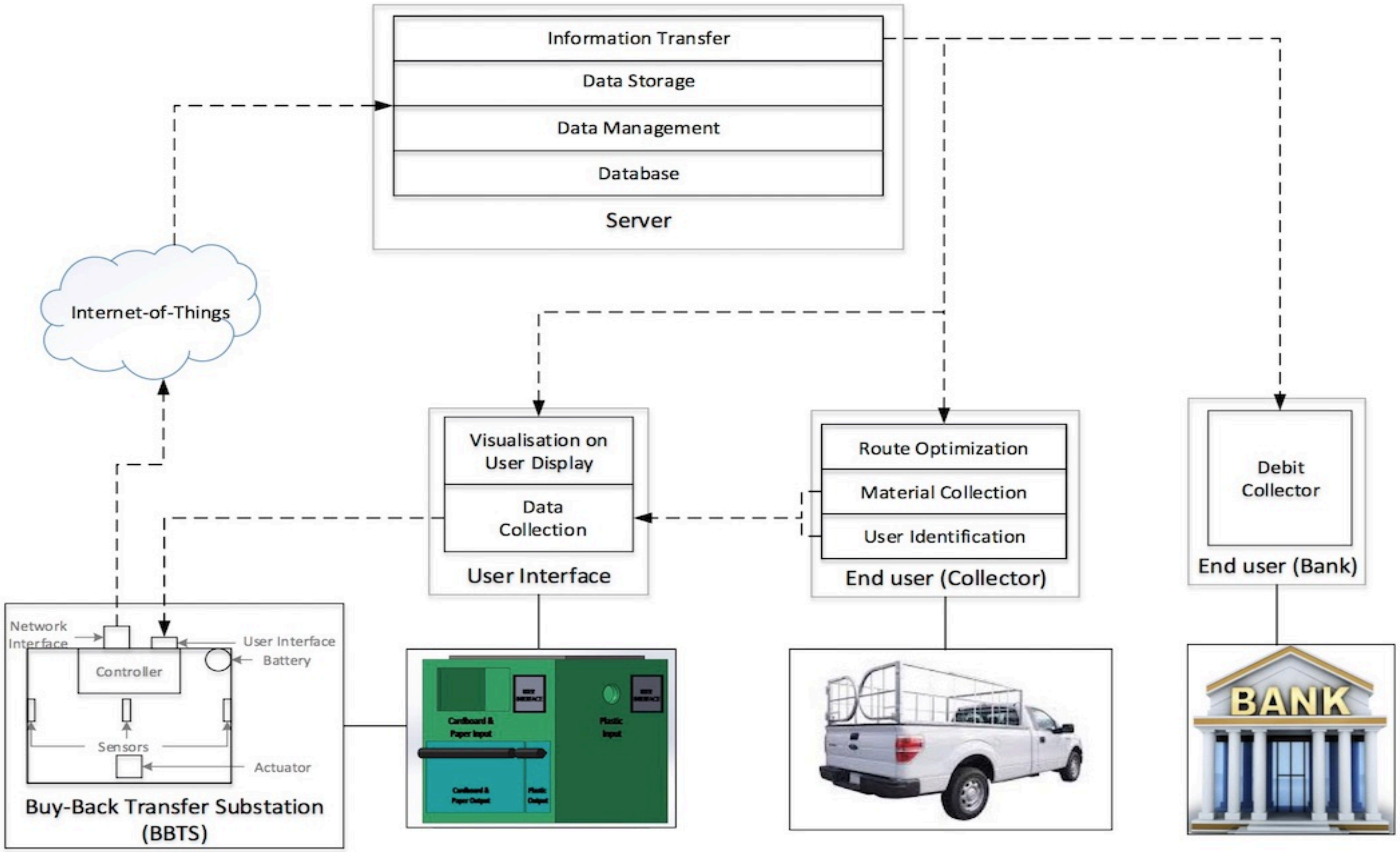


Figure 5-6 Data flow model for waste collectors



5.3.4 Approximate efficiency gains

The first generation of the internet-of-waste pickers, will be designed to process recyclable paper and plastic materials, seeing as these are the most popular fractions recovered by waste pickers in South African cities (see section 4.6). Seeing as majority of materials processed by buy-back-centres is supplied by waste pickers, a ratio of recyclable material fraction collected by waste pickers was derived from material flow data reported by registered buy-back-centres in eThekwini Municipality (eThekwini Municipality, 2016a). Hence, the approximate ratio of recyclable material fractions collected by waste pickers: 60% cardboard and paper, 17% plastic, 4% cans, 8% glass and 11% metal (eThekwini Municipality, 2016a). The material recovery profile for waste pickers in eThekwini Municipality, is used to formulate an efficiency model, to illustrate the approximate efficiency gains (measured against a baseline scenario) which will result from the implementation of the internet-of-waste pickers. Similarly, a set of input data based on the findings from the case study analysis is used to build the efficiency model:

- Number of waste pickers operating in South African cities is conservatively estimated to be approximately 60 000 (Godfrey, 2015)
- Total mass of recyclable material collected per waste picker per annum, is estimated to be 16 tonnes (Godfrey, 2015)
- Waste picker recyclable material recovery profile: 60% cardboard and paper, 17% plastic, 4% cans, 8% glass and 11% metal (eThekwini Municipality, 2016a).
- Average rebate received by waste pickers for recyclable paper and cardboard (per tonne): ZAR 930 (Source: Remade Recycling, 2017)
- Average rebate received by waste pickers for recyclable plastics (per tonne): ZAR 1750 (Source: Atlantic Plastics Recycling, 2017)
- Global warming potential (GWP) emissions factor paper: 3.87 tCO_2eq (WARM, 2017)
- GWP emissions factor paper: 1.65 tCO_2eq (WARM, 2017)

The scenarios in the efficiency model (see table 5-2) are based on the set of assumptions:

- 20% increase in waste picker rebate for recyclable paper and plastics, accrued through EPR price support mechanisms and built in service fees paid by waste collectors
    - 10% increase in price for plastic and paper will be accessed through price support schemes built in extended producer responsibility programmes

- 10% fee paid by waste collector for accessing materials processed through the infrastructural recycling network
- Waste picker rebate for recycled paper and cardboard will increase to ZAR 1116 per tonne
- Waste picker rebate or recycled plastics will increase to ZAR 2625 per tonne

- Scenario 1 – 25 % increase in material recovery, buy-back and transfer efficiency
- Scenario 2 – 50% increase in material recovery, buy-back and transfer efficiency

Table 5-2 Efficiency model – internet-of-waste pickers scenario analysis

Legend: *IowP – Internet-of-waste pickers *ZAR – South African Rand Currency Exchange rate (2017): € 1 = ZAR 15 *EPR – Extended producer responsibility	Mass collected per waste picker for paper (tonnes/month)	Mass collected per waste picker for plastics (tonnes/month)	Income earned by waste picker for paper recycling (ZAR/month)	Income earned by waste picker for plastics recycling (ZAR/month)	Environmental performance (tCO_2eq,global_warming_potential) of paper recycling (per month)	Environmental performance (tCO_2eq,global_warming_potential) of plastics recycling (per month)
Baseline: Status quo with waste collector kerbside buy-back and buy-back centre exchange	0.8 tonnes	0.23 tonnes	*ZAR 744	ZAR 396	3.1 tCO_2eq	0.38 tCO_2eq
Scenario 1 *IoWP: • 25% increase in material recovery, buy-back and transfer efficiency • 20% increase in rebate to waste picker: (factoring price support from EPR programmes)	1 tonnes	0.28 tonnes	ZAR 1116	ZAR 739.38	3.9 tCO_2eq	0.47 tCO_2eq
Scenario 2 IoWP: • 50% increase in material recovery, buy-back and transfer efficiency • 20% increase in rebate to waste picker (factoring price support from EPR programmes)	1.2 tonnes	0.34 tonnes	ZAR 1339.30	ZAR 896.88	4.65 tCO_2eq	0.57 tCO_2eq

