KTH ROYAL INSTITUTE
OF TECHNOLOGY

Licentiate Thesis in Planning and Decision Analysis

Exploring the circular economy of urban organic waste in sub-Saharan Africa: opportunities and challenges

DANIEL DDIBA

Stockholm, Sweden 2020

Exploring the circular economy of urban organic waste in sub-Saharan Africa: opportunities and challenges

DANIEL DDIBA

Academic Dissertation which, with due permission of the KTH Royal Institute of Technology, is submitted for public defence for the Degree of Licentiate of Engineering on Monday the 8th June 2020, at 1:00 p.m. in U1, Brinellvägen 28A, Stockholm.

Licentiate thesis in Planning and Decision Analysis
KTH Royal Institute of Technology
Stockholm, Sweden 2020

Cover page image: David Kaggwa

ISBN 978-91-7873-543-3
TRITA-ABE-DLT-2016

Printed by: Universitesservice US-AB, Sweden 2020

Abstract

Globally, there is increasing awareness of the importance of applying circular economy principles to the management of organic waste streams through resource recovery. In the urban areas of sub-Saharan Africa which are going to host a significant part of population growth over the next three decades, this is especially relevant. Circular economy approaches for sanitation and waste management can provide incentives to improve infrastructure and consequently contribute resources for water, energy and food that power urban livelihoods. This thesis is situated at the intersection of the circular economy on one hand and sanitation and waste management systems on the other. It aims to contribute to knowledge about the circular economy by investigating the potential contribution of resource-oriented urban sanitation and waste management towards the implementation of a circular economy in sub-Saharan Africa and the opportunities and challenges thereof.

In pursuit of the above aim, the thesis employs a mixed methods approach and is operationalized in two case study locations: Kampala (Uganda) and Naivasha (Kenya). The findings reveal the quantities of resource recovery products like biogas, compost and black soldier fly larvae that can be obtained from the organic waste streams collected in a large city, demonstrate the viability of valorizing dried faecal sludge as a solid fuel for industrial applications, and identify the factors that facilitate or impede the governance capacity to implement circular economy approaches to the management of organic waste streams in urban areas in sub-Saharan Africa. The methods used for quantifying the potential for valorizing organic waste streams and for assessing governance capacity demonstrate approaches that could be applied in other urban contexts with interest in implementing circular economy principles. The discussion highlights some key implications of these findings for sanitation and waste management practices, arguing that it is time for a shift in sub-Saharan Africa from designing sanitation and waste management systems for disposal to designing them for resource recovery.

Keywords

Biowaste; governance capacity; resource recovery; sub-Saharan Africa; sustainable sanitation; sustainable urban development; circular economy

Sammanfattning

Globalt ökar medvetenheten om vikten av att tillämpa principer för cirkulär ekonomi för att hantera organiska avfallsströmmar genom resursåtervinning. I de urbana områdena i Subssahariska Afrika är detta särskilt relevant, då dessa förväntas stå för en betydande del av befolkningsökningen under de kommande tre decennierna. En mer cirkulärekonomi för sanitet och avfallshantering kan ge incitament för att förbättra infrastrukturen och därmed bidra med resurser till produktion av vatten, energi och mat som driver städernas försörjning. Denna licentiatuppsats befinner sig i skärningspunkten mellan cirkulär ekonomi å ena sidan och sanitets- och avfallshanteringssystem å andra sidan. Syftet är att bidra med kunskap om cirkulär ekonomi genom att undersöka potentialen för resursorienterad stadssanitet och avfallshantering att bidra till genomförandet av cirkulär ekonomi i Subsahariska Afrika, samt dess möjligheter och utmaningar.

För att uppnå ovanstående syfte används flera olika metoder och genomförs i två fallstudiestäder: Kampala i Uganda respektive Naivasha i Kenya. Resultaten visar på de mängder av resursåtervinningsprodukter som biogas, kompost och svarta soldatflugelarver som kan erhållas från organiska avfallsströmmar som samlas in i en stor stad. Dessutom visar resultaten livskraftigheten för att valorisera torkat avföringsslam som ett fast bränsle för industriella tillämpningar. Slutligen identifierar resultaten faktorer som underlättar eller hindrar styrningskapaciteten för att genomföra cirkulär ekonomi-strategier för hantering av organiska avfallsströmmar i stadsområden i Subsahariska Afrika. Metoderna som används för att kvantifiera potentialen att valorisera organiska avfallsströmmar och att utvärdera styrningskapacitet är metoder som kan tillämpas i andra urbana sammanhang där det finns intresse för att genomföra cirkulära ekonomiska principer. Diskussionen belyser några viktiga konsekvenser av dessa fynd för sanitets- och avfallshanteringspraxis och argumenterar för att det är dags för en övergång i SSA från att utforma sanitets- och avfallshanteringssystem för bortskaffande till att utforma dem för resursåtervinning.

Acknowledgements

When I was much younger, I dreamt of becoming a billionaire one day. I did not envision being a PhD student as one of the steps on my journey to billionaire status and my focus was on identifying the one thing I could sell to at least a billion people for at least a dollar each so as to meet my goal. As fate would have it, I soon figured out that every human being needs water, energy and food and therein lay my opportunity! Once I was done with undergrad and scouting about for how to start my business adventures, a chance email from Charles Niwagaba put my plans on hold and got me hooked to the FaME research project. So, if I never become a billionaire, I can always blame you Charles for stopping me in my tracks! But for now, I'm very grateful that you helped kickstart my academic career and offered the first opportunities for me to see up-close how the circular economy in sanitation brings water, energy and food together.

Arno Rosemarin and Kim Andersson later provided opportunities for me to nurture my interest in the circular economy, sanitation and waste management at SEI and I'm grateful for the time we have worked together thus far. My line manager Fedra Vanhuyse and various colleagues at SEI, especially SEI-HQ and SEI-Africa have provided great support for me throughout this work and I'm very grateful. I cannot imagine how this work would have been possible without the resources, conducive environment and warm collegiality you have all provided.

I'm grateful also to all the wonderful people that I've had the opportunity to collaborate with at Makerere University, Eawag-Sandec, ISE, IFAN, Sanivation and Egerton University. Your contributions to the work in this thesis made it all possible and I look forward to more fruitful collaborations in the future. In the same vein, I would like to acknowledge the European Union Water Initiative Research Area Network (EUWI ERA-net) SPLASH program, the Swiss Agency for Development and Cooperation (SDC), the Swedish International Development Cooperation Agency (Sida) and the Swedish Ministry of Environment as well as the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas), whose generous funding made the work presented in this thesis possible.

To my supervisors; Göran Finnveden, Elisabeth Ekener and Sarah Dickin. Thank you for guiding me through this process and for always challenging me to think like a researcher. I've enjoyed working with you so far and I look forward to completing this PhD marathon with your support. I'm also grateful to Louise Karlberg who made great contributions as co-advisor in the earlier stages of my work.

To all my colleagues at KTH-SEED, thank you for making it such a warm environment for me to work in. I've thoroughly enjoyed walking this journey with my fellow PhD students and I have many great memories of interactions with multiple SEEDers in both professional and social activities. Thanks also to Cecilia

Sundberg who provided very helpful feedback as advance reviewer for this thesis and to Tina Ringenson for helping with the Swedish version of the abstract.

I'm grateful also to my parents, extended family and friends, especially those in Uganda and Sweden, and the NewLife network, for all the support and encouragement.

To my friend Bryans Mukasa, this thesis is dedicated to you. I am sure that this journey of scholarship would have been much more fun with you but alas! You are in a far better place now.

To my dear Deborah, thank you for all that you are and for your support throughout this journey. I'm glad to have you for a best friend and life-long companion.

Daniel Ddiba

Stockholm, April 2020

List of appended papers

Paper I

Ddiba, D., Andersson, K., Rosemarin, A., Schulte-Herbrüggen, H. & Dickin, S. (2020). The circular economy potential of urban organic waste streams in low- and middle-income countries. (*Submitted to Environment, Development and Sustainability*).

Paper II

Gold, M., **Ddiba, D.**, Seck, A., Sekigongo, P., Diene, A., Diaw, S., Niang, S., Niwagaba, C., & Strande, L. (2017). Faecal sludge as a solid industrial fuel: a pilot-scale study. *Journal of Water Sanitation and Hygiene for Development*, *7*(2), 243–251. doi:10.2166/washdev.2017.089

Paper III

Ddiba, D., Andersson, K., Koop, S. H. A., Ekener, E., Finnveden, G. & Dickin, S. (2020). Governing the circular economy: assessing the capacity to implement resource-oriented sanitation and waste management systems in sub-Sahara Africa. (*Submitted to Earth System Governance*).

Author's contribution to papers

As lead author for Paper I, I had primary responsibility for research design, literature review, data collection, analysis and writing the manuscript. The spreadsheet model in which the analysis was operationalized was partly developed during my master's thesis[1]. It was refined and developed further prior to writing Paper I. For Paper II, I contributed mainly to the Kampala case including the design of the experiments at the kiln, leading the kiln operations, conducting the faecal sludge sampling and the lab analysis for some of the parameters, part of the data analysis and also writing part of the manuscript. For Paper III, I contributed to the research design and had primary responsibility for case study development, literature review, field data collection, analysis and writing the manuscript.

---

[1] Ddiba, D. 2016. "Estimating the potential for resource recovery from productive sanitation in urban areas." TRITA-LWR Degree Project 2016:13 86 p.

Relevant additional publications

The papers listed below are not discussed in this thesis, but they are related to the thesis topic.

Strande, L., Schöbitz, L., Bischoff, F., **Ddiba, D.**, Okello, F., Englund, M., Ward, B. J., & Niwagaba, C. B. (2018). Methods to reliably estimate faecal sludge quantities and qualities for the design of treatment technologies and management solutions. *Journal of Environmental Management*, *223*, 898–907. doi:10.1016/J.JENVMAN.2018.06.100

Oster, M., Reyer, H., Ball, E., Fornara, D., McKillen, J., Sørensen, K. K. U., Poulsen, H. D. H., Andersson, K., **Ddiba, D.**, Rosemarin, A., Arata, L., Sckokai, P., Magowan, E., & Wimmers, K. (2018). Bridging gaps in the agricultural phosphorus cycle from an animal husbandry perspective - The case of pigs and poultry. *Sustainability*, *10*(6), 1825. doi:10.3390/su10061825

Contents

List of figures

List of tables

Abbreviations

AD	Anaerobic Digestion
BCR	Biomass Conversion Rate
BMP	Bio-methane Potential
BSF	Black Soldier Fly
CBOs	Community Based Organizations
CE	Circular Economy
CV	Calorific Value
DM	Dry Mass
DMR	Dry Mass Reduction
FS	Faecal Sludge
GCF	Governance Capacity Framework
KCCA	Kampala Capital City Authority
NGOs	Non-Governmental Organizations
NPK	Nitrogen, Phosphorus and Potassium
NWSC	National Water and Sewerage Corporation
OMSW	Organic Municipal Solid Waste
SDGs	Sustainable Development Goals
SS	Sewage Sludge
SSA	sub-Saharan Africa
SuSanA	Sustainable Sanitation Alliance
TK	Total Potassium
TN	Total Nitrogen
TP	Total Phosphorus
TS	Total Solids
UNICEF	United Nations Children's Fund
US	United States of America
VS	Volatile Solids
WHO	World Health Organization

1 Introduction

1.1 Background

By 2050, the global population is expected to surpass 9 billion people (UN DESA, 2019a). Over half of the global population already live in cities and the population increase over the next few decades is expected to be mostly concentrated in cities, especially in Africa and Asia. Urban residents in sub-Saharan Africa (SSA) are expected to constitute about half of the region's projected total population of 1.4 billion by 2030 (UN-Habitat and IHS-Erasmus University Rotterdam, 2018; UN DESA, 2019b). These trends of urbanization and population growth will likely lead to even more pressure on natural resources in the metropolitan areas of the globe as a result of increasing demand for food, water, energy as well as other natural resources.

Cities already consume three quarters of global natural resources; including 80% of the global energy supply (Madlener and Sunak, 2011) and over 600 billion litres of water daily, yet one in four cities are in a water stressed situation (McDonald et al., 2014). The 2017-2018 water crisis in Cape Town – a South African city with about four million people, made global news headlines (Robins, 2019) but reports indicate that many other major cities spread across all continents are in danger of similar acute water shortages (Leahy, 2018). While cities need resources to function, they are also centers of immense pressures on the environment. The consequences of urban metabolism include air pollution, heat islands, land-cover change and biodiversity loss (Bai, 2007; McDonnell and MacGregor-Fors, 2016) and it is estimated that over 70% of global carbon emissions come from cities (Satterthwaite, 2008).

The environmental impacts of cities manifest further through sanitation and waste management systems. Urban dwellers altogether generate about 3.5 million tonnes of solid waste (Hoornweg and Bhada-Tata, 2012), with about half of it being organic in nature, as well as over 715 billion litres of sewage (Mateo-Sagasta et al., 2015) every day. Global estimates indicate that possibly two million tonnes of human waste end up in watercourses on a daily basis, due to no or poor treatment (WWAP, 2012) and about two-thirds of municipal solid waste ends up at landfills and open dumpsites where the decomposition of organic waste contributes to 12% of global emissions of methane (Kaza et al., 2018).

A 2007 study revealed that about half of all European cities with more than 150,000 residents were not complying with the wastewater treatment requirements of the European Union (EU) Urban Wastewater Treatment Directive and 17 of them had no treatment facilities at all (Lüthi et al., 2009). In SSA, the challenges of managing organic waste streams start way upstream. Only 31% of the one billion people in SSA have access to basic sanitation services (UNICEF and WHO, 2019). The investments that have been made in centralized wastewater or faecal sludge treatment systems have often not been impactful since recent studies indicate that in SSA, the majority of these plants end up being non-functional or ineffective (Dodane et al., 2012; Klinger et al., 2019). By 2018, only 44% of municipal solid waste was being collected in South Asia and sub-Saharan Africa (Kaza et al., 2018) and the rest is often disposed of haphazardly in the environment or in pit latrines (Rogers et al., 2014), generating additional challenges.

In recent years, attention has increasingly been drawn to the vast amounts of resources embedded within organic waste streams in terms of water (Drechsel et al., 2015; Qadir et al., 2020), nutrients (Mihelcic et al., 2011; Schroder et al., 2010), energy (Mukherjee and Chakraborty, 2016; Otoo et al., 2016; Schuster-Wallace et al., 2015) and other material components like precious metals (Das, 2010; Ueberschaar et al., 2017). It has become apparent that the prevailing *linear* or *end-of-pipe* approach to the management of waste in general and organic waste streams in particular, is no longer feasible. The circular economy (CE) concept has been presented as an approach that can simultaneously help address the contemporary challenges of waste management and resource scarcity (Ellen MacArthur Foundation et al., 2012) through recovering and reusing the resources embedded in waste streams within the production systems in urban economies. This is in contrast to the linear "take-make-dispose" approach which leads to increasing consumption of virgin resources and the accumulation of waste in sinks, along with their associated environmental impacts (Ellen MacArthur Foundation, 2017).

Cities, with their high population densities import most of the food, water and energy they need (Hoff et al., 2014) from their rural hinterlands and beyond national borders, yet they return little of the nutrients and organic matter to the agricultural system (Ellen MacArthur Foundation, 2017). Therefore, they have a significant supply of resource-rich organic waste streams, large workforces who are also potential consumers of resource recovery products and a variety of stakeholders within their boundaries which provides for an appropriate scale that can often make resource recovery feasible. Cities can be an appropriate scale for the necessary governance, institutional, legal and regulatory framework within which resource recovery initiatives can be implemented.

Although the recovery of resources from organic waste streams was widely practiced in traditional agricultural societies with historical examples from Asia, South and Central America from as far back as 2500 years ago (Brown, 2003; Lüthi et al., 2011), full scale circularity within the management of organic waste streams in urban areas is a relatively niche practice in most of contemporary society. Moreover, most of the literature on circular economy policy and implementation has focused on countries in the Global North (see e.g. Ghisellini *et al.,* 2016) and there is much less written about circular economy in the sub-Saharan Africa context especially regarding urban organic waste streams. Furthermore, while the circular economy has been highlighted as part of environmental strategies in some African countries like Kenya and Uganda (Desmond and Asamba, 2019; KCCA, 2017), not much is mentioned about the governance arrangements made in preparation for implementation or how resource recovery from organic waste streams can contribute to achieving those strategies. It is in this context that this thesis hopes to contribute towards a better understanding of the landscape of organic waste streams in SSA cities, quantifying the circular economy opportunity therein and identifying avenues for accelerating the implementation of resource recovery initiatives at city scale.

1.2 Aims of the thesis and research questions

The overall objective of this thesis is to investigate the potential contribution of resource-oriented urban sanitation and waste management towards the implementation of a circular economy in SSA and the opportunities and challenges thereof. The specific research questions that this thesis aims to answer are listed below and further elaborated in the paragraphs that follow.

- Research question I (RQ1): What is the potential for organic waste streams to contribute to a circular economy in the context of a large city in sub-Saharan Africa?
- Research question 2 (RQ2): What are the factors that facilitate or impede the governance capacity to implement circular economy approaches to the management of organic waste streams in urban areas in sub-Saharan Africa?

The above aim and research questions are addressed in the appended papers, with RQ1 being tackled in Paper I and Paper II while RQ2 is tackled in Paper III.

In Paper I, RQ1 is addressed through assessing the quantitative potential of valorizing the major organic waste streams in Kampala, Uganda to generate resource recovery products that can be utilized in a local circular economy. The assessment focused on faecal sludge, sewage sludge and organic municipal solid waste and the resource recovery products biogas, solid fuel, black soldier fly larvae and compost. The potential quantities for each of these products that can be generated from the waste streams were determined as well as their energy and nutrient contents and their revenue potentials.

In Paper II, RQ1 is addressed through an empirical study investigating the viability of using dried faecal sludge as a solid industrial fuel in the context of Kampala, Uganda as a case study. Previous research suggested that solid biofuels have relatively higher economic potential compared to other resource recovery products from faecal sludge (Gold et al., 2014) and hence could provide financial incentives for improving services across the sanitation value chain. Moreover, wastewater sludge has been used in cement production and power plants in Europe and North America for decades (Werther and Ogada, 1999), suggesting that faecal sludge could be viable as a fuel even though it has more variable characteristics than sewage sludge (Niwagaba et al., 2014). Hence the focus in Paper II was to determine the viability of FS fuel in industrial settings through laboratory analysis of dried faecal sludge and pilot kiln experiments, and also to compare with the solid fuels that are currently used as well as the quality of products generated using the different fuels.

In Paper III, RQ2 is addressed through an assessment based on the governance capacity framework to determine the factors that facilitate or impede the governance capacity to implement circular economy approaches that recover resources from organic waste streams. The assessment was conducted in Naivasha, Kenya as a case study.

1.3 Outline of the thesis

This thesis is arranged in two parts: the cover essay and the appended papers. In the cover essay, the introduction (this chapter) covers a background on the motivations behind the global interest in the circular economy concept and the expected outcomes of implementing circular approaches to sanitation and waste management. Chapter 2 contains a description of key theoretical concepts that underpin the work in this thesis while Chapter 3 outlines the research design followed through the thesis work, describing the research projects in which the thesis work was conducted as well as the methods and approaches employed. In Chapter 4, the results are described and thereafter discussed in detail in Chapter 5, in relation to the literature and the geographical context of the case study cities. Some reflections about the methodological choices made and the limitations of this research are also provided towards the end of chapter 5. Overall conclusions and some suggestions for further research are provided in Chapter 6. The appended papers in the second part of the thesis are arranged as outlined in the “List of appended papers”.

2 Context and theory

The context of this thesis is at the intersection of sanitation and waste management, the circular economy and governance in urban areas.

2.1 Circular economy

The circular economy as a concept has gained increasing popularity over the past decade among a spectrum of stakeholders across academia, governments, the private and civil society sectors (Ghisellini et al., 2016). There is no consensus as yet on a single definition of the circular economy and the multiple existing definitions and conceptions of what the circular economy is have been widely discussed in the literature. Kirchherr *et al.* (2017) found at least 114 definitions used by stakeholders from different sectors and Korhonen *et al.* (2018b) described the circular economy as an essentially contested concept. So far, the most cited definition is from the Ellen MacArthur Foundation which defines the circular economy as follows;

> *"[CE] an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models" (Ellen MacArthur Foundation et al., 2012).*

The origins of the circular economy concept, as described by Blomsma and Brennan (2017) are in the environmental movement of the 1960s and 1970s and can be traced to the seminal work of Boulding (1966) who made the case for a transition from the *linear cowboy economic model* with a *take-make-dispose* approach to a *closed cyclic system* where materials are reused. In its present form, the circular economy concept is closely related to other concepts (Ddiba et al., 2018b) like the performance economy (Stahel, 2010), cradle-to-cradle (McDonough and Braungart, 2002), the bioeconomy (D'Amato et al., 2017) and the sharing economy (Korhonen et al., 2018a) among others. Much of the conceptual discussions about the circular economy concept are in their infancy (Korhonen et al., 2018a) and the discourse is only starting to move towards policy and implementation (Ghisellini et al., 2016). So far, a considerable amount of research has been done and several case studies highlighted about the implementation of a circular economy approach within the realm of technical materials from a wide range of perspectives like remanufacturing, the sharing economy, biomimicry among others (Ellen MacArthur Foundation et al., 2012; Ghisellini et al., 2016; Korhonen et al., 2018a, 2018b; Lieder and Rashid, 2016).

Although the CE concept is popular among policy makers and the business community, it has also received quite a lot of criticism. Some see CE as an attempt by corporate interests to align sustainability with economic growth (Valenzuela and Böhm, 2017) and this seems to be a valid concern considering that CE has gained traction among concepts expected to operationalize sustainable development through "green economy" and "green growth" (Kirchherr et al., 2017). From a conceptual perspective, Zink and Geyer (2017) highlighted the potential rebound effects of the CE and Korhonen *et al.,* (2018a) highlighted the limitations of CE with regards to thermodynamics, definitions of physical material flows and spatial and temporal system boundaries. Furthermore, Moreau *et al.,* (2017) demonstrate that there is little consideration for the social dimension of sustainability within the CE discourse, yet it is a pre-requisite for real progress towards sustainability given that environmental challenges are intertwined with social challenges like inequality and democratic struggle and hence cannot be tackled in piecemeal fashion (Valenzuela and Böhm, 2017).

