HUMAN SETTLEMENTS AND THE CIRCULAR ECONOMY

Creating more resilient, liveable human settlements through a circular economy

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EXECUTIVE SUMMARY

This study explores the potential of the circular economy for human settlements in South Africa. It reviews current human settlement development pathways and draws on emerging concepts from the circular economy to identify and evaluate more sustainable alternatives. Seventeen (17) circular economy interventions (CEIs) were assessed to determine their appropriateness for South Africa, the sector's readiness to implement them, and the current level of implementation in South African human settlements.

Engagement with private and public sector stakeholders showed a high level of familiarity with the 17 identified CEIs. The three most familiar interventions were *virtualisation*, *roof gardens* and *composting*. The three least familiar CEIs were found to be *loose-fit*, *long-life design*; *equipment libraries*; and *design for disassembly*. There was consensus amongst stakeholders that the adoption of circular practices would be beneficial for South African human settlements. The three most beneficial and appropriate circular interventions to South African human settlements included: *greywater reuse; localising supply chains*; and *urban agriculture*. The three least beneficial circular interventions were seen to be *biobased construction materials*, *composting,* and *reuse of materials and products*.

In terms of readiness to implement, *virtualisation; smart sensors and connected technologies;* and *shared use of buildings* were scored by respondents as having the highest levels of readiness. The lowest levels of readiness were noted for *equipment libraries*, *design for disassembly*, and *biobased construction materials*. In terms of actual implementation, respondents noted that all identified CEIs had some level of implementation in South African human settlements, but not all at a scale for impact. According to respondents the three most implemented CEIs in South Africa are *virtualisation; localising supply chains*; and *urban agriculture*. The three least implemented CEIs included *design for disassembly; loose fit, long-life design;* and *equipment libraries*.

These options were analysed and modelled to understand differences with current development pathways and potential impacts. Modelled results indicate that substantial benefits could be achieved from the adoption of circular approaches. These include improved quality of life, the creation of new enterprises and jobs, and reductions in waste and carbon emissions. The modelled impacts of selected CEIs are outlined below and provided in more detail in the report.

Urban planning based on 15-minute neighbourhood principles ensures that the facilities required for everyday living such as workplaces and schools are within 15 minutes' walk of homes. For the City of Johannesburg (CoJ), modelling based on the city's Spatial Development Framework (SDF) indicates that if 15-minute neighbourhood principles are followed, an additional 100,000 households, compared to the current trend, would be able to access primary schools, secondary schools, health facilities, and commercial buildings within a 15-minute walk by 2042.

A circular approach that integrates urban agriculture within human settlements indicates that substantial fresh produce could be grown. Modelling food gardens within the City of Johannesburg neighbourhoods suggests that 320,000 t of fresh produce per year could be targeted. It is estimated that this option could provide approximately 20% of vegetable requirements for a projected urban population of 10.3 million people (3.4 million households) who will live in Johannesburg in 2042 and make a valuable contribution to improving food security.

Instead of directing organic waste to landfill, a circular approach that composts organic waste within human settlements provides fertility for soils and urban agriculture. For the City of Johannesburg, modelling suggests that about 550 kt (about 24% of all domestic solid waste) could be diverted from landfill sites. At the same time, 5,050 full-time jobs could be created and carbon emissions between 165 and 330 kt could be avoided.

Greywater systems use lightly soiled water from, for instance, showers, for irrigation and flushing toilets in buildings, thereby conserving valuable potable water. Modelling this option for households in the City of Johannesburg indicates that 307.7 ML per day could be generated, saving large amounts of potable water.

Rainwater harvesting systems capture rainfall from collection surfaces such as roofs and use this within buildings. Modelling the adoption of rainwater systems within human settlements in the City of Johannesburg indicates that 46,531 ML could be harvested per year. This water could be used to flush toilets and for irrigation, substantially reducing requirements for potable water. Thus, greywater and rainwater harvesting could be used to conserve scarce water resources and reduce the pressure on stretched municipal systems.

Reusing materials and products salvaged during the deconstruction of buildings reduces resource consumption and avoids waste. Modelling this circular option for the City of Johannesburg shows that 225,210 t of building materials and components per year could be reused. This represents a 44% reduction in construction waste that would normally end up in landfill or be illegally dumped in urban open spaces.

The study finds that circular options have the potential to make substantial contributions to the development of more sustainable and liveable human settlements. It is hoped this document can be drawn on in identifying and developing circular human settlement systems that reduce resource inefficiencies and waste, create new small enterprises and jobs, and improve quality of life for all.

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ACRONYMS

AI	Artificial Intelligence
ABT	Alternative Building Technology
BFI	Budget Facility for Infrastructure
C&D	Construction and Demolition Waste
CE	Circular Economy
CEIs	Circular economy interventions
CIDB	Construction Industry Development Board
CoJ	City of Johannesburg
CO2e	Carbon dioxide equivalent
CPD	Continuous Professional Development
CSIR	Council for Scientific and Industrial Research
DSI	Department of Science and Innovation
EaaS	Energy-as-a-service
EPC	Energy Performance Certificate
EPR	Extended producer responsibility
GDP	Gross Domestic Product
IBT	Innovative Building Technology
IDP	Integrated Development Plan
IF	Infrastructure Fund
kt	Kilotonne
LCA	Life-cycle Assessment
LCC	Life-cycle Costing
ISO	International Standards Organisation
ML	Megalitre
MPCC	Multi-purpose community centres
MSP	Municipal Service Partnerships
MW	Megawatt
NDC	Nationally Determined Contribution
NGO	Non-government organisation
NIP	National Infrastructure Plan
NRW	Non-revenue Water
OFMSW	Organic Fraction of Municipal Solid Waste
PaaS	Product-as-a-service
SABS	South African Bureau of Standards
SANS	South African National Standard
SDF	Spatial Development Framework
StatsSA	Statistics South Africa
SUDS	Sustainable urban drainage systems

1 Introduction

1.1 Background

Human settlements are the built environments, including parks, where people live and work. Human settlements are responsible for 60-80% of the energy consumption, and 75% of the world's natural resource extraction, despite occupying only 3% of the earth's land surface (UN, 2015). They are also responsible for 75% of global carbon emissions, with transport and buildings among the largest contributors (UNEP, 2024). These impacts result from large-scale, linear consumption of resources, and the production of waste, within our built environment.

Circular economy approaches have been identified as a key strategy for enabling the earth's 9 billion people to live within planetary boundaries, and for achieving climate change targets and the Sustainable Development Goals (WBCSD, 2024).

A circular economy requires us to redesign systems, products and services to decouple development from resource consumption. Using principles such as durability, renewability, reuse, repair, refurbishment, efficiency and sufficiency, circular approaches can reduce negative environmental impacts, while creating beneficial social and economic opportunities, such as new enterprises and jobs, and improve quality of life (Gibberd, 2020; Godfrey, 2022). Figure 1 shows how some of these circular economy principles can be applied to cities.

This report explores the potential of the circular economy for human settlements in South Africa. It reviews current human settlement development pathways in South Africa and draws on emerging concepts from the circular economy to identify and evaluate more sustainable alternatives. Applying the three circular economy principles of the Ellen MacArthur Foundation to South African human settlements, points to the following opportunities (EMF, 2019):

1. *Designing out waste and pollution*: e.g., green, energy-efficient buildings, more compact cities, pedestrian-friendly neighbourhoods.
2. *Keeping products and materials in use*: e.g., circular construction value chains, circular food systems, waste beneficiation.
3. *Regenerating natural systems*: e.g., urban agriculture, renewable energy, green roofs, green open spaces, alternative building technologies.

These circular economy principles provide a useful framework through which to explore circular economy opportunities in South Africa's built environment.

Circular human settlements and buildings have an emphasis on aspects of built environments that enable and encourage more sustainable living and working patterns. A circular building "*optimizes the use of resources while minimizing waste throughout its whole life cycle. The building's design, operation and deconstruction maximize value over time using:*

- *Durable products and services made of secondary, non-toxic, sustainably sourced, or renewable, reusable or recyclable material.*
- *Space efficiency over time through shared occupancy, flexibility and adaptability.*
- *Disassembly, reuse or recycling of embedded material, components and systems.*
- *Life-cycle assessment (LCA), life-cycle costing (LCC) and readily available digital information (such as building material passports)*" (WBCSD, 2024a:3).

Figure 1. Circular and regenerative cities (adapted from UCL, 2021)

1.2 Objectives

This study, which explores the opportunities for greater circularity in South African human settlements, is a component of a larger CSIR project titled '*Identifying opportunities for a more circular South African economy – A resource perspective*'.

The first phase of this project produced a series of short briefing notes, including one for human settlements, titled "*Creating resilient, inclusive, thriving human settlements through a more circular economy*" (Cooper *et al.*, 2021). These notes provide context to the circular economy broadly, as well as within seven resource-intensive sectors of the South African economy (mining, agriculture, manufacturing, human settlements, mobility, energy, and water). The note on human settlements was taken further in "*The circular economy, human settlements and municipal government*", which also explored the synergies with the other sectors (Cooper *et al.*, 2024).

The second phase of the project undertook a more comprehensive assessment of the circular economy in resource-intensive sectors of the South African economy. The technical report on *mining* and the circular economy showed that resource scarcity is a driver for South Africa to transition to a more circular economy (Khan *et al*., 2022). Four further technical studies showed that South Africa has already adopted circular practices in *agriculture*, *manufacturing*, *energy*, and *water*, but that these practices have not (yet) achieved a scale for meaningful impact. As such, the circular economy is not new to these sectors. While for some interventions the levels of readiness to adopt is still low, there is consensus that most of the circular interventions put forward can provide very real economic, social, and environmental benefits for the country.

The final stage of the project explores the opportunities to adopt circular approaches in two of the most diverse, cross-cutting, and human-centric sectors – that of *mobility* and *human settlements*. These two sectors were left to the end as they include many of the circular interventions already explored through the previous studies. They are also, based on international research, the two sectors that typically provide the greatest opportunities (and benefits) for a circular economy transition.