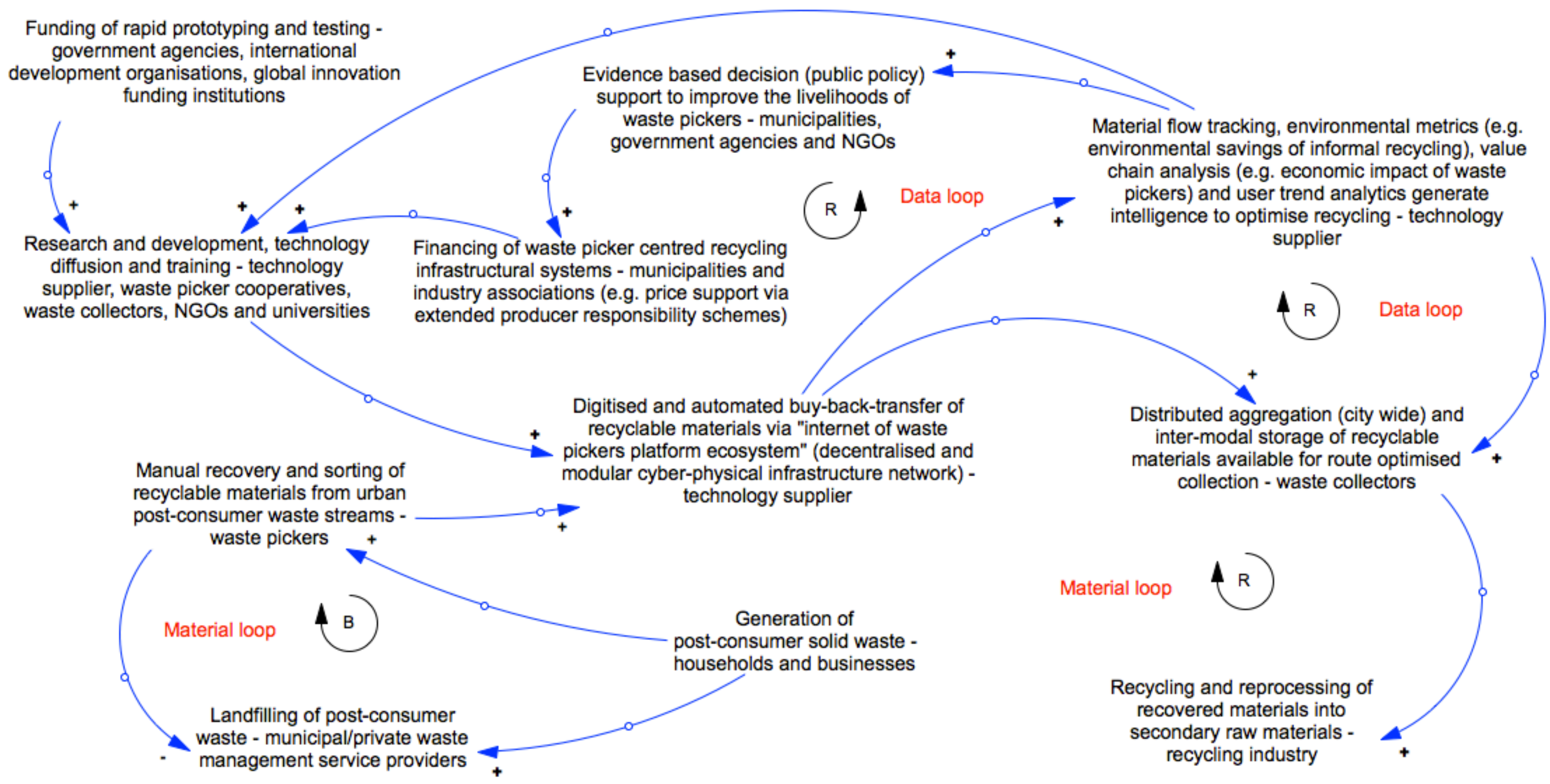
Table 5-2 portrays the efficiency gains under two scenarios in comparison to the baseline situation. The social impact is measured by the proxy variable – monthly income earned by waste pickers. The environmental impact by the offset in emissions (per month) from diverting waste from landfill, depicted by the global warming potential (GWP) metric. The upstream economic impact can be measured by the increase in the mass of recyclable materials recovered and their respective market related value, enhancing circular material flows and contributing towards the expansion of the secondary resources economy.

5.3.5 Mapping relationships and patterns

The development of qualitative models, e.g. causal loop diagram (CLD), is an effective method to illustrate stakeholder involvement and construct a holistic understanding of the system, i.e. patterns of configuration. A CLD portrays casual linkages between respective variables, in turn highlighting the polarity of the linkages and the consequent feedback loops arising in the system (Lane, 2008). The arrows refer to the causal influences between the variables and the nature of their polarity (Sterman, 2000). A positive polarity infers that a positive change to the independent variable (source of the arrow) results in a positive change to the dependent variable (end of the arrow), conversely a negative polarity infers that a positive change to the independent variable will result in a negative change to the dependent variable and vice versa.

Figure 5-7 denotes the events variables that comprise the system, furthermore identifying involvement of relevant stakeholders at respective events. The CLD below was created in the system dynamics modelling software, Vensim PLE. The loops codified by *R* and *B*, refer to *reinforcing* and *balancing* loops respectively. Figure 5-7 also illustrates where *data loops* and *material loops* occur in the model.

Figure 5-7 Causal loop diagram – the internet-of-waste pickers



From an innovation management perspective, the fundamental primary relationship is the relationship between funding organisations and the technology developers/suppliers, to initiate the prototyping and proof of concept phase. A transdisciplinary innovation process, will entail active engagement and coproduction of knowledge with key stakeholders in the proof of concept phase.

A key part of the design visioning process is explaining how an alternative future state will yield positive outcomes for stakeholders. Table 5-3 identifies the key stakeholders and explicates the potential benefits the system will yield for stakeholders.

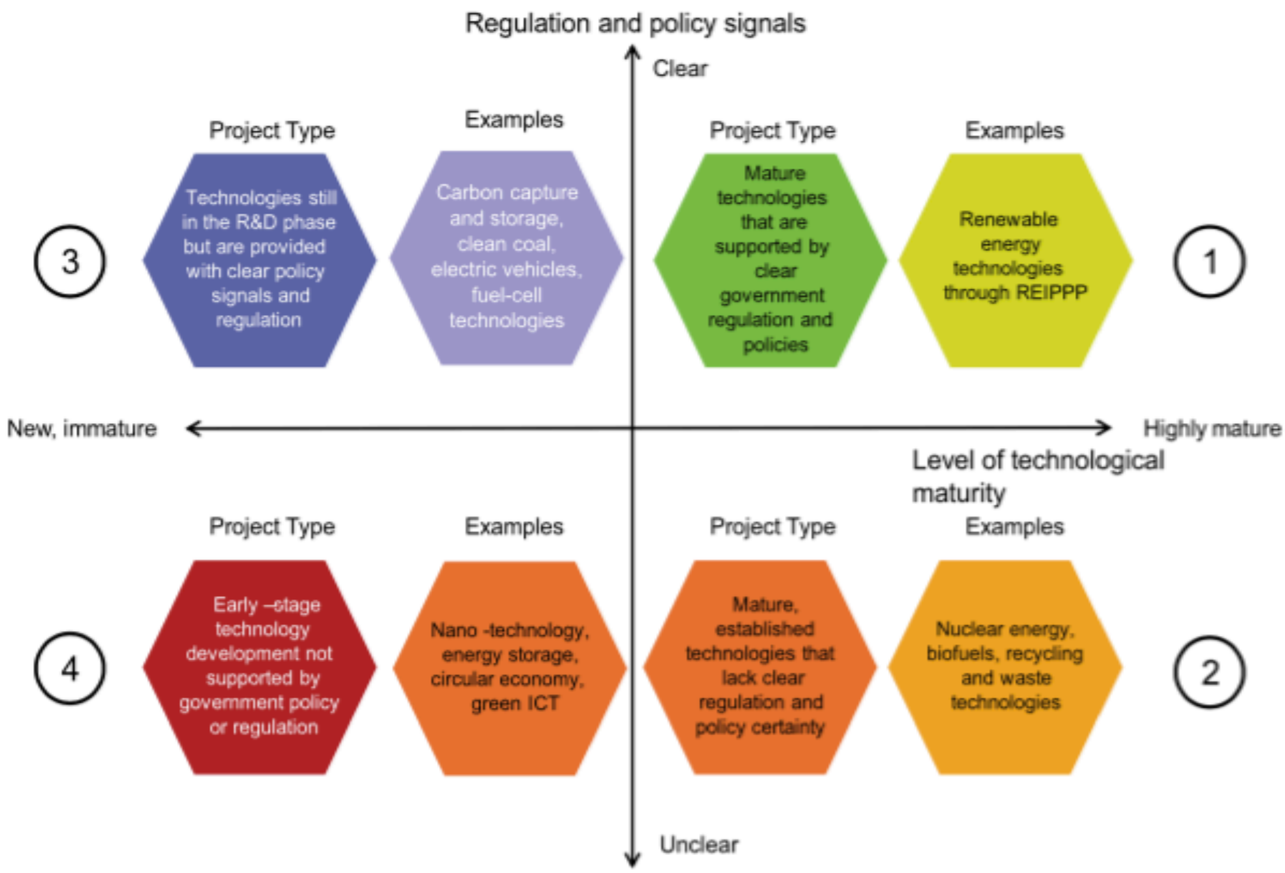
Table 5-3 Stakeholder benefits matrix for the internet-of-waste pickers

Stakeholders	Benefits
Waste pickers	• Better working conditions • Higher wages • Transport (manually) recyclable materials shorter distances • Time saved during buy-back-transfer process – automated and digitised • Cashless payment system accessed with e-card via connected buy-back-transfer substations • Basic financial services – customised fee-less waste picker savings account • Material flow and user behaviour data analytics will be used to increase the efficiency of the infrastructural system city wide, improving the user experience for waste pickers
Waste collectors	• Time and energy saved during the buy-back-transfer and collection process • Intermodal storage – protecting materials from weathering • Real time material flow data – characterisation, mass flow, location and frequency • Route optimisation (reducing transport emissions) via mobile application • Cashless payment via mobile application • Material flow and user behaviour data analytics will be used to increase the efficiency of the infrastructural system city wide, improving the user experience for waste collectors
Municipalities	• Increased recycling efficiencies and improved urban metabolism • Emissions reduction – diversion of waste from landfill • Semi-formalised waste picker networks
Industry – recyclers and reprocessors	• Material flow tracking – predictive analytics • Supply chain consistency
Households and businesses	• Better recycling services – source separation, collection and intermodal storage • Designated bag system for dry recyclable materials to be collected by waste pickers

5.4 Circular economy innovation outlook

In South Africa, there are various policy, institutional and market related barriers to sustainable innovation and the subsequent diffusion of new sustainable technologies (see chapter two, section 2.2.3). As depicted in quadrant four in figure 5-8, circular economy and green information and communications technologies that are still in the research and development phase lack investment (public and private) and an enabling policy framework (Academy of Science of South Africa, 2014). If the *internet-of-waste pickers* were to mature beyond a virtual design experiment, it would fit into quadrant four (in figure 5-8). Consequently, due to high levels of risk associated with early stage and immature sustainable technologies, there is a need to construct protected and multidisciplinary spaces to support collaborative design, stakeholder engagement, rapid prototyping and pilot testing.