Despite this criticism, the CE concept when viewed from the perspective of its industrial ecology origins can have positive outcomes for environmental sustainability especially due to avoiding primary production (Zink and Geyer, 2017). CE approaches also provide a way to simultaneously deal with the problem of accumulation of wastes and resource scarcity. In this thesis, the understanding of the circular economy builds from Kirchherr *et al.* (2017) who defines it as;

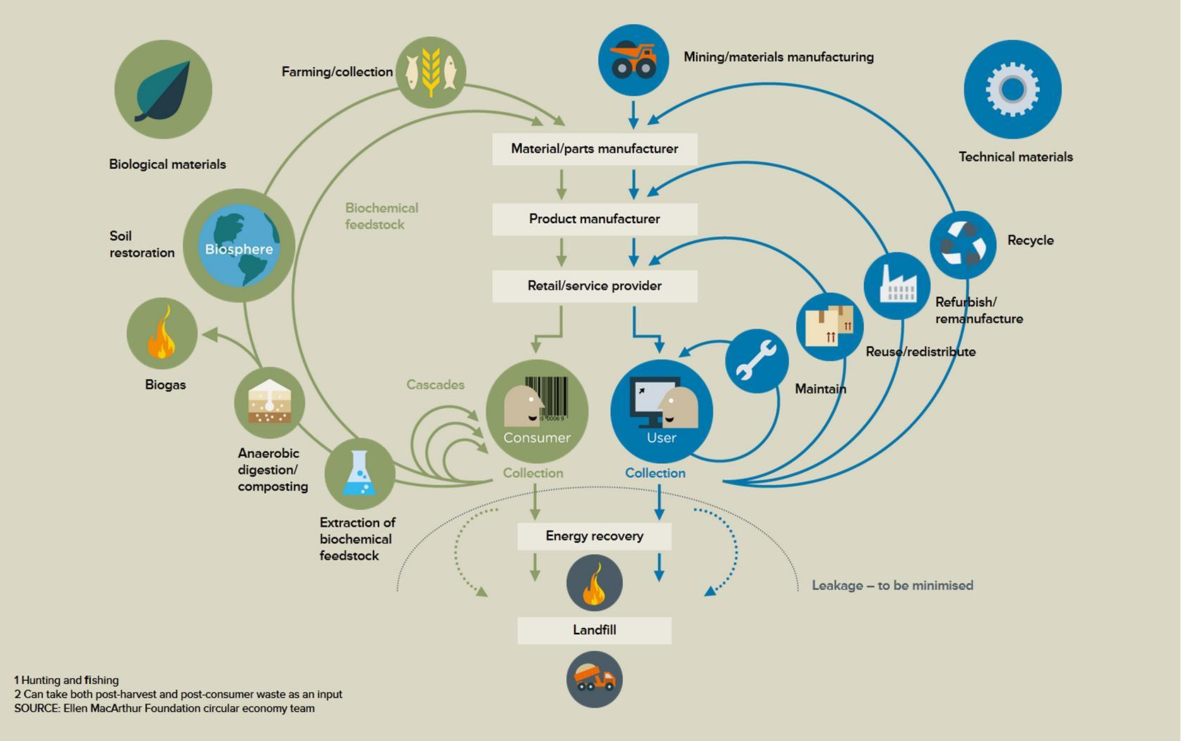
> *"an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes … with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations."*

This definition, which is generally aligned with the origins of the CE concept, is supplied in this thesis to provide transparency about the perspective from which I aim to contribute to the CE discourse. From a normative perspective, I focus here on resource recovery from organic waste streams and how it contributes to CE implementation and consequently to sustainable development.

The Ellen MacArthur Foundation (2012) conceptualize the circular economy as being comprised of two cycles, the *technical materials* cycle and the *biological materials* cycle as shown in Figure 1. In this thesis, the focus is on the "biological materials cycle" whereby the circular economy is operationalized through resource recovery from organic waste streams.

The Kirchherr definition of CE does not explicitly mention energy but it should be noted that both energy and material flows are essential components of the CE, as depicted in Figure 1. There are limits to materials reuse, recycling, and recovery due to the second law of thermodynamics and activities for reusing and recycling materials require energy (Korhonen et al., 2018a). This is why an increasing use of renewable energy sources is a key principle of the circular economy (Ellen MacArthur Foundation et al., 2012). Other definitions of CE that elaborate on energy flows include Lehtoranta *et al.* (2011), Geng *et al.* (2013) and Geissdoerfer *et al.*

(2017). In this thesis, CE is discussed from the perspective of both material flows and energy flows, especially in Paper I and Paper II.



1 Hunting and fishing
2 Can take both post-harvest and post-consumer waste as an input
SOURCE: Ellen MacArthur Foundation circular economy team

Figure 1: The circular economy concept including both biological and technical materials Source: Ellen MacArthur Foundation (2012)

As can be seen from Figure 1 above, the linkages between the various stages of each materials cycle can be quite complex to comprehend. Material flow analysis (MFA) approaches are often used to track the flows of resources within economies or production systems and hence understand the potential for circularity and the extent to which resources return to the system. This can be at geographical scales like cities (e.g. Zeller et al., 2019) or sectors (e.g. Cordova-Pizarro et al., 2019) or even specific substances (e.g. Wu et al., 2016).

2.2 Urbanization and sustainability in sub-Saharan Africa

Presently, about 55% of the global population live in cities and by 2050, another 2.5 billion people will have been added to the world's urban areas with most of these being in Asia and Africa. While SSA is still mostly rural with only 40% of the population living in cities (UN DESA, 2019b), the region nevertheless has one of the highest urbanization rates. This is accompanied by increasing industrialization and a growing middle class (UN-Habitat and IHS-Erasmus University Rotterdam, 2018). Through agglomeration and economies of scale, urbanization can result into benefits like increasing employment opportunities and higher productivity, improved communication and efficiency in providing access to social services, among others. However, cities are consumption hotspots for natural resources including energy, water, food and other land-based resources and some cities exceed their ecological footprint by up to 200 times (Doughty and Hammond, 2004).

Around the world, about 11 billion tonnes of biomass are harvested annually for food and animal feed, in addition to about 110 million tonnes of marine fisheries (Ellen MacArthur Foundation, 2017) and these are mainly consumed in urban areas. However, a third of all food produced globally goes to waste (Gustavsson et al., 2011) and of the portion that is consumed, a significant amount still ends up as human excreta considering that for instance, humans consume about 30% more protein than the daily adult requirement on average (Ranganathan et al., 2016). In SSA, a number of environmental and social challenges have come about as a result of urban metabolism and the increasing urbanization rate. These include urban sprawl and the development of slums, deforestation due to the reliance on wood-based fuels, biodiversity loss, wetland encroachment and ineffective sanitation and waste management systems (UN Habitat, 2015).

A number of global commitments aim to tackle these challenges related to urbanization and sustainability through the agenda 2063 of the African Union (African Union Commission, 2018), the new urban agenda (United Nations, 2017) and the sustainable development goals (SDGs) (United Nations, 2015). The new urban agenda and SDG 11 have the explicit aim of making cities safe, inclusive, resilient and sustainable. However, there are tight linkages between achieving sustainable cities and most of the other SDGs including water and sanitation (SDG 6), energy (SDG 7), food (SDG 2), sustainable production and consumption (SDG 12) among others. These linkages have been covered widely in the literature (e.g. Finnveden and Gunnarsson-Östling, 2016; Pradhan et al., 2017). The linkages between the targets for sustainable cities and other SDGs indicate that urban areas are an important arena for dealing with sustainability challenges (Measham et al., 2011). This is not only because cities host and will continue to host the majority of global population but also because how urban areas are planned and how they develop influence the pathways to sustainability (Valencia et al., 2019). Urban areas and their governance structures have responsibility for establishing policies, urban planning, infrastructure development and natural resource management (Satterthwaite, 2016) and hence this level of influence has led some to conclude that the battle for sustainability will be won or lost in cities (Corbett and Mellouli, 2017).

2.3 Sanitation and waste management

Maurer *et al.,* (2012) described a sanitation system as being “a set of technologies, which in combination, treat human excreta from the point of generation to the final point of reuse or disposal” while Demirbas (2011) described waste management systems as consisting of the various “activities related to handling, treating, disposing or recycling waste materials”. The set-up of a typical waste management system includes the collection, conveyance, treatment or processing and final disposal or end-use of the waste residues (Demirbas, 2011). This is analogous to Tilley *et al.,* (2014) who describe sanitation systems as comprising of functional groups of technologies for capturing, containing, transporting, treating and finally reusing or disposing excreta-based waste streams. In this thesis, I refer to “sanitation and waste management systems” as a collective term, as well as to “sanitation and waste management service chain” as the collection of linked technologies for handling the various subsequent stages of the system.

The concept of a service chain is commonly used in the sanitation sector, drawing from the earlier work of Tilley *et al.*, (2008) and further popularized in a graphic by the Bill & Melinda Gates Foundation (2010). From an organic waste perspective, sanitation and waste management systems handle the waste streams covered within the biological materials cycle of the circular economy including excreta and other excreta-based waste streams, greywater, organic municipal solid waste, food waste, agro-processing waste and manure. However, sanitation and waste management systems are about much more than the technological aspects of the infrastructure and also include the governance and institutional arrangements for managing them as well as the business models for their operation.

As of 2017, about 709 million people in SSA still did not have access to basic sanitation services and ten of the countries with the highest rates of open defecation were in SSA (UNICEF and WHO, 2019). In SSA’s urban areas, this corresponds to about 56% of the population (UNICEF and WHO, 2019). Basic sanitation refers to the use of improved sanitation facilities which are not shared with other households (UNICEF and WHO, 2019). The majority of the population in SSA use on-site sanitation systems including pit latrines and septic tanks (Andersson et al., 2016). In urban areas, only about 20% of those using improved sanitation facilities have safely managed services implying that the excreta collected in the sanitation system is transported and treated off-site or safely treated and disposed of in situ (UNICEF and WHO, 2019). Even where sewer-based infrastructure is used in SSA cities and towns, less than 50% of the wastewater is effectively treated (Peal et al., 2020; UNICEF and WHO, 2019).

Statistics on solid waste generation, collection and treatment and disposal in SSA are relatively limited but the solid waste generation rates in SSA are expected to double by 2050 to about 516 million tonnes/year (Kaza et al., 2018). The general waste collection rates are about 44% in SSA, but it is much lower in rural areas (Kaza et al., 2018). About 43% of the waste is organic in nature and over two-thirds of the solid waste ends up at open dumpsites while the rest is divided between landfills, composting and recycling (Kaza et al., 2018).

The Sustainable Sanitation Alliance (SuSanA) stipulates that a sustainable sanitation system is one that “protects and promotes human health, is economically viable, socially acceptable, technically and institutionally appropriate, and protects the environment and natural resources” (SuSanA, 2008). These criteria overlap with criteria that have been listed by others to define “sustainable waste management systems” (see e.g. Ekvall and Malmheden, 2014; Seadon, 2010). While the focus of sanitation and waste management systems used to be on protecting public health (Asase et al., 2009), environmental and natural resource concerns have in recent decades made the recovery of resources a major aim of what can be referred to as sustainable sanitation and waste management systems.

Resource recovery from organic waste streams is not necessarily new as it has been practiced for millennia (Brown, 2003). The fertilizer value of human excreta was well known in the ancient Americas and the Arab world as well as in Korean, Greek and Roman cultures. Dried excreta was also used an energy for cooking in ancient urban areas like Sana'a. As urban areas developed in the 19th and 20th centuries and agricultural activities moved further away from cities, more excreta than could be quickly re-used was generated and hence various dry sanitation technologies were developed to mitigate the odour problems while still exploiting the resource value. Even with the advent of flush toilets and centralized sewerage systems that became ubiquitous in western society, there was still recognition of the resource value of sewage which resulted in efforts like the "Liernur-system" which enabled the use of blackwater for agricultural purposes (Lüthi et al., 2011). Right up to the 21st century, various initiatives have focused on recovering the resources embedded in excreta-based waste streams and this has come to be conceptualized as *ecological sanitation* or *resource-oriented sanitation* (Esrey et al., 1998; Langergraber and Muellegger, 2005). The principles of ecological sanitation focus on "*rendering human excreta safe, preventing pollution rather than attempting to control it after we pollute, and using the safe products of sanitized human excreta for agricultural purposes*" (Esrey et al., 1998).

Within the field of solid waste management, resource recovery has been operationalized through concepts like integrated solid waste management (Memon, 2012), the 3Rs of the waste hierarchy (reduce, reuse and recycle) which have been further extended by some authors to 9Rs (Kirchherr et al., 2017), waste-to-energy (Malinauskaite et al., 2017; Mutz et al., 2017), urban mining which tends to focus on metals and other technical materials (Krook and Baas, 2013) and zero waste (Zaman, 2014). It is evident that these concepts are not new in and of themselves as resource strategies. However, gathering them under the umbrella of the CE concept provides a new framing and also draws attention to their role in prolonging the use of resources and to the inter-linkages between them (Blomsma and Brennan, 2017).

There is vast literature on various aspects of resource recovery including technological aspects (Lohri et al., 2017; Polprasert and Koottatep, 2017) and social, environmental and economic assessments (Bernstein, 2004; Finnveden et al., 2007). Recently, there is interest in innovative business models for resource recovery especially in the context of low- and middle-income countries (Otoo and Drechsel, 2018). However, there is much less in the literature about the governance and institutional aspects of circularity with respect to organic waste streams.

Moreover, the city scale potential for resource recovery from organic waste streams is not well understood in the context of SSA and quantitative estimates of the circular economy valorization potential are rare. What is available in the literature so far focuses on cities in Europe like London (Villarroel Walker et al., 2014) and Brussels (Zeller et al., 2019) or on a specific waste stream (e.g. Diener et al., 2014). There are limited tools available to urban stakeholders in SSA to enable them to estimate the circular economy valorization potential in their city. Decision support tools within the sanitation and waste management sector have historically focused on the selection, design and optimization of waste treatment facilities (Hamouda et al., 2009; Palaniappan et al., 2008) or the environmental and economic assessment of treatment technologies (Blikra Vea et al., 2018; Vitorino de Souza Melaré et al., 2017). For those tools that could be used to some extent to explore resource recovery potential like EASETECH (Clavreul et al., 2014) and ORWARE (Eriksson et al., 2002), they are limited by their steep learning curve and heavy data requirements. This demonstrates the need for simpler tools that urban stakeholders in SSA could use in the upstream stages of decision-making to explore the circular economy potential of organic waste streams in their cities.

2.4 Urban governance

In recent decades, the social sciences have had a major shift from the concept of "government" to "governance" (Kooiman et al., 2008; Mayntz, 2019; Sørensen, 2006). Governance refers to the "processes of interaction and decision-making among the actors involved in a collective problem that lead to the creation, reinforcement, or reproduction of social norms and institutions" (Hufty, 2011). In the urban context, the governance arena comprises multiple actors and institutions who engage in the continuous process of shaping urban development through decision making about planning, infrastructure development, social services etc.

Traditional modes of governance focus on expert-led processes aimed at identifying solutions to narrowly defined problems and they also assume an approach to natural resource management that is linear, predictable and controllable (Koop, 2019). They tend to involve techno-centric arrangements that create path-dependency and lock-in to specific solutions to sustainability challenges (Brown et al., 2011; Fuenfschilling and Truffer, 2014), hence leading to limited comprehensive understanding of complex challenges (Pahl-Wostl, 2002). These approaches to governance tend to be fragmented across sectors and levels and are also hierarchical (Koop, 2019; Pahl-Wostl, 2009). This could be illustrated by the New Urban Agenda which was negotiated by national governments yet it was largely expected to be implemented by city and local governments around the globe (Satterthwaite, 2016). While there can be benefits from efficiency under these traditional modes of governance in the short run, they can lead to inflexibility and prevent learning and adapting to changing circumstances due to institutional inertia in the long run (Koop, 2019).

There has been increasing awareness that the state are not the only relevant actors in solving societal challenges (Hysing, 2009). Roles and responsibilities can be shared among diverse actors across multiple levels of governance, as described by concepts of multi-level governance (Ekane, 2018) and also across various decision-making centers as described by concepts of polycentric governance (Carlisle and Gruby, 2019). There is also a recognition that decision making occurs amidst uncertainties, complexities and risks and hence the role of experimentation, evaluation and learning have to be emphasized so as to cope with unexpected circumstances, as described in adaptive governance theory (Brunner et al., 2005). Approaches to governance that derive from multi-level, polycentric and adaptive perspectives seem well-suited for dealing with sustainability transitions since they are horizontal and network-based (Koop, 2019). They also take into account top-down and bottom-up processes, the influence and direction of social change by various societal actors and the experimentation and learning that occurs while steering societal change (Loorbach, 2010).

Within the water sector, adaptive and polycentric governance approaches have been applied through concepts like integrated water resource management (IWRM) and adaptive management (Grigg, 2016). However, when it comes to contexts like the circular economy, there is a need to move from intra to inter-sectoral management. Applying circular economy approaches to the management of urban organic waste streams implies involving a wide range of stakeholders across supply chains and reverse supply chains. In an urban context, the multiple stakeholders across the sanitation and waste management service chain with respect to organic waste streams bring about issues like who bears the greater risks and who should obtain the greater gains, how can problems be collectively identified and solved and how do the different stakeholders collaborate despite their varying values, interests and cultures (Koop et al., 2017). Therefore, assessing governance capacity can enable us to explore the interactions between various stakeholders; individuals, households, and institutions, public and private, profit and non-profit and hence enable a better understanding of the pre-requisites for implementing resource-oriented urban sanitation and waste management systems.

3 Research design and methods

The research described in this thesis was conducted within three research projects namely; the Faecal Management Enterprises (FaME) project, the SEI Initiative on Sustainable Sanitation (SISS) and the Urban waste into circular economy benefits (UrbanCircle) project. The FaME project aimed at investigating resource recovery-oriented solutions for faecal sludge management that could incentivize investments into improved sanitation services in low-income countries (Gold et al., 2014). The work was conducted with case studies in Dakar, Senegal; Accra, Ghana; and Kampala, Uganda with partners from Makerere University, Hydrophil, National Sanitation Utility of Senegal (ONAS), Waste Enterprisers Limited, Cheikh Diop University and the Swiss Federal Institute of Aquatic Sciences and Technology. The UrbanCircle project aims at illustrating the multi-sector benefits and trade-offs of resource-oriented urban waste management so as to stimulate integrated policymaking and action by stakeholders (Ddiba et al., 2018a). The project involves case studies in Naivasha, Kenya; Chia, Colombia; and Stockholm, Sweden and is being conducted in collaboration with partners at KTH, Stockholm Environment Institute, Egerton University, Sanivation and El Bosque University. The SISS is an umbrella for a variety of sanitation-related projects at SEI, all with the aim of "boosting sustainable sanitation provision at scale in low- and middle-income countries, through research, knowledge exchange, capacity development, policy dialogue, with a focus on productive sanitation approaches that yield multiple economic, social and environmental co-benefits" (Andersson and Dickin, 2017).

To answer the research questions mentioned in section 1.2, a mixed methods approach has been employed in this research, involving desk studies and empirical work with both qualitative and quantitative methods. What follows in this section is a brief background to each of the methods applied and a description of how they were used in this PhD research. An overview of the methods used in the research is provided here but the details are elaborated in the appended papers as specified in sections 3.1 to 3.4.

3.1 Case study methodology

A case study "is an empirical enquiry that investigates a contemporary phenomenon in depth and within its real-world context, especially when the boundaries between phenomenon and context are not clearly evident" (Yin, 2009). Case studies are used in multiple scientific disciplines and professional fields and they are especially relevant for answering "How" and "Why" research questions in the context of exploratory, descriptive or explanatory research when the focus is on contemporary phenomena and the researcher has little control over ongoing events (Rowley, 2002; Yin, 2009). Moreover, case studies are crucial for generating context-dependent knowledge (Flyvbjerg, 2006) and it is for this reason that they are used as an overarching methodology in this thesis.

Two case study locations are included in this thesis, the city of Kampala, Uganda (used in Paper I and Paper II) and the town of Naivasha, Kenya (Paper III). Kampala is the capital city of Uganda and it has a resident population of 1.5 million people, though it has been noted that the day-time population swells up to about 3 million due to commuters from neighboring municipalities (Nkurunziza et al., 2017). Naivasha is located about 90 km north-west of Nairobi, the Kenyan capital. The population of Naivasha is currently about 250,000 people and it's expected to grow to about 670,000 by 2040 (Mott MacDonald, 2017). Kampala's economy is largely dependent on trade, industries, urban agriculture and the services sector (KCCA, 2017) while Naivasha depends on tourism, trade and horticulture (Mugambi et al., 2020). Considering the size of the population in other cities and towns in sub-Saharan Africa (World Population Review, 2019), Kampala could be described as a large city with its day time population being over 2 million people and Naivasha as a small city (less than 800,000 people).

It is important to define the boundaries of a case study (Yin, 2009). The boundaries of the case studies in this research were defined both geographically in terms of the locations of the cities, but also by the scope of the sanitation and waste management infra-systems that handle organic waste streams and the social, economic, technical and environmental aspects surrounding these systems in the context of resource recovery. The majority of the population in both cities depend on on-site sanitation systems (Bohnert, 2017; Schöbitz et al., 2016) but the overall infrastructure for sanitation and waste management is inadequate for the growing populations.

Kampala and Naivasha were selected for case studies for this thesis, and for the research projects in which it is situated, primarily to build on previous and ongoing research initiatives and collaborations among the partners in those cities. However, it should also be noted that these two cases are characterized by features which are prominent in most cities in SSA including rapid growth, a high level of informality and the prominence of on-site sanitation systems among others (Lall et al., 2017). While Kampala and Naivasha may not necessarily be statistically representative of other cities in sub-Saharan Africa, they can nevertheless be useful for achieving and transferring knowledge through e.g. forming theories that may relate to other cases (Runeson and Höst, 2009). As Yin (2009) argues, a case study can indeed be the basis for significant explanations and analytical generalizations. This basis has informed my discussion of the results from these cases (see section 5).