The objectives of this study are to understand the implications and potential of the circular economy for human settlements, including the built environment.

1.3 Methodology

The methodology adopted for this study is based on a desktop study to understand the current human settlement development pathways. This ascertained the current and future environmental, economic, and social impacts of current development. This was followed by a review of circular economy interventions in buildings and the construction sector, aimed at identifying alternative models that could be applied in South Africa.

An online stakeholder survey was carried out to evaluate the potential of the identified circular economy interventions. The survey targeted human settlement stakeholders and practitioners. In addition, a focus group was undertaken to validate and add depth to the survey results. The survey and focus group aimed to ascertain the readiness of the human settlements sector to adopt circular approaches.

An analysis of the results from the survey were used to select circular interventions for further investigation. These interventions were explored through modelling to enable the potential impact of these options to be better understood and quantified. Based on this comprehensive desktop, stakeholder and modelling approach, conclusions and recommendations from the study are made.

1.4 Structure of the Study

The study is structured in the following way:

- *Current development path for the South African Human Settlements Sector* (Chapter 2). This chapter sets out the current development pathway of human settlements in South Africa.
- *The Circular Economy – A human settlements perspective* (Chapter 3): This section provides insights into current and future trends in human settlements and their implications.
- *Circular economy development pathways for Human Settlements* (Chapter 4): This section outlines potential circular economy interventions in human settlements. These are evaluated in terms of the readiness of the sector to receive these and the potential benefits that could be achieved. This is informed by stakeholder feedback gained through the survey and focus group.
- *Quantifying systemic impacts* (Chapter 5): Modelling is carried out of the most promising circular interventions. This enables potential impacts of circular interventions to be projected and understood. Comparisons with current development paths are undertaken to understand the advantages and disadvantages of proposed approaches.
- *Conclusions and recommendations* (Chapter 6)*:* Key findings and recommendations from the study are provided. This includes proposals on how recommendations could be implemented.

2 Current development path for South African human settlements

2.1 Introduction

Human settlements play a central role in the economy of countries and in how citizens relate to each other and the environment. They create multiple impacts, both in the way they are constructed, as well as in the way they are planned, designed, and operated.

This chapter provides a brief overview of the sector in terms of human settlement and construction impacts. It also presents future trends and how these present opportunities to adopt alternative circular development paths.

2.2 Current situation

2.2.1 Urban form, mobility and access to services

Formal housing in South African human settlements is characterised by stand-alone, low-density buildings. An apartheid legacy, reinforced by zoning laws has meant that South African cities suffer from urban sprawl.

In global terms, South African cities have a low density. Cities like Johannesburg (190 m^2/person) and Cape Town (309 m^2/person) rank at the lower end for built density compared to higher-density Asian and European cities such as Lahore and Paris (Figure 2).

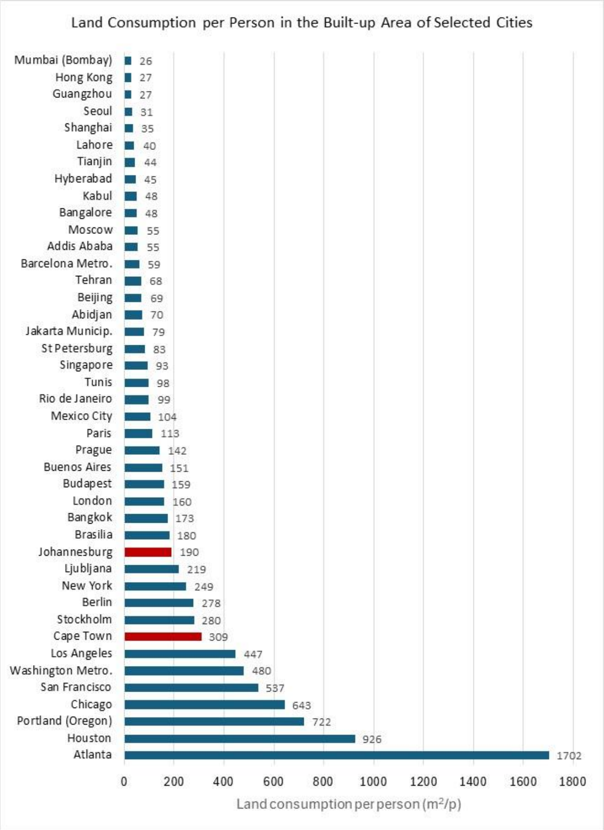

Figure 2. Land consumption per person (adapted from Bertaud, 2010)

Johannesburg has a density of about 30 persons/hectare (Atlas of Urban Expansion, 2024). This compares to a 150 person/ha density advocated for sustainable neighbourhoods by UNHabitat (2024).

The low density of South African cities, growing urban sprawl, and inefficient urban form and services, result in users experiencing disproportionately higher costs and reduced access to services and amenities (UNHabitat, 2014). The South African Households Travel Survey (2020) indicates that workers who used public transport experienced long travel times in the morning to access their workplaces, with train users travelling 107 minutes, bus travellers 84 minutes, and taxi users 63 minutes (StatsSA, 2022a). Data from Statistics South Africa shows that two-thirds of South Africa’s poorest households spend 20% of their monthly household income on transport (StatsSA, 2024a). The long commuting distances associated with the sprawling urban form of South African cities often place the greatest burden on the poorest households who cannot afford higher-value, better-located land and housing (Kerr, 2017).

There are many drawbacks to low-density development. Low densities make public transport, roads, energy, water, and sanitation relatively expensive to build and maintain (NPC, 2024). Low-density settlements have to rely on vehicular transport which has substantial negative social, economic and environmental impacts including high carbon emissions, pollution, accidents, long commuting times and a high-cost burden on households.

These deficiencies can be addressed through more circular approaches to urban planning including the adoption of 15-minute neighbourhoods, which provide access to facilities within easy walking distance.

2.2.2 Unreliable water and energy supplies

Municipalities in South Africa struggle to maintain existing infrastructure and provide bulk services for new development. Non-revenue water (NRW) losses in South Africa are a growing issue, with average physical water losses in municipal systems estimated at around 35% (real losses), against a global best practice of 15% (DWS, 2018). This figure can be higher in larger cities, and in 2023 the City of Johannesburg classified 46.2% of the water supply as “non-revenue”, meaning it was lost to leaks or not paid for (Haffajee, 2024).

The South African Institution of Civil Engineering (SAICE) estimates that 40% of treated water is lost to leaks and illegal connections (SAICE, 2022). In 2022, the Department of Water and Sanitation rated 34% of South Africa’s 1186 urban water supply systems as being at high to critical risk of failure (SAICE, 2022). It indicated that only 40% of systems achieved microbiological compliance and 23% chemical compliance. A deterioration in wastewater systems was also identified with only 22 of 995 sanitation systems complying with the Green Drop system. Of particular concern is the extent to which substandard effluent is being discharged into rivers, increasing the risk of disease, such as Cholera, to communities downstream.

Unreliable water supplies encourage building owners to investigate improved water efficiency, greywater reuse and rainwater harvesting. This is being supported by the development of a water efficiency in buildings standard which is likely to be included in the building regulations soon (SABS, 2019).

Persistent load-shedding has also meant that many households have experienced regular power outages. This has led to households and businesses investing in solar energy and battery systems that reduce their reliance on municipal energy supplies. This trend has been supported by tax incentives by the National Treasury and a decrease in equipment prices. It is likely that the trend in investment in renewable energy systems will continue as municipalities increasingly provide feed-in tariffs that allow system owners (both businesses and households) to earn income by feeding excess electricity into the grid (Venter, 2024). In addition, innovative leasing and other financing models are making renewable energy systems more accessible and affordable (Businesstech, 2024; Gibberd, 2019).

Unreliable and wasteful bulk service systems provide opportunities to apply circular approaches. Circular models draw on off-grid technologies and innovative business models to provide more affordable and reliable services and can promote the development of local small enterprises and create local jobs.

2.2.3 Building materials and construction

The construction sector contributes about 3% to South Africa’s GDP and had an income of R436,7 billion in 2020 (StatsSA, 2022). As an industry, it creates significant employment. The CIDB (2015) indicates that it accounts for around 8% of total formal employment and 17% of total informal employment in South Africa. It is also a significant job creation multiplier, and about 4.2 formal jobs and 2.3 informal jobs are created for every million rand invested. If manufacturing and distribution of materials are included, this increases to around 9 jobs created per million rand invested (CIDB, 2007).

Very large quantities of materials are mined from the earth for construction. According to the Global Resources Outlook (UNEP, 2024:26), non-metallic minerals, which include sand, gravel, limestone, gypsum and clay used for construction and industrial purposes, represent the largest category of extracted material, growing from 9.6 billion t in 1970 to 45.3 billion t in 2020.

According to Haas *et al.* (2023), 269 Mt of metal ores were extracted in South Africa in 2017. Non-metallic minerals ores mined made up 162 Mt, with nearly three-quarters of these being construction minerals, mainly gravel and sand (93 Mt), followed by chalk, dolomite and limestone (17 Mt) and clays and kaolin (10 Mt). These minerals are used as sand and gravel in construction (44 Mt), in bricks (7 Mt), or further processed as compound materials like concrete (54 Mt) and asphalt (4 Mt) (Figure 3).