Figure 5-8 Categories of green technology projects according to level of technological maturity and policy signals (Academy of Science of South Africa, 2014)



Ultimately, prototyping new sustainable technologies within a weak national technological innovation system calls for structuring resilient bottom-up and *globally networked niches*, i.e. sufficiently resourced and protected transdisciplinary spaces in which technological innovations can be vigorously tested and developed (Kemp, 1998). Social and environmental technology niches like the *internet-of-waste pickers*, although locally based can be strengthened through global cooperation and collaboration with relevant actors, e.g. engineering faculties at world class universities, international development organisations and global innovation funding organisations. Hence, it is posited that social and environmental technology niches in emerging economies should be purposively structured to engender *global-local innovation networks*.

5.5 Conclusion

In an age of real time climate change, it is critical that emerging economies decouple the economic development from ecological degradation. As clusters of complex economic and industrial activity, cities will play a vital role in reducing resources consumed per unit of economic output. Therefore, improving the metabolic and aggregate efficiency of cites is an important starting point in the race to adapt to the pending resource constraints presented by the adverse impacts of climate change. This study argues that a key factor in improving the metabolism of cities, is closing material loops and extracting greater value from technical nutrients, i.e. divert waste from landfill, in turn transitioning toward *circular economy* practices. To this end, in cities in emerging economies, informal recycling networks play an indispensable role in recovering recyclable materials from urban waste streams – herein waste pickers are identified as the *primary looping agents* in underpinning closed material loops especially in regard to recirculating technical nutrients, e.g. post-consumer packaging waste. Based on the case study analyses, the study argues that circular economy transitions hinges on discovering *lost bits* of information that characterise material flows and *looping this data* to generate the requisite ecodesign intelligence (i.e. correct information asymmetries) to stimulate the development of closed material loops.

From an interdisciplinary perspective, the articulated virtual circular city experiment, *internet-of-waste pickers*, strives to harness the intrinsic self-organising quality of existing informal recycling networks, by reimagining the role of waste pickers in a *cyber-physical-social pattern of organisation*. To this end, co-producing and embedding intelligence in cyber-physical urban symbiosis networks and fostering greater recycling efficiency, value chain transparency and income equality. Alternative modalities of non-profit organisation are a fundamental component of the proposed intervention as it is envisioned within the techno-economic metanarrative of the Third Industrial Revolution, which promulgates *"distributed, collaborative, laterally scaled* *internet communication system, with its open systems architecture and commons-style management"* (Rifkin, 2014).

Chapter 6 – Conclusion

In an era of real time climate change, one of the main challenges facing humanity is to design and nurture ecologically sustainable cities. To successfully achieve this will necessitate a fundamental paradigm shift from *bad to good economic growth*. In the case of emerging market economies, with pressing social and economic development agendas, it is even more pressing to migrate from linear and outdated modalities of production and consumption towards more eco-efficient and egalitarian modalities of economic development. Capra (2014) defines bad economic growth as the *"production processes and services that externalise social and environmental costs, are based on fossil fuels, involve toxic substances, deplete our natural resources, and degrade the earth's ecosystems"*. Whereas, good growth is *"the growth of more efficient production processes and services that fully internalise costs and involve renewable energies, zero emissions, continual recycling of natural resources, and restoration of the earth's ecosystems"* (Capra and Luisi, 2014).

The transition towards ecologically sustainable cities will entail re-designing urban and industrial infrastructural systems to cultivate good economic growth practices, for example developing strategic circular economy practices to recycle technical nutrients and improve the overall metabolism of cities. The following interdisciplinary study explores technology enabled (i.e. cyber-physical-social ecosystems) circular economy (CE) solutions to *designing out waste* in the context of cities in middle-income developing countries like South Africa. The metanarrative is framed in chapters one (problem structuring) and two (literature review) of the study, in doing so revealing the systemic inefficiencies in the delivery of municipal and industrial waste management services in South African cities.

The principal shared learnings from the embedded case study analyses, in chapters three (industrial symbiosis) and four (urban symbiosis), illicit that to stimulate CE practices it is first essential to harness material flow data. In short, it is imperative to generate real time analytics about material flow patterns at a city level. Then to map, analyse and visualise this data to identify opportunities for reusing and recycling materials. The study posits that to close material loops, will depend on *looping material stock and flow data* in doing so connecting generators, recyclers and users of waste in cities and industrial hinterlands. Moreover, the study argues that engendering frictionless resource recovery in urban and industrial systems is predicated upon fostering nested stakeholder networks underpinned by the unrestricted flow of material flow data and supporting big data analytics. Actionable residual resource intelligence is a precursor to cultivating hyperconnected and diverse urban and industrial symbiosis networks.

One of the key contributions of the research is the comprehensive synthesis and testing of an iterative problem structuring, theory building and design visioning *(problem-theory-design)* continuum to inform circular economy experimentation. The research argues that to design a contextualised and meaningful transition experiment, a logical starting point is to use the findings from a theoretically embedded case study to inform the design of a virtual experiment and simulation sketch. In chapter five, a mixed methods design visioning approach is developed through an experiential and iterative design practice nested in a network of interdisciplinary theoretical constructs: 1) philosophical construct – *ecological literacy* (systems thinking), 2) techno-economic construct – *Third Industrial Revolution* (internet-of-things enabled general purpose technology platform), and *circular economy (urban and industrial symbiosis)*, and 3) design construct – properties of ecodesign derived from the dynamic renewable design of natural ecosystem.

The findings from the industrial symbiosis (IS) case study illustrate that firms and supply chain networks recognise the environmental importance of improving industrial waste management practices, however they are locked-in to end-of-pipe solutions. Firms highlighted regulation, price sensitivity, customer pressure and top management as key drivers of pro-environmental behaviour change (e.g. waste beneficiation). The findings highlight the unrealised IS potential in the SDB. In addition, revealing significant barriers to IS, i.e. lack of information sharing between firms and a weak regulatory environment. To increase the detection, matching and emergence of IS relationships will command the dynamic co-production of codified resource flow data; herein a big data analytics approach can be employed to construct open source platforms for interfirm information (e.g. residual resource flows) sharing and knowledge production – *an industrial commons internet*.

The findings from the case study on waste pickers are extrapolated in a CE design visioning exercise. Culminating in the sketch of a virtual circular city experiment; *a cyber-physical-social ecosystem (CPSE)* designed to increase recycling rates in cities by addressing the infrastructural needs of waste pickers. The hardware, software and social ecosystem is built out of an internet-of-things (IoT) platform. Firstly, the platform improves material recovery efficiencies (of post-consumer recyclable materials) by increasing connectivity between waste pickers and waste collectors, in turn looping material flow data. Secondly, the integrated hardware and software platform provides an automated, digitised and decentralised buy-back-transfer service – delivered through connected and solar-powered collection modules strategically distributed throughout the city. Thirdly, the platform aggregates big data and employs advanced analytics to generate actionable residual resource intelligence, consequently enabling evidence-based decision making by key stakeholders, e.g. government agencies, industry associations, recyclers and material reprocessors. The next step is to structure a real-world transition experiment based on the virtual circular city design experiment – *the internet-of-waste pickers*.

To promote a circular economy agenda in South African cities, it is necessary to formulate a collaborative and multilevel eco-design strategy, concurrently emanating across the socio-technical spectrum; public policy arenas, firm-level top management and technology innovation niches. There is a greater likelihood to foster systemic transitions, by illustrating proof of concept via theoretically informed and user-centred transition experiments. To this end, the research elucidates a *problem-theory-design continuum*. The first step is framing the problem in a robust interdisciplinary theoretical framework. The second step is structuring a substantive problem through an embedded case study approach. The third step is distilling the key findings from a case study to inform the design visioning process, culminating in a virtual experiment and simulation sketch. In summation, the research proposes a problem-theory-design continuum as an antecedent to constructing real world circular economy transition experiments. Building upon this study, future research will explore an iterative *problem-theory-design-experiment continuum*, through the prototyping and pilot testing of the *internet-of-waste pickers*.

From a broader socio-technical perspective, the research contributes towards the discourse on how emerging economies will adapt to the next industrial revolution (digitisation, automation and artificial intelligence), i.e. the next great technological leap forward? In this regard, the research highlights the potential for employing a *cyber-physical-social ecosystem* approach to increase recycling efficiency in South African cities.