3.2 Methods applied to answer research question 1

3.2.1 Quantitative estimation of circular economy valorization potential

The Kampala case study was the focus of Paper I, with an aim of quantifying the circular economy valorization potential of urban organic waste streams in the city. The scope of the quantification was on three waste streams – faecal sludge, sewage sludge and organic municipal solid waste. Four resource recovery options were assessed; anaerobic digestion (AD), drying and densification to generate solid fuels, black soldier fly (BSF) breeding to generate animal feed and fertilizer, and composting. The assumption was made that the residues from AD and BSF breeding/processing are subjected to composting before they can be applied to agricultural land as soil conditioner. The three waste streams are the most abundant and readily available in the city (Schöbitz et al., 2014) while the four resource recovery options are among the most mature technologies (Lohri et al., 2017; Strande et al., 2014) and there is considerable experience with implementing these among local stakeholders in Kampala (Schöbitz et al., 2014).

The available quantities of the waste streams in Kampala and their physical and chemical quality were established based on available data in peer-reviewed and grey literature. A material flow analysis approach was used for the quantification with equations describing the assumed linear relationship between the physical and chemical quality parameters of the waste streams and the potential amounts of resource recovery products that can be generated from each waste stream. The relationships between physical and chemical quality parameters and potential amounts of products were based on literature e.g. the influence of volatile solids (VS) on the amount of biogas from the anaerobic digestion process (Vögeli et al., 2014). To determine the nutrient and energy content in the resource recovery products as well as their potential revenues, data from literature was obtained about the physical and chemical transformation of the waste streams through treatment processes and the potential prices that products could be sold at in Kampala. The quantification was operationalized in a spreadsheet model for ease of calculations. The equations and the detailed data used in the calculations are not reproduced here but are described in detail in Paper I. Table 1 provides an overview of the physical-chemical quality parameters and the treatment process parameters used for determining the amount of each corresponding resource recovery product.

Table 1: Physical-chemical quality parameters and the treatment process parameters used for determining the amounts of resource recovery products

Resource recovery product	Main physical and chemical quality parameters used to determine the potential amounts of the product
Biogas	Total solids (TS), Volatile solids (VS), Biomethane potential (BMP), Volatile solids degradation rate
Solid fuel	Total solids (TS), Calorific value (CV)
Black soldier fly larvae	Total solids (TS), Biomass conversion rate (BCR)
Compost	Total solids (TS), Percentage dry mass reduction during composting (DMR), Nitrogen, phosphorus and potassium content in the waste stream (NPK)

Two scenarios were assessed for Kampala; one based on the amounts of waste streams that are presently collected in the city (Scenario 1) and another based on the potential amounts of waste streams that could be collected with increased coverage and efficiency of the sanitation and waste management logistical infrastructure (Scenario 2). Table 2 illustrates the annual waste amounts for each scenario.

Table 2: Amounts of waste streams for the two valorization scenarios in Kampala (Source: Paper I)

Waste stream	Units	Current waste collection (scenario 1)	Potential waste collection (scenario 2)
Faecal sludge	m^3/year	219,000	509,175
Sewage sludge	tonnes/year	31,317	92,345
Organic municipal solid waste	tonnes/year	436,540	671,600

3.2.2 Faecal sludge analysis and pilot kiln operations

In Paper II, the methodology to investigate the viability of using dried faecal sludge as a solid industrial fuel involved drying faecal sludge on drying beds, sampling and laboratory analysis and kiln operations with the faecal sludge fuel and unfired clay bricks, all in Kampala. The laboratory analysis was aimed at assessing the physical and chemical characteristics of dried faecal sludge and hence its fuel quality. The pilot kiln experiments were intended to assess the performance of dried faecal sludge as a solid fuel in a context that mimicked industrial conditions. To obtain faecal sludge for the kiln operations, faecal sludge was discharged from vacuum emptier trucks on four full-scale drying beds at the National Water and Sewerage Corporation (NWSC) wastewater treatment plant in the Bugolobi area. One drying bed had faecal sludge from pit latrines, another had faecal sludge from septic tanks and two had mixed sludge from both sources. The faecal sludge was removed from the beds when it had attained a level of dryness of approximately 90% total solids (TS). For laboratory analysis, grab samples were obtained and mixed to create a homogenous composite sample which was then kept on ice during transport to the laboratory. Before being used in the kiln, the faecal sludge was milled into a fine powder with a density of 424 ± 15 kg/m^3 with a hand-driven mill.

The pilot kiln (see Figure 2) and its operations were designed to mimic the industrial kiln at Uganda Clays factory in Kajjansi, Uganda. During operations, the kiln was loaded each time with 340-460 unfired clay bricks obtained from Uganda Clays. The kiln was pre-heated with firewood for 2.3 to 5.3 hours to reduce the moisture content in the bricks and then it was fed with dried faecal sludge fuel for 2.3 to 2.5 hours through the holes at the top of the kiln. Combustion with dried faecal sludge was conducted four separate times, each with 70 to 160 kg of dried faecal sludge. For comparison, kiln experiments were also conducted, in duplicate, with coffee husks which is one of the fuels used by Uganda Clays currently. The pre-heating process before combustion with coffee husks took 4 to 4.5 hours and then 140 to 180 kg of crushed coffee husks were fed into the kiln for 3 to 3.2 hours. Kiln temperatures were monitored with type K thermocouples at three locations inside the kiln and recorded with a data logger at every 30 seconds interval throughout the combustion process.

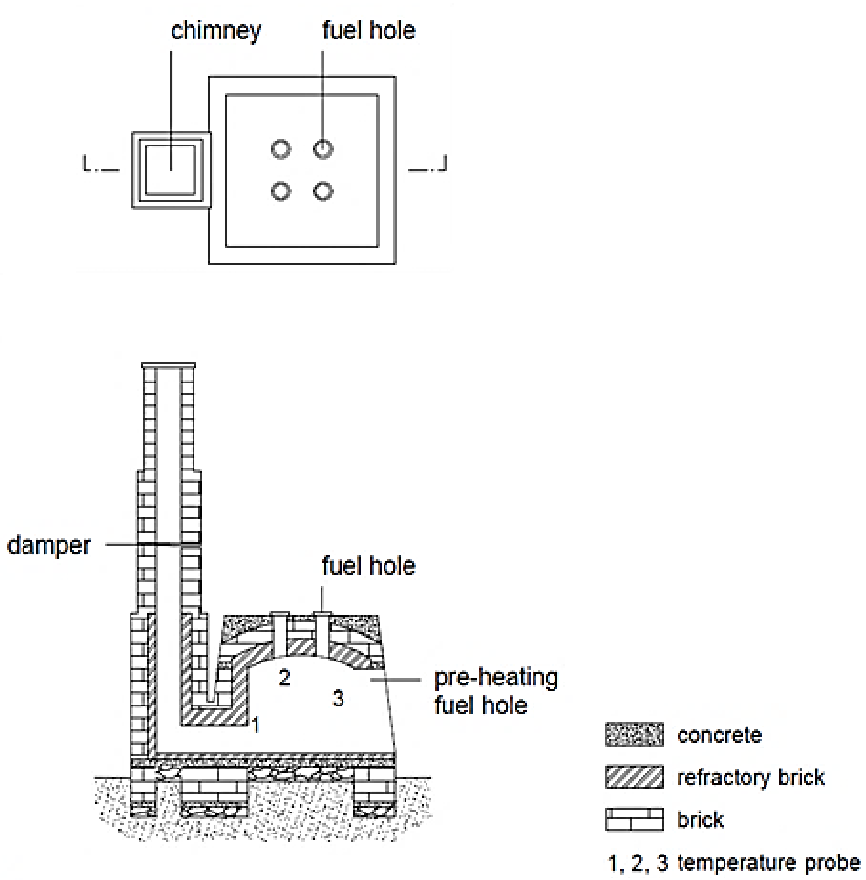


Figure 2: Design of the pilot kiln in Kampala to a scale of 1:100, indicating the position of the temperature probes at locations 1, 2 and 3.
(Source: Paper II. Reproduced with permission from IWA Publishing)

Laboratory analysis was done on the dried faecal sludge and the cured bricks. For faecal sludge, dry mass (DM), ash content and total volatile solids (VS) were measured according to standard methods (APHA, 2005). Calorific value (CV) was determined using a Gallenkamp Auto-Bomb calorimeter according to manufacturer’s instructions and helminth eggs were enumerated according to Moodley et al. (2008). For ultimate analysis, X-ray fluorescence (XRF) with a Spectro Xepos was used as per the manufacturer’s instructions. The samples were pulverized using a Retch mixer mill and then pressed into 32 mm pellets prior to analysis. For carbon, nitrogen and sulfur, duplicate pulverized samples were analyzed using a HEKAtech Eurovector plus a Leco TruSpec CHNS Marco Analyzer. The compressive strength of cured bricks was determined using an Avery Denison Universal Compressive Testing Machine according to standard methods (BSI, 1983) while the brick color was determined by qualitative comparison with bricks cured in the industrial scale kiln at Uganda Clays.

3.3 Methods applied to answer research question 2

3.3.1 Governance Capacity Framework

For assessing the governance capacity to implement circular economy approaches to the management of organic waste streams (Paper III), the governance capacity framework (Koop et al., 2017) was adapted and applied. The governance capacity framework is a diagnostic empirical approach that consists of three dimensions, each with three conditions and each of these in turn comprising of three indicators, hence a total of 27 indicators as shown in Table 3. When applying the framework, each of the indicators is assigned a score out of a five-point Likert-type scale, ranging from very encouraging (++) to very limiting (– –), to gauge the overall capacity to govern the environmental challenge that is being assessed.

Table 3: The dimensions, conditions and indicators of the Governance Capacity Framework Source: (Koop et al., 2017).

Dimensions	Condition	Indicators
Knowing	**1 Awareness**	1.1 Community knowledge
		1.2 Local sense of urgency
		1.3 Behavioural internalization
	2 Useful knowledge	2.1 Information availability
		2.2 Information transparency
		2.3 Knowledge cohesion
	3 Continuous learning	3.1 Smart monitoring
		3.2 Evaluation
		3.3 Cross-stakeholder learning
Wanting	**4 Stakeholder engagement process**	4.1 Stakeholder inclusiveness
		4.2 Protection of core values
		4.3 Progress and variety of options
	5 Management ambition	5.1 Ambitious and realistic management
		5.2 Discourse embedding
		5.3 Management cohesion
	6 Agents of change	6.1 Entrepreneurial agents
		6.2 Collaborative agents
		6.3 Visionary agents
Enabling	**7 Multi-level network potential**	7.1 Room to manoeuvre
		7.2 Clear division of responsibilities
		7.3 Authority
	8 Financial viability	8.1 Affordability
		8.2 Consumer willingness-to-pay
		8.3 Financial continuation
	9 Implementing capacity	9.1 Policy instruments
		9.2 Statutory compliance
		9.3 Preparedness

The GCF was selected for this research because it's standardized triangulation approach can enable reproducibility as well as comparison with other cases. While there are other governance frameworks that have been applied within the context of sanitation, waste management and sustainability in general (see e.g. Nilsson *et al.* (2009), Loorbach (2010), Mutisya & Yarime (2014) and Peal *et al.* (2014)) many of them are used for implementing governance strategies or for other analytical purposes and not necessarily diagnostics unlike the GCF. The GCF is based on an extensive knowledge base on how normative principles and enabling or adaptive capacities can be used to overcome governance barriers (Koop et al., 2017). It has been applied in multiple cases with a focus on governance challenges connected to the water sector (Brockhoff et al., 2019; Koop et al., 2017; Madonsela et al., 2019; Šteflová et al., 2018). In the Naivasha case, the framework is taken beyond the water sector to a multi-sectoral context involving other crucial sectors that are related to resource recovery from organic waste streams in urban areas.

Applying the GCF to the Naivasha context involved adapting the pre-defined questions to Naivasha and to a multi-sectoral context, followed by a desk study of literature to generate preliminary scores for the indicators. Afterwards, a set of stakeholders were selected to participate in semi-structured interviews (see section 3.3.2). The interviews and the further feedback obtained from the interviewees subsequently provided information for the final scores on the indicators as well as a narrative summary of the results. By analyzing the information obtained from the literature and the interviews in relation to the pre-defined questions, each indicator was assigned a score out of the five-point Likert-type scale hence illustrating the overall governance capacity.

3.3.2 Interviews

Interviews are an essential part of conducting qualitative research (Qu and Dumay, 2011). They are a mode of knowledge production through which an interviewee's experiences, knowledge, ideas and impressions may be considered and documented (Alvesson, 2003). There are various types of interviews including structured and semi-structured interviews and an extensive overview of interview techniques is provided by (King et al., 2018). The interviews conducted for Paper III were of semi-structured type and their format followed the GCF methodology (Koop et al., 2017), guided by the pre-defined questions for the 27 indicators.

Based on a comprehensive list of stakeholders collated in collaboration with partners in Naivasha, a diverse set of stakeholders representing national public authorities, local public authorities, private sector, research & innovation institutions, NGOs & cluster organizations, citizens and user groups were selected to participate in the interviews. These categories represented various stakeholder types and effort was made to select stakeholders representing various stages of the sanitation and waste management service chain. Altogether, 21 interviews were conducted, each lasting between 45 to 90 minutes and taking place typically at the interviewee's place of work. After the interviews, summaries were made of the responses from each interviewee and they were asked to give feedback or make corrections in case any information they provided had been misunderstood. This feedback was integrated into an overall summary combining all interview and desk review information and the analysis of this was the basis for the GCF scores.

3.4 Literature review and document analysis

Throughout this research, literature reviews and document analyses have been conducted both to provide an understanding of the theoretical concepts connected to the research and also to collect data for the research. For Paper III, the literature review and document analysis were more systematic. It followed the governance capacity framework approach (Koop et al., 2017), using the pre-defined questions developed for the Naivasha case study with the aim of generating preliminary scores on the 27 indicators.

4 Results

The key results from the research, based on the appended papers, are presented in this section according to the research questions.

4.1 The potential for a circular economy of urban organic waste in sub-Saharan Africa

The results obtained within Paper I indicated that there is significant potential to implement a circular economy through resource recovery from organic waste streams in cities. In the Kampala case study, up to 39.6 million Nm^3 of biogas could be generated from the amounts of the waste streams that are currently collected (Scenario 1) as shown in Table 4. With increasing collection and efficient in the waste management systems, the amount of biogas could rise up to 62.5 million Nm^3 annually (Scenario 2) as shown in Table 5. Alternatively, up to 214,700 tonnes of solid fuel could be obtained if the waste streams that can be potentially collected were dried and densified. If the waste streams were processed using black soldier fly larvae, up to 23,900 tonnes of larvae could be harvested and this could be used as animal feed. Alternatively, the waste streams could be treated through composting and this could generate up to 173,000 tonnes of compost annually. The potential annual revenues that could be obtained from these products ranges from US$ 5.1 million from compost within the first scenario up to US$ 77 million from products of anaerobic digestion in the second scenario.

The results also indicate that significant amounts of nutrients could be recovered in the Kampala case in the form of digestate, compost and the residue from black soldier fly larvae production. As illustrated in Figure 3 and Table 4, the quantities of nutrients that could be recovered from digestate is almost similar to the quantities recoverable via compost. It can also be seen that the quantities of nutrients recovered from faecal sludge is significantly higher than the quantities recoverable from sewage sludge and organic municipal solid waste. Table 4 and Table 5 also indicate that the potential revenues from nutrient-containing products are relatively lower that the potential revenues from other products, in both scenarios. From an energy perspective, Figure 3 indicates that more energy could be recovered from turning the waste streams into solid fuel than using them to generate biogas. This could also generate relatively higher revenues in the case of faecal sludge and sewage sludge, although the reverse is true for organic solid waste.

Table 4: Resource recovery estimates for Kampala from the amount of waste streams that are currently collected (scenario 1)
(Source: Paper I)

		FS	SS	OMSW	Total
ANAEROBIC DIGESTION Biogas	**Amount of Biogas in Nm^3**	1,372,000	384,000	37,848,000	39,604,000
	Energy Content (TJ)	30	8	818	855
	Energy Content (GWh)	8	2	227	238
	Potential biogas revenue (US$)	1,630,000	456,000	44,963,000	47,049,000
Residue for fertilizer/soil amendment	**Amount of AD Residue (tonnes, dry mass)**	1,800	400	33,000	35,200
	Potential AD residue revenue (US$)	85,000	19,000	1,555,000	1,659,000
	N% of AD residue	26.4%	0.0%	0.0%	
	N by mass (kg)	476,253	26	1,567	477,845
	P% of AD residue	4.4%	0.0%	0.0%	
	P by mass (kg)	79,858	23	318	80,200
	K% of AD residue	1.3%	0.0%	0.0%	
	K by mass (kg)	23,126	9	2,165	25,300
	Total potential AD revenue (US$)	1,715,000	475,000	46,519,000	48,709,000
SOLID FUEL	**Amount of solid fuel (tonnes, dry mass)**	6,900	1,600	126,200	134,700
	Energy content (TJ)	111	25	2,183	2,319
	Energy content (GWh)	31	7	606	644
	Total potential solid fuel revenue (US$)	2,292,000	522,000	42,053,000	44,867,000
BLACK SOLDIER FLY Larvae	**Amount of BSF Larvae (tonnes, dry mass)**	340	80	14,870	15,290
	Protein content (tonnes)	140	30	5,950	6,120
	Fat content (tonnes)	100	20	4,460	4,580
	Potential larvae revenue (US$)	278,500	63,000	12,048,000	12,390,000
Residue for fertilizer/soil amendment	**Amount of BSF Residue (tonnes, dry mass)**	2,200	500	32,300	35,000
	Potential BSF residue revenue (US$)	104,000	24,000	1,521,000	1,649,000
	N% of BSF residue	6.2%	0.0%	0.0%	
	N by mass (kg)	138,113	7	454	138,575
	P% of BSF residue	1.7%	0.0%	0.0%	
	P by mass (kg)	38,332	11	153	38,496
	K% of BSF residue	0.5%	0.0%	0.0%	
	K by mass (kg)	11,101	4	1,039	12,144
	Total potential BSF revenue (US$)	383,000	87,000	13,569,000	14,039,000
COMPOST	**Amount of compost (tonnes, dry mass)**	5,500	1,300	101,700	108,500
Fertilizer/Soil conditioner from composting	**Total potential compost revenue (US$)**	261,000	59,000	4,785,000	5,105,000
	N% of compost	8.6%	0.0%	0.0%	
	N by mass (kg)	476,253	26	1,567	477,845
	P% of compost	1.4%	0.0%	0.0%	
	P by mass (kg)	79,858	23	318	80,200
	K% of compost	0.4%	0.0%	0.0%	
	K by mass (kg)	23,126	9	2,165	25,300

Table 5: Quantities of products that could be obtained from the waste streams in Kampala and their potential revenues, if the entire waste amount is used for one resource recovery option only in each case for Scenario 2.
(Source: Paper I)

Resource recovery options		Faecal Sludge	Sewage Sludge	Organic MSW	Total Annual Quantity	Total Potential Revenue (US$/year)
Anaerobic Digestion	**Biogas (Nm^3)**	3,190,000	1,131,000	58,228,000	62,549,000	74,308,000
	Digestate (tonnes)	4,200	1,200	50,800	56,200	2,647,000
Densification: Solid Fuel (tonnes)		16,000	4,600	194,100	214,700	71,565,000
BSF processing	**BSF Larvae (tonnes)**	800	200	22,900	23,900	19,370,000
	BSF residue (tonnes)	5,200	1,500	49,700	56,400	2,653,000
Composting: Compost (tonnes)		12,900	3,700	156,400	173,000	8,144,000

4.2 The potential of dried faecal sludge as a solid fuel

The results from drying faecal sludge and using it as a solid fuel in a pilot kiln (Paper II) indicate that it has significant potential to substitute for some of the fuels currently used in industry. In Table 6, the physical and chemical characteristics of dried faecal sludge are shown as an illustration of its fuel quality, in comparison with the characteristics of other related waste streams and fuels which were obtained from literature. The calorific value and ash content of dried faecal sludge in Kampala of 10.9 ± 3.5 MJ/kg and 58.7 ± 12 % respectively, compared well to reported values for wastewater sludge and were well within recommended industrial limits. Concentrations of elements that influence ash formation and ash fusion temperature (calcium, magnesium, phosphorus, potassium, silicon and sodium) were also comparable with wastewater sludge and within guideline values in some cases, although higher than in coal for parameters like phosphorus and silicon.

Concentrations of elements which influence the formation of dioxins, furans, NO_x, N_2O, SO_2, HCl, HF and C_xH_y during combustion (chlorine, nitrogen and sulfur) were relatively high in the dried faecal sludge when compared to guideline values. However, concentrations of heavy metals (mercury, arsenic, cadmium, chromium, copper, nickel, lead and zinc) were generally lower than those reported for wastewater sludge although higher than in excreta.