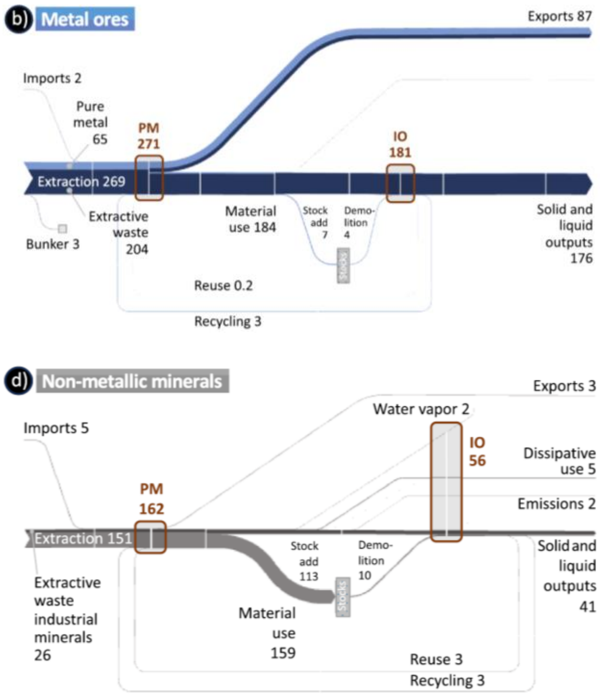

Figure 3. Sankey diagram for metal ores and non-metallic minerals (in Mt) (Haas *et al.*, 2023)

In 2017, the sector produced 4.48 million t of construction and demolition (C&D) waste, approximately 8% of the total waste generated (Department of Environmental Affairs, 2018). C&D waste, in addition to having to be disposed of in landfill sites, is often dumped illegally within cities and towns, creating significant challenges for local government (Schenck *et al.*, 2022).

Construction in South Africa is generally masonry and cement based. Cement and concrete production in South Africa have significant impacts and it is estimated that 39.7 million t of raw materials are consumed and 4.92 x 109 kg CO2e are generated per year to produce cement and aggregates for concrete production in South Africa (Muigai *et al.,* 2014).

These levels of resource consumption and waste are not sustainable and provide opportunities for adopting less resource-intensive and wasteful circular approaches.

2.2.4 Building design and operation

According to StatsSA (2024), 83.5% of South Africans lived in formal dwellings, 12.2% in informal dwellings and 3.9% in traditional dwellings. However, in the Western Cape and Gauteng, the number of citizens living in informal dwellings increases to 19.2% and 18.4% respectively.

Metropolitan municipalities such as Ekurhuleni (19.2%), Cape Town (18.9%) and Johannesburg (18.2%) have significantly higher numbers of informal dwellings than the national average, reflecting the influx of people into these economic hubs, seeking work (StatsSA, 2024).

Building designs in South Africa are often not optimised for daylight and occupant comfort and tend to have out-of-date and inefficient electrical and water fittings. While SANS 10400 XA and Energy Performance Certificates have been developed to improve energy efficiency in buildings, these need to be strengthened and enforced to accelerate the achievement of climate change targets (SABS 2021; SANEDI, 2024; Wu and Sky, 2022). This is particularly urgent given South Africa's dependence on coal-fired power stations that are responsible for 42% of South Africa's carbon emissions (Eskom, 2024).

About 45% of households have access to piped water in their dwellings (StatsSA, 2024). Other households access water from communal taps, neighbours' taps or rivers and streams. Water fittings, such as taps, showerheads and flush toilets in buildings are generally inefficient and very few buildings have greywater or rainwater harvesting systems.

Consumption of water is estimated to vary between 22 to 221 litres per person per day for residential households in South Africa, as shown in Table 1 (WRC, 2020). Using a benchmark of 80 litres per person per day indicates that some households are below, while others are well above this (Department for Communities and Local Government, 2010).

Table 1. Water consumption in households (WRC, 2020)

Water consumption for households of 4 people	**Estimated water use (ℓ/c/d)**
Standpipes	22
Communal ablution blocks	34
Yard connections	46
Low-cost housing – limited fixtures	76
Full house connections (indoor)	143
Full house connections (including outdoor)	221

Municipal water supplies are becoming increasingly unreliable, with 30% of households reporting a dysfunctional water supply service in 2021 (StatsSA, 2021). Systems and controls, such as sub-metering and timers, that can be used to manage and reduce energy and water consumption are rarely in place.

Only 60% of households have their household refuse removed at least once per week (StatsSA, 2024). An estimated 37% of South African households are required to find their own solutions to waste disposal, through communal dumpsites, own dumpsites, or illegal dumping in open spaces.

Metropolitan municipalities are facing growing landfill shortages as existing landfill sites fill up, and new sites for landfills are becoming more difficult to find, particularly near cities. It is also estimated that fewer than 45% of general landfill sites in South Africa are licensed and therefore many are not monitored for compliance with pollution standards (SAICE, 2022; Stafford *et al.*, 2022).

The capacity to manage and maintain buildings is limited. Building maintenance is often neglected leading to significant cost and disruption when repairs and replacement is required (SAICE, 2022). Social infrastructure, such as schools may not be efficiently used and be vacant during afternoons, weekends, and holidays. Low utilisation rates coupled with increasing energy, water, sanitation, security, cleaning, and maintenance costs can result in operating costs being a substantial burden for organisations, such as schools (Gibberd, 2018).

High levels of wastage and inefficiencies associated with building designs and operations provide opportunities for circular approaches. Circular approaches can be drawn on in developing buildings, which by being highly responsive to their users, contexts and climate, avoid waste and are more efficient.

2.3 Future trends

While it is difficult to predict future trends, current developments indicate what these may be. This section draws on emerging patterns to identify potential future trends in human settlements.

2.3.1 Infrastructure investment

To grow the economy and reduce unemployment and poverty, capital investment in infrastructure of 30% of GDP has been set as a target in the National Development Plan (NPC, 2012). To achieve this target, public-sector investment in infrastructure must grow from 3.8% of GDP in 2021 to 10% of GDP by 2030 and private-sector investment from 9.3% of GDP in 2021 to 20% in 2030 (Treasury, 2024).

The National Infrastructure Plan (NIP) has been developed to guide the implementation of the government's strategic integrated projects and improve economic growth and service delivery. It is supported by the Budget Facility for Infrastructure (BFI) which improves the planning and execution of large infrastructure projects and the Infrastructure Fund (IF) which aims to increase the participation of private-sector investors. To date, the Fund has helped to package 13 blended finance projects to the value of R48.8 billion (Treasury, 2024).

This development trajectory is supported by the projected public sector spending of R903 billion on infrastructure over the medium term announced in 2023. Around R448 billion will be spent by state-owned companies, public entities and through public-private partnerships.

Investment in renewable energy has resulted in an increase in generation from 1,501 MW in 2013 to 10,623 MW in 2023 (Statista, 2024). This trend is likely to continue with the mobilisation of Just Energy Transition funding of $8.5 billion between 2023 and 2027 (Presidency, 2024). This catalytical funding aims to leverage additional funding from private and public sources for infrastructure to upscale impact.

New infrastructure funding offers a significant opportunity to adopt more circular approaches and integrate this into the planning, design, construction, and operation of urban areas and building projects. Viewing South Africa's development through a circular economy lens provides an opportunity to rethink how we develop our cities and towns and create more liveable, resource-efficient, and sustainable human settlements.

2.3.2 Innovative building technologies

There has been an increased interest in innovative and alternative building technologies (sometimes referred to as IBT and ABTs) for public projects. These are alternative construction systems to masonry construction and include light-steel construction, structural insulated panels, and timber and concrete prefabricated systems.

IBTs and ABTs are seen as having the potential to reduce construction time and environmental impact. They usually have an Agrément certificate which confirms they meet minimum structural and other standards and have been promoted for public projects such as schools, clinics, housing, and student housing projects (NHBRC, 2024).

An interest in alternative construction systems provides an opening to introduce more circular building products. This could include biobased building panels based on wood or agricultural waste, which could be prefabricated and assembled on-site, speeding up construction times. These types of products can be used to promote small–scale circular building manufacturers that supply, install and maintain components for new buildings being built by government, the private sector, and self-builders.

2.3.3 Municipal Service Partnerships

Municipalities have the mandate to provide bulk services to communities however, a lack of capacity and finance has meant that these are not always provided, hampering the development of urgently needed human settlements. This can be addressed through Municipal Service Partnerships (MSP) which enable municipalities to partner with private providers and communities to provide bulk services (Department of Provincial and Local Government, 2000; 2004).

The MSP model is increasingly being explored in human settlements as it allows development to be unblocked. It also enables the installation of off-grid technologies and decentralised systems, such as energy microgrids, that can be developed rapidly and managed by the private sector. These systems may also be more reliable than municipal systems and provide services at a lower cost while creating local benefits in the form of jobs and small enterprise development.

Municipal Service Partnership can be used for energy, water, sanitation, and solid waste and offer a significant opportunity to integrate more circular approaches to bulk service supplies in human settlements.

2.3.4 Climate change

Climate change is already having a substantial impact on human settlements in South Africa. Impacts include increasing average temperatures, more very hot days, reduced rainfall and more extreme weather events (CSIR, 2024).

Projections indicate that *annual average* daily maximum temperatures for Tshwane, Polokwane, Kimberley, Musina and Mahikeng will be over 27°C by 2050, and Tshwane, Bloemfontein, Polokwane, Kimberley, Musina and Mahikeng will experience 1-2 months of *additional* very hot days that are well over the 32°C. This will have health impacts as a sustained heat index[1] of 27°C can cause fatigue and a heat index of over 32°C can cause heatstroke. Table 2 shows expected temperature changes for South African cities, including temperature increases (inc), average temperatures (Ave), maximum temperatures (Max) and the number of very hot days (Vhd).

Table 2. Expected changes by 2050 (CSIR, 2024).

City	inc	Ave	Max	Vhd
Johannesburg	+3	19.1	24.4	18
Tshwane	+3	21.4	28.2	48
Ekurhuleni	+3	19.2	25.6	13
Cape Town	+2	19.7	24.4	20
eThekwini	+2	22.3	25.5	4
East London	+2	20.6	24.6	5
Gqeberha	+2	20.2	23.3	7
Bloemfontein	+3	18.8	25.2	35
Polokwane	+3	21.2	28.4	49
Kimberley	+3	21.5	28.4	54
Musina	+3	25.1	32.1	58
Mahikeng	+3	22.4	29.3	54

It is not only unsafe to work in extreme heat, but this also kills livestock and crops, increases pollution and fire risk,

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[1] The air temperature adjusted by humidity. Relative humidity above 45% increases the heat index.

and damages infrastructure. High temperatures create particularly unhealthy conditions in informal dwellings where internal temperatures may be higher than ambient conditions.