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Appendix A – Firm level survey questionnaire (industrial symbiosis case study)

Identification:

Name of Organization:

Industrial Sector:

Area:

Physical (street) address:

Code:

Postal address:

Code:

Telephone Number:

Fax Number: E-mail address:

Completed by (name and surname):

Age: Please circle appropriate option

< 30 yrs.	30 – 39 yrs.	40 – 49 yrs.	50 > yrs.

Gender: Please circle appropriate option

Male	Female

Position:

Signed:

Date:

1. General business information

Indicate the status of the establishment?

Circle appropriate option:

Head office/holding firm	1
Branch	2
Subsidiary	3
Independent unit	4

1.2 When did this plant start production at this location?

1.3 When did the present owner(s) of this establishment take over in this capacity?

1.4 What type of products does this establishment produce?

1.5 Do you produce for the local market or for export purposes or both?

	1. Yes	2. No
Local Markets		
Overseas Markets		
Both		

1.6 How many employees does this firm have?

Full-time employees	0-5 10-19 20-49 50-99 100-249 250+	Part-time/contract employees	0-5 10-19 20-49 50-99 100-249 250+

1.7 What was your firm's annual revenue (estimated)?

2. Waste management

2.1 Do you have a person responsible for Waste Management?		Name:
		Job Title:
		Telephone:
		Email:
	2.2 Are the required permits/licences available? (e.g. effluent and waste)	Yes No
Waste Type (Please tick applicable)	2.3 What type(s) of waste does your firm produce?	Chemical Wastes Spent solvents Acid, alkaline or saline wastes Used oils Spent chemical catalysts Chemical preparation wastes Chemical deposits and residues Industrial effluent sludges Metallic Wastes Metallic wastes Healthcare Wastes Health care and biological wastes Non-metallic Wastes Glass wastes Paper and cardboard wastes Rubber wastes Plastic wastes Wood wastes Textile wastes Waste containing PCB Discarded Equipment Discarded vehicles

		Batteries and accumulators wastes WEEE and other discarded equipment Animal & Vegetable Wastes Animal waste of food preparation and products Animal faeces, urine and manure Animal & vegetal wastes Mixed Ordinary Wastes Household and similar wastes Mixed and undifferentiated materials Sorting residues Common Sludges Common sludges (excluding dredging spoils) Dredging spoils Filter cake Mineral Wastes Combustion wastes Contaminated soils and polluted dredging spoils Solidified, stabilised or vitrified wastes Other mineral wastes Construction and demolition wastes Asbestos wastes Waste of naturally occurring minerals Non-wastes Blast furnace slag Virgin timber		
Physical Form			Yes	2. No

	2.4 Identify whether the waste is solid or liquid?	Solid		
		Liquid		
		Sludge		
Nature of Waste	2.5 Is the waste hazardous or non-hazardous?	Hazardous		
		Non-hazardous		
	2.6 If your firm generates hazardous waste, are there emergency procedures in place?	Yes No		
Treatment	2.7 Is waste separated at source?	Yes No		
	2.8 Does the waste require any special treatment?	Yes No		
	2.9 Do you pre-treat any of your waste?	Yes No		
Source of waste data	2.10 What type of waste data do you have for 2010?		1.Yes	2.No
		Weight (tonnes)		
		Volume (m^3)		
		None		
Weight/volume	2.11What is the source of the weight/volume?	Firm records		
		Waste collector returns		
		Other, please state		
		Actual		

	2.12 Are these actual weights or estimated weights?	Estimated		
		Don't know		
	2.13 If A (Actual) or B (Estimated) enter the total tonnage for 2010	[ ] Tonnes		
Waste contractor	2.14 Do you contract a specialist (private) waste contractor?	Yes No		
	2.15 If yes (2.14), what is the name of your waste contractor?			
	2.16 What services do they provide?			
	2.17 Are the fees of waste collection, recovery and disposal a financial burden for your firm?	Yes No		
	2.18 If waste transport/reuse/recycling/treatment/disposal is outsourced, has an audit of the waste contractor been done and when?	Yes No		
	2.19 Are safe treatment/disposal certificates available	Yes No		
	2.20 Do you have a signed operational agreement with your transporter/s of hazardous waste?	Yes No		
Destination of waste	2.21 Where is the waste managed?		1.Yes	2.No
		On-site		
		Off-site		
		Don't know		

<table>
<tr><td></td><td>2.22 Do you know the facilities which the materials are being sent to? (Please state destination; e.g. name of treatment facility or landfill site)</td><td colspan="3">If yes, please state...

Don’t know</td></tr>
<tr><td rowspan="4"></td><td rowspan="4">2.23 Please confirm the type of contract arrangement you have with your waste contractor?</td><td></td><td>1.Yes</td><td>2.No</td></tr>
<tr><td>Set frequency e.g. weekly, daily</td><td></td><td></td></tr>
<tr><td>Collect when full</td><td></td><td></td></tr>
<tr><td>Other</td><td></td><td></td></tr>
<tr><td>Drivers of Waste Strategy (e.g. government regulation)</td><td>2.24 What are the key internal and external drivers of your firm’s waste strategy and practices?</td><td colspan="3">Internal drivers (intra-organisational factors):

External drivers:</td></tr>
</table>

Waste Management	2.25 How is the waste managed?	Land disposal Landfill Land recovery Compost-like output Landfill Inert wastes Unknown Thermal with Energy Recovery Energy from waste (EfW) facilities Pyrolysis Gasification Waste Derived Fuel Unknown Thermal without Energy Recovery Incinerators Crematoriums Pyrolysis Gasification Unknown Transfer Station Treatment Mechanical Biological Treatment (MBT) Biological Mechanical Treatment Autoclave Mechanical Heat Treatment Alternative Treatment Technologies Unknown Recycling Materials Recycling Facility (MRF) Bring banks Reprocessor

		Unknown Composting Windrow Composting In-Vessel Composting (IVC) Anaerobic Digestion (AD) Unknown Reused off-site Recycled Aggregates Secondary Aggregates Unknown Don't know
	2.26 Have you carried out a waste audit in the last 3 years?	Yes No
	2.27 If yes to 2.26, please describe	

	2.28 Do you undertake any waste minimization, re-use or recycling initiatives?	Yes No
	2.29 Have you performed a waste minimization analysis? If so, when?	Yes No
Reused	2.30 Could this waste be reused in production or elsewhere on site?	Yes No Don't know
	2.31 Could this waste be reused offsite by another organization?	Yes No Don't know
Recyclable	2.32 Could this waste be recycled if it is not already?	Already recycled Yes No Don't know
Recoverable	2.33 Could this material be recovered if it is not already, or if it is already recycled? i.e. via incineration with energy, MTB etc.	Already recovered Yes No Don't know
Waste Management Awareness	2.34 Do you have shop floor awareness and involvement in waste management?	Yes No Don't know
	2.35 Is there formal management training in place?	Yes No Don't know

2.36 Waste water discharged (circle and fill in correct answers):

Frequency:	Type:	Estimated Quantity (Tonnes/day):
Periodic	a. Domestic	....
Weekday only	b. Industrial	....
None	c. Combined	....
Other (comment)	d. Floor drain/wash-down	....
	e. Cooling water	....
	f. Other (comment)	....
	g. Total	....

2.37 Waste water characteristics (other than domestic), circle correct answer.

Acid

Alkaline

Metallic

2.38 Describe any pre-treatment facilities or practices used to remove pollutants:

2.39 Is waste water recycled and reused?

1. Yes	2. No

2.40 Which of the following waste categories are problematic for your firm?	1.Yes	2. No
Municipal waste		
Hazardous waste		
Organic waste		
Other waste types (excluding hazardous waste)		

2.41 What kind of evaluations do you undertake?	1. Yes	2. No
Material evaluation		
Energy evaluation		
Other evaluation		
None		

2.42 If other evaluation, please specify...................................

2.43 How do you dispose your municipal waste?	1.Yes	2.No
Landfill disposal		
Disposal by incineration without energy recovery		
Another method		

Other disposal		

2.44 Does your firm have access to or employ the following tools and resources?	1.Yes	2.No
Best Available Technologies		
On-site recycling		
Treatment of 'waste'/by-products		
Environmental Policy		
'Company Industry Waste Management Plan'		
Global Reporting Initiative (GRI)		
Recycling Fund		
Local Waste Market - Economic Use of Waste		

2.45 Does your firm belong to any of the following? Mark the relevant box with a tick).	1.Yes	2.No
IWMSA (Institute of Waste Management of Southern Africa)		
RPMASA (Responsible Packaging Management Association of South Africa)		
NACA (National Association of Clean Air)		
WISA (Water Institute of Southern Africa)		
KZN Waste Minimization Reuse and Recycling Forum		
Responsible Care		
Other (Specify)		

3. Industrial symbiosis

3.1 Does your firm apply the following Industrial Ecology tools/concepts?	1. Yes	2. No
Material Flow Analysis		
Life-cycle Assessment		
Extended Producer Responsibility		
Environmental Management Systems (ISO 14001)		

Design for the Environment		
Supply Chain Management		
Cleaner Production		

3.2 Does your firm have any type of waste which could serve as an input material for other companies?

1. Yes	2. No

3.3 In your industrial area would your firm be able to use waste (by-product) of another firm as an input material for its own processes, under conditions that it meets certain quality requirements?