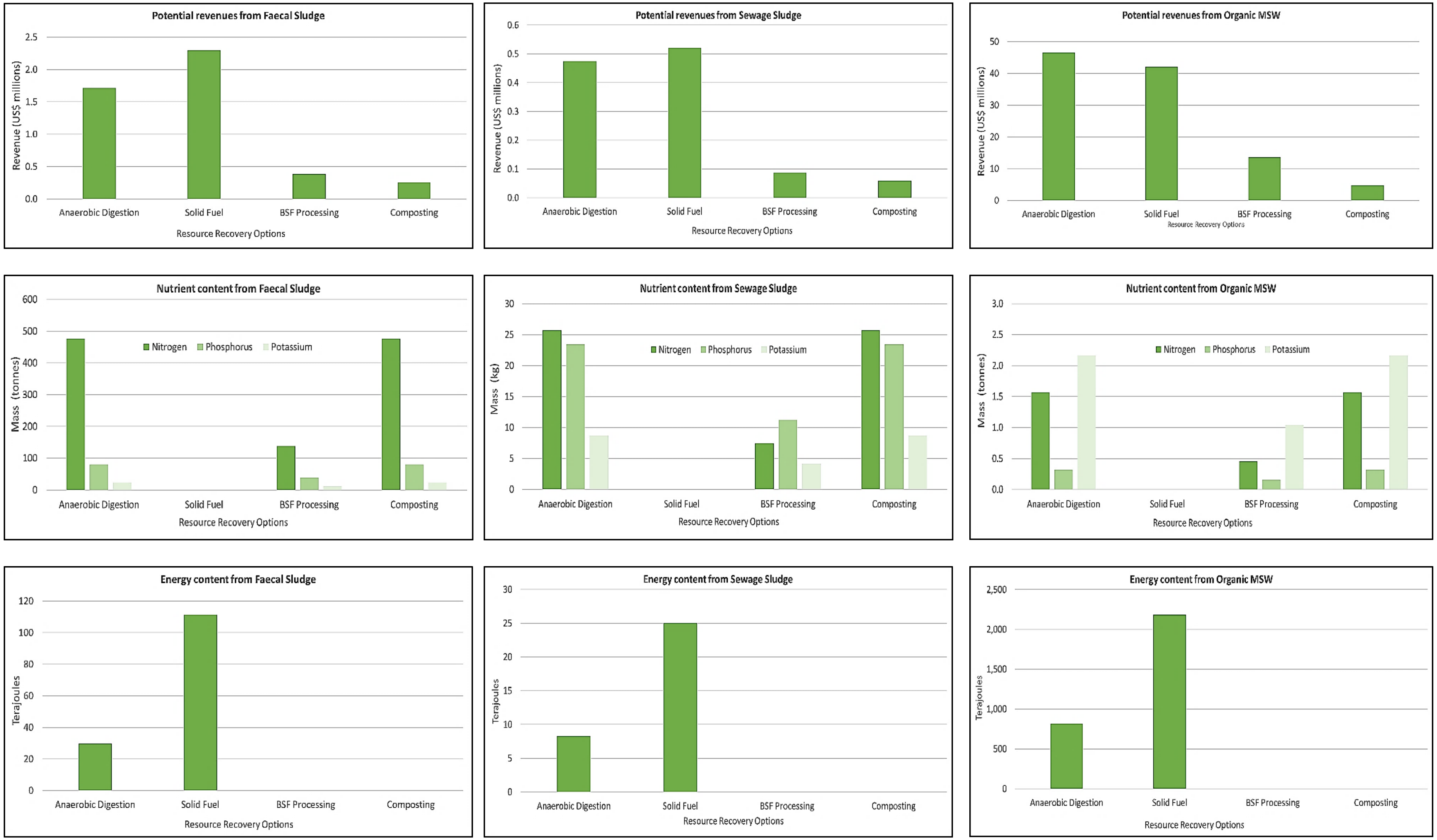


Figure 3: Comparison of four resource recovery options based on potential revenue generation, nutrient recovery and energy recovery from the amount of waste streams that are currently collected in Kampala (Scenario 1)
(Source: Paper I)

Table 6: Characteristics (all in dry mass) of dried FS from Kampala in comparison to values from literature for wastewater sludge, excreta, coal, industrial limits and guideline values for use of solid fuels in industrial applications
(Source: Paper II)

Parameter	Unit	Kampala Faecal sludge		Wastewater sludge[a,b,c,d]	Excreta[e], faeces[f,g]	Coal[a,b]	Guiding values[h,i]	Industrial limits[j,k,l,m,n]
		Mean	SD					
Calorific value	MJ/kg	10.9	3.5	7.0–14.4	–	31–34.9	–	>8–14
Helminth eggs	eggs/g	75	96	–	–	–	–	–
Moisture	%	8.1	2.9	6.6–26	–	1.6–10	–	<10
Ash	%	58.7	12	39.5–57	7.9–21.1	7.5–15	–	<60–15
Calcium	%	2.05	0.2	5.3–8.5	–	0.2–0.45	15–35	–
Carbon	%	27.8	3.1	16.9–31.6	–	70–79.1	–	–
Chlorine	%	0.04	0	0.07–0.4	–	0.06	<0.3-0.03	<0.5–0.2
Hydrogen	%	4.2	0.5	3.3–7.6	–	4–5.0	–	–
Magnesium	%	1.2	0.4	0.35–0.5	–	0.02–0.3	–	–
Nitrogen	%	3.2	0.4	0.4–4.2	3.9–11.8	1.2–1.8	<2.5-0.6	–
Phosphorus	%	1.4	0.4	3.1	1.3–2.3	0.51	-	<1.0
Potassium	%	0.36	0	0.5–0.7	–	0.04–0.4	<7.0	–
Silicon	%	7.91	2.7	5.1–9.2	–	2.4–4.2	–	–
Sodium	%	0.36	0.1	0.2–0.4	–	0.03–0.14	–	–
Sulfur	%	0.7	0.1	0.7–1.6	0.5–1.6	0.7–2.1	<0.2-0.1	<2.5–0.5
Arsenic	ppm	0.6	0.4	<0.3–14	–	<0.3–4	-	–
Cadmium	ppm	<2.0	0	4–10.1	0.3–0.4	<1–0.17	<5	–
Chromium	ppm	485	298	190–530	0.7	12.2–33	–	–
Copper	ppm	114	12	5.3–400	22–36	1.8–32	–	<3,000–1,000
Lead	ppm	28	8	220–365	0.7–1.2	2.0–19	–	–
Mercury	ppm	<0.9	0.5	2.1–5.4	0.3	0.08–0.2	–	<10
Nickel	ppm	24	4	40–45	2.5–4.8	12–19	–	–
Zinc	ppm	646	56	1,132–4,900	135–355	22.8–50	<800	–

SD = standard deviation.

[a] Helena Lopes et al. (2003).

[b] Luts (2000).

[c] Otero et al. (2007).

[d] Judex et al. (2012)

[e] Schouw et al. (2002)

[f] Vinnerås et al. (2006).

[g] DWA (2008)

[h] Obernberger et al. (2006)

[i] van Loom & Jaap (2008)

[j] Diaw (personal communication; Directeur Qualité-Sécurité-Environnement, Sococim Industrie, Rufisque, Senegal).

[k] Holcim (Schweiz) AG (2013).
[l] Barikurungi (personal communication; Industrial Ecology Coordinator, Hima Cement Ltd, Kampala, Uganda).
[m] Madlool et al. (2011)
[n] WBCSD (2014)

The temperature profiles during the kiln experiments with faecal sludge and coffee husks are shown in Figure 4. Throughout the experiments, there was high variability in the temperatures and the recorded temperatures were highest in the combustion zone. Over the four repetitions with faecal sludge, average temperatures were 524 °C while the maximum temperatures obtained were over 800 °C. During the two experiments with coffee husks, average temperatures of 421 °C and 552 °C were obtained, with maximum temperature of 850 °C. The compressive strength of the resulting cured bricks was 8.3 ± 2.4 MPa for faecal sludge and 5.9 to 8.4 MPa for coffee husks. For commercially produced bricks from Uganda Clays Ltd, the compressive strength was 6.2 MPa and 7.9 MPa.

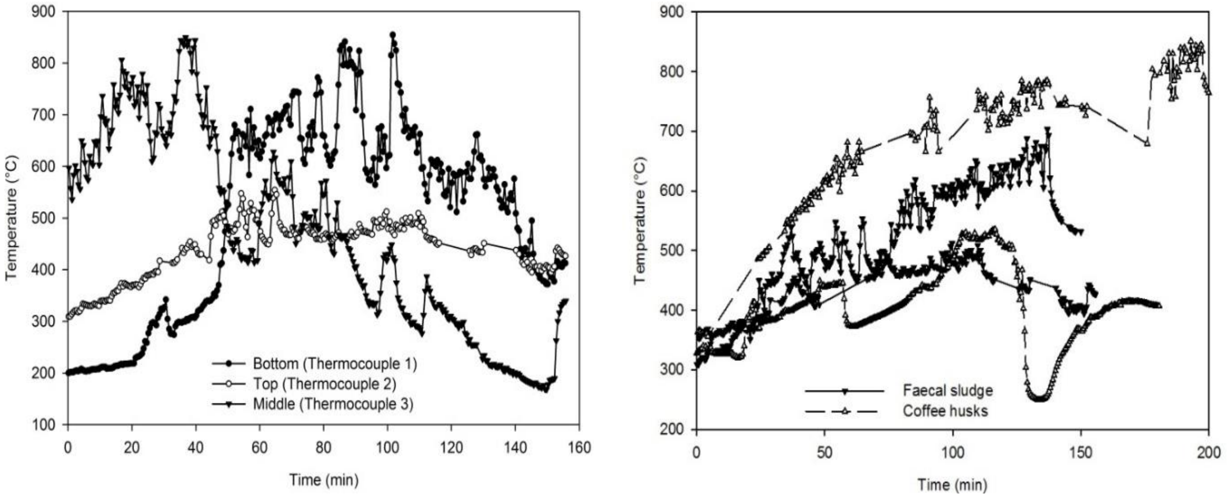


Figure 4: Temperature profiles from different points within the kiln during one experiment with FS (left) and from the top area of the kiln (Thermocouple 2) during two experiments with FS and coffee husks (right)
(Source: Paper II)

4.3 Governance factors for implementing circular economy approaches to the management of organic waste streams

The overall profile from the governance capacity assessment for Naivasha (Paper III) is shown in Figure 5. The scores on the diagram illustrate the extent to which each indicator is encouraging or limiting to the overall governance capacity and hence how it could manifest as an opportunity or a challenge for implementing circular approaches that recover resources from organic waste streams in the town. The aggregate scores for the three indicators in each condition are illustrated in Figure 6.

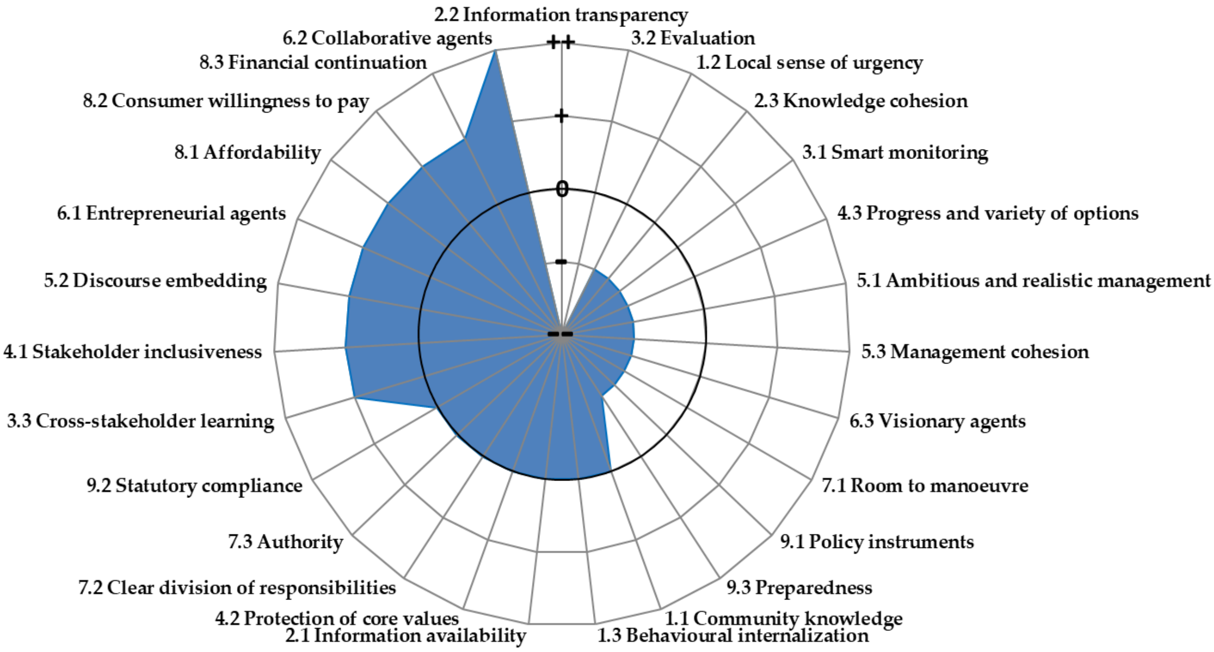


Figure 5: GCF results of Naivasha for the 27 indicators depicted in a spider diagram with the indicators arranged in clockwise manner according to scores from very limiting (--) to very encouraging (++).
(Source: Paper III)

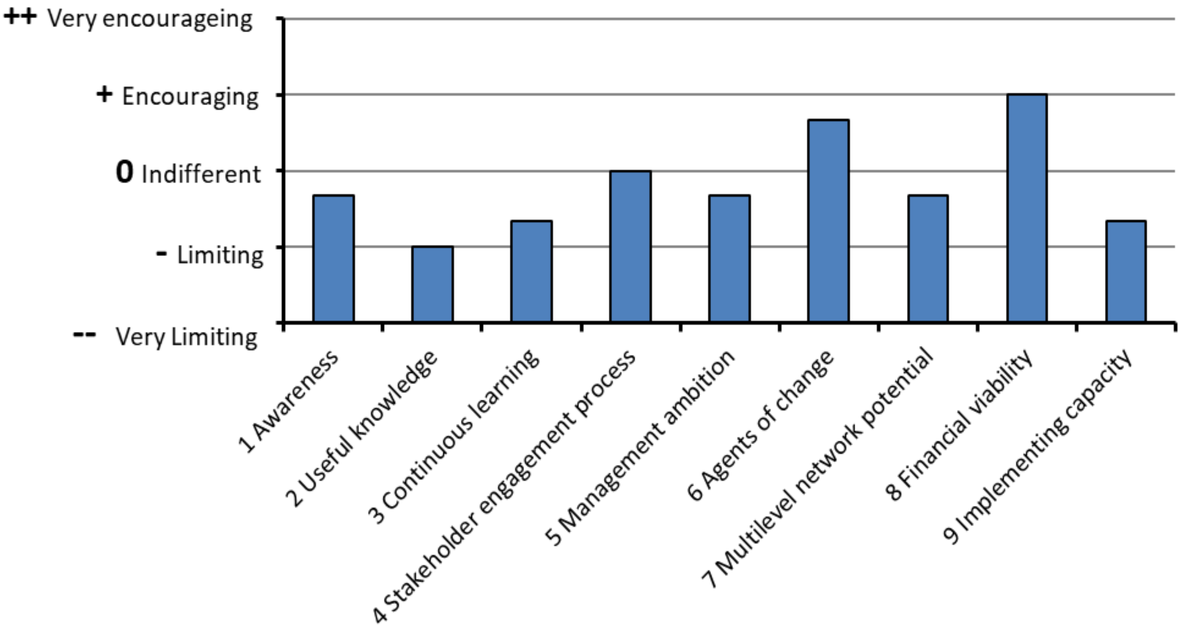


Figure 6: Summary scores of Naivasha's governance capacity to implement resource-oriented sanitation and waste management systems. The bars represent the average scores for each governance condition.
(Source: Paper III)

4.3.1 Encouraging factors

The results indicate that there are several stakeholders in Naivasha from both the civil society and private sectors who started initiatives for resource recovery from organic waste streams, hence illustrating the presence of entrepreneurial agents (indicator 6.1). These include *Sanivation* which makes solid fuels from excreta, *Tropical Power/BioJoule* which set up the first grid-connected biogas plant in the East African region as well as *Waste to Best* and *Kwa Muhia Environmental Group* which are local community based organizations (CBOs) that established composting initiatives. There is a well-established culture of forming associations and self-help groups in Kenya and this has enabled the establishment of various CBOs that enable collaboration between stakeholders whose work relates to resource recovery from organic waste streams (indicator 6.2). This is further augmented by the growing interest in public-private partnerships in Kenya as a mode for service delivery and the establishment of collaborative platforms like the *Imarisha Naivasha* environmental management coordination program for the Lake Naivasha Basin and the Naivasha Subcounty Sanitation Steering Committee (Duma, 2019). This is illustrated in Figure 6 within condition 6 – *agents of change*.

While the ability and willingness to pay for water, sanitation and waste management services varies and is largely determined by household income levels, products of resource recovery from organic waste streams are viewed by some stakeholders as affordable (indicator 8.1 and 8.2). Some products like briquettes and compost are perceived by some as price-competitive with alternative traditional products like charcoal and chemical fertilizers respectively. This could indicate the potential market size for resource recovery products in Naivasha and Kenya in general given that some stakeholders who make resource recovery products are not able to satisfy the existing demand. At the same time, there are multiple opportunities for funding initiatives for resource recovery from organic waste streams from both public and private sources (indicator 8.3). These include sources aligned with closely related sectors like the Water Fund and the National Environment Trust Fund as well as other sources of funding that are indifferent to investment type e.g. banks and investment associations which are locally known as *chamas*[2]. While private sources of finance are often limited to initiatives with proven commercial viability, public sources of financing can be accessed for early-stage ventures as has been done in some cases. This is illustrated in Figure 6 within condition 8 – *financial viability*.

4.3.2 Impeding factors

In Naivasha, most of the available information about the circular economy and resource recovery from organic waste streams can only be accessed from

---

[2] An overview of what *Chamas* are and how they operate is provided in *The Chama Handbook* (2016, 3rd ed.) by the Kenya Association of Investment Groups (KAIG), Nairobi, Kenya.

stakeholders who have been involved in projects and initiatives related to resource recovery in the past (indicator 2.1). In many cases, contextual information is available only in print form and one may have to encounter a lot of bureaucracy to access it. Moreover, the reports and documents available for local stakeholders about resource recovery from organic waste streams are often written using expert terminology that lay people cannot easily comprehend, and in English although the lingua franca in Kenya is actually Kiswahili. Some information has been translated and made available in lay language e.g. about how to make briquettes on small scale but this is more of an exception than is typical (indicator 2.2). Moreover, some of the concepts related to the circular economy and resource recovery from organic waste streams have not been connected to equivalents in the local knowledge context, leading some local stakeholders to think that the circular economy is more of a "European concept" (indicator 2.3). This is illustrated in Figure 6 within condition 2 – *useful knowledge*.

Implementing a circular economy through resource recovery from organic waste streams implies connecting multiple sectors like water and sanitation, waste management, agriculture, energy, natural resources and environmental management. However, the monitoring infrastructure and systems connected to these sectors in Naivasha and Kenya in general including quality assurance laboratories, audit and certification systems, are fragmented along sectoral lines. There are no initiatives as yet to connect them in a way that could generate insights for monitoring circular economy implementaiton (indicator 3.1). The evaluation of policies, strategies and their implementation is also done infrequently and on ad hoc basis, hence missing insights that could be gained from more routine evaluations (indicator 3.2). While there are some formal and informal platforms that have been created over the years for multi-stakeholder collaboration in Naivasha, they are still aligned with sectoral divides e.g. the Naivasha Green Grassroots Waste Management Association, the Naivasha Subcounty Sanitation steering committee. There is yet to emerge formal platforms that can enable interaction and learning across the different sectors that are connected to resource recovery from organic waste streams. This is illustrated in Figure 6 within condition 3 – *continuous learning*.

Some of the policy and regulatory instruments that are used in collection to the sanitation and the waste management services in Naivasha and Kenya in general include licenses, permits, service level guidelines and even mandatory public participation in governance processes. However, some of these policy instruments are difficult to enforce due to the limited capacity of the public sector. This also impacts the extent to which policy instruments are monitored and evaluated to gain insights about their implementation and possible improvements (indicator 9.1). The level of statutory compliance in Naivasha (indicator 9.2) is impacted by the limited capacity of the public sector to monitor and oversee the implementation of multiple policy instruments, coupled with the costs that households and other stakeholders have to incur in complying with regulatory measures. Moreover, the existing infrastructure for sanitation and waste management in Naivasha has not kept up with the rising population and the layers of bureaucracy that public sector stakeholders have to navigate at the sub-county, county, regional and national governance levels often limit their preparedness and ability to respond to emerging challenges especially in the short and medium term (indicator 9.3). This is all illustrated in Figure 6 within condition 9 – *implementing capacity*.

5 Discussion

In this chapter, the results are discussed in relation to the research objectives and also positioned in the wider context of existing literature.

5.1 Opportunities for implementing circular economy approaches to the management of urban organic waste streams

5.1.1 The quantitative potential for valorizing organic waste streams

The results described in section 4 indicate the considerable potential for recovering resources that are embedded in organic waste streams and hence implementing circular economy approaches in cities. As of 2016, about 174 million tonnes of municipal waste was generated in sub-Saharan Africa, and this is expected to triple by the year 2050. About 40% of this waste is organic in nature (Kaza et al., 2018), implying that about 70 million tonnes of organic municipal solid waste is generated in sub-Saharan Africa annually. Assuming a daily per capita excreta generation of 1.5 litres (Rose et al., 2015), the 472 million urban residents in Africa (Lall et al., 2017) altogether generate about 258 billion litres of excreta annually. Organic waste streams form a significant part of the circular economy (Figure 1) and hence progress in resource recovery from organic waste streams is crucial to advancing circular economy principles.

The Kampala case illustrates how the organic waste streams presently collected in a city with 1.5 to 3 million people can be valorized to generate 39.6 million Nm^3 of biogas, 134,700 tonnes of solid fuel, 15,290 tonnes of black soldier fly larvae or 108,500 tonnes of compost. The quantification approach used in this thesis also presents an alternative way to undertake a rapid assessment of circular economy valorization potential and generate estimates in other urban areas where such assessments have not been done previously and where other decision support tools that could have been used are not appropriate. SSA presently has at least 28 cities which have a population greater than 2 million people (Lall et al., 2017). Moreover, these cities have similar arrangements for sanitation and waste management infrastructure, characterized largely by on-site systems. This indicates the possibility that the potential for circular economy valorization of organic waste streams illustrated for Kampala could be replicated in other urban contexts in SSA. Besides Kampala and Naivasha, many other cities in SSA have previous experiences with resource recovery from organic waste and some cases have been described in Otoo and Drechsel (2018). This also indicates the further possibilities to raise awareness about circular economy approaches and create markets for resource recovery products.