While climate adoption guidelines are being developed, such as the CSIR's green book, their adoption has not been widespread (CSIR, 2024a; Gibberd, 2018a). It will become increasingly important to integrate climate adoption measures, including circular options, into human settlements to reduce disasters and disruption, such as flooding, fires, water shortages and extreme weather events.

2.3.5 Tightening legislation

To support the built environment's contribution to meeting South Africa's Nationally Determined Contributions (NDCs), buildings need to become more energy efficient and eventually achieve net zero energy. This is being reinforced in updated building regulations and city bylaws (SABS, 2021; C40, 2021).

Tightening legislation is driving increased demand for improved building design and technologies including more efficient lighting, controls, glazing, insulation and hot water systems. More stringent legislation has promoted improved capacity in the sector and driven the development of innovative technologies and techniques.

Demand for higher-performance products and services can be used to support the development and upscaling of circular approaches. An example of this is the development of cellulose-based insulation that can be manufactured by small-scale enterprises and used to improve the thermal performance of buildings and create local jobs.

3 The Circular Economy – A human settlements perspective

3.1 Introduction

The review in the last chapter indicates that current development paths in South Africa are associated with a range of negative impacts. These include highly inefficient urban form, deteriorating water, energy and waste services, high levels of waste and limited access to social infrastructure and economic opportunities.

In this section, alternative, circular economy models for human settlements are presented. These show how products and services in human settlements can be decoupled from resource consumption and waste using principles such as sharing, sufficiency, virtualisation, localisation, durability, renewability, reuse, repair, replacement, refurbishment, and efficiency.

3.2 Circular economy theme

Circular economy models for human settlements can be organised into broad themes. These can be described in the following way:

- Localise, diversify and enhance local access and opportunities
- Regenerate productive ecosystems and services
- Harness partnerships and technologies to improve efficiency and access to services
- Embed circularity in new designs

These themes, with examples, are outlined next.

3.2.1 Localise, diversify and enhance local access and opportunities

Resource consumption and waste generation can be reduced through localisation, diversification and local access. Ensuring that services and products required for everyday life are within walking distance reduces the need for private cars and public transport and cuts household costs (Wagner and Gibberd, 2022). A vibrant diversified economy provides enterprise development opportunities and local jobs. Local systems and partnerships can be used to support the development of linked-up, efficient, diversified and resilient economic systems.

Examples of '*localisation, diversification, enhanced local access and opportunity*' are provided below.

- **15-minute neighbourhoods:** 15-minute neighbourhoods are designed so that residents can access their daily requirements within a 15-minute walk. Increased densities enable facilities that are used regularly, such as schools, recreation, workspaces and retail to be within close proximity to homes. Paris has adopted this model for urban development and uses this to create vibrant neighbourhoods which support local small businesses and improve quality of life (Moreno, 2024).
- **Localise supply chains:** Using locally produced materials and products reduces transport requirements, costs and carbon emissions. Local capacity for repair and maintenance enhances the service life and functionality of buildings and systems and avoids waste and disruption associated with refurbishments and breakdowns. An emphasis on local content can promote the creation of new small enterprises and jobs. South Africa has a procurement policy that requires the government to purchase locally produced products, such as furniture and solar water heaters, in preference to imported goods (DTI, 2024). There are also South African standards that detail how local content targets can be set and measured (SABS, 2024).
- **Virtualisation:** Virtualisation refers to the dematerialization of processes. For example, online resources be used to provide access to high-quality learning opportunities in education while reducing the need for materials and facilities, such as books, libraries and laboratories. Similarly, telemedicine enables doctors and medical staff to access powerful diagnostic equipment and guidance online, limiting the need for these resources to be physically available locally.

3.2.2 Regenerate productive ecosystems and services

Natural ecosystems can be regenerated through the careful design and management of urban fabric and systems. Integrating ecosystems within urban environments improves microclimates and can create efficient water management and filtration systems. Including urban agriculture in human settlements enables healthy food and bio-based products to be provided locally (Gibberd, 2014). Composting organic waste within neighbourhoods provides fertility for plant growth and avoids this being directed to landfill. This approach blurs the boundaries between natural and man-made systems to create products and services that benefit both nature and human settlements.

Examples of '*regenerating productive ecosystems and services'* models are provided below.

- **Biobased construction materials:** Bio-based building materials included timber, straw and hemp. These are materials that can be farmed sustainably, sequestrate carbon and are renewable. Biobased materials can replace many materials, such as steel and cement-based components, that have to be mined, are carbon intensive and have large waste streams. There is an increasing interest in biobased materials in South Africa. This has resulted in timber being considered more widely for buildings and the development of the world's tallest building (12 storeys) built of industrial hemp in Cape Town (Bourdin, 2023).

- **Onsite composting:** Onsite composting of the Organic Fraction of Municipal Solid Waste (OFMSW) from houses and businesses, avoids waste being directed to landfill, and supports local soil fertility and planting. Equipment and vermiculture (worms) can be used to speed up decomposition and avoid smells and rodents. Composting also provides business opportunities for local entrepreneurs.
- **Roof gardens:** Roof gardens are roofs with soil and planting. Roof gardens act as a reservoir during heavy rain and by retaining water, contribute to reduced peak flows and flooding risks. They also have an important role in reducing the urban heat island effect in cities by creating cooler microclimates and can be used for agriculture (see urban agriculture). Roof gardens growing vegetables are being developed in several South African cities such as Johannesburg (City of Joburg, 2024).
- **Sustainable urban drainage systems (SUDS):** SUDS mimic nature to manage rainwater close to where it falls. Swales, retention ponds and porous surfaces control urban water flows and replenish local ground water. This reduces the need for large-scale storm water infrastructure and the risks of flooding. Retained moisture promotes plant growth and reduces the urban heat island effect. While SUDS are not widespread in South Africa, aspects such as retention ponds, are increasingly included in municipal building development requirements to reduce peak stormwater floors (City of Joburg, 2010).
- **Urban agriculture:** Urban agriculture uses open urban space to produce fresh vegetables and fruit. Intensive production methods such as hydroponics provide for efficient production of food with reduced water and fertilizer requirements. Local, efficiently grown fresh food promotes health and has lower resource and waste impacts compared to food that is highly processed and has been transported long distances. The FAO (2024) indicates that the average Latin American urban family spends 1 to 1.5 working days a week on urban gardens and saves between 10-30 per cent of its food bill. Globally, it is estimated that over 200 million urban farmers supply food to 700 million people and that 30% of the vegetables consumed in Kathmandu, 50% in Karachi and 85% in Shanghai, are from urban agriculture (FAO, 2024).

3.2.3 Harness partnerships and technologies

Partnerships and smart technologies can be used to improve resource efficiency and access to services. Communication and sensor technologies reduce the need to travel and enable improved management of systems and buildings.

Product-as-a-service (PaaS) models are business models where customers pay a recurring fee to access a product's services and benefits, instead of owning the physical product. These models, combined with smart sensors and meters, can be applied to provide energy (renewable energy systems), hot water (solar hot water systems), and water (rainwater and greywater systems). These systems are often highly efficient as service providers use premium equipment and carefully manage and maintain systems to maximise returns. PaaS approaches can also improve the feasibility of new developments, such as housing, by distributing capital costs and risks to more parties (Gibberd, 2019a).

Equipment libraries provide affordable access to specialist and expensive equipment. This enables small contractors to bid for, and undertake, a greater variety of work allowing them to grow. Sharing also reduces waste as less equipment is purchased, and these are more intensively used.

Sharing can also be applied to facilities, where buildings and sites are used by two or more organisations. More intense use of facilities and the sharing of costs between parties enable facilities to be operated much more affordably than conventional models (Gibberd, 2024). Smart technologies and partnerships, thus, can be used to create linked synergistic systems that are highly efficient, avoid waste and create multiple benefits.

Examples of '*harnessing partnerships and technologies to improve efficiency and access to services*' interventions include:

- **Smart sensors and connected technologies:** Smart sensors and connected technologies can be used to provide valuable data on building performance such as occupancy, energy and water use. This can be used to optimise building performance and avoid waste. Smart sensors are not widely used in South African buildings; however, escalating electricity and water prices mean these are being investigated more widely both for existing and new buildings. Smart building management systems (BMS) with online dashboards, sensors, meters and controls are increasingly available locally and have the potential to provide substantial savings in large buildings (Gibberd, 2019b).
- **Energy-as-a-service:** Energy-as-a-service (EaaS) is a business model where customers pay a recurring subscription fee for access to energy, rather than buying and installing the energy generation equipment themselves. It enables renewable energy systems to be installed, operated and maintained efficiently by energy entrepreneurs and for building owners and occupants to access reliable power affordably. Improved system design and operation efficiencies are usually achieved as high-quality technologies are specified and these are well-maintained. The Energy-as-a-service model is becoming increasingly widespread in South Africa as residential as well as commercial projects are now being targeted (Smith, 2024).

- **Greywater systems:** Greywater systems reuse lightly soiled water from showers and handwash basins to flush toilets and irrigate gardens. Greywater can generate significant water savings and can support urban agriculture and improved biodiversity. Despite local water shortages, greywater systems have not been widely installed in South Africa. However, equipment and design and operational guidance are available locally (WRC, 2024).
- **Equipment libraries:** Equipment libraries use the "lend instead of buy" principle to allow contractors and households to access equipment, such as power tools, that they may only need for a short time. Equipment libraries enable increased access to specialist equipment, reduce waste by using less equipment more intensively, and can support social cohesion and learning (Library of Things, 2024).
- **Shared use of facilities:** Shared use of facilities between different organisations improves the utilisation of buildings and grounds. For example, a community college holding adult education classes may use school buildings in the late afternoon and evening when these are not needed by the school. This reduces resource consumption and improves efficiency as fewer buildings are needed, and those constructed are used more intensively (Land and Aitchison, 2017).