1. Yes	2. No

3.4 If yes, please explain what type of waste and how it could potentially be exchanged?

Please tick appropriate option:	1= Not at all	2=Limited extent	3= Not sure	4=Certain extent	5=Large extent
3.5 To what extent does industrial waste exchange (treatment and trading of by-products) occur in your industrial area?					

Please tick appropriate option:	1= Not at all	2=Limited potential	3= Not sure	4=Certain potential	5=Large potential
3.6 What is the economic potential of reusing industrial waste in your industrial area (e.g. trading of 'waste'/by-products between firms from different sectors)?					

3.7 Does your firm own any unused/vacant spaces, which could be offered to another firm?

1. Yes	2. No

3.8 Would your firm be able to use any unused/vacant spaces of another firm?

1. Yes	2. No

3.9 Does your firm have resources/spare capacities (e.g. infrastructure, logistics) that could be offered to other companies?

1. Yes	2. No

If yes, specify some of these

3.10 Would your firm be interested to join a co-operation system between firms which will result in saving costs related to waste management, input materials, unused capacities and other methods (system of industrial symbiosis)?

1. Yes	2. No

3.11 Based on the quantity, please indicate (tick the appropriate option) the 3 most important types of resources your firm uses as input:

Material	
Energy	
Logistics	
Water	
Expertise	
Land	

3.12 In your industrial area what are the opportunities for inter-firm cooperation (industrial symbiosis) with regard to industrial waste management (e.g. 'waste'/by-product exchange)?

3.13 In your industrial area what are the barriers to inter-firm cooperation with regard to industrial waste management?

3.14 In your opinion what can be done by industry to stimulate the growth of the waste economy?

3.15 In your opinion what can be done by government to stimulate the growth of the waste economy?

4. Environmental management

4.1 Do you have an Environmental Policy that incorporates integrated waste management?

Yes	No

4.2 Has your firm implemented ISO 14001 or other environmental management systems in order to reduce its environmental impact?

1. Yes	2. No

If yes, specify the kinds of systems that are in place.

4.3 Which of the following types of pollution are significant in relation to the activities of your firm?	1.Yes	2.No
Waste generation		
Air pollution		
Water pollution		

4.4 Has your firm tried to reduce its environmental impact with the following methods?

	1. Yes	2. No
Energy conservation		
Waste minimization, reuse		
Pollution prevention (e.g. air, water)		
Sustainable means of transportation		

4.5 Reasons for not trying to reduce environmental impact with the above methods	1.Yes	2.No
Lack of information		
Lack of resources		
Lack of expertise		
Lack of financial resources		
Lack of interest		

4.6 Does your firm take into account the potential environmental impact when developing new products and services (e.g. energy use, recycling or pollution assessment)?

Yes	No

4.7 Would your firm be able to save money by reducing its environmental impact?

Yes	No

4.8 What types of monitoring and reporting mechanisms does your firm use to report on sustainability issues?

4.9 Does your annual report include waste management?

Yes	No

4.10 Is there a community/social outreach programme(s) to promote environmental awareness?

Yes	No

5. Corporate environmentalism

5.1 Please describe your firm's environmental orientation by ticking the appropriate option in the statement evaluation below:	1=Strongly	2=Disagree	3=Undecided	4=Agree	5=Strongly
At our firm, we make a concerted effort to make every employee understand the importance of environmental preservation					
Our firm has a clear policy statement urging environmental awareness in every area					
Environmental preservation is a high-priority activity in our firm					
Preserving the environment is a central corporate value in our firm					
The financial well-being of our firm does not depend on the state of the natural environment					
Our firm has a responsibility to preserve the environment					
Environmental preservation is vital to our firm's survival					
Our firm's responsibility to its customers, stockholders, and employees is more important than our responsibility toward environmental preservation					
The natural environment does not currently affect our firm's business activity					
In our firm, environmental preservation is largely an issue of maintaining a good public image					
It is difficult for our firm to be successful and preserve the environment at the same time					
In our firm profits are more important than our environmental activities					

It is our firm's mission to be a leader in environmental protection in our industry					

5.2 Please describe your firm's environmental strategy by ticking the appropriate option in the statement evaluation below:	1=Strongly	2=Disagree	3=Undecided	4=Agree	5=Strongly
Our firm has integrated environmental issues into our strategic planning process					
In our firm, ''quality'' includes reducing our environmental impact					
At our firm, we link environmental objectives with our other corporate goals					
Our firm is engaged in developing products and processes that minimize environmental impact					
Environmental issues are always considered when we develop new products.					
We emphasize the environmental aspects of our products and services in our advertise					
Our marketing strategies for our products and services have been influenced by environmental concerns					
In our firm, product-market decisions are always influenced by environmental concerns					
Environmental issues have been integrated into all functional areas of our business					
Our firm must be accountable for the way its actions affect the natural environment					
Environmental issues are always considered when we discuss our strategic plans					
All employees in our firm are responsible for developing environmental initiatives					
Our firm has established environmental standards as a performance criterion for all our products and services					
All functional managers in our firm have clear instructions for implementing company environmental goals					

Our firm's environmental efforts mainly revolve around compliance with current environmental regulation					
Environmental protection is the driving force behind our firm's strategies					
In our firm, technology decisions are always influenced by environmental concerns					
Our firm is engaged in exploring markets for environmental goods and services					

5.3 Which of the following has your firm adopted? (Please tick appropriate option)	Yes	No
Redesign equipment or process to reduce resource consumption		
Redesign equipment or process to reduce pollution emission		
Passed or will pass ISO14001 certification		
Recycle production scraps		
Launch new environmentally friendly products		
Use environmentally friendly materials in product production		
Reduce environmental pollution in product utilization		
Reduce resource consumption in product utilization		

5.4 Describe your firm's environmental strategic approach, by completing the following statement evaluation:	1=Never	2=Rarely	3=Sometimes	4=Very often	5=Always
Take environmental protection as an opportunity rather than an issue affecting cost minimization					
Pay attention to market and policy change and promptly adjust corporate behaviour as market and policy change					
Pay attention to the existing market and short-term costs/benefits and single out efficiency as the overriding principle					

Minimal compliance to environmental regulations to pursue most cost-effective solutions					

5.5 The following statements relate to your firm's communication activities with your primary suppliers. Our firm …	1=Never	2=Rarely	3=Sometimes	4=Very often	5=Always
Provides information to help our primary suppliers improve					
Exchanges operational and logistical information with primary suppliers					
Exchanges information informally with primary suppliers without pre-specific agreements					
Informs our primary suppliers about events or changes that may affect them					
Has face-to-face communication with primary suppliers for planning purpose					

5.6 The following statements relate to your primary suppliers' commitment to your firm. Our primary suppliers …	1=Never	2=Rarely	3=Sometimes	4=Very often	5=Always
Visit our premises to help us to improve our performance					
Provide training on their products					
Help us in process improvement activities (e.g. value analysis, cost reduction, problem solving)					
Collaborate in the design of new products or new product lines to be introduced at our firm					

5.7 During the past two years, to what extent did your firm engage in the following environmental activities with your primary suppliers?	1=Not at all	2=Small extent	3=Moderately	4=Fairly great	5=Great Extent
Achieving environmental goals collectively					
Developing a mutual understanding of responsibilities regarding					

environmental performance					
Working together to reduce environmental impact of our activities					
Conducting joint planning to anticipate and resolve environmental related problems					
Making joint decisions about ways to reduce overall environmental impact of our products					

5.8 Our firm's involvement in green activities has been motivated by:	1=Not at All	2=Small	3=Moderatel	4= Fairly	5=Great
The example top-management provides					
Requirements made by senior management					
Top-down initiatives					

5.9 Our firm's green activities have been motivated by:	1=Not At All	2=Small	3=Moderately	4=Fairly	5=Great
Current government legislation					
The threat of future legislation					
Targeted threat of future activist groups					

5.10 Our firm's involvement in green activities has been impacted by:	1=Not at All	2=Small	3=Moderatel	4=Fairly great	5=Great
Uneconomic recycling					
Uneconomic reusing					

High cost of cleaner production technologies and environmental programmes (e.g. staff training)					

5.11 Our firm's involvement in green activities has been motivated by:	1=Not at all	2=Small extent	3=Moderately	4=Fairly great	5=Great Extent
Green programmes that our customers have in place					
Customers who seek green suppliers					
Increased awareness of green issues among our customers					

5.12 The following statements relate to your firm's adoption of green purchasing. Our firm has executed:	1=Not at all	2=Small extent	3=Moderately	4=Fairly great	5=Great Extent
Providing design specification to suppliers that include environmental requirements for purchased items.					
Cooperation with suppliers for environmental objectives					
Environmental audit of suppliers' internal management					
Suppliers' ISO14001 certification					

Appendix B – Waste picker questionnaire (urban symbiosis case study)

Identification:

Name of Respondent:

Landfill Site:

Household Residence (Area):

Physical (street) address:

Code:

Telephone Number:

Interviewer (name and surname):

Age:

< 18 yrs.	18 – 20 yrs.	20 – 30 yrs.	30 – 39 yrs.	40 – 49 yrs.	50 > yrs.