The results from the Kampala case study (Paper I) indicate that organic municipal solid waste has relatively higher circular economy valorization potential in terms of the quantities of resource recovery products and the energy and revenue potentials.

This is partly due to the fact that far larger quantities of organic municipal solid waste are presently collected in the city in comparison to faecal sludge and sewage sludge. About 65% of all solid waste generated in Kampala is collected (Tukahirwa and Lukooya, 2015), as compared to about 43% of the faecal sludge (KCCA, 2018). It could also be explained by the differences in moisture content in the various waste streams, which influences the quantity of products like solid fuel, compost and black soldier fly larvae. Both faecal sludge and sewage sludge in Kampala have a moisture content of over 90% (Schöbitz et al., 2014) and this is similar to other cities in sub-Saharan Africa (Gold et al., 2016; Niwagaba et al., 2014). On the other hand, organic municipal solid waste is just above 70% moisture content (Komakech, 2014).

5.1.1.1 Nutrient recovery

Nutrients like nitrogen, phosphorus and potassium can be recovered along with other resource recovery products like in the case of anaerobic digestion and the residue from black soldier fly breeding. This provides the opportunity for recovering multiple resources from waste streams to meet different needs in urban areas. In the case of BSF breeding, nutrient recycling occurs through the residues which can be applied to agricultural land for example in the form of soil conditioner and also through the larvae, although these are used as feed rather than for direct application to soil. Since the assessment in this thesis focused on nutrient products in a form that can be applied directly to soil, the results indicated that the nutrient content in the residue from BSF breeding is relatively less compared to that from AD or composting processes even though from a wider system perspective, nutrient cycling through using BSF larvae as feed is acknowledged.

The amount of nutrients in resource recovery products depends on the amount of nutrients in the raw waste streams and the treatment process they go through. For example, there is negligible nutrient reduction in the residue from the anaerobic digestion process as compared to that from the BSF breeding process (Harrison et al., 2013; Van Huis et al., 2013; Wang et al., 2010). The results in the Kampala case indicate that there are far higher quantities of nutrients that could be recovered from faecal sludge as compared to sewage sludge and organic municipal solid waste. This implies that different resource recovery options could be targeted according to waste stream and in this case, nutrient recovery options would be earmarked for faecal sludge, and not for sewage sludge or organic municipal solid waste. Otherwise, the alternative would be co-treatment of waste streams e.g. via co-composting and there are cities in sub-Saharan Africa where this is already happening (Cofie et al., 2009; Otoo and Drechsel, 2018).

5.1.1.2 Fly larvae production

In Uganda, sources of protein that have been traditionally used for making animal feed like soybeans and fish meal have seen erratic supply as well as price fluctuations in recent years (Onen et al., 2019). The production of black soldier fly larvae on a wide range of organic waste streams is therefore seen as an attractive alternative, given the constant supply of organic feedstock from municipal solid waste, agricultural waste and excreta-based waste streams like faecal sludge (Joly and Nikiema, 2019; Shumo et al., 2019). The results for scenario 1 in the Kampala case study (Table 4) show that up to US$ 278,500 could be obtained annually from producing black soldier fly larvae out of Kampala's faecal sludge and up to US$ 12.4 million from all organic waste streams combined. This is much higher than the estimate from Diener *et al.* (2014) of US$ 109,200 annually. The difference can be attributed to the fact that Diener *et al.* (2014) focused their assessment on faecal sludge as the waste stream and also used price estimates based on fish meal prices. In this thesis however, the price used in the assessment are based on reported prices from ongoing black soldier fly production initiatives in Uganda.

There are other insect larvae and worms that can be used to valorize organic waste streams with the products being used for animal feed or other applications (Lohri et al., 2017; Ogunji et al., 2007; St-Hilaire et al., 2007). Black soldier fly larvae have gained relatively more prominence in recent years compared to other insect larvae and there is an increasing number of small and large scale facilities producing the larvae from multiple waste streams in different areas in sub-Saharan Africa (Joly and Nikiema, 2019; Moya et al., 2019; Nakato, 2018). The majority of these facilities are producing black soldier fly larvae mainly for use as animal feed ingredient since applications for energy generation are still in their infancy (Nguyen et al., 2018). It is for this reason also that the energy content of BSF larvae was not assessed in the scope of this thesis.

5.1.1.3 Energy recovery

Energy can be recovered from organic waste streams in various ways (see e.g. Lohri et al., 2017; Otoo and Drechsel, 2018; Qadir et al., 2020). Two options are considered in this thesis which are via anaerobic digestion and the production of solid fuels. Biogas is used as a vehicle fuel and to generate heat and power in Europe, Asia and the Americas. However, the applications in sub-Saharan Africa have so far focused on its use as a fuel for cooking and lighting and for producing electricity (Kamadi, 2017; Otoo and Drechsel, 2018; Yousuf et al., 2016). Solid fuels from organic waste streams have also been used mainly for cooking in the form of briquettes and pellets (Asamoah et al., 2016; Mwampamba et al., 2013; Romallosa and Kraft, 2017). However, there is potential for industrial applications as demonstrated in Paper II and this has interest from some stakeholders (Diener et al., 2014).

It is seen from the results in Paper I that more energy recovery is possible from producing solid fuel than by generating biogas in the Kampala case. This could be attributed to the fact that during combustion of solid fuel, all organic material is transformed into heat while during AD, only part of the organic material is transformed into biogas and subsequently into energy. However, while the potential revenues from solid fuels made from faecal sludge and sewage sludge are relatively higher than those from anaerobic digestion, the reverse applies for organic municipal solid waste. This could be due to the higher biomethane potential of solid organic waste, 400 Nm^3 CH4/tonne VS (Vögeli et al., 2014) as opposed to 300 Nm^3

CH4/tonne VS for faecal sludge (Rose et al., 2015), and hence higher biogas yields. Organic municipal solid waste also consist largely of fruit and vegetable waste which generally has higher carbon/nitrogen ratio and this leads to better biogas yields (Müller, 2009). This implies that co-treatment of waste streams could be necessary to improve the carbon/nitrogen ratio, in instances where the goal is to optimize biogas yields (Minale and Worku, 2014; Valencia et al., 2009).

5.1.2 The viability of dried faecal sludge as an industrial fuel

The characteristics of dried faecal sludge in Kampala and its performance in the pilot kiln experiments generally illustrated its potential for use in industrial applications (Paper II). The calorific value of dried faecal sludge of 10.9 ± 3.5 MJ/kg TS is comparable to reported values for wastewater sludge which has for long been used in industrial heating applications in Europe and North America, as well as reported values for faecal sludge from elsewhere in sub-Saharan Africa (Muspratt et al., 2014). It is also within the range for other biomass fuels that are commonly used in sub-Saharan Africa e.g. rice husks, coffee husks and sawdust (Muspratt et al., 2014). The ash content was however relatively higher than reported values for wastewater and excreta, yet it diminishes the fuel value (Hafford et al., 2018). The high ash content could possibly originate from the sand in the drying beds and hence could be reduced through methods like using geotextiles for drying faecal sludge so as to reduce contact between faecal sludge and sand.

While the heavy metal concentrations in the faecal sludge were higher than reported values for excreta, they were lower than reported values for wastewater sludge and the industrial limits and were in the same range as those reported by Bassan *et al.* (2013) and Appiah-Effah et al. (2015). Heavy metals do not necessarily have much influence on the combustion process of a solid fuel, but they contribute to deposit formation and aerosol emissions (Obernberger et al., 2006) and they are also of interest for public health reasons as discussed in section 5.2.5.

The concentrations of ash forming elements in dried faecal sludge from Kampala were comparable with those in wastewater sludge. While ash forming elements impact fuel quality (Hafford et al., 2018), they also indicate further potential for resource recovery from the ash that remains after the combustion of organic waste streams. Obviously, some of the elements listed in Table 6 are emitted into the air as gaseous compounds during combustion but others remain in the ash. In countries where sewage sludge incineration has been ongoing for decades, several valorizations options have been explored for incinerated sewage sludge ash including; the manufacturing of sintered materials like bricks, tiles, pavers and glass-ceramics, the manufacturing of cement, the recovery of phosphorus, soil amendments and coper adsorbents (Donatello and Cheeseman, 2013). There is little in the literature about the application of these valorization options in an African context and to waste streams like faecal sludge. However, one could assume that as waste and sanitation infrastructure improves on the continent and waste-derived solid fuels become increasingly used on an industrial scale, resource recovery of the various elements in ash could be interesting to develop, hence further contributing to material circularity.

5.1.3 The environmental impact of organic waste valorization

While this thesis did not include a detailed environmental assessment of the waste valorizations options considered, the results still provide insight into some of the potential impacts that could result from circular approaches. For example, Trimmer et al. (2017) conducted a review of the potential of sanitation to contribute to the sustainable development goals and they concluded that energy recovery could have limited impact. However, this is attributed to the fact that their analysis was based on electricity use data yet most households in sub-Saharan Africa, as in many other low and middle income countries, rely on other forms of energy (Njenga and Mendum, 2018). About 75% of household energy demand in sub-Saharan Africa is met with firewood (Smith et al., 2011). In Kampala, the annual per capita wood-based fuel consumption is about 240 kg of firewood and 120 kg of charcoal annually (MEMD, 2012; World Bank Group, 2015). Given that the calorific value of firewood and charcoal is 16 MJ/kg TS and 28 MJ/kg TS respectively (Diener et al., 2014), this implies that Kampala's resident population of 1.5 million consume about 10.8 PJ annually from wood-based fuels. Solid fuels from Kampala's organic waste streams have the potential to generate 2.32 PJ to 3.69 PJ of energy in scenario 1 and 2 respectively (Paper I), hence illustrating that up to 34.2% of Kampala's wood-based fuel consumption could be replaced with organic waste derived fuel. This indicates that energy recovery from organic waste streams could make a significant contribution not only towards progress in SDG 7 – affordable and clean energy, but also towards reducing the reliance on firewood and charcoal along with the associated adverse environmental impacts.

Another valorization option highlighted in Paper I also has a significant impact in terms of waste reduction, which is a key objective of waste management systems. Black soldier fly larvae have been reported to be able to reduce waste amounts by between 50 and 80% (Lohri et al., 2017), while at the same time having low greenhouse gas emissions (Ermolaev et al., 2019). The potential of black soldier fly larvae to reduce pathogens like *Salmonella* spp. and emerging contaminants like pharmaceuticals and pesticides has also been documented in recent studies (Lalander et al., 2016, 2013). Given that there is an increasing demand for animal-based protein especially in regions like sub-Saharan Africa (Boland et al., 2013), the demand for animal feed is expected to increase. Replacing animal feed ingredients like fish and fish meal with black soldier fly larvae could mitigate some of the adverse impacts of the changes in people's diets and hence contribute to achieving the SDG target 14.4 – restoring fish stocks by ending overfishing and illegal fishing practices.

5.1.4 Existing circular economy initiatives

From a governance perspective, the results from the Naivasha case indicate that there are several initiatives for resource recovery from organic waste that are being run by local stakeholders and this is akin to urban areas in other countries in sub-

Saharan Africa (Otoo and Drechsel, 2018). The experience built from these ongoing initiatives is key to building knowledge in the local ecosystem about the possibilities for a circular economy. Knowledge is a building block for governance (Kooiman et al., 2008) and is essential for informing decision-making and also for fostering coherent approaches to policy formulation and implementation (Rowley, 2007; van Rijswick et al., 2014).

The ongoing resource recovery initiatives in Naivasha have also raised public awareness about the circular economy to some extent, as seen from the reported demand for products. Public awareness is a building block for creating market for products of circular economy valorization and the availability of a market can make the difference between success and failure of circular economy initiatives (Danso et al., 2017; Otoo and Drechsel, 2018). Furthermore, the present level of public awareness provides a good foundation to build upon for stakeholder engagement campaigns that can mitigate the “yuck” factor that is often associated with some products of resource recovery from organic waste streams (Polprasert and Koottatep, 2017; Wester et al., 2015).

5.1.5 Stakeholder collaboration

The results also indicate that while still largely arranged along sectoral lines, the collaborative nature of stakeholders in Naivasha provides a foundation to build cross-sectoral collaborations for the circular economy. Collaboration is an essential element for the foundations of circular economy implementation (Abreu and Ceglia, 2018; Moreau et al., 2017) and its importance is well treated in the governance literature (Akhmouch et al., 2018; Kooiman et al., 2008; Weitz et al., 2017). While some models of circular economy implementation illustrate collaboration explicitly through renting, sharing, bartering and other collaborative consumption approaches (Ghisellini et al., 2016), the valorization of organic waste streams also requires collaboration. In most cities, organic waste streams are typically management by different stakeholders (Velenturf, 2016) and hence collaboration is needed to take advantage of approaches like co-treatment and co-valorization where applicable. Recovering resources like energy, water and nutrients introduces the need for collaborating with stakeholders from multiple sectors, hence demonstrating the boundary-transcending nature of circular economy valorization.

5.2 Challenges to implementing circular economy approaches to the management of urban organic waste streams

5.2.1 Variable waste quality

Resource recovery is largely influenced by physical and chemical characteristics of waste streams as discussed in Paper I and II. The quality of waste streams determines the amounts of the products that can be obtained from circular economy valorization, as well as the quality of those products. However, the quality of organic waste streams like faecal sludge and organic municipal solid waste is highly variable due to factors like seasons, demographics and technologies used for their handling prior to valorization (Niwagaba et al., 2014; Strande et al., 2018). The total solids concentration in faecal sludge could range from 12,000 mg/L to 52,500 mg/L (Niwagaba et al., 2014), for example. Such variations create challenges for implementing some circular economy valorization initiatives e.g. large-scale anaerobic digestion facilities which are sensitive to changes in feedstock quality (Ammenberg and Feiz, 2017; Feiz and Ammenberg, 2017).

5.2.2 Uncertainties due to contextual factors in implementation

Besides the quality of the organic waste streams, a number of other contextual factors can influence the potential quantities of resource recovery products that can be obtained from a valorization initiative, including the primary objective for resource recovery, the appropriate technologies available for treating the waste streams, logistical issues around waste collection and transport and the local climate. There are multiple technologies available for any one resource recovery option as discussed by e.g. Lohri et al (2017) and Strande *et al.* (2014) and novel technologies keep emerging. This presents a challenge for decision-makers, which could be tackled by using decision-support tools (Spuhler et al., 2018; Vea et al., 2018). The logistical challenges associated with organic waste stream management in sub-Saharan Africa are also increasingly being discussed in the literature e.g. by Schöbitz *et al.* (2017) and Kinobe (2015).

Different options for valorizing organic waste streams can lead to different outcomes with some focusing on energy recovery, others on nutrients recovery, others on water recovery and others providing approaches for recovering multiple resources simultaneously. The circular economy concept includes circularity of both both material flows and energy flows as described in section 2.1 but from an environmental perspective, the priority would be to recover materials like nutrients as opposed to energy. This is elaborated in the principles of the waste hierarchy and other such "R" frameworks (Gharfalkar et al., 2015; Kirchherr et al., 2017). Using waste streams for combustion as solid fuels can imply that nutrients and other material components embedded within the waste are "lost" and cannot be re-used again, unlike other energy generations options like anaerobic digestion. Even though some technologies provide for the recovery of materials like phosphorus from ash in case waste streams have undergone combustion (Donatello and Cheeseman, 2013), other nutrients and materials are emitted into the air and can also contribute to global warming and other health-related challenges (see section 5.2.5).

Managing the trade-offs between materials recovery and energy recovery requires a wholistic perspective that takes into account all relevant environmental, social and economic considerations. Tools like life cycle sustainability assessment (Guinée et al., 2011) and the SuSanA principles for sustainable sanitation (SuSanA, 2008) could be used to undertake an assessment with such a wholistic perspective. Taking such a wholistic perspective could imply making interventions further upstream in the sanitation and waste management system e.g. through establishing sourceseparation infrastructure for excreta management, so as to mitigate cross-contamination of waste streams and also optimize resource recovery yields (Andersson et al., 2016).

5.2.3 Costs, revenues, and business models

The potential revenues from resource recovery products discussed in Paper I may seem attractive to some extent but they do not include costs for implementing and operating treatment facilities to generate the products. Costs for sustaining resource recovery initiatives can be quite significant and have resulted in the failure of some schemes (Otoo and Drechsel, 2018). In any given urban area, the viability of different resource recovery options may vary and this could be assessed through detailed feasibility studies that track cost-related indicators (Murray et al., 2011) and evaluate business models (Otoo and Drechsel, 2018). However, it is also worth noting that revenues from resource recovery products could be seen as an additional revenue source that complements the traditional sources of revenues that sustain sanitation and waste management systems in cities. In sub-Saharan Africa where most of the population rely on on-site sanitation systems, most of the costs for sanitation are borne by households rather than other stakeholders in the service chain (Dodane et al., 2012). Additional revenue streams from resource recovery could therefore lighten the cost burden that households presently incur.

As indicated in Figure 3, the revenue potential from nutrient recovery products like compost and digestate is much lower relative to energy recovery products. This reflects findings from previous research which has indicated that the revenue potential from energy products is often higher than other products like soil conditioner and compost (Diener et al., 2014). The lower potential prices for compost-like products are attributed to the lower value that farmers attach to them, relative to chemical fertilizers. This arises from concerns about potential health risks, low nutrient content and even difficulties with handling on farms (Danso et al., 2017). Some of the proposed solutions to mitigate these concerns include organic fertilizer certifications schemes, fortification of compost and the use of appealing packaging and these seem to have a positive impact on market prices in some cases where they have been implemented (Danso et al., 2017; Moya et al., 2019).

5.2.4 Mismatch between theory and practice

From a governance perspective, the Naivasha case study (Paper III) demonstrates some level of mismatch between theory and practice which could impact circular economy implementation. While there are several examples of local initiatives for recovering resources from organic waste streams, some stakeholders do not seem to see it as part of circular economy approaches and this could be problematic given that knowledge cohesion across stakeholders and sectors is a crucial indicator of governance capacity (Koop et al., 2017). The disconnect between present practices and knowledge about circular economy concepts could perhaps be explained in terms of cultural evolution theory (Henrich and McElreath, 2003). This is where the imitation of techniques, behaviors and strategies by individuals leads to the transmission of practical solutions to everyday challenge down generations even when society cannot really explain the theoretical underpinnings of why those solutions work (Henrich, 2017). This therefore underscores the importance of taking into account the knowledge accumulated in communities of practice and weaving it into theoretical concepts of the circular economy when implementing initiatives in sub-Saharan Africa.

5.2.5 Health risks and safety

In the Naivasha case, the use of products of resource recovery from organic waste streams is perceived by some members of the public as associated with disgust and potential risks to health. This is akin to experiences in many other parts of sub-Saharan Africa (Danso et al., 2017; Wilson and Pfaff, 2008), which also often negatively impact the uptake of nutrient products like compost by farmers. As discussed by Ekane et al. (2016), resource recovery from organic waste streams like those derived from excreta is perceived in terms of risks and benefits. Implementation of circular approaches to organic waste management in any urban areas could be determined by whether the perceptions of risks among local stakeholders outweigh the perception of benefits or otherwise. This also demonstrates the need for strong monitoring systems (indicator 3.1) that can detect risks and mobilize effective responses.

In the case of using faecal sludge as an industrial fuel (Paper II), the relatively higher levels of chlorine, nitrogen and sulfur in faecal sludge, compared to other fuels and guideline values, indicate the potential for the formation of dioxins and furan as well as other gaseous pollutants like NO_x, N_2O, SO_2, as well as HCl, HF and C_xH_y. Dioxins and furans are destroyed at temperatures above 600°C (Kilgroe, 1996; Werther and Ogada, 1999) and this implies that industrial applications for faecal sludge should aim to achieve temperatures higher than that. There are many industrial processes that involve temperatures above 600°C including kilns for brick curing (Gita, personal communication; Ugandan Clays, Kampala) and some production stages in cement kilns (Werther and Ogada, 1999). The kiln experiments described in Paper II were able to reach that temperature threshold in some repetitions. However, the emission of dioxins and other gaseous pollutants could be problematic in instances where industrial use occurs near people's residences or in the case of household applications of dried faecal sludge fuel. Industrial applications typically occur in controlled environments where temperatures above 600°C can be guaranteed but the same may not be true for household applications of soild fuel use which raises the risk of household indoor air pollution, depending on the cookstove technology used.

While the heavy metal concentrations in dried faecal sludge were generally lower than industrial limits and those reported for waste water sludge, it should be noted that some heavy metals like copper are catalysts for dioxin formation (Obernberger et al., 2006). Heavy metals are also of concern in case there is interest in recovering nutrients from ash for use in agriculture. This therefore necessitates monitoring systems such as highlighted in Paper III for parameters like heavy metal concentrations from a pollution and public health perspective. The helminth egg concentrations, a key pathogen indicator, were also within the range of values reported by Seck et al. (2015) of 69 Ascaris eggs/g TS. However, the pathogen transmission pathways are minimal for solid fuel applications of faecal sludge, in comparison to applications in agriculture.

5.2.6 The roles of the private sector and the public sector

Presently, circular economy initiatives in the Naivasha case are mostly being led by private sector and civil society stakeholders and this is not different from other urban areas in both high income and low- and middle-income countries (Prendeville et al., 2018; Preston et al., 2019; Velenturf, 2016). The reluctance of public sector stakeholders to lead circularity implementation is problematic given that some municipalities elsewhere have reported challenges with relying on the private sector e.g. for handling urban waste (Williams, 2019) and the public sector, at the various levels from the local to the national, has crucial roles to play which should not be overshadowed (Flynn and Hacking, 2019; Kooiman and Jentoft, 2009). Some of the roles that the public sector has to fulfill and which should not simply be delegated to the private sector include developing regulations and standards (Flynn et al., 2019), establishing systems for monitoring circular economy implementation (Otoo and Drechsel, 2018), financing research and development as well as early stage ventures (Mazzucato, 2018) and using their convening power to foster cross-sectoral collaborations (Chaturvedi et al., 2015).