The potential of some of these models is also explored in the modelling in Chapter 5.

3.2.4 Embed circularity in new designs

The potential for developing highly efficient sustainable built environments and systems is greatest in the early stages of conceptualisation and development. During this stage, buildings can be designed for flexibility, adoption, easy repair and maintenance, and to accommodate change over their lifespan. Materials with the lowest environmental impacts, such as grown materials (see biobased materials), reused materials and components with high recycled content can also be specified. This approach aims to retain materials and components at their highest value throughout the lifespan of the building by careful design, specification, installation, maintenance and end-of-life strategies.

Examples of strategies that can be used to '*embed circularity in new designs*' are outlined below.

- **Design for disassembly:** Designing buildings to be easy to assemble and disassemble enables their components to be reused in new buildings once a building's useful life has come to an end. In this way, materials can be used for longer and waste is avoided. Examples of this approach are the use of accessible bolted, screwed or nailed rather than welded, glued or sealed connections. This enables assemblies to be readily taken apart and ensures that materials and components are not damaged and can be reused (Cutieru, 2020).
- **Loose fit, long-life design:** Design for loose fit, long life is a design strategy that enables buildings to accommodate change and different functions over their life by being flexible and adaptable. This increases the useful life of buildings and avoids waste. Design principles that enable buildings to accommodate change were set out by Steward Brand (1995) who described buildings as layers such as skin, services and structure. Brand suggested that designs where these elements could be accessed independently from others, repaired and replaced, enabled change to be accommodated more easily and with less waste.
- **Modular design:** Modular design is an approach that designs buildings based on standard materials and product sizes. By using a modular grid, designs avoid cutting materials and reduce the requirement for specially made components. This provides for more efficient, lower waste construction and repairs. While the approach is not widespread in South Africa, it is increasingly being investigated for retail buildings and student housing. Recent examples suggest that modular approaches can result in costs that are 80% of a similar brick-and-mortar structure and that erection can be rapid, with buildings ready for occupation within 2 months from initiation (City of Joburg, 2024a).
- **Recycled content building products:** Recycled content products refer to products that include elements that have been recycled. For instance, steel products may contain steel recycled from products that have reached the end of their life and steel from virgin sources. Recycled content products reduce virgin material demand, energy use and waste. This option has not been widely applied in South Africa. However, it is being increasingly adopted in buildings targeting green building ratings as recycling content is a criterion (Huang *et al.*, 2020).
- **Reuse of materials and products from deconstruction:** Reusing materials and products when buildings are demolished avoids these being directed to landfill and wasted. It also reduces resource consumption; transport impacts and energy requirements as fewer new materials and products are required. The reuse of construction materials and products can also create new local entrepreneurs and jobs. While the reuse of materials in the informal sector is extensive, it is relatively rare in the formal building sector. An exception is the Tsoga Environmental Centre which made extensive use of reclaimed materials such as bricks (ARG Design, 2024).


PLAN W

4 Circular economy development path for human settlements

The models presented in the previous section indicate the potential benefits of adopting circular approaches. Circular economy models improve efficiencies and make services and products more affordable and accessible. Regeneration enables natural environments and systems to be revitalised and provide valuable climate change mitigation, adoption services and biobased industries such as forestry and timber manufacturing. Resource efficiency, the use of renewable resources and extending the operational life of products provide opportunities for new enterprises and jobs.

4.1 Circular economy interventions

The proposed circular economy interventions (CEIs) for human settlements (Table 3) were based on an analysis of current trends that seek to reduce our built environment's dependence on finite resources, minimize waste, and promote sustainable growth. These interventions focus on addressing key challenges experienced by the sector, such as urban sprawl, high carbon emissions, food security, and waste. The adoption of CEIs can support a transition to human settlements that not only support economic development but also contribute to environmental sustainability and social equity.

By implementing these interventions, South Africa can leapfrog the resource-intensive development paths followed in the global north. It can also position itself as a leader in the development of sustainable and circular human settlement designs and systems which can be drawn on by other African countries wishing to follow a similar path.

This section explores the applicability of the identified CEIs. It reviews the appropriateness of these interventions to South Africa; our readiness to adopt these interventions; and the current levels of implementation within the sector.

Table 3. Proposed circular economy interventions for the human settlements sector.

Circular Economy Intervention	Description
15-minute neighbourhoods	Neighbourhoods that enable residents to access all their daily requirements within a 15-minute walk.
Biobased construction materials	Renewable building materials such as timber, straw and hemp that can be farmed sustainably, sequestrating carbon.
Composting	Diverting food and garden waste away from landfill, to produce compost that can be used for gardens.
Design for disassembly	Designing buildings to be easy to assemble and disassemble enabling their components to be reused in new buildings.
Energy-as-a-service	Energy-as-a-service allows customers to pay a subscription fee rather than buy and install equipment.
Equipment libraries	Equipment libraries use the "lend instead of buy" principle to allow people to access equipment that they may only need for a short time for a small fee.
Greywater systems	Grey water systems reuse lightly soiled water from showers and handwash basins to flush toilets and irrigate gardens.
Localise supply chains	Using locally produced materials and products reduces transport requirements and associated carbon emissions.
Loose fit, long-life design	A design strategy that enables buildings to accommodate change and different functions over their life by being flexible and adaptable.
Recycled content building products	Including material with recycled content, e.g., steel, in new infrastructure.
Reuse of material and products from deconstruction	Reusing materials and products from building demolition in new infrastructure.
Roof gardens	Roof top gardens, also referred to as turf roofs, are roofs with soil and planting instead of impervious materials such as corrugated iron and concrete.
Shared use facilities	Shared use of facilities improves the utilisation of buildings and grounds by sharing this between different organisations.
Smart sensors and connected technologies	Smart sensors and connected technologies can be used to provide valuable data on building performance such as occupancy, energy and water use.
Sustainable urban drainage systems (SUDS)	SUDS, such as swales, retention ponds and porous surfaces are used to manage urban water flows.
Urban agriculture	Urban agriculture uses urban space to produce fresh vegetables and fruit.
Virtualisation	Virtualization refers to dematerialization of processes, for example, the use of smart meters avoids the need for meters to be read manually.

4.2 Appropriateness of circular economy interventions

The assessment of opportunities to implement CEIs within South African human settlements was conducted through an online survey followed by targeted stakeholder interviews and focus groups. The focus groups provided in-depth insights into the sector's readiness for adopting circular practices; identified specific areas of opportunity; and highlighted the key challenges faced by the sector. By engaging with industry experts and practitioners, the interviews captured valuable perspectives on how various circular interventions could be effectively integrated into the local sector, supporting sustainable growth and resource efficiency. The findings from these interviews contribute to a nuanced understanding of the potential for CEIs and serve as a foundation for developing targeted strategies to transform our human settlements.

4.2.1 Stakeholder engagement

Human settlement stakeholders were engaged to better understand the appropriateness of various CEIs to South African human settlements; and the potential benefits they bring to the country.

The majority of respondents (33%) were from the private sector, followed by government (22%). Participants brought a wealth of knowledge and experience to this study, with 60.7% of respondents having >10 years of experience working in the South African human settlements / building sector, followed by 21.4% of respondents with 5-10 years of sector experience. 39.3% of respondents were at a senior or executive management level, with 28.6% of respondents in a technical role. In terms of their knowledge of the circular economy, 48.0% of respondents had a “working knowledge” of the circular economy, with 36.0% having a good or excellent knowledge of the concept. In terms of actual involvement in circular economy-related projects, 45.5% of respondents had less than two years of practical experience. 31.8% of respondents indicated that they had more than 5 years of circular economy-related experience, highlighting that some circular interventions are not new within our human settlements. Areas of the circular economy that participants indicated they had experience working on, included design for disassembly, modular design, reuse of material and products from deconstruction, urban agriculture; and sustainable urban drainage systems (SUDS).

In terms of respondents’ familiarity with CEIs in human settlements, the three most familiar interventions were *virtualisation*, *roof gardens* and *composting*. Awareness of virtualisation may have been fast-tracked by the onset of the COVID-19 pandemic which required increased use of ICT and remote working. The three least familiar CEIs were found to be *loose-fit*, *long-life design*; *equipment libraries*; and *design for disassembly*.

There was consensus amongst stakeholders, that the adoption of circular practices would be beneficial for South African human settlements. The three most beneficial and appropriate circular interventions to South African human settlements included: *greywater reuse*, *localising supply chains*; and *urban agriculture* (**Figure 4**). There will have to be some reflection on how easy these are to implement and whether they can provide rapid, high-impact returns.

Meanwhile, the three least beneficial circular interventions identified were: *biobased construction materials* (there were concerns about durability, thermal properties and insects (termite damage), *composting,* and *reuse of materials and products* (**Figure 4**).