Gender:

Male	Female

Education:

Primary School	High School (incomplete)	Matriculation	Tertiary Education

Signed by Respondent:

Date:

1. Household Profile

1.1 Marital status:

Single	Married	Divorced	Widow/widower

1.2 Do you have any children? If so, how many and what are their ages?

1.3 What is your employment status?

Unemployed	Employed	Self-employed

1.4 If employed, please describe the type of employment and contractual agreement with employer?

1.5 If unemployed, please provide reasons why?

1.6 Do you have a bank account? If yes, which bank?

1.7 Are you apart of a community savings club (e.g. stokvel)?

1.8 Do you own a cell phone?

1.9 What is your personal average weekly and monthly income? How much do you earn per day?

1.10 How much of this income do you earn from waste picking?

1.11 Do you have other sources of income, if so what are your weekly and monthly earnings?

1.12 Does anyone in your household receive any government grants (e.g. child support grant)?

1.13 What is the average weekly income of your household?

1.14 How many people live in your household?

1.15 Number of dependents (e.g. children, grandparents)?

1.16 Who is the head of your household (e.g. father)?

2. Waste picking

2.1 How long have you been working in the waste picking sector?

2.2 How did you get this job?

2.3 Do any of your household members work in the waste picking sector? If yes, who (e.g. brother) and for how long?

2.4 Do you any of your community members or friends work in the waste picking sector?

2.5 How many days per week do you work? On a typical day how many hours do you spend at work?

2.6 What form of transport do you use?

2.7 Approximately how far do you live from your work place? How long does it take you to get to work?

2.8 Please can you describe a typical work day? What activities do you do?
(Create a time line of the respondent’s typical work day: allow respondent to explain how much time each activity takes, for example “I wake up at 5am and take one hour to prepare my children for school and then I go to work, and it takes one hour to go to work....”)

2.9 What, if any, relations do you have with other landfill workers or waste pickers?

2.10 If yes, who do you interact with and what type of interactions occurs?

3. Value chain analysis

3.1 Please describe the waste picking process?

3.2 Who are the main actors? Please list them:

3.3 What is your role in the waste picking sector?

3.4 What materials do you collect/sort? Please list them:

3.5 Rate the value of the different materials you collect. Which is the most valuable? Which is the least valuable?

3.6 How is the value of materials decided?

3.7 What do you do with the collected material?

3.8 Who collects the waste/recyclable materials (e.g. DSW, EnviroServ, WasteMan)?

3.9 Who transports the waste/recyclable materials?

3.10 Who buys the waste/recyclable materials?

3.11 Who sells the waste/recyclable materials?

3.12 How are you compensated for your work? Are you paid per kilogram of waste collected? Are you paid according to the type of material you collect?

3.13 Do men and women earn the same amount of money?

3.14 Do some waste pickers earn more than others? If so why?

3.15 Do you know of any waste pickers who started their own waste collecting/recycling micro-enterprise (small business)?

4. Waste picker organisations

4.1 Are you a part of a waste picker association?

4.2 If yes, what are the advantages and disadvantages of x association?

4.3 If no, in your opinion are there any potential advantages or disadvantages of forming an association?

5. Safety and health

5.1 Are there any risks/dangers associated with your line of work? If so, please describe them.

5.2 Have you developed any health problems since you started working as a waste picker?

5.3 Do you use any safety measures or safety equipment when carrying out your work?

5.4 If no, is there a need for safety measures to be put in place? Please describe.

5.5 How do you personally attempt to protect your safety and your health whilst doing your job?

6. Barriers/challenges

6.1 What barriers/challenges do you encounter as a waste picker?

6.2 How do these barriers affect the sector?

6.3 How do these barriers affect you personally?

6.4 How do you think these barriers can be overcome?

7. Benefits/opportunities

7.1 What are the benefits of waste picking?

7.2 Does waste picking benefit your family and community? If so how?

7.3 What opportunities does waste picking provide?

7.4 What can be done by government to improve the lives of waste pickers?

Appendix C – Conference paper (published)

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A MIXED METHODS DESIGN TO ASSESS CORPORATE ATTITUDES TOWARDS INDUSTRIAL ECOLOGY: ADVANCING SUSTAINABLE WASTE MANAGEMENT

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SUMMARY: *To advance sustainable industrial waste management, it is imperative to cultivate concepts of industrial ecology (IE) at a strategic decision-making level within firms. In the context of South Africa this study is premised on the suppositiom that one of the key drivers of sustainable industrial waste management practice, is the proactive environmental strategic orientation (grounded in a pro-NEP worldview) of top management espoused within the domain of IE. The proposed mixed methods design will test this hypothesis by investigating the relationship between the level of corporate environmental strategic orientation and the taxonomy of waste management planning and practices exhibited by firms in the South Durban Basin, KwaZulu-Natal.*

1. INTRODUCTION

In South Africa industrial waste management remains problematic. Waste management practices primarily focus on the treatment and disposal of waste, consequently firms' exhibit low levels of waste minimization and reuse, recovery and recycling. However, the attitude of South African industries is starting to change as waste management becomes more costly due to stringent environmental regulations. This paper posits that in order to transform the management and treatment of waste, it is imperative to incubate, nurture and advance concepts of industrial ecology at all institutional levels. Overall, there is a paucity of reliable and comprehensive data on the waste sector in South Africa; hence there is a need to conduct in-depth firm-level industrial studies on waste management policies and practices.

Firstly, this paper provides an overview of recent South African state economic policy and legislative discourse, calling for transitioning towards a green economy, of which, the implementation of a national integrated waste management (IWM) framework is integral.

Secondly, this paper draws on an extensive literature review to illustrate to what extent waste management policies and practices can be formulated within an industrial ecology conceptual framework. Thirdly, this paper informs the design of a mixed methodology framework to explore the key drivers (internal and external factors) influencing waste management policies and practices; and in turn investigating if corporate strategic environmental orientation aligns with concepts of industrial ecology (IE) in advancing sustainable waste management practices within the policy prescribed IWM planning framework.

This paper is the first of a series of papers which feeds into a broader research project which undertakes an assessment of waste management by manufacturing firms situated in the South Durban Basin (SDB) in the industrial province of KwaZulu-Natal (KZN), South Africa. The objectives of broader research project are: to understand what types of waste is generated, to understand the economic costs and drivers of this waste, to assess the economics of how this waste is processed and managed, and to examine the possible economic opportunities arising from the management of this waste. Furthermore, the project aims to understand how management of waste in the SDB can contribute towards the growth of a green economy and contribute to employment creation.

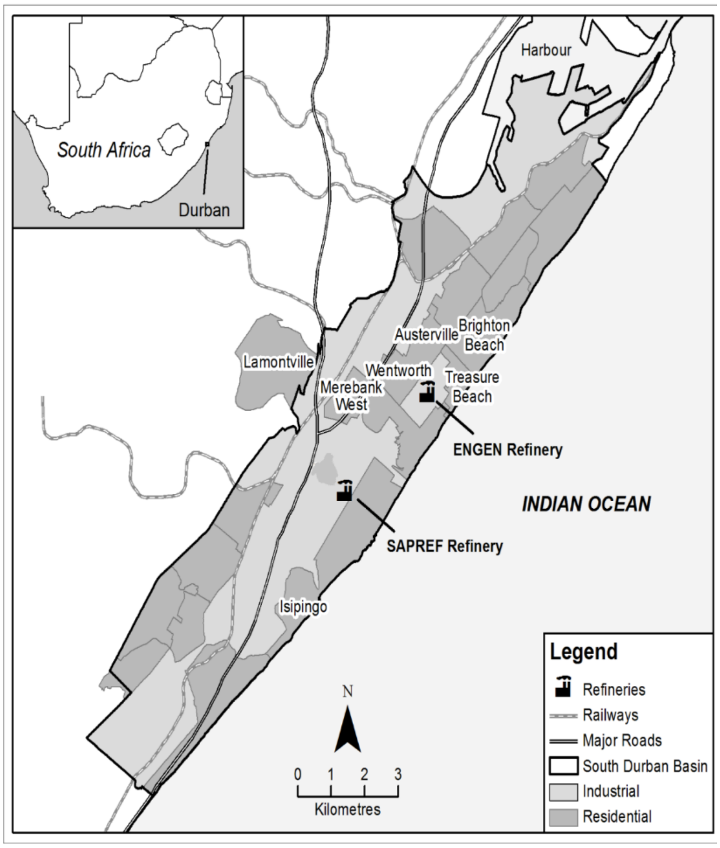

Figure 1: South Durban Industrial Basin, South Africa

The SDB is the major manufacturing and industrial zone in the city and is estimated to contribute some 30% of Durban's GDP, and is seen as the second-largest concentration of industrial activity in South Africa. The development of SDB has its origin in apartheid spatial planning, with the site identified in the 1950s for industrial development in addition to serving as a residential node housing African, Coloured and Indian communities (van Alstine, 2007). Today it is estimated that the area is home to approximately 300 000 people, with majority of the population from black communities[50], living alongside four crude oil refineries, two of which are the largest crude oil refineries in South Africa – refining approximately 60% of the country's petroleum (see Figure 1). Moreover, the SDB comprises "Africa's largest chemical storage facility, and over 180 smokestack industries," many associated with the petro-chemicals sector, in addition to being the largest regional employers (van Alstine, 2007). Pollution in the SDB remains a serious environmental and public health concern; threatening resident communities' constitutionally protected right to a clean and healthy environment. These low-income communities are exposed to a disproportionate exposure to a hazardous environment and sulphur dioxide pollution; faced