The public sector also has a role to play in mobilizing stakeholders for action (Abreu and Ceglia, 2018) through an explicit vision and policy strategies. This is especially crucial in Naivasha where the overall level of policy and management ambition is low (condition 5). Cities which have explicit strategies for circular economy implementation have been able to incentivize local action for implementation (Prendeville et al., 2018) and this demonstrates the importance of a vision as a key governance element (Kooiman et al., 2008) and also a catalyst for sustainability transitions (Frantzeskaki et al., 2012; Köhler et al., 2019; Loorbach, 2010). A common vision at a local level is also necessary for providing clarity given that the circular economy as a concept can mean different things to different stakeholders (Flynn et al., 2019; Kirchherr et al., 2017).

5.3 Implications of the circular economy for sanitation and waste management practices

Given that cities are a suitable scale for implementing solutions to sustainability challenges (Koop et al., 2017; Measham et al., 2011), the findings in this thesis demonstrate the need for urban areas in sub-Saharan Africa to consider a shift from waste treatment for disposal to aiming for resource recovery. Circular economy approaches to the management of organic waste streams can provide incentives for improvements in the urban sanitation and waste management service chain due to the additional revenue streams. In considering potential improvements to sanitation and waste management services in urban areas, planning processes should consider not just public health considerations but also natural resource management considerations, as suggested by SuSanA (2008). This of course implies making considerations for local needs to determine what resource recovery products to aim for.

There are multiple products and resources that can be recovered from organic waste streams and new technologies for valorizing higher value products keep emerging (van Leeuwen et al., 2018; Vaneeckhaute et al., 2017). This means that decision makers for urban sanitation and waste management, as well as the consultants that typically support planning processes, increasingly need to look further afield for infrastructure solutions beyond the traditional approaches. Catalogues of both old and emerging technologies e.g. Tilley et al. (2014) can aid in this respect as well as decision support tools created with this aim in mind (Blikra Vea et al., 2018; Spuhler et al., 2018). However, these need to be combined with contextual assessments that include comprehensive social, environmental and economic considerations (Otoo et al., 2016). The valorization options have varying environmental impacts and life cycle assessments as done by e.g. Komakech (2014) can enable in-depth insights into the potential impacts in a specific context. Applying business model canvas thinking to the planning for sanitation and waste management infrastructure could also enable more comprehensive assessments of options (Otoo et al., 2018), going beyond unilateral decision making that focuses on only capital and operational costs.

Implementing circular economy approaches to sanitation and waste management in sub-Saharan Africa cities also implies that monitoring systems connected to these sectors need to be strengthened. Monitoring and “early warning” systems are necessary for enhancing governance capacity (Koop et al., 2017; March, 1994, p. 250) and in the multi-sectoral context of circular economy implementation, they can enable the identification of potential risks associated with resource recovery from organic waste streams. Such systems could also enable stakeholders to track the quantities and qualities of organic waste streams and hence inform the development and operation of resource recovery facilities.

5.4 Reflections on methods and limitations

5.4.1 Choice of case study locations

As mentioned in section 3.1, the case study locations in this thesis were not selected out of a systematic approach but due to existing collaborations and research networks with partners in those cities. It is for this reason also that the case study work was structured in such a way that the more quantitative aspects were conducted in Kampala and the qualitative governance aspects in Naivasha, since different projects were involved. Perhaps it would have been preferable to have some systematic way to select out of large number of appropriate cities in sub-Saharan Africa with pre-determined criteria and this could possibly have led to different findings from those presented here. However, it is also the nature of contemporary research practice that such studies aim to build on previous projects and existing networks of collaborators, especially for projects that involve significant aspects of stakeholder engagement.

Yin (2009) noted that good case studies are difficult to do because unlike other research approaches like experiments, there is higher chance for experiencing challenges towards achieving a high level of rigor and not having bias. These challenges related to bias are less frequently overcome in case study research compared to other methods and it is probable that some biases could have come through in this thesis. At the same time, the case study approach in this thesis relied on multiple sources of evidence to track the different variables of interest as recommended by Yin (2009) and not just case study methodology per se. The work in each case study involved multiple methods including both quantitative and qualitative approaches and hence the assumption can be made that this mitigated some of the potential areas of bias.

Although the case studies in this thesis were not chosen in a systematic way to be representative, they still have features that characterize both large and small cities in other countries in SSA. Both Kampala and Naivasha have relatively high rates of population growth, insufficient coverage of infrastructure for sanitation and waste management and they are characterized by informality. The findings herein could therefore be relevant for many other cities in SSA and perhaps cities with similar conditions in other regions across the globe.

5.4.2 Quantitative estimation of circular economy potential and rational decision making models

Reflecting about Paper I from the perspective of decision-making, it seems that the methodological approach in the paper assumes that the information is relevant for a rational decision-making model (see e.g. March, 1994) which is sometimes applied within urban planning and policy making. Therefore if the study in Paper I is assumed to be in line with a rational decision making model, the decision makers who in this case are the urban stakeholders, would have some pre-determined preferences concerning aspects of energy content, nutrient content and revenue potential and would use these to assess and select from among the various decision options like AD, solid fuels and compost. While the decision options and preferences covered within the scope of this thesis are quite few, they could ideally be expanded to include several others. However, decision making processes are rarely rational in practice due to a number of limitations (March, 1994). Therefore, the limitations pointed out in Paper I including variability in waste characteristics, contextual factors that could determine what quantities of resource recovery products are obtained and other waste streams which are not included in the analysis could be seen from the perspective of limited rationality and some of these could manifest as elements of uncertainty.

5.4.3 Governance frameworks

By using the governance capacity framework, the research in Paper III contrasted with typical inductive studies where empirical work is done first and then theories and frameworks developed afterwards. There is therefore an inherent risk that through the research process, we could have been blinded from observing certain phenomena or variables of interest in the case study due to being limited to the GCF. It seems to me however that this risk is small for two reasons; first, before using the GCF approach, we made significant effort to identify other aspects of governance capacity that had perhaps not been included in the GCF's indicators and we were unable to find anything substantial that was not covered. Second, our aim in the research was to undertake a diagnostic assessment of governance capacity rather than a comprehensive analysis. Therefore, what was important was not necessarily to cover all aspects that we could find in the case study but to focus on those within the scope of our definition of governance capacity. Ultimately, a research design is fashioned in such a way to respond to the research questions being asked and it seems to me that the GCF was sufficient for our case to undertake a diagnostic governance capacity assessment, even though there could be a risk that it perhaps did not cover all aspects of governance. However, given that this research involved the first application of the GCF to a circular economy context, further research and applications to other cases could result into refinements to the framework, the addition of other relevant indicators or the subtraction of those that can be extraneous in some instances.

6 Conclusions and outlook

This thesis aims to investigate the potential contribution of resource-oriented urban sanitation and waste management towards the implementation of a circular economy in sub-Saharan Africa and the opportunities and challenges thereof. The findings, as illustrated in the case study cities of Kampala and Naivasha, demonstrated the following;

- There is a significant quantity of resources embedded in urban organic waste streams like faecal sludge, sewage sludge and organic municipal solid waste and these can be recovered through circular approaches to generate products like biogas, solid dry fuels, black soldier fly larvae and compost. The energy and nutrients that could be availed in these products could lead to significant environmental and socio-economic benefits for urban areas and these could further increase with an increase in the coverage and efficiency of sanitation and waste management infrastructure.
- Dried faecal sludge fuel can be used for industrial applications and knowledge obtained from sewage sludge combustion in Europe and North America is transferrable to some extent for faecal sludge fuel applications in sub-Saharan Africa. Faecal sludge fuel can effectively provide energy and be an alternative to other fuels like charcoal and coffee husks. However, faecal sludge characteristics are variable and need to be refined further to fit industrial applications better.
- There is a mismatch between theoretical concepts of the circular economy and the local communities of practice which could impede knowledge cohesion among stakeholders implementing circular approaches to organic waste streams.
- Circular economy implementation is largely being led by the private sector and civil society and public sector actors who should be providing collective vision and who have the convening power to foster cross-sectoral collaboration are reluctant to be at the forefront.

From a policy perspective, it can be inferred from the insights in this thesis that policy makers in SSA should consider a shift from designing sanitation and waste management systems for disposal to designing them for resource recovery. Infrastructure solutions for sanitation and waste management systems need to go beyond traditional approaches and consider the ever-widening gamut of solutions available to recovery water, energy, nutrients and other materials from organic waste streams. At the same time, given the variability of the quality of organic waste streams, there is a need to put in place and strengthen monitoring systems connected to sanitation and waste management systems. Such monitoring systems can enable the routine tracking of waste quantities and qualities so as to inform and modify resource recovery approaches accordingly and also the identification of potential risks introduced due to circularity.

Further research in this area could potentially look into the following issues;

- How insights about the potential for circular economy valorization can fit into planning processes for sanitation and waste management systems and for the various sectors that are inter-connected to the circular economy, and how decision support tools can enable urban stakeholders to operationalize these insights.
- Improvements to the performance of treatment technologies for faecal sludge that can enhance its value and performance as a solid fuel.
- Environmental and social assessments of different options for the valorization of organic waste streams, and sensitivity analysis to characterize the uncertainty in the estimates of valorization potential in case study cities.
- Costs for establishing and operating circular economy valorization facilities as well as innovative business models that can be implemented in the sub-Saharan Africa context.

Bibliography

Abreu, M.C.S. de, Ceglia, D., 2018. On the implementation of a circular economy: The role of institutional capacity-building through industrial symbiosis. *Resources, Conservation and Recycling* 138, 99–109. https://doi.org/10.1016/j.resconrec.2018.07.001

African Union Commission, 2018. Agenda 2063: The Africa we want - Framework Document. African Union Commission.

Akhmouch, A., Clavreul, D., Glas, P., 2018. Introducing the OECD Principles on Water Governance. *Water International* 43, 5–12. https://doi.org/10.1080/02508060.2017.1407561

Alvesson, M., 2003. Beyond Neopositivists, Romantics, and Localists: A Reflexive Approach to Interviews in Organizational Research. *The Academy of Management Review* 28, 13. https://doi.org/10.2307/30040687

Ammenberg, J., Feiz, R., 2017. Assessment of feedstocks for biogas production, part II—Results for strategic decision making. *Resources, Conservation and Recycling* 122, 388–404. https://doi.org/10.1016/j.resconrec.2017.01.020

Andersson, K., Dickin, S., 2017. The SEI Initiative on Sustainable Sanitation. Stockholm Environment Institute, Stockholm, Sweden.

Andersson, K., Rosemarin, A., Lamiozana, B., Kvarnstrom, E., McConville, J., Seidu, R., Dickin, S., Trimmer, C., 2016. *Sanitation, Wastewater Management and Sustainability: from waste disposal to resource recovery*, 1st ed. United Nations Environment Programme and Stockholm Environment Institute, Nairobi and Stockholm.

APHA, 2005. *Standard Methods for the Examination of Water and Wastewater*. American Public Health Association (APHA)/ American Water Works Association (AWWA)/Water Environment Federation (WEF), Washington, D.C.

Appiah-Effah, E., Nyarko, K.B., Antwi, E.O., Awuah, E., 2015. Heavy metals and microbial loads in raw fecal sludge from low income areas of ashanti region of ghana. *Water Practice and Technology* 10, 124–132. https://doi.org/10.2166/wpt.2015.014

Asamoah, B., Nikiema, J., Gebrezgabher, S., Odonkor, E., Njenga, M., 2016. A review on production, marketing and use of fuel briquettes. International Water Management Institute (IWMI), Colombo, Sri Lanka. https://doi.org/10.5337/2017.200

Asase, M., Yanful, E.K., Mensah, M., Stanford, J., Amponsah, S., 2009. Comparison of municipal solid waste management systems in Canada and Ghana: A case study of the cities of London, Ontario, and Kumasi, Ghana. *Waste Management*. https://doi.org/10.1016/j.wasman.2009.06.019

Bai, X., 2007. Industrial Ecology and the Global Impacts of Cities. *Journal of Industrial Ecology* 11, 1–6. https://doi.org/10.1162/jie.2007.1296

Bassan, M., Tchonda, T., Yiougo, L., Zoellig, H., Mahamane, I., Mbéguéré, M., Strande, L., 2013. Characterization of faecal sludge during dry and rainy seasons in Ouagadougou, Burkina Faso, in: Proceedings of the 36th WEDC International Conference, Nakuru, Kenya. pp. 1–5.

Bernstein, J., 2004. Social assessment and public participation in municipal solid waste management. *World Bank Working Paper* 463617–1202332338898.

Bill & Melinda Gates Foundation, 2010. Water, Sanitation & Hygiene: Factsheet. Bill & Melinda Gates Foundation, Seattle, WA.

Blikra Vea, E., Martinez-Sanchez, V., Thomsen, M., 2018. A Review of Waste Management

Decision Support Tools and Their Ability to Assess Circular Biowaste Management Systems. *Sustainability* 10, 3720. https://doi.org/10.3390/su10103720

Blomsma, F., Brennan, G., 2017. The Emergence of Circular Economy: A New Framing Around Prolonging Resource Productivity. *Journal of Industrial Ecology* 21, 603–614. https://doi.org/10.1111/jiec.12603

Bohnert, K., 2017. Shit Flow Diagram Report for Naivasha Sub-county, Kenya. SFD Promotion Initiative, Sanivation, Naivasha, Kenya.

Boland, M.J., Rae, A.N., Vereijken, J.M., Meuwissen, M.P.M.M., Fischer, A.R.H.H., van Boekel, M.A.J.S.J.S., Rutherfurd, S.M., Gruppen, H., Moughan, P.J., Hendriks, W.H., 2013. The future supply of animal-derived protein for human consumption. *Trends in Food Science & Technology* 29, 62–73. https://doi.org/10.1016/j.tifs.2012.07.002

Boulding, K.E., 1966. The economics of the coming spaceship earth, in: Jarrett, H. (Ed.), Environmental Quality Issues in a Growing Economy. Resources for the Future/Johns Hopkins University Press, Baltimore, MD, pp. 3–14.

Brockhoff, R.C., Koop, S.H.A., Snel, K.A.W., 2019. Pluvial Flooding in Utrecht: On Its Way to a Flood-Proof City. *Water* 11, 1501. https://doi.org/10.3390/w11071501

Brown, A.D., 2003. *Feed or feedback: agriculture, population dynamics and the state of the planet*. International Books, Utrecht, The Netherlands.

Brown, R., Ashley, R., Farrelly, M., 2011. Political and Professional Agency Entrapment: An Agenda for Urban Water Research. *Water Resources Management* 25, 4037–4050. https://doi.org/10.1007/s11269-011-9886-y

Brunner, R.D., Steelman, T.A., Coe-Juell, L., Cromley, C.M., Tucker, D.W., Edwards, C.M., 2005. *Adaptive governance: integrating science, policy, and decision making*. Columbia University Press.

BSI, 1983. BS 1881-116:1983: Testing Concrete. Method for Determination of Compressive Strength of Concrete Cubes. British Standards Institution (BSI), London, UK.

Carlisle, K., Gruby, R.L., 2019. Polycentric Systems of Governance: A Theoretical Model for the Commons. *Policy Studies Journal* 47, 921–946. https://doi.org/10.1111/psj.12212

Chaturvedi, A., Arora, R., Saluja, M.S., 2015. Private Sector and Waste Management in Delhi: A Political Economy Perspective. *IDS Bulletin* 46, 7–16. https://doi.org/10.1111/1759-5436.12140

Clavreul, J., Baumeister, H., Christensen, T.H., Damgaard, A., 2014. An environmental assessment system for environmental technologies. *Environmental Modelling and Software* 60, 18–30. https://doi.org/10.1016/j.envsoft.2014.06.007

Cofie, O., Kone, D., Rothenberger, S., Moser, D., Zubruegg, C., 2009. Co-composting of faecal sludge and organic solid waste for agriculture: Process dynamics. *Water Research* 43, 4665–4675. https://doi.org/10.1016/J.WATRES.2009.07.021

Corbett, J., Mellouli, S., 2017. Winning the SDG battle in cities: how an integrated information ecosystem can contribute to the achievement of the 2030 sustainable development goals. *Information Systems Journal* 27, 427–461. https://doi.org/10.1111/isj.12138

Cordova-Pizarro, D., Aguilar-Barajas, I., Romero, D., Rodriguez, C., 2019. Circular Economy in the Electronic Products Sector: Material Flow Analysis and Economic Impact of Cellphone E-Waste in Mexico. *Sustainability* 11, 1361. https://doi.org/10.3390/su11051361

D’Amato, D., Droste, N., Allen, B., Kettunen, M., Lähtinen, K., Korhonen, J., Leskinen, P., Matthies, B.D., Toppinen, A., 2017. Green, circular, bio economy: A comparative analysis of sustainability avenues. *Journal of Cleaner Production* 168, 716–734.

https://doi.org/10.1016/J.JCLEPRO.2017.09.053

Danso, G.K., Otoo, M., Ekere, W., Ddungu, S., Madurangi, G., 2017. Market Feasibility of Faecal Sludge and Municipal Solid Waste-Based Compost as Measured by Farmers' Willingness-to-Pay for Product Attributes: Evidence from Kampala, Uganda. *Resources* 6, 31. https://doi.org/10.3390/resources6030031

Das, N., 2010. Recovery of precious metals through biosorption — A review. *Hydrometallurgy* 103, 180–189. https://doi.org/10.1016/J.HYDROMET.2010.03.016

Ddiba, D., Andersson, K., Ogol, T., 2018a. UrbanCircle: Turning Urban Waste into Circular Economy Benefits. Stockholm Environment Institute, Stockholm, Sweden.

Ddiba, D., Starkholm, A., Zhaoxuan, F., 2018b. Transitioning to a Circular Economy: perspectives on innovation management in organizations (Unpublished manuscript). Stockholm, Sweden.

Demirbas, A., 2011. Waste management, waste resource facilities and waste conversion processes. *Energy Conversion and Management* 52, 1280–1287. https://doi.org/10.1016/j.enconman.2010.09.025

Desmond, P., Asamba, M., 2019. Accelerating the transition to a circular economy in Africa, in: The Circular Economy and the Global South. Routledge, pp. 152–172. https://doi.org/10.4324/9780429434006-9

Diener, S., Semiyaga, S., Niwagaba, C.B., Muspratt, A.M., Gning, J.B., Mbéguéré, M., Ennin, J.E., Zurbrugg, C., Strande, L., 2014. A value proposition: Resource recovery from faecal sludge—Can it be the driver for improved sanitation? *Resources, Conservation and Recycling* 88, 32–38. https://doi.org/10.1016/J.RESCONREC.2014.04.005

Dodane, P.H., Mbéguéré, M., Sow, O., Strande, L., 2012. Capital and operating costs of full-scale fecal sludge management and wastewater treatment systems in Dakar, Senegal. *Environmental Science and Technology* 46, 3705–3711. https://doi.org/10.1021/es2045234

Donatello, S., Cheeseman, C.R., 2013. Recycling and recovery routes for incinerated sewage sludge ash (ISSA): A review. *Waste Management* 33, 2328–2340. https://doi.org/10.1016/j.wasman.2013.05.024

Doughty, M.R.C., Hammond, G.P., 2004. Sustainability and the built environment at and beyond the city scale. *Building and Environment* 39, 1223–1233. https://doi.org/10.1016/j.buildenv.2004.03.008

Drechsel, P., Qadir, M., Wichelns, D., 2015. *Wastewater: Economic Asset in an Urbanizing World*, 1st ed. Springer Netherlands, Dordrecht. https://doi.org/10.1007/978-94-017-9545-6

DWA, 2008. Neuartige Sanitärsysteme [Novel Sanitation Systems].

Ekane, N., 2018. 'Making Sanitation Happen': An Enquiry into Multi-Level Sanitation Governance. KTH Royal Institute of Technology.

Ekane, N., Mertz, C.K., Slovic, P., Kjellén, M., Westlund, H., 2016. Risk and benefit judgment of excreta as fertilizer in agriculture: An exploratory investigation in Rwanda and Uganda. *Human and Ecological Risk Assessment: An International Journal* 22, 639–666. https://doi.org/10.1080/10807039.2015.1100515

Ekvall, T., Malmheden, S., 2014. Towards Sustainable Waste Management: Popular Summary Report from a Swedish EPA Research Programme. IVL Swedish Environmental Research Institute & Naturvårdsverket, Stockholm, Sweden.

Ellen MacArthur Foundation, 2017. Urban Biocycles. Ellen MacArthur Foundation and the

World Economic Forum, London, United Kingdom.

Ellen MacArthur Foundation, World Economic Forum, McKinsey & Company, Foundation, E.M., Forum, W.E., Company, M.&, 2012. Towards the Circular Economy Vol. 1: Economic and business rationale for an accelerated transition. The Ellen MacArthur Foundation, World Economic Forum and McKinsey & Company.

Eriksson, O., Frostell, B., Björklund, A., Assefa, G., Sundqvist, J.O., Granath, J., Carlsson, M., Baky, A., Thyselius, L., 2002. ORWARE - A simulation tool for waste management. *Resources, Conservation and Recycling* 36, 287–307. https://doi.org/10.1016/S0921-3449(02)00031-9

Ermolaev, E., Lalander, C., Vinnerås, B., 2019. Greenhouse gas emissions from small-scale fly larvae composting with Hermetia illucens. *Waste Management* 96, 65–74. https://doi.org/10.1016/j.wasman.2019.07.011

Esrey, S.A., Gouch, J., Rapaport, D., Sawyer, R., Simpson-H'ebert, M., Vargas, J., Winblad, U., 1998. *Ecological sanitation*, 1st ed. International Development Cooperation Agency (SIDA), Stockholm, Sweden.

Feiz, R., Ammenberg, J., 2017. Assessment of feedstocks for biogas production, part I—A multi-criteria approach. *Resources, Conservation and Recycling* 122, 373–387. https://doi.org/10.1016/j.resconrec.2017.01.019

Finnveden, G., Björklund, A., Moberg, Å., Ekvall, T., Moberg, Å., 2007. Environmental and economic assessment methods for waste management decision-support: possibilities and limitations. *Waste Management & Research* 25, 263–269. https://doi.org/10.1177/0734242x07079156

Finnveden, G., Gunnarsson-Östling, U., 2016. Sustainable development goals for cities, in: Urban Transitions Pathways Symposium: Shaping Common Ground in Urban Sustainability? JPI Urban Europe, Brussels, Belgium.