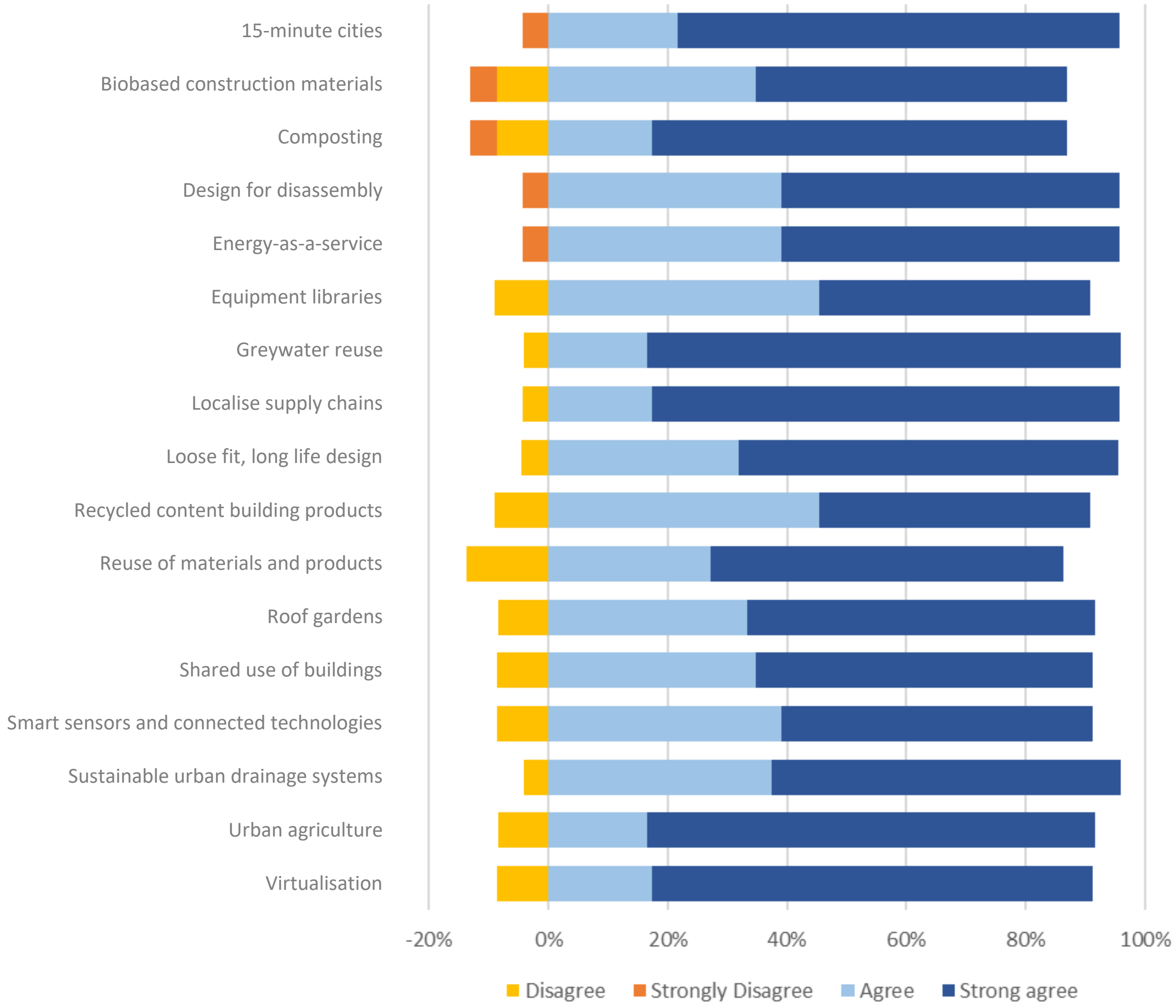

Figure 4. Extent to which circular economy interventions can benefit the South African human settlements.

4.3 Readiness to implement interventions

Many CEIs have found application in the Global North but are yet to be widely applied in developing countries that face their unique circumstances. Stakeholders were asked to rate the sectoral readiness to implement CEIs in South Africa (**Figure 5**) and the current level of implementation of the proposed CEIs in South African human settlements (**Figure 6**).

4.3.1 Stakeholder engagement

Stakeholders agreed that all identified CEIs have some level of readiness for implementation in South Africa, given current levels of adoption within our built environment.

Virtualisation, *smart sensors and connected technologies*, and *shared use of buildings* were scored by respondents as having the highest level of readiness to implement. *Urban agriculture*, including *roof gardens*, *sustainable urban drainage systems* (SUDS) and *energy-as-service* (EaaS) also scored high for readiness.

The lowest levels of readiness were noted for *equipment libraries*, *design for disassembly*, and *biobased construction materials*, despite a well-established, mature local forestry sector (**Figure 5**).

In terms of actual implementation, respondents noted that all identified CEIs had some level of implementation in South African human settlements, but not all at a scale for impact (**Figure 6**). More effective planning and implementation are needed to scale these interventions, with the government playing a stronger role in overcoming current challenges. According to respondents the three most implemented CEIs in South Africa are *virtualisation*, *localising supply chains*; and *urban agriculture*.

The three least implemented CEIs included *design for disassembly; loose fit, long-life design;* and *equipment libraries*.

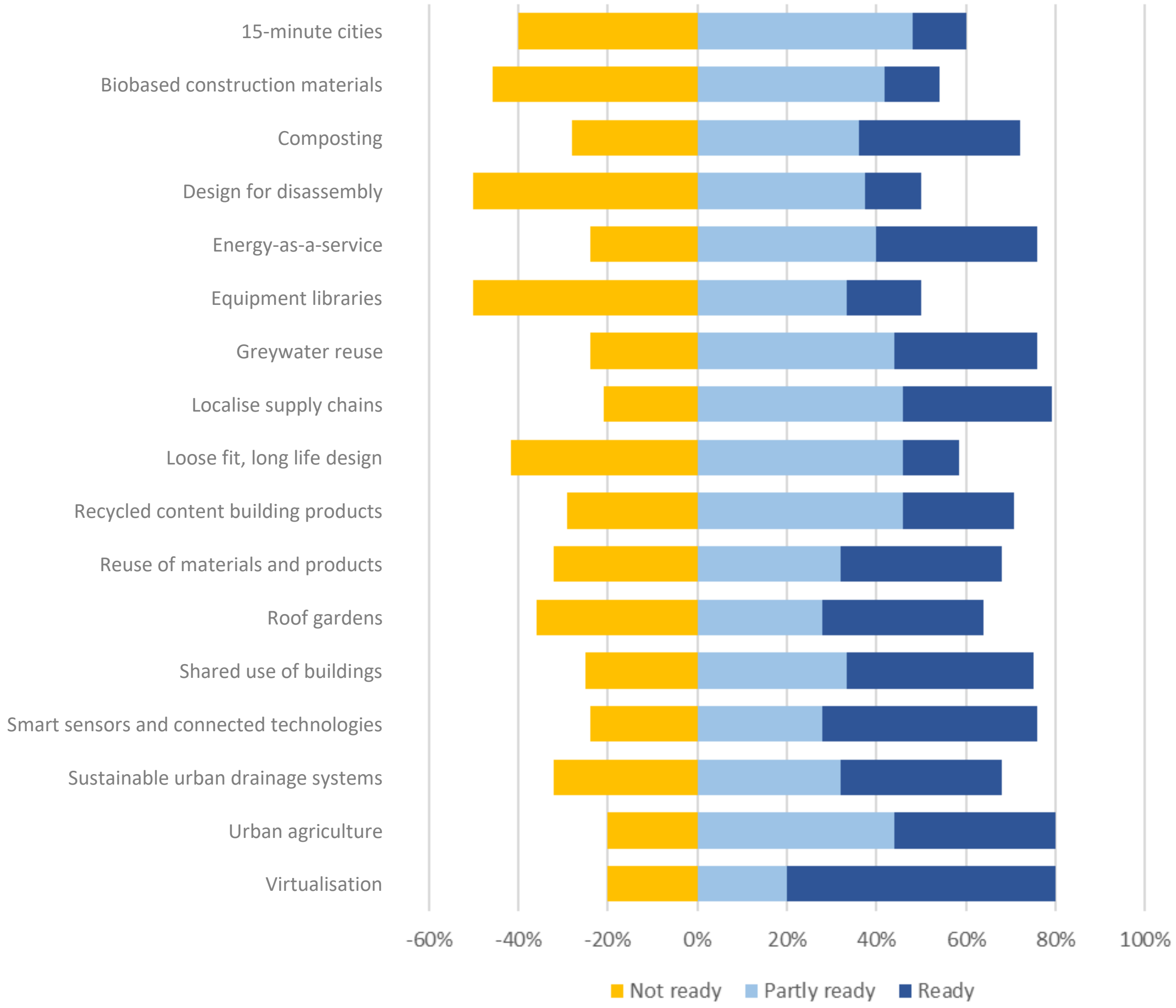

Figure 5. State of readiness to implement circular economy interventions in South African human settlements.

4.4 Opportunities for implementation and upscaling

The following opportunities for implementation and upscaling CEIs were identified.

- **Localise supply chains:** Initiatives related to localising the supply chain are likely to be successful in South Africa because of existing policies and standards, such as SATS 1286 (SABS, 2011). Familiarity with the concept of localisation means that Government and built environment professionals are able to readily support the upscaling of initiatives in this area.
- **Energy-as-a-service:** Energy-as-a-service (EaaS) is already happening in South Africa. Energy entrepreneurs with tailored funding from the banks install photovoltaic and battery systems in commercial and residential buildings and receive income from customers to cover capital and operational costs. This model is likely to develop as technologies become more available and cheaper. Future markets are likely to include affordable housing as well as the provision of other services, such as hot water (solar hot water systems) and recycled water (grey water systems). Increasing costs of municipal-supplied energy and water, coupled with reducing reliability, is likely to result in increased product-as-service (PaaS) offerings which enable households and businesses to use off-grid technologies to reduce their reliance municipal supplies.
- **Smart sensors and connected technologies:** The introduction of new smart technologies in South Africa can be rapid as there is strong technical and implementation capacity and an awareness of the benefits that can be generated. Examples are the rapid adoption of AI-enhanced closed-circuit TV (CCTV) systems in neighbourhoods to improve security. Increasing costs of electricity and water as well as the requirement to report on building performance, for instance through Energy Performance Certificates (EPCs), is likely to drive increased uptake in sensors, loggers and controls that enhance efficiencies in buildings.