[50] According to South African legislation, the Broad-Based Black Economic Empowerment Act of 2003 defines "black people" as a generic term that includes "Africans, Coloureds and Indians" (http://www.southafrica.info).

with health hazards linked to petrochemical industrial production. However, the SDB is also demarcated as a strategic site for South Africa's economic growth, particularly in the value added manufacturing sectors such as chemicals, plastics, metalworking, and the motor industry (Barnett and Scott, 2007). It is within this context that issues of industrial pollution and waste are juxtaposed against socio-economic development and understanding the parameters shaping waste management in the SDB. So far research on firm behaviour in the SDB has yet to critically analyse the production and management of waste within an understanding of strategic firm-level decision-making. To this end, this paper constructs a comprehensive theoretical framework to cultivate a mixed methodology approach; to explore the attitudes of top management towards corporate environmental strategic orientation and waste management. In short, to what degree do firms in SDB incorporate innovative environmental thinking (aligned with IE principles) to inform strategic actions regarding waste management?

2. SOUTH AFRICA'S NEW GROWTH PATH AND WASTE MANAGEMENT POLICY

The South African government's support for the transitioning towards a green economy as outlined in the New Growth Path (NGP) (2010), is premised on the fact that not only is it a response to growing concerns of climate change, but that it also represents a key growth strategy proposing to create 400 000 decent jobs nationally by 2030.[51] The development of an effective national integrated waste management strategy forms a central component to this, motivated by increasing levels of urbanisation, costs associated with waste as well as sheer scale of waste, with the current municiple solid waste output at 24Mt/yr, with mining related waste contributing a further "430 Mt/yr and 34Mt/yr of power station ashes" (Peter and Swilling, 2011).

In 2004, "the Environmental Goods and Services (EGS) sector in South Africa was valued at between R14, 5 billion and R23, 2 billion (US$ 3-4 billion or 1%-1,6% of GDP)," of which the waste management sector accounted for 80% of this activity (Peter and Swilling, 2011). More recent figures in the 2010 Green Economy Summit held in Johannesburg argue, the waste management sector accounts for a total direct expenditure of R10 billion per annum, in addition to significant indirect returns on investment for health, including poverty alleviation through preventative governance (GES, 2010:52). The development of a green economy is however contingent, or hinged upon, the development of a sophisticated knowledge economy. This transition towards a green and knowledge intensive economy will be realised through focusing research and development capacity to maximise growth in existing sectors in manufacturing and

[51] Keynote address by Mr. Ebrahim Patel, Minister of Economic Development at the Green Economy Summit, held on the 18-20 May 2010 in Johannesburg, South Africa.

primary resource processing sectors, in addition to transitioning to a sustainable growth path (NGP, 2010:17).

Reform however, cannot be a stand-alone policy process, but rather requires a sophisticated synchronisation of environmental governance, impact analyses and technological innovation. The need for environmental governance is especially pertinent where economic activity "places heavy demands on the environment," such as "the raw material industries, and equally so of energy, transport, building and agriculture" (Jänicke and Jörgens, 2009). Without due consideration given to the sustainability of the environment, persistent ecological problems arise, often complex in nature and vast in scale, requiring specialised and costly intervention to mitigate ecological crisis. In abscence of a coordinated response to ecological governance the state is often faced with the financial and ecological costs as a result of private sector actors absconding from responsibility, due in part either to weak state precedent or governance. For example, soil or ground water contamination, or ozone depletion associated with heavy carbon orientated industry (Jänicke and Jörgens, 2009).

Taking this into consideration, there is thus a critical need for ecological governance by way of synchronisation of policy premised on socio-ecological sustainability through a bargaining and building process with relevant stakeholders (Jänicke and Jörgens, 2009). In a developing context such as South Africa, this requires a capacitated state-led process to build upon institutional knowledge and to foster partnerships with key private sector actors. This is necessitated that even though "sustainable development is widely accepted as a policy framework in planning and development....in South Africa," the implementation of such a policy has proven to be difficult due to a dearth of state institutional capacity, in both implementation capacity, and institutional precedent (Jänicke and Jörgens, 2009). On this basis the state follows a path of reactive ecology-economy governance rather than preventative governance (Oelofse et al., 2009).

This is evidenced specifically in the "lagging" development of an national integarted waste management strategy, with the state, for the first time in 2009, introducing the globally recognised 3R's principle reduce, recycle and re-use, in the National Integrated Waste Management Act (Peter and Swilling, 2011). Core to the introduction of the Waste Managment Act (2009) concerns the introduction of a National Waste Mangment Strategy (2009) requesting industry to submit Industry Waste Mangment Plans (IndWMPs) as per section 28 to section 34 of the Waste Mangagement Act, however, failing to make this a universal mandatory policy commitment. It is within such a context that the onus for ecological governance enforcement and the realistion of a green economy through policy interventions alone will fail to materialise. On this basis the potential and value of industrial ecology resides in linking growth potential through ecologically sustainable development practices driven by community-public-private partnerships, with a particular emphasis on the role of firms.

3. THEORETICAL FRAMEWORK

3.1 The Industrial Ecology Paradigm

IE is a relatively new interdisciplinary field of academic study emerging as an important set of concepts from the theory and practice of sustainable development. The main ontological commitment of IE is founded on the metaphorical insight that unsustainable industrial systems should observe nature and learn from the structure and dynamics of natural ecosystems. In the first edition of the seminal book *Industrial Ecology*, the concept is defined as (Graedel and Allenby, 1995):

> Industrial ecology is the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital.

Later, in the second edition of their textbook Graedel and Allenby (2003) they refine their definition of industrial ecology, inspired by biological ecology, in which they say (Hermansen, 2006):

> A working definition of Biological Ecology (BE) is the study of the distribution and abundance of organisms and their interaction with the physical world. Along the same lines, IE can be defined as follows: Industrial ecology is the study of technological organisms, their use of resources, their potential environmental impacts, and the ways in which their interactions with the natural world could be restructured to enable global sustainability.

The overarching thesis is that if production and consumption methods and trends in human designed systems could be re-engineered to emulate the synergetic efficiencies of natural systems then greater sustainability would arise. In essence seeking to transform current industrial processes from linear (open loop) to closed loop systems based on the principles of ecology; whereby the wastes and by-products created within one system are utilized as energy or raw materials for another system (Nanas and Bellestri, 2011). Hence, “raw material and fuel costs on the input side and waste and emission management and control costs on the output side can be reduced while new market opportunities can emerge for products with less impacts” (Korhonen et al., 2004).

The most common practical example for the industrial ecosystem concept is the local industrial symbiosis, also referred to as an eco-industrial park, at Kalundborg in Denmark; where companies have achieved "environmental and economic gains through waste and by-product utilisation in industrial ecosystem-type cooperation" (Korhonen et al., 2004). Some of what the Kalundborg industrial park has achieved includes:

- Significant reductions of the consumption of energy and resources such as coal, oil, and water
- Reduction of harmful emissions and reduced volumes of effluent water
- Conversion of traditional waste products into raw materials for production

IE involves the design of industrial processes and products from the dual perspectives of product competitiveness and environmental interaction (Pongracz, 2006). The conceptual framework provided by IE can be useful to firms seeking to improve their resource productivity and in turn their competitiveness. The systems perspective that IE promotes can cultivate a certain type of strategic corporate thinking that may lead to innovations that improve efficiency, lower costs, and raise the value created by production processes and up and down the supply chain (Esty and Porter, 1998). In regard to the institutionalisation and application of IE principles Korhoen (2004) states:

> IE has mainly been developed in engineering and natural sciences, cultural studies, management and organisational aspects are now observed as those that would enable us to identify and analyse the deciding factors of sustainable development, and in particular, in practice when dealing with the practical challenges in organisations and business strategy as well as when learning about and trying to change the behaviour of individuals or their groups and network.

Furthermore, Korhonen argues that strategic thinking is the imperative antecedent, to achieving real success in practice, because ultimately IE principles must be embedded in the business strategy and decision-making structures at an intra-organisational level. In addition, "the systems and network philosophy of IE can be coupled with inter-organisational management studies to complement the more traditional intra-organisational environmental management" (Korhonen et al., 2004). IE, presents a conceptual framework for: environmental analysis and decision making, promoting technological innovation, developing a preventive stance toward environmental problems, and highlighting the vital role of firms in realizing environmental goals (Graedel and Allenby 1995).

Since IE has been largely unexplored in management and policy studies; there is an opportunity to investigate this topic through the transdisciplinary lens of mixed methods research. As a systems-oriented approach, IE concentrates on groups of firms and their stakeholders and how they interact to achieve more sustainable outcomes. Therefore, "stakeholder management theory" is an important path to pursue in linking corporate environmental management theory to IE (Korhonen et al., 2004). Furthermore, environmental management issues have extended the narrow scope of traditional stakeholder theory in that more stakeholders need to be taken into account (Madesn and Ulhoi, 2001). Korhonen et al conclude that "stakeholders should include not only the standard members – the owner, the employees and the authorities – but also neighbours and non-governmental organisations concerned with environmental issues such as waste and pollution".