Flynn, A., Hacking, N., 2019. Setting standards for a circular economy: A challenge too far for neoliberal environmental governance? *Journal of Cleaner Production* 212, 1256–1267. https://doi.org/10.1016/j.jclepro.2018.11.257

Flynn, A., Hacking, N., Xie, L., 2019. Governance of the circular economy: A comparative examination of the use of standards by China and the United Kingdom. *Environmental Innovation and Societal Transitions* 33, 282–300. https://doi.org/10.1016/j.eist.2019.08.002

Flyvbjerg, B., 2006. Five Misunderstandings About Case-Study Research. *Qualitative Inquiry* 12, 219–245. https://doi.org/10.1177/1077800405284363

Frantzeskaki, N., Loorbach, D., Meadowcroft, J., 2012. Governing societal transitions to sustainability. *International Journal of Sustainable Development* 15, 19. https://doi.org/10.1504/IJSD.2012.044032

Fuenfschilling, L., Truffer, B., 2014. The structuration of socio-technical regimes - Conceptual foundations from institutional theory. *Research Policy* 43, 772–791. https://doi.org/10.1016/j.respol.2013.10.010

Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J., 2017. The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production* 143, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Geng, Y., Sarkis, J., Ulgiati, S., Zhang, P., 2013. Measuring China's circular economy. *Science*. https://doi.org/10.1126/science.1227059

Gharfalkar, M., Court, R., Campbell, C., Ali, Z., Hillier, G., 2015. Analysis of waste hierarchy in the European waste directive 2008/98/EC. *Waste Management* 39, 305–313. https://doi.org/10.1016/j.wasman.2015.02.007

Ghisellini, P., Cialani, C., Ulgiati, S., 2016. A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, Towards Post Fossil Carbon Societies: Regenerative and Preventative Eco-Industrial Development 114, 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007

Gold, M., Dayer, P., Faye, M.C.A.S., Clair, G., Seck, A., Niang, S., Morgenroth, E., Strande, L., 2016. Locally produced natural conditioners for dewatering of faecal sludge. *Environmental Technology* 37, 2802–2814. https://doi.org/10.1080/09593330.2016.1165293

Gold, M., Niang, S., Niwagaba, C., Eder, G., Muspratt, A.M., Diop, P.S., Strande, L., 2014. Results from FaME (Faecal Management Enterprises) - can dried faecal sludge fuel the sanitation service chain?, in: Shaw, R.J., Anh, N.V., Dang, T.H. (Eds.), Sustainable Water and Sanitation Services for All in a Fast Changing World: Proceedings of the 37th WEDC International Conference. WEDC, Loughborough University, Hanoi, Vietnam.

Grigg, N.S., 2016. *Integrated Water Resource Management*. Palgrave Macmillan UK, London. https://doi.org/10.1057/978-1-137-57615-6

Guinée, J.B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., Ekvall, T., Rydberg, T., 2011. Life Cycle Assessment: Past, Present, and Future. *Environmental Science & Technology* 45, 90–96. https://doi.org/10.1021/es101316v

Gustavsson, J., Cederberg, C., Sonesson, U., Van Otterdijk, R., Meybeck, A., 2011. Global food losses and food waste – Extent, causes and prevention. FAO Rome, Rome, Italy.

Hafford, L.M., Ward, B.J., Weimer, A.W., Linden, K., 2018. Fecal sludge as a fuel: characterization, cofire limits, and evaluation of quality improvement measures. *Water Science and Technology* 78, 2437–2448. https://doi.org/10.2166/wst.2019.005

Hamouda, M.A., Anderson, W.B., Huck, P.M., 2009. Decision support systems in water and wastewater treatment process selection and design: a review. *Water Science and Technology* 60, 1757–1770. https://doi.org/10.2166/wst.2009.538

Harrison, J.H., Whitefield, E., Saunders, O., Fortuna, A.M., Bary, A., Cogger, C.G., 2013. Transformation and Agronomic Use of Nutrients From Digester Effluent [WWW Document]. *eXtension: Issues, Innovation, Impact*. URL https://articles.extension.org/pages/67900/transformation-and-agronomic-use-of-nutrients-from-digester-effluent (accessed 4.10.16).

Henrich, J., 2017. *The Secret of Our Success: How Culture Is Driving Human Evolution, Domesticating Our Species, and Making Us Smarter*, 1st ed. Princeton University Press, Princeton, NJ, US.

Henrich, J., McElreath, R., 2003. The evolution of cultural evolution. *Evolutionary Anthropology: Issues, News, and Reviews* 12, 123–135. https://doi.org/10.1002/evan.10110

Hoff, H., Döll, P., Fader, M., Gerten, D., Hauser, S., Siebert, S., 2014. Water footprints of cities - Indicators for sustainable consumption and production. *Hydrology and Earth System Sciences* 18, 213–226. https://doi.org/10.5194/hess-18-213-2014

Holcim (Schweiz) AG, 2013. Allgemeine Annahmebedingungen Trockenklärschlamm (TKS) Zementwerk Siggenthal [General acceptance conditions for dry sewage sludge, Siggenthal Cement Plant].

Hoornweg, D., Bhada-Tata, P., 2012. What a Waste: A Global Review of Solid Waste Management, Urban Development Series; Knowledge Papers no.15. World Bank Group, Washington, D.C.

Hufty, M., 2011. Investigating policy processes: the governance analytical framework (GAF). *Research for sustainable development: Foundations, experiences, and perspectives* 403–424.

Hysing, E., 2009. From government to governance? A comparison of environmental governing in Swedish forestry and transport. *Governance* 22, 647–672. https://doi.org/10.1111/j.1468-0491.2009.01457.x

Joly, G., Nikiema, J., 2019. Global experiences on waste processing with black soldier fly (Hermetia illucens): from technology to business. International Water Management Institute (IWMI), Colombo, Sri Lanka. https://doi.org/10.5337/2019.214

Judex, J.W., Gaiffi, M., Burgbacher, H.C., 2012. Gasification of dried sewage sludge: Status of the demonstration and the pilot plant. *Waste Management* 32, 719–723. https://doi.org/10.1016/j.wasman.2011.12.023

Kamadi, G., 2017. Africa's first grid-connected biogas plant powers up - Reuters [WWW Document]. *Reuters*. URL https://www.reuters.com/article/kenya-energy-biogas/africas-first-grid-connected-biogas-plant-powers-up-idUSL5N1EZ1KL (accessed 7.5.19).

Kaza, S., Yao, L., Bhada-Tata, P., Van Woerden, F., 2018. *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. World Bank Group, Washington, D.C. https://doi.org/10.1596/978-1-4648 -1329-0

KCCA, 2018. Kampala Faecal Sludge Management: Improving feacal sludge management for on-site sanitation. Kampala Capital City Authority (KCCA), Kampala, Uganda.

KCCA, 2017. Kampala climate change action: Energy and climate profile. Kampala Capital City Authority (KCCA), Kampala.

Kilgroe, J.D., 1996. Control of dioxin, furan, and mercury emissions from municipal waste combustors. *Journal of Hazardous Materials* 47, 163–194. https://doi.org/10.1016/0304-3894(95)00108-5

King, N., Horrocks, C., Brooks, J., 2018. *Interviews in qualitative research*. SAGE Publications Limited.

Kinobe, J.R., 2015. Assessment of urban solid waste logistics systems: the case of Kampala, Uganda. PhD Thesis, SLU Swedish University of Agricultural Sciences.

Kirchherr, J., Reike, D., Hekkert, M., 2017. Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling* 127, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Klinger, M., Gueye, A., Manandhar Sherpa, A., Strande, L., 2019. Scoping Study: Faecal Sludge Treatment Plants in South-Asia and sub-Saharan Africa. eFSTP Project Report. Swiss Federal Institute of Aquatic Science and Technology (Eawag), Delvic Sanitation Initiatives & Environmental and Public Health Organization (ENPHO), Dübendorf, Switzerland.

Köhler, J., Geels, F.W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Fünfschilling, L., Hess, D., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., McMeekin, A., Mühlemeier, M.S., Nykvist, B., Pel, B., Raven, R., Rohracher, H., Sandén, B., Schot, J., Sovacool, B., Turnheim, B., Welch, D., Wells, P., 2019. An agenda for sustainability transitions research: State of the art and future directions. *Environmental Innovation and Societal Transitions* 31, 1–32. https://doi.org/10.1016/j.eist.2019.01.004

Komakech, A.J., 2014. Urban waste management and the environmental impact of organic waste treatment systems in Kampala, Uganda. Department of Energy and Technology, SLU Swedish University of Agricultural Sciences.

Kooiman, J., Bavinck, M., Chuenpagdee, R., Mahon, R., Pullin, R., 2008. Interactive governance and governability: an introduction. *The journal of transdisciplinary environmental studies* 7, 1–11.

Kooiman, J., Jentoft, S., 2009. Meta-governance: values, norms and principles, and the making of hard choices. *Public Administration* 87, 818–836. https://doi.org/10.1111/j.1467-9299.2009.01780.x

Koop, S.H.A., 2019. Towards water-wise cities: Global assessment of water management and governance capacities. Utrecht University, Utrecht.

Koop, S.H.A., Koetsier, L., Doornhof, A., Reinstra, O., Van Leeuwen, C.J., Brouwer, S., Dieperink, C., Driessen, P.P.J., 2017. Assessing the Governance Capacity of Cities to Address Challenges of Water, Waste, and Climate Change. *Water Resources Management* 31, 3427–3443. https://doi.org/10.1007/s11269-017-1677-7

Korhonen, J., Honkasalo, A., Seppälä, J., 2018a. Circular Economy: The Concept and its Limitations. *Ecological Economics* 143, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041

Korhonen, J., Nuur, C., Feldmann, A., Birkie, S.E., 2018b. Circular economy as an essentially contested concept. *Journal of Cleaner Production* 175, 544–552. https://doi.org/10.1016/j.jclepro.2017.12.111

Krook, J., Baas, L., 2013. Getting serious about mining the technosphere: A review of recent landfill mining and urban mining research. *Journal of Cleaner Production* 55, 1–9. https://doi.org/10.1016/j.jclepro.2013.04.043

Lalander, C., Diener, S., Magri, M.E., Zurbrügg, C., Lindström, A., Vinnerås, B., 2013. Faecal sludge management with the larvae of the black soldier fly (Hermetia illucens) — From a hygiene aspect. *Science of The Total Environment* 458–460, 312–318. https://doi.org/10.1016/J.SCITOTENV.2013.04.033

Lalander, C., Senecal, J., Gros Calvo, M., Ahrens, L., Josefsson, S., Wiberg, K., Vinnerås, B., 2016. Fate of pharmaceuticals and pesticides in fly larvae composting. *Science of the Total Environment* 565, 279–286. https://doi.org/10.1016/j.scitotenv.2016.04.147

Lall, S.V., Henderson, J.V., Venables, A.J., 2017. *Africa's Cities: Opening Doors to the World*, 1st ed. The World Bank, Washington, D.C. https://doi.org/10.1596/978-1-4648-1044-2

Langergraber, G., Muellegger, E., 2005. Ecological Sanitation - A way to solve global sanitation problems? *Environment International* 31, 433–444. https://doi.org/10.1016/j.envint.2004.08.006

Leahy, S., 2018. From Not Enough to Too Much, the World's Water Crisis Explained [WWW Document]. *National Geographic*. URL https://www.nationalgeographic.com/news/2018/03/world-water-day-water-crisis-explained/ (accessed 3.16.20).

Lehtoranta, S., Nissinen, A., Mattila, T., Melanen, M., 2011. Industrial symbiosis and the policy instruments of sustainable consumption and production. *Journal of Cleaner Production* 19, 1865–1875. https://doi.org/10.1016/j.jclepro.2011.04.002

Lieder, M., Rashid, A., 2016. Towards circular economy implementation: a comprehensive review in context of manufacturing industry. *Journal of Cleaner Production* 115, 36–51. https://doi.org/10.1016/j.jclepro.2015.12.042

Lohri, C.R., Diener, S., Zabaleta, I., Mertenat, A., Zurbrügg, C., 2017. Treatment technologies for urban solid biowaste to create value products: a review with focus on low- and middle-income settings. *Reviews in Environmental Science and Biotechnology*. https://doi.org/10.1007/s11157-017-9422-5

Loorbach, D., 2010. Transition management for sustainable development: A prescriptive, complexity-based governance framework. *Governance* 23, 161–183. https://doi.org/10.1111/j.1468-0491.2009.01471.x

Lopes, M.H., Abelha, P., Lapa, N., Oliveira, J.S., Cabrita, I., Gulyurtlu, I., 2003. The behaviour of ashes and heavy metals during the co-combustion of sewage sludges in a fluidised bed. *Waste Management* 23, 859–870. https://doi.org/10.1016/S0956-053X(03)00025-4

Lüthi, C., McConville, J., Norström, A., Panesar, A., Ingle, R., Saywell, D., Schütze, T., 2009. Rethinking sustainable sanitation for the urban environment, in: The 4th International Conference of the International Forum on Urbanism (IFoU). Amsterdam/Delft. p. 12.

Lüthi, C., Panesar, A., Schütze, T., Norström, A., McConville, J., Parkinson, J., Saywell, D., Ingle, R., 2011. *Sustainable Sanitation in Cities: A Framework for Action*, 1st ed. Sustainable Sanitation Alliance (SuSanA) & International Forum on Urbanism (IFoU), Papiroz Publishing House, Rijswijk, The Netherlands.

Luts, D., Devoldere, K., Laethem, B., Bartholomeeusen, W., Ockier, P., 2000. Co-incineration of dried sewage sludge in coal-fired power plants: A case study. *Water Science and Technology* 42, 259–268. https://doi.org/10.2166/wst.2000.0221

Madlener, R., Sunak, Y., 2011. Impacts of urbanization on urban structures and energy demand: What can we learn for urban energy planning and urbanization management? *Sustainable Cities and Society* 1, 45–53. https://doi.org/10.1016/j.scs.2010.08.006

Madlool, N.A., Saidur, R., Hossain, M.S., Rahim, N.A., 2011. A critical review on energy use and savings in the cement industries. *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2011.01.005

Madonsela, B., Koop, S., Van Leeuwen, K., Carden, K., 2019. Evaluation of Water Governance Processes Required to Transition towards Water Sensitive Urban Design—An Indicator Assessment Approach for the City of Cape Town. *Water* 11, 292. https://doi.org/10.3390/w11020292

Malinauskaite, J., Jouhara, H., Czajczyńska, D., Stanchev, P., Katsou, E., Rostkowski, P., Thorne, R.J., Colón, J., Ponsá, S., Al-Mansour, F., Anguilano, L., Krzyżyńska, R., López, I.C., A.Vlasopoulos, Spencer, N., 2017. Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe. *Energy* 141, 2013–2044. https://doi.org/10.1016/J.ENERGY.2017.11.128

March, J.G., 1994. *Primer on decision making: How decisions happen*. Simon and Schuster.

Mateo-Sagasta, J., Raschid-Sally, L., Thebo, A., 2015. Global Wastewater and Sludge Production, Treatment and Use, in: Wastewater: Economic Asset in an Urbanizing World. Springer Netherlands, Dordrecht, pp. 15–38. https://doi.org/10.1007/978-94-017-9545-6_2

Maurer, M., Bufardi, A., Tilley, E., Zurbrügg, C., Truffer, B., 2012. A compatibility-based procedure designed to generate potential sanitation system alternatives. *Journal of Environmental Management* 104, 51–61. https://doi.org/10.1016/j.jenvman.2012.03.023

Mayntz, R., 2019. From government to governance: Political Steering in Modern Societies, in: Governance of Integrated Product Policy. Routledge, pp. 18–25. https://doi.org/10.4324/9781351282604-2

Mazzucato, M., 2018. *The entrepreneurial state: debunking public vs. private sector myths*, Revised. ed. Penguin, London, UK.

McDonald, R.I., Weber, K., Padowski, J., Flörke, M., Schneider, C., Green, P.A., Gleeson, T., Eckman, S., Lehner, B., Balk, D., Boucher, T., Grill, G., Montgomery, M., 2014. Water on an urban planet: Urbanization and the reach of urban water infrastructure. *Global Environmental Change* 27, 96–105. https://doi.org/10.1016/J.GLOENVCHA.2014.04.022

McDonnell, M.J., MacGregor-Fors, I., 2016. The ecological future of cities. *Science*. https://doi.org/10.1126/science.aaf3630

McDonough, W., Braungart, M., 2002. *Cradle to Cradle: Remaking the way we make things*. North Point Press, New York.

Measham, T.G., Preston, B.L., Smith, T.F., Brooke, C., Gorddard, R., Withycombe, G., Morrison, C., 2011. Adapting to climate change through local municipal planning: barriers and challenges. *Mitigation and Adaptation Strategies for Global Change* 16, 889–909. https://doi.org/10.1007/s11027-011-9301-2

MEMD, 2012. Renewable Energy Investment Guide. Ministry of Energy and Mineral Development (MEMD), Uganda, Kampala, Uganda.

Memon, M.A., 2012. Integrated solid waste management based on the 3R approach, in: Sustainable Solid Waste Management. Apple Academic Press, pp. 133–149. https://doi.org/10.1007/s10163-009-0274-0

Mihelcic, J.R., Fry, L.M., Shaw, R., 2011. Global potential of phosphorus recovery from human urine and feces. *Chemosphere* 84, 832–839. https://doi.org/10.1016/J.CHEMOSPHERE.2011.02.046

Minale, M., Worku, T., 2014. Anaerobic co-digestion of sanitary wastewater and kitchen solid waste for biogas and fertilizer production under ambient temperature: Waste generated from condominium house. *International Journal of Environmental Science and Technology* 11, 509–516. https://doi.org/10.1007/s13762-013-0255-7

Moodley, P., Archer, C., Hawksworth, D., Leibach, L., 2008. Standard Methods for the Recovery and Enumeration of Helminth Ova in Wastewater, Sludge, Compost and Urine Diversion Waste in South-Africa. Water Research Commission (WRC), Pretoria, South Africa.

Moreau, V., Sahakian, M., van Griethuysen, P., Vuille, F., 2017. Coming Full Circle: Why Social and Institutional Dimensions Matter for the Circular Economy. *Journal of Industrial Ecology* 21, 497–506. https://doi.org/10.1111/jiec.12598

Mott MacDonald, 2017. Nakuru integrated solid waste management PPP: Project feasibility study report and PPP implementation plan. Prepared by Mott MacDonald for the World Bank Group and County Government of Nakuru, Nakuru, Kenya.

Moya, B., Sakrabani, R., Parker, A., Moya, B., Sakrabani, R., Parker, A., 2019. Realizing the Circular Economy for Sanitation: Assessing Enabling Conditions and Barriers to the Commercialization of Human Excreta Derived Fertilizer in Haiti and Kenya. *Sustainability* 11, 3154. https://doi.org/10.3390/su11113154

Mugambi, J.K., Windberg, C., Ddiba, D., Ogol, T., Andersson, K., Gicheru, T., Akinyi, E., 2020. Setting the stage for the circular economy: mapping waste resource recovery opportunities in Naivasha, Kenya. Stockholm Environment Institute.

Mukherjee, S., Chakraborty, D., 2016. Turning Human Waste into Renewable Energy: Scope and Options for India.

Müller, C., 2009. Decentralised co-digestion of faecal sludge with organic solid waste, Case Study in Maseru, Lesotho. Swiss Federal Institute of Aquatic Science and Technology (Eawag). Dübendorf, Switzerland. Dübendorf, Switzerland.

Murray, A., Cofie, O., Drechsel, P., 2011. Efficiency indicators for waste-based business models: fostering private-sector participation in wastewater and faecal-sludge management. *Water International* 36, 505–521. https://doi.org/10.1080/02508060.2011.594983

Muspratt, A.M., Nakato, T., Niwagaba, C., Dione, H., Kang, J., Stupin, L., Regulinski, J., Mbéguéré, M., Strande, L., 2014. Fuel potential of faecal sludge: calorific value results from Uganda, Ghana and Senegal. *Journal of Water, Sanitation and Hygiene for Development* 4, 223. https://doi.org/10.2166/washdev.2013.055

Mutisya, E., Yarime, M., 2014. Moving towards urban sustainability in Kenya: A framework for integration of environmental, economic, social and governance dimensions. *Sustainability Science*. https://doi.org/10.1007/s11625-013-0223-7

Mutz, D., Hengevoss, D., Hugi, C., Gross, T., 2017. *Waste-to-Energy Options in Municipal Solid Waste Management-A Guide for Decision Makers in Developing and Emerging Countries*, 1st ed. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Eschborn, Germany.

Mwampamba, T.H., Owen, M., Pigaht, M., 2013. Opportunities, challenges and way forward for the charcoal briquette industry in Sub-Saharan Africa. *Energy for Sustainable Development* 17, 158–170. https://doi.org/10.1016/j.esd.2012.10.006

Nakato, T., 2018. Juicy maggots earn Ssemulema cash [WWW Document]. *Daily Monitor*. URL https://www.monitor.co.ug/Magazines/Farming/Juicy-maggots-earn-Ssemulema-cash--/689860-4696650-k364tf/index.html (accessed 8.6.19).

Nguyen, H.C., Liang, S.-H., Li, S.-Y., Su, C.-H., Chien, C.-C., Chen, Y.-J., Huong, D.T.M., 2018. Direct transesterification of black soldier fly larvae (Hermetia illucens) for biodiesel production. *Journal of the Taiwan Institute of Chemical Engineers* 85, 165–169. https://doi.org/10.1016/j.jtice.2018.01.035

Nilsson, M., Eklund, M., Tyskeng, S., 2009. Environmental Integration and Policy Implementation: Competing Governance Modes in Waste Management Decision Making. *Environment and Planning C: Government and Policy* 27, 1–18. https://doi.org/10.1068/c0794j

Niwagaba, C.B., Mbéguéré, M., Strande, L, 2014. Faecal sludge quantification, characterisation and treatment objectives, in: Strande, Linda, Ronteltap, M., Brdjanovic, D. (Eds.), Faecal Sludge Management: Systems Approach for Implementation and Operation. IWA Publishing, London, UK.