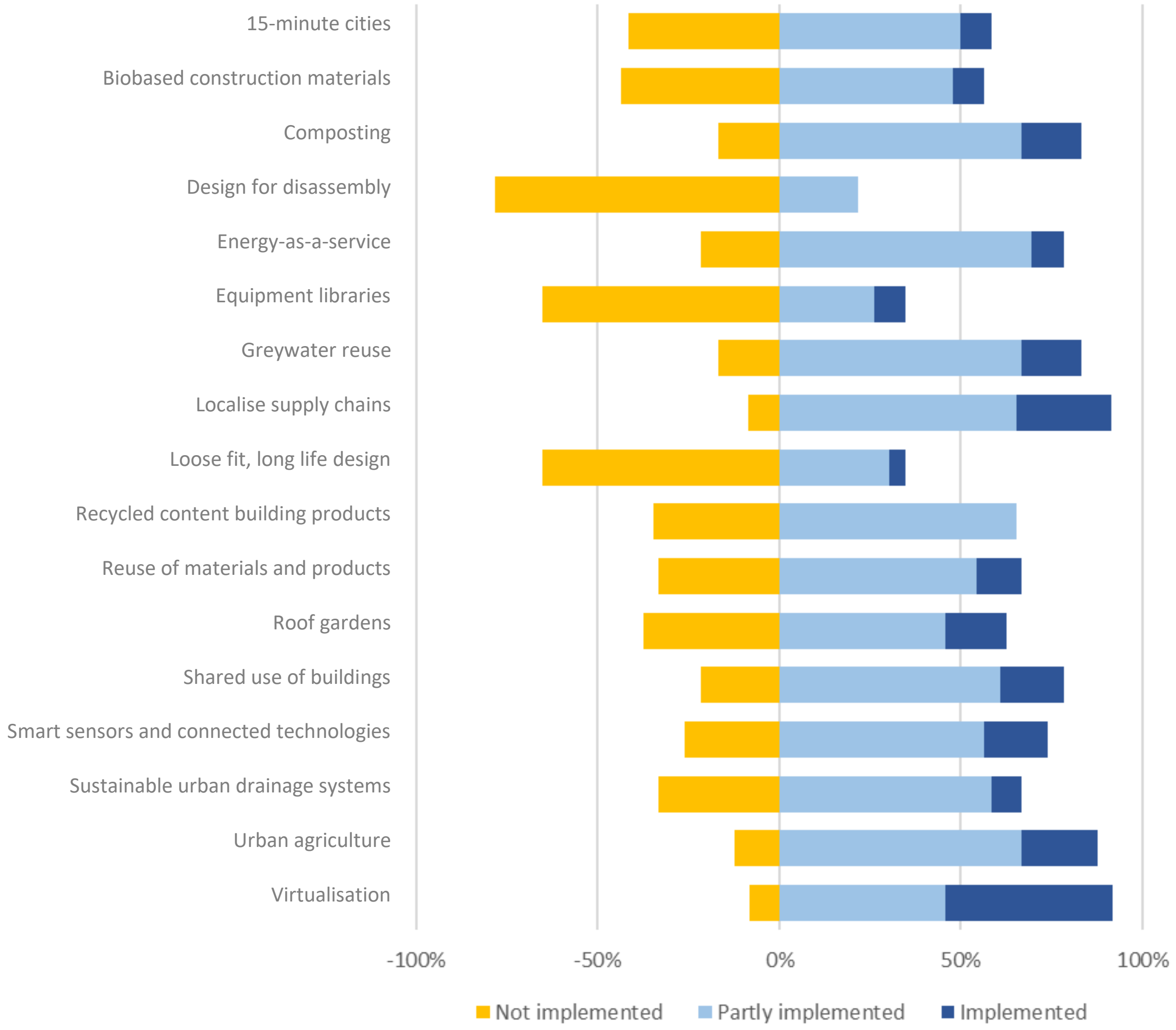

Figure 6. Level of implementation of circular interventions in South African human settlements.

- **Virtualisation:** Virtualisation refers to the dematerialization of processes. For example, online resources can be used to reduce the need for materials and facilities, such as books, libraries and laboratories, in education. As a result of the Covid-19 pandemic, there has been a greater awareness of the benefits of this approach. This can be drawn on in promoting wider use, including, for instance, increased use in health (through telemedicine) and in education (through online learning).
- **Food gardens:** The concept of food gardens was well supported by human settlement stakeholders. There is a strong awareness of the need to improve food security and the availability of land around or near houses and water means that this option could be readily implemented. Upscaling this option could be supported through increased awareness, subsidies for fencing, rainwater tanks and simple irrigation systems, and the development of local markets where fresh produce could be sold.

4.5 Challenges and obstacles to implementation

A number of challenges and obstacles to implementing CEIs were also identified by stakeholders. Actions that can be taken to address these obstacles are also described.

- **15-minute cities:** A major obstacle to developing more efficient cities and 15-minute neighbourhoods is the low-density urban fabric based on apartheid planning that exists in South Africa. In addition, change is hampered by the lack of an urban planning policy that supports more circular approaches as well as limited capacity and fragmented implementation processes. This, however, is being addressed through local government sustainability initiatives such as the green building development policies supported by C40 and the CSIR in Tshwane and Johannesburg (C40, 2021; WGBC, 2024).
- **Biobased materials:** Most buildings in South Africa are built of masonry products and both built environment professionals and the public tend to be sceptical of new and alternative materials. Lightweight biobased products may be regarded as less durable and inferior to traditional materials. If not

integrated carefully, lightweight materials can also result in poorer thermal performance of buildings relative to those constructed of high thermal mass materials. This is because the 'thermal flywheel effect' which creates comfort during the day by retaining the coolth of lower night-time temperatures is lost. For the use of biobased materials to be more widespread, perceptions about durability of the materials and their associated social status will have to be countered. Similarly, further research, including thermal modelling will be required to demonstrate how passive environmental control strategies can create comfort in lightweight building structures. Despite this, wood is a popular building material in many developed countries. In the USA, for example, 92% of new homes built in 2021 were wood framed (NAHB, 2021). In New Zealand, timber framing remains the predominant structural material in new housing, at ~ 90% of market share (BRANZ, 2020).

- **Composting and greywater systems:** There is limited understanding of composting and grey water systems amongst human settlement stakeholders and there are negative perceptions that may affect uptake. Perceptions include that onsite composting and grey water systems smell, attract pests such as rats, and require extensive maintenance. These perceptions will need to be countered through increased awareness and appropriate technologies, to promote wider adoption.
- **Equipment libraries and shared use facilities:** Feedback from human settlement stakeholders indicate that they understand the benefits of these approaches, however, they were sceptical about whether these could be successful. They indicated that low levels of trust and high crime rates in South Africa made these models difficult to implement. Examples of sharing models working in practice and effective mechanisms will need to be shared to address scepticism. In addition, the current low density of our cities and towns, means that residents would often need to travel some distance to access such shared facilities, reducing the convenience of the initiative and increasing costs.
- **Embedding circularity in new designs**: Stakeholder interaction indicated limited understanding about how more circular buildings can be designed and built. There was little awareness of concepts such as *design for disassembly*, *loose-fit, long-life design*, *modular design* and *recycled content building products*. Until there is better awareness about these concepts, and this is integrated into the training of building designers, such as architects, it is unlikely these will be widely adopted.

While there is some level of uptake of CEIs in South African human settlements, there is clearly much to be done in terms of education and awareness. This includes building circularity into training programmes and qualifications for the construction industry.

5 Quantifying systemic impacts

5.1 Introduction

The previous chapters provided insight into South Africa's current human settlement development paths. To investigate alternative development paths, seventeen circular economy interventions were identified. Stakeholder engagement was used to assess these in terms of their *appropriateness* to the local context, current *levels of implementation*, and the sector's *readiness to adopt* them. Qualitative feedback from stakeholders indicates that there is consensus that adopting circular economy interventions will provide benefits to South African human settlements.

To provide a more quantitative, objective view of the potential impacts (positive and negative) of adopting these circular economy initiatives, modelling exercises were conducted of selected circular economy interventions (CEIs). The following five CEIs were selected for modelling based on stakeholder responses and data availability:

- 15-minute cities
- Urban agriculture
- Composting
- Greywater and rainwater systems
- Reuse of material from deconstruction.

While the transition to a more circular economy requires appropriate policy at the national level, CEIs are typically implemented at the city or local government level. As such, these five CEIs have been modelled at city level rather than a national level in order to provide a detailed and practical understanding of their potential impacts.

The City of Johannesburg (CoJ) was selected as the basis for modelling as the team could use existing data from the CoJ Urban Growth Model, including current and projected data on households, jobs, and buildings (CSIR, 2024).

For the modelling exercises, households were divided into three income groups, with two housing types per group (Table 4). These groups were created by the CSIR based on StatsSA and other resources. The full models for each of the CEIs and detailed results are provided in Annexure 1. The key results are presented in this section.

Table 4. Income and housing type breakdown.

Household income	Annual household income (R/year)	Housing type
Low	R0 – R82,500	Informal
		RDP
Middle	R82,501 – R353,500	Freestanding
		High-rise
High	> R353,500	Freestanding
		High-rise

5.2 15-minute city

The 15-minute city is an urban planning concept in which activities carried out on a daily basis such as work, shopping, education, healthcare and leisure, can be reached by a 15-minute walk. This section aims to determine to what extent the CoJ currently meets the requirements of the 15-minute city and explores the extent to which the city can draw on this concept in implementing the Spatial Development Framework (SDF) (City of Joburg, 2021).

To quantify the impact of a 15-minute city, two simulations were carried out using the CSIR's UrbanSim platform (CSIR, 2024). One simulation determined the location of households if the current urban trends in CoJ continued. The other scenario determines household locations if the SDF (incorporating the 15-minute city concept) is successfully implemented. Data were obtained for schools, secondary schools, health facilities and commercial buildings using CSIR's social facilities toolkit. The analysis used a walking speed of 5 km/h (Browning, 2006).

The results show that the CoJ's current SDF supports the 15-minute city and, if followed, will enable about 100,000 additional households to access primary schools, secondary schools, health facilities and commercial buildings within a 15-minute walk by 2042 compared to the current trend. This number increases to about 300,000 households if a 30-minute walk criteria is used.