3.1.1 Advancing Industrial Ecology in South Africa

From an IE life cycle perspective, South Africa still finds itself in the birth and growth life-cycle phases, with some informal and formal networks, and mostly in the regional efficiency stage. Regional learning has occurred due to; integrated waste exchange using an internet based exchange platform, the establishment of waste minimization clubs and the increase of cleaner production initiatives (Brent et al., 2008). Furthermore, Brent et al assert that the public and private sectors have in the past adopted only the tools that are used in terms of the dematerialization and decarbonization focus of industrial ecology, namely life-cycle assessment (LCA) and material flow analysis (MFA). In turn, the application of these tools has been incentivised by the establishment of the Designated National Authority (DNA) for the Clean Development Mechanism (CDM). CDM provides the means to finance projects that minimize greenhouse gas (GHG) emissions; with IE tools employed to quantify potential GHG reductions (Brent et al., 2008).

To advance IE in the context of South Africa progress in terms of institutionalizing the field can be made via industrial symbiosis strategies at local and regional levels. In this regard, the concept of international eco-industrial parks (EIPs) is envisaged in the planning of South African industrial development zones (IDZs) however the ideal has yet to manifest in practice. There are various barriers to the formation and management of an industrial ecosystem (Brent et al., 2008):

- Company concerns with regard to propriety or confidential information;
- negotiating balance of payments;
- reluctance on the part of business to be involved in inflexible contractual commitments that do not relate directly to their core activity; for instance, guaranteeing a waste stream for a contractual period;
- supervision and operation of co-treatment facilities; and
- the complexity managing the wastes produced by the companies

Brent et al highlight that an additional barrier in the context of South Africa is that "there is no legislative support for industrial symbiosis; specifically there is no clear guidance as to the responsibilities of the parties associated with the waste streams". More importantly they stipulate that more emphasis should be on the development of mechanisms that encourage firms to manage waste streams effectively while leaving them the necessary freedom to develop new and profitable uses for by-products. In sum, Brent et al (2008) propose five mechanisms to promote industrial symbiosis in South Africa:

- Working through public-private partnerships, for example, between local authorities who operate treatment facilities and landfill sites, industries that discharge problem waste to these facilities and sites, waste companies that specialize in waste re-use and recycling, and national government that is responsible for legislative guidelines;
- using the South African National Cleaner Production Centre (NCPC) to develop and assist with the implementation of appropriate technologies and procedures for industrial symbiosis;
- use of trading platforms to link waste generators and waste re-users and recyclers;
- introducing funding mechanisms, particularly to enhance and support the exchange of low value commodities; and
- linking waste minimization clubs, waste exchanges and future industrial ecological parks and zones.

3.2 Industrial Ecology and Sustainable Waste Management

The traditional reductionist approach towards waste is fundamentally unsustainable as it lacks flexibility and long term thinking (Seadon, 2010). A transition to a sustainable society requires a critical systems approach towards waste management, especially at an intra and inter-organisational levels. In this regard, "waste management has many of the characteristics reminiscent of a living system, an example of a complex adaptive system" (Seadon, 2010). A systems-oriented vision, constructed on the principle that industrial design and manufacturing processes are to be considered in partnership with the environment, is what sustainable waste management needs to grow into (Pongracz, 2006). Seadon (2010) posits that "a sustainable waste management system incorporates feedback loops, is focuses on processes, embodies adaptability and diverts waste from disposal".

Therefore, IE as a systems-oriented approach of industry-environment interactions to aid in evaluating and minimising environmental impacts, provides an ideal scientific canopy to frame Waste Management Theory (WMT) (Pongracz, 2006). WMT offers procedural models to achieve the goals of waste minimisation and resources use optimisation under the IE paradigm. In this regard, Pongracz argues that WMT will be instrumental in "optimising resources use from virgin material, to finished material, to component, to product, to obsolete product, to disposal and, eventually, re-integration into the material cycle". WMT is essentially based on the following considerations (Pongracz, 2006):

- Waste management is to prevent waste from causing harm to human health and the environment.
- The primary aim of waste management is the conservation of resources.

- By applying waste management, we shall avoid loss of resources.
- Prevent waste from being produced by creating useful products (non-wastes) primarily.
- The role of waste management is to turn waste into non-waste.

4. HYPOTHESIS DEVELOPMENT

Arguably, in the case of South Africa due to the lack of state institutional and technical capacity, the move towards a green economy will primarily have to be driven by the private sector, in particular at an inter and intra-organisational level. To this end the IE paradigm promotes ‘the eco-efficiency ideal’; thereby providing a conceptual framework for firms to design and pilot innovative strategies to pursue more sustainable business scenarios. Although firms and supply chain networks may recognize the importance of environmental performance and improving waste management systems, the critical issue is how to induce strategic long-term sustainable firm activities? In a study, addressing organisational challenges to IE, findings indicated that while technical solutions to improve waste management systems can be developed, the difficulty resides in the organisational issues connected to introducing IE (Dahl et al., 2001). The main challenge is to include proactive environmental thinking in production processes and strategic actions. Hence, it is argued that apart from technologies, environmental legislation and environmental management systems, human attitudes and environmental awareness are delineated as one of the significant drivers of waste prevention (Pongracz, 2009). At a firm level, top management commitment is the a decisive driver for success in balancing economic and environmental performance (Yen and Yen, 2011). Thus, it is contended that at a firm level, top management’s proenvironmental strategic orientation (aligned with IE principles) and commitment is a critical antecedent to systemically integrating environmental concerns into product design and industrial process design.

4.1 Research Questions

Based on the hypothesis, the following research questions and sub-questions will be probed through the implementation of a mixed methods research design:

- What is the nature of top management’s strategic orientation towards environmental management?
- In regard to waste management, to what degree is top management’s strategic orientation aligned with IE principles?
    - What are the key internal and external factors influencing waste management policies and practices of firms?
    - What types of waste is generated by firms in the SDB?

  - How is waste generated by firms based in the SDB being processed and managed?
  - Do firms in SDB cooperate in managing their waste? If so how and to what degree? What are the opportunities and threats to inter-organisation cooperation in regard to managing waste streams?
  - How are firms adapting their production techniques to minimize waste and reuse waste generated in the SDB?
  - What is the scope and potential for further reusing the waste generated in the SDB?
- In regard to waste management do firms use tools and methods that contribute to IE?

5. MIXED METHODS RESEARCH DESIGN

The outcome of this paper is the design of a mixed methods research design which is based on previous literature. Mixed methods research is described as an intellectual and practical synthesis based on qualitative and quantitative research (Johnson et al., 2007). The chosen mixed methods design consists of qualitative and quantitative approaches, includes a questionnaire survey and semi-structured interviews.

The questionnaire survey is a follow-up to the 2002-3 Greater Durban Metropolitan Area (GDMA) firm survey, which was important for an understanding of manufacturing performance and allowed some areas of policy change tailored to the local context. However, the initial firm level survey did not specifically explore the complexities of waste management in the SDIB. Therefore, the 2011 re-survey will have an explicit focus on waste management and sustainability issues; with a designated focus on investigating corporate attitudes towards IE as a conceptual framework to advance sustainable waste management. Top management (CEO and senior managers) are responsible for setting corporate strategic orientation, hence their views are valid in assessing a firm’s environmental management strategic orientation and waste management practices (Wang and Li, 2010). The initial questionnaire survey will target top management (including environmental managers) of medium and large-sized manufacturing firms in SDB; including firms from the 2002-3 GDMA sample. The questionnaire will consist of closed and open-ended questions, including the application of the New Ecological Paradigm (NEP) scale to measure the environmental orientation of top management (Dunlap et al., 2000). The questionnaire will be pre-tested by a selection of academics, environmental consultants and senior managers. The quality of responses to the mailed questionnaire will inform the selection of a convenience sample of firms, to conduct follow-up interviews to verify and substantiate results.

To capture the perspectives of other stakeholders, a range of semi-structured interviews will be conducted with key informants representing civil society, industry associations, waste sector experts and local government. It is envisaged that the proposed mixed methods design will be utilised to re-survey the same sample of firms and key informants in three years' time; in an attempt to collect comparative longitudinal data on waste management practices in the SDB and map the evolution of environmental management strategic orientation in influencing firm-level decision-making regarding waste management practices.

6. CONCLUSION

In summation, the IE metaphor provides a source of inspiration and creativity in the transformation of management and strategic visions towards a contemporary sustainability culture (Korhonen et al., 2004). In the context of South Africa this study is premised on the supposition that one of the key drivers of firm level sustainable waste management practice, is the proactive environmental strategic orientation (grounded in a pro-NEP worldview) of top management espoused within the domain of IE. The proposed mixed methods design will test this hypothesis by investigating the relationship between the level of corporate environmental strategic orientation and the taxonomy of waste management planning and practices exhibited by firms in the SDB.

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Appendix D – Industrial Ecology Gordon Research Conference Poster

(See next page)