Njenga, M., Mendum, R., 2018. Recovering bioenergy in Sub-Saharan Africa: gender dimensions, lessons and challenges. Colombo, Sri Lanka. https://doi.org/10.5337/2018.226

Nkurunziza, A.G., Bateganya, N.L., Byansi, J.Z., Rokob, J., Busingye, J., 2017. FSM Innovation: Leveraging FSM to Close the Urban Sanitation Loop in Kampala, in: Blackett, I., Hawkins, P. (Eds.), FSM Innovation Case Studies - Case Studies on the Business, Policy and Technology of Faecal Sludge Management. Bill & Melinda Gates Foundation, Seattle, USA, p. 15.

Obernberger, I., Brunner, T., Bärnthaler, G., 2006. Chemical properties of solid biofuels-significance and impact. *Biomass and Bioenergy* 30, 973–982. https://doi.org/10.1016/j.biombioe.2006.06.011

Ogunji, J.O., Nimptsch, J., Wiegand, C., Schulz, C., 2007. Evaluation of the influence of housefly maggot meal (magmeal) diets on catalase, glutathione S-transferase and glycogen concentration in the liver of Oreochromis niloticus fingerling. *Comparative Biochemistry and Physiology - A Molecular and Integrative Physiology* 147, 942–947. https://doi.org/10.1016/j.cbpa.2007.02.028

Onen, H., Odong, R., Chemurot, M., 2019. Exploitation of locally available organic wastes for rearing black soldier fly (Hermetia illucens) larvae as a potential protein ingredient for poultry and fish feeds in Uganda. *Journal of Biology and Nature* 10, 18–23.

Otero, M., Gómez, X., García, A.I., Morán, A., 2007. Effects of sewage sludge blending on the coal combustion: A thermogravimetric assessment. *Chemosphere* 69, 1740–1750. https://doi.org/10.1016/j.chemosphere.2007.05.077

Otoo, M., Drechsel, P., 2018. *Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse*, 1st ed. Routledge, London. https://doi.org/10.4324/9781315780863

Otoo, M., Drechsel, P., Danso, G., Gebrezgabher, S., Rao, K., Madurangi, G., 2016. Testing the implementation potential of resource recovery and reuse business models: from baseline surveys to feasibility studies and business plans. International Water Management Institute (IWMI), Colombo, Sri Lanka. https://doi.org/10.5337/2016.206

Otoo, M., Gebrezgabher, S., Drechsel, P., Rao, K.C., Fernando, S., Pradhan, S.K., Hanjra, M.A., Qadir, M., Winkler, M., 2018. Defining and analyzing RRR business cases and models, in: Otoo, M., Drechsel, P. (Eds.), Resource Recovery from Waste: Business Models for Energy, Nutrients and Water Reuse. Routledge, pp. 16–31.

Pahl-Wostl, C., 2009. A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change* 19, 354–365. https://doi.org/10.1016/j.gloenvcha.2009.06.001

Pahl-Wostl, C., 2002. Towards sustainability in the water sector – The importance of human actors and processes of social learning. *Aquatic Sciences* 64, 394–411. https://doi.org/10.1007/PL00012594

Palaniappan, M., Gleick, P.H., Change, E., 2008. *A Review of Decision-Making Support Tools in the Water, Sanitation, and Hygiene Sector*. Pacific Institute.

Peal, A., Evans, B., Blackett, I., Hawkins, P., Heymans, C., 2014. Fecal sludge management (FSM): analytical tools for assessing FSM in cities. *Journal of Water, Sanitation and Hygiene for Development* 4, 371. https://doi.org/10.2166/washdev.2014.139

Peal, A.J., Evans, B.E., Sangaralingam, A., Ban, R., Blackett, I., Hawkins, P.M., Schoebitz, L., Scott, R., Sleigh, A., Strande, L., Veses Roda, O., 2020. Estimating safely managed sanitation in urban areas; lessons learned from a global implementation of excreta-flow diagrams. *Frontiers in Environmental Science* 8, 1. https://doi.org/10.3389/FENVS.2020.00001

Polprasert, C., Koottatep, T., 2017. *Organic Waste Recycling: Technology, Management and Sustainability*, 4th ed, Water Intelligence Online. IWA Publishing, London, UK. https://doi.org/10.2166/9781780408217

Pradhan, P., Costa, L., Rybski, D., Lucht, W., Kropp, J.P., 2017. A Systematic Study of Sustainable Development Goal (SDG) Interactions. *Earth's Future* 5, 1169–1179. https://doi.org/10.1002/2017EF000632

Prendeville, S., Cherim, E., Bocken, N., 2018. Circular Cities: Mapping Six Cities in Transition. *Environmental Innovation and Societal Transitions* 26, 171–194. https://doi.org/10.1016/j.eist.2017.03.002

Preston, F., Lehne, J., Wellesley, L., 2019. An Inclusive Circular Economy: Priorities for Developing Countries. Chatham House: the Royal Institute of International Affairs, London, United Kingdom.

Qadir, M., Drechsel, P., Jiménez Cisneros, B., Kim, Y., Pramanik, A., Mehta, P., Olaniyan, O., 2020. Global and regional potential of wastewater as a water, nutrient and energy source. *Natural Resources Forum* 44, 40–51. https://doi.org/10.1111/1477-

8947.12187

Qu, S.Q., Dumay, J., 2011. The qualitative research interview. *Qualitative Research in Accounting and Management*. https://doi.org/10.1108/11766091111162070

Ranganathan, J., Vennard, D., Waite, R., Dumas, P., Lipinski, B., Searchinger, T., 2016. Shifting Diets for a Sustainable Food Future. World Resources Institute, Washington D.C.

Robins, S., 2019. 'Day Zero', Hydraulic Citizenship and the Defence of the Commons in Cape Town: A Case Study of the Politics of Water and its Infrastructures (2017–2018). *Journal of Southern African Studies* 45, 5–29. https://doi.org/10.1080/03057070.2019.1552424

Rogers, T.W., de los Reyes, F.L., Beckwith, W.J., Borden, R.C., 2014. Power earth auger modification for waste extraction from pit latrines. *Journal of Water, Sanitation and Hygiene for Development* 4, 72. https://doi.org/10.2166/washdev.2013.183

Romallosa, A.R.D., Kraft, E., 2017. Feasibility of biomass briquette production from municipal waste streams by integrating the informal sector in the Philippines. *Resources* 6. https://doi.org/10.3390/resources6010012

Rose, C., Parker, A., Jefferson, B., Cartmell, E., 2015. The Characterization of Feces and Urine: A Review of the Literature to Inform Advanced Treatment Technology. *Critical Reviews in Environmental Science and Technology* 45, 1827–1879. https://doi.org/10.1080/10643389.2014.1000761

Rowley, J., 2007. The wisdom hierarchy: Representations of the DIKW hierarchy. *Journal of Information Science* 33, 163–180. https://doi.org/10.1177/0165551506070706

Rowley, J., 2002. Using case studies in research. *Management Research News* 25, 16–27. https://doi.org/10.1108/01409170210782990

Runeson, P., Höst, M., 2009. Guidelines for conducting and reporting case study research in software engineering. *Empirical Software Engineering* 14, 131–164. https://doi.org/10.1007/s10664-008-9102-8

Satterthwaite, D., 2016. A new urban agenda? *Environment and Urbanization* 28, 3–12. https://doi.org/10.1177/0956247816637501

Satterthwaite, D., 2008. Cities' contribution to global warming: notes on the allocation of greenhouse gas emissions. *Environment and Urbanization* 20, 539–549. https://doi.org/10.1177/0956247808096127

Schöbitz, L., Bischoff, F., Lohri, C., Niwagaba, C., Siber, R., Strande, L., Schoebitz, L., Bischoff, F., Lohri, C.R., Niwagaba, C.B., Siber, R., Strande, L., 2017. GIS Analysis and Optimisation of Faecal Sludge Logistics at City-Wide Scale in Kampala, Uganda. *Sustainability* 9, 194. https://doi.org/10.3390/su9020194

Schöbitz, L., Niwagaba, C.B., Strande, L., 2016. Shit Flow Diagram Report for Kampala, Uganda, SFD promotion Initiative. Kampala, Uganda.

Schöbitz, L., Niwagaba, C.B., Strande, L., 2014. RRR Project - From Research to Implementation: Waste Supply and Availability in Kampala. Swiss Federal Institute of Aquatic Science and Technology (Eawag) - Department of Water and Sanitation in Developing Countries (Sandec), Dübendorf, Switzerland.

Schouw, N.L., Danteravanich, S., Mosbaek, H., Tjell, J.C., 2002. Composition of human excreta - A case study from Southern Thailand. *Science of the Total Environment* 286, 155–166. https://doi.org/10.1016/S0048-9697(01)00973-1

Schroder, J.J., Cordell, D., Smit, A.L., Rosemarin, A., 2010. Sustainable use of phosphorus. Plant Research International, Wageningen, The Netherlands.

Schuster-Wallace, C.J., Wild, C., Metcalfe, C., 2015. Valuing Human Waste as an Energy

Resource: A Research Brief Assessing the Global Wealth in Waste. United Nations University - Institute for Water, Environment and Health (UNU-INWEH), Hamilton, ON, Canada.

Seadon, J.K., 2010. Sustainable waste management systems. *Journal of Cleaner Production* 18, 1639–1651. https://doi.org/10.1016/j.jclepro.2010.07.009

Seck, A., Gold, M., Niang, S., Mbéguéré, M., Diop, C., Strande, L., 2015. Faecal sludge drying beds: increasing drying rates for fuel resource recovery in Sub-Saharan Africa. *Journal of Water, Sanitation and Hygiene for Development* 5, 72–80. https://doi.org/10.2166/washdev.2014.213

Shumo, M., Osuga, I.M., Khamis, F.M., Tanga, C.M., Fiaboe, K.K.M., Subramanian, S., Ekesi, S., van Huis, A., Borgemeister, C., 2019. The nutritive value of black soldier fly larvae reared on common organic waste streams in Kenya. *Scientific Reports* 9, 10110. https://doi.org/10.1038/s41598-019-46603-z

Smith, J.U., Austin, G., Avery, L., Balana, B., 2011. The potential of small-scale biogas digesters to alleviate poverty and improve long term sustainability of ecosystem services in Sub-Saharan Africa, in: Interdisciplinary Expert Workshop, Kampala (Group I) and Addis Ababa (Group II). pp. 4–5.

Sørensen, E., 2006. Metagovernance: The Changing Role of Politicians in Processes of Democratic Governance. *The American Review of Public Administration* 36, 98–114. https://doi.org/10.1177/0275074005282584

Spuhler, D., Scheidegger, A., Maurer, M., 2018. Generation of sanitation system options for urban planning considering novel technologies. *Water Research* 145, 259–278. https://doi.org/10.1016/j.watres.2018.08.021

St-Hilaire, S., Sheppard, C., Tomberlin, J.K., Irving, S., Newton, L., McGuire, M.A., Mosley, E.E., Hardy, R.W., Sealey, W., 2007. Fly Prepupae as a Feedstuff for Rainbow Trout, Oncorhynchus mykiss. *Journal of the World Aquaculture Society* 38, 59–67. https://doi.org/10.1111/j.1749-7345.2006.00073.x

Stahel, W.R., 2010. *The performance economy*, 2nd ed. Palgrave Macmillan, London.

Šteflová, M., Koop, S., Elelman, R., Vinyoles, J., Van Leeuwen, C., 2018. Governing Non-Potable Water-Reuse to Alleviate Water Stress: The Case of Sabadell, Spain. *Water* 10, 739. https://doi.org/10.3390/w10060739

Strande, L., Ronteltap, M., Brdjanovic, D., 2014. *Faecal sludge management: systems approach for implementation and operation*, 1st ed. IWA Publishing, London, UK.

Strande, L., Schoebitz, L., Bischoff, F., Ddiba, D., Okello, F., Englund, M., Ward, B.J., Niwagaba, C.B., Schöbitz, L., Bischoff, F., Ddiba, D., Okello, F., Englund, M., Ward, B.J., Niwagaba, C.B., 2018. Methods to reliably estimate faecal sludge quantities and qualities for the design of treatment technologies and management solutions. *Journal of Environmental Management* 223, 898–907. https://doi.org/10.1016/J.JENVMAN.2018.06.100

SuSanA, 2008. Towards more sustainable sanitation solutions - SusanA Vision Document. Sustainable Sanitation Alliance (SuSanA).

Tilley, E., Lüthi, C., Morel, A., Zurbrügg, C., Schertenleib, R., 2008. *Compendium of Sanitation Systems and Technologies*, 1st ed. Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland.

Tilley, E., Ulrich, L., Lüthi, C., Reymond, P., Zurbrügg, C., 2014. *Compendium of sanitation systems and technologies*. Swiss Federal Institute of Aquatic Science and Technology (Eawag).

Trimmer, J.T., Cusick, R.D., Guest, J.S., 2017. Amplifying Progress toward Multiple

Development Goals through Resource Recovery from Sanitation. *Environmental Science & Technology* 51, 10765–10776. https://doi.org/10.1021/acs.est.7b02147

Tukahirwa, J.T., Lukooya, N.B., 2015. The role of policy and institutional reforms in enhancing technical efficiency of urban authorities: Reference to solid waste management in Kampala city, Uganda, in: Mohee, R., Simelane, T. (Eds.), Future Directions of Municipal Solid Waste Management in Africa. Africa Institute of South Africa, pp. 136–154.

Ueberschaar, M., Dariusch Jalalpoor, D., Korf, N., Rotter, V.S., 2017. Potentials and Barriers for Tantalum Recovery from Waste Electric and Electronic Equipment. *Journal of Industrial Ecology* 21, 700–714. https://doi.org/10.1111/jiec.12577

UN-Habitat, IHS-Erasmus University Rotterdam, 2018. *The State of African Cities 2018: The geography of African investment*, 1st ed. United Nations Human Settlements Programme (UN-Habitat).

UN DESA, 2019a. *World Population Prospects 2019: Highlights (ST/ESA/SER.A/423).* United Nations, Department of Economic and Social Affairs (UN DESA), Population Division, New York, NY, USA.

UN DESA, 2019b. World Urbanization Prospects 2018: Highlights (ST/ESA/SER.A/421). United Nations, Department of Economic and Social Affairs (UN DESA), Population Division, New York, NY, USA.

UN Habitat, 2015. *The State of African Cities 2014: Re-Imagining Sustainable Urban Transitions*, The State of African Cities 2014. UN. https://doi.org/10.18356/109f7efd-en

UNICEF, WHO, 2019. Progress on household drinking water, sanitation and hygiene 2000-2017: Special focus on inequalities. United Nations Children's Fund (UNICEF) and World Health Organization (WHO), New York, NY, USA.

United Nations, 2017. New Urban Agenda. Quito.

United Nations, 2015. Transforming our world : the 2030 Agenda for Sustainable Development. United Nations General Assembly, New York, NY, USA.

Valencia, R., den Hamer, D., Komboi, J., Lubberding, H.J., Gijzen, H.J., 2009. Alternative treatment for septic tank sludge: Co-digestion with municipal solid waste in bioreactor landfill simulators. *Journal of Environmental Management* 90, 940–945. https://doi.org/10.1016/j.jenvman.2008.02.007

Valencia, S.C., Simon, D., Croese, S., Nordqvist, J., Oloko, M., Sharma, T., Taylor Buck, N., Versace, I., 2019. Adapting the Sustainable Development Goals and the New Urban Agenda to the city level: Initial reflections from a comparative research project. *International Journal of Urban Sustainable Development* 11, 4–23. https://doi.org/10.1080/19463138.2019.1573172

Valenzuela, F., Böhm, S., 2017. Against wasted politics: A critique of the circular economy. *ephemera: theory & politics in organization* 17, 23–60.

Van Huis, A., Van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G., Vantomme, P., 2013. *Edible insects: future prospects for food and feed security*. Food and Agriculture Organization of the United Nations.

van Leeuwen, K., de Vries, E., Koop, S., Roest, K., 2018. The Energy & Raw Materials Factory: Role and Potential Contribution to the Circular Economy of the Netherlands. *Environmental Management* 61, 786–795. https://doi.org/10.1007/s00267-018-0995-8

van Loom, S., Jap, K., 2008. *The handbook of biomass combustion and co-firing*. Earthscan, London, UK.

van Rijswick, M., Edelenbos, J., Hellegers, P., Kok, M., Kuks, S., 2014. Ten building blocks for sustainable water governance: an integrated method to assess the governance of water. *Water International* 39, 725–742. https://doi.org/10.1080/02508060.2014.951828

Vaneeckhaute, C., Lebuf, V., Michels, E., Belia, E., Vanrolleghem, P.A., Tack, F.M.G., Meers, E., 2017. Nutrient Recovery from Digestate: Systematic Technology Review and Product Classification. *Waste and Biomass Valorization* 8, 21–40. https://doi.org/10.1007/s12649-016-9642-x

Vea, E.B., Romeo, D., Thomsen, M., 2018. Biowaste Valorisation in a Future Circular Bioeconomy. *Procedia CIRP* 69, 591–596. https://doi.org/10.1016/j.procir.2017.11.062

Velenturf, A., 2016. Analysing the governance system for the promotion of industrial symbiosis in the Humber region, UK. *People, Place and Policy Online* 10, 146–173. https://doi.org/10.3351/ppp.0010.0002.0003

Villarroel Walker, R., Beck, M.B.B., Hall, J.W.W., Dawson, R.J.J., Heidrich, O., 2014. The energy-water-food nexus: Strategic analysis of technologies for transforming the urban metabolism. *Journal of Environmental Management* 141, 104–115. https://doi.org/10.1016/j.jenvman.2014.01.054

Vinnerås, B., Palmquist, H., Balmér, P., Jönsson, H., 2006. The characteristics of household wastewater and biodegradable solid waste—A proposal for new Swedish design values. *Urban Water Journal* 3, 3–11. https://doi.org/10.1080/15730620600578629

Vitorino de Souza Melaré, A., Montenegro González, S., Faceli, K., Casadei, V., 2017. Technologies and decision support systems to aid solid-waste management: a systematic review. *Waste Management* 59, 567–584. https://doi.org/10.1016/j.wasman.2016.10.045

Vögeli, Y., Lohri, C.R., Gallardo, A., Diener, S., Zurbrügg, C., 2014. *Anaerobic digestion of biowaste in developing countries: Practical information and case studies*. Department of Water and Sanitation in Developing Countries (Sandec), Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf, Switzerland.

Wang, L., Li, Y., Chen, P., Min, M., Chen, Y., Zhu, J., Ruan, R.R., 2010. Anaerobic digested dairy manure as a nutrient supplement for cultivation of oil-rich green microalgae Chlorella sp. *Bioresource Technology* 101, 2623–2628. https://doi.org/10.1016/j.biortech.2009.10.062

WBCSD, 2014. Guidelines for Co-Processing Fuels and Raw Materials in Cement Manufacturing. World Business Council for Sustainable Development, Geneva, Switzerland.

Weitz, N., Strambo, C., Kemp-Benedict, E., Nilsson, M., 2017. Closing the governance gaps in the water-energy-food nexus: Insights from integrative governance. *Global Environmental Change* 45, 165–173. https://doi.org/10.1016/j.gloenvcha.2017.06.006

Werther, J., Ogada, T., 1999. Sewage sludge combustion. *Progress in Energy and Combustion Science* 25, 55–116. https://doi.org/10.1016/S0360-1285(98)00020-3

Wester, J., Timpano, K.R., Çek, D., Lieberman, D., Fieldstone, S.C., Broad, K., 2015. Psychological and social factors associated with wastewater reuse emotional discomfort. *Journal of Environmental Psychology* 42, 16–23. https://doi.org/10.1016/j.jenvp.2015.01.003

Williams, J., 2019. Circular Cities: Challenges to Implementing Looping Actions. *Sustainability* 11, 423. https://doi.org/10.3390/su11020423

Wilson, Z., Pfaff, B., 2008. Religious, philosophical and environmentalist perspectives on potable wastewater reuse in Durban, South Africa. *Desalination* 228, 1–9. https://doi.org/10.1016/j.desal.2007.07.022

World Bank Group, 2015. Promoting Green Urban Development in African Cities: Urban Environmental Profile of Kampala, Uganda. World Bank Group, Washington, D.C. https://doi.org/10.1596/22941

World Population Review, 2019. Cities In Africa by Population 2019 [WWW Document]. *World Population Review*. URL http://worldpopulationreview.com/cities-in-africa/ (accessed 6.11.19).

Wu, J., Franzén, D., Malmström, M.E., 2016. Anthropogenic phosphorus flows under different scenarios for the city of Stockholm, Sweden. *Science of The Total Environment* 542, 1094–1105. https://doi.org/10.1016/j.scitotenv.2015.09.024

WWAP, 2012. The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. World Water Assessment Programme, United Nations Educational, Scientific and Cultural Organization, Paris, France.

Yin, R.K., 2009. *Case study research: design and methods*, 4th ed. Sage Publications Inc., Los Angeles, CA.

Yousuf, A., Khan, M.R., Pirozzi, D., Ab Wahid, Z., 2016. Financial sustainability of biogas technology: Barriers, opportunities, and solutions. *Energy Sources, Part B: Economics, Planning, and Policy* 11, 841–848. https://doi.org/10.1080/15567249.2016.1148084

Zaman, A.U., 2014. Identification of key assessment indicators of the zero waste management systems. *Ecological Indicators* 36, 682–693. https://doi.org/10.1016/j.ecolind.2013.09.024

Zeller, V., Towa, E., Degrez, M., Achten, W.M.J., 2019. Urban waste flows and their potential for a circular economy model at city-region level. *Waste Management* 83, 83–94. https://doi.org/10.1016/j.wasman.2018.10.034

Zink, T., Geyer, R., 2017. Circular Economy Rebound. *Journal of Industrial Ecology* 21, 593–602. https://doi.org/10.1111/jiec.12545

ISBN 978-91-7873-543-3
TRITA-ABE-DLT-2016

www.kth.se