This result reflects impacts generated by an SDF that supports densification but is not specifically aimed at the 15-minute city. If the 15-minute city CEI was more central to the SDF, a much greater impact could be expected (more households with accessibility and reduced transport impacts). Large changes can also be brought about by building additional facilities in key areas with low accessibility.

5.3 Urban agriculture

Urban agriculture involves growing, processing, and distributing food within urban areas and was modelled for the City of Johannesburg (CoJ). Available land data and crop yield estimates were used to determine the potential amount of food that could be produced. Crop yields were categorized into conservative, likely, and target output values for different crops, such as beetroot, carrot, cauliflower, and tomatoes.

The study identified about 90,000 hectares of open land in the CoJ, with varying types of land use. These included areas like grasslands, urban recreational fields, and backyards. It was assumed that 10% of green spaces and 5% of backyards could be used for urban agriculture. Using crop yield data and adjusting for increased yields in small-scale farming, the study estimated the potential output of urban agriculture.

The results of the modelling show that approximately 6,100ha of land could be used for urban agriculture. If this was intensively farmed, a target of 320,000 t of fresh produce could be aimed for. Using a figure of 400g of vegetables per person, this target would provide about 20% of vegetable requirements for an urban population of 10.3 million people (3.4 million households) that are projected to be in the city by 2042. While this figure is lower than other cities, it will appreciably contribute to improved food security and reduce the associated ecological footprint. However, this CEI will have to be complimented with an urban densification programme, such as in the 15-minute city CEI, to reduce conflicting land-use demands.

5.4 Composting

Composting uses organic waste to create valuable fertiliser for plants. This avoids the carbon emissions and loss of resources associated with disposing this waste to landfill. Composting can be undertaken on-site by households or at centralised community facilities. The potential impact of composting was modelled based on waste data from the 2024 City of Johannesburg (CoJ) urban growth scenario. Key findings from the modelling are outlined below.

Households in CoJ are estimated to generate 2,273 kt of waste, with 1,101 kt being compostable. With a 50% adoption rate for composting, 24% of the total waste (551 kt) can be diverted from landfills.

Decentralised (at-home) composting can produce 186.50 kt of compost. Centralised composting can increase production to 241.56 kt due to more efficient methods. Centralised composting could generate significant employment. Neighbourhood-scale sites could create up to 5,050 jobs, while medium and large city-scale facilities could create 1,650 and 560 jobs, respectively. Composting could reduce carbon emissions by between 165.17 and 330.33 kt per year, depending on the composting method used.

Thus, composting offers a substantial opportunity to reduce landfill waste, create jobs, and mitigate carbon emissions. The modelling indicates that with a 50% adoption rate, up to 550 kt of waste could be diverted annually, creating significant environmental and economic benefits. Local composting schemes, especially decentralised ones, could further reduce carbon emissions by minimizing transportation-related impacts.

This innovative CEI model could make a substantial contribution by reducing organic waste streams of urban areas by half and at the same time create valuable local economic opportunities.

5.5 Greywater and rainwater

5.5.1 Greywater

Greywater recycling involves reusing domestic wastewater, typically from showers, basins, bathtubs, and washing machines to flush toilets and for irrigation. Benefits of greywater systems include:

- Reduced pressure on stretched municipal water supplies.
- Reduced pressure on municipal wastewater and sanitation systems.
- Lower costs for households as they use less municipal-treated potable water.

Greywater can be used to flush toilets and irrigation. Greywater must be used within 24 hours to prevent bacterial growth and odours.

Rainwater harvesting can also be used to reduce demand on municipal water supplies. While rainwater is cleaner and can be stored longer, its availability is seasonal, unlike the consistent supply of greywater. Rainwater can be used for a wider range of uses including drinking (with filtration if required).

Typically, 60-70% of wastewater in households is classified as grey water and can be recycled (Friedler, 2004 Oteng-Peprah *et al.* 2018) Other wastewater, from kitchens and toilets, is classified as black water and cannot be recycled in greywater systems.

The formula used to estimate greywater production is:

$$\text{Greywater (litres)} = \text{Number of persons} \times \text{Number of households} \times \text{Water usage} \times 0.6$$

Analysis showed that the amount of greywater depends on income levels, household types, and water usage patterns. The following factors and risks should be considered in modelling greywater systems.

- Greywater collection efficiency depends on the sophistication of the system.
- Improperly managed greywater can contaminate groundwater.
- Limitations in storage and quality control must be considered for safe reuse.

Estimates indicate that greywater systems, by recycling water, can reduce potable water consumption in households by 27-38% (Yu, *et al.,* 2015).

Thus, greywater recycling offers substantial potential to reduce potable water consumption and save associated costs. However, implementation requires careful management, appropriate systems, and public awareness to mitigate health and environmental risks.

5.5.2 Rainwater

Rainwater harvesting offers an alternative to greywater for reducing the consumption of municipal-supplied potable water. Rainwater can be used for showering, dishwashing, and toilet flushing. It is important to note that rainwater availability is seasonal and therefore the supply is less consistent compared to greywater.

The potential rainwater harvest is calculated using:

$$\text{Potential rainwater captured (litres/year)} = \text{Roof area (m}^2\text{)} \times \text{Rainfall (mm/year)} \times \text{Runoff factor}$$

Rainwater harvesting is limited by the size of the collection area and storage tanks. Modelling shows that rainwater harvesting within the City of Johannesburg could yield approximately 46.53 billion litres per year, with the largest amounts harvested in RDP and informal housing. This could potentially reduce potable water demand by 25%, as rainwater could be used for applications like toilet flushing and irrigation.

Greywater and rainwater harvesting systems have the potential to provide for most residential uses. This could substantially reduce the very high pressure being experienced by current municipal water systems and trans-catchment water supply systems.

5.6 Reuse of material from deconstruction

Construction and demolition waste constitutes a significant waste stream in South Africa and makes up 8.1% of the total waste (Department of Environmental Affairs, 2018). One strategy to reduce this waste is the careful deconstruction of buildings and reuse of materials and components instead of demolition and directing materials to landfill (Gibberd, 2024).

Urban growth data from the SDF scenario (2024–2042) indicates that there will be a need to remove existing freestanding houses to densify areas. This process provides an opportunity to deconstruct these buildings and reuse materials and components. Modelling this option indicates that 754 houses, each potentially generating 675 t of waste would need to be removed per year. The waste composition of these houses is primarily concrete and masonry (69%), asphalt (16.3%), metal (2.1%), and plastic (1.1%). The modelling assumes that 50% of these houses are deconstructed and materials and components reused and 50% are demolished. For this scenario, the modelling projects the following impacts over 18 years (2024–2042):

- A total of 508,950 t of materials and components will be generated from the deconstruction and demolition of these houses for densification.
- If 50% of these houses are deconstructed, 225,210 t (44%) of the materials and components can be salvaged and reused, thereby diverting this waste from landfills.

- Job creation from deconstruction and reuse ranges from 4 to 16 jobs annually, with the potential for more jobs at existing recycling facilities for materials like metal and plastic.

Thus, the modelling shows that deconstruction and building material and component reuse can significantly reduce landfill waste, with substantial environmental and economic benefits, including small enterprises and job creation.

The modelling was done for a localised small-scale example and if this CEI is integrated effectively within the sector, much greater impacts could be created.

5.7 Circular economy at a household level

To demonstrate the integrated application of the circular economy on a household level, 3 case studies were conducted. Figure 7 shows how rainwater, greywater, composting and urban agriculture could work together to provide efficient circular systems at the household level.

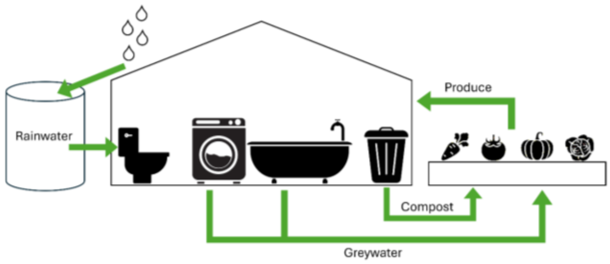

Figure 7. Circular processes at a household level.

For Case Study A (low-income house), harvested rainwater catered for toilet flushing for part of the year, after which municipal water was required. In this example, harvesting rainwater produced 24,848 litres of water. If this was used to flush the toilets, a 39% saving in water used for toilet flushing is possible. The house also produces 63,247 litres of greywater per year. If treated and used for irrigation, the household could produce between 122 kg and 256 kg of vegetables per year. This is between 10.19 kg and 21.32 kg of fresh produce per month. The household would also produce 800kg of compostable waste and this could be used to generate 241kg of compost per year which could be used to fertilize local urban agriculture.

For Case Study B (middle-income house), rainwater can be used for toilet flushing for part of the year. In this case, 44,292 litres of rainwater can be captured and used to flush toilets. This reduces the need to use municipally supplied water for flushing toilets by 69%. The house generates 119,004 litres of greywater per year. If this is used for agriculture the household could produce between 230.15kg and 481.64kg of produce per year. This is equivalent to between 19.18kg and 40.14kg of fresh produce per month. This household produces 1.24 t of compostable waste that can generate 430kg of compost in a year which can then be used to fertilize local urban agriculture.

For Case Study C (high-income house), rainwater can be used for a substantial portion of the water required for toilet flushing. Here, 51,256 litres of rainwater can be captured, and if used to flush the toilets, reduces the requirement for municipal-supplied water used for this purpose by 80%. The house generates 183,916 litres of greywater per year. If this is used for urban agriculture, between 356kg and 744 kg of fresh produce per year could be grown. This is the equivalent of between 29.64kg and 62.03kg per month. The household produces 1.90 t of compostable waste and 759kg of compost per year that can then be used to fertilize urban agriculture.

Table 5. Circular Economy Intervention (CEI) Impacts per household income.

Circular Economy Intervention (CEI) Impacts	Household		
	Low-income	Middle-income	High-income
Rainwater harvested used (ℓ/a)	24,848	44,292	51,256
Flush water savings (%)	39%	69%	80%
Greywater generation (ℓ/a)	63,247	119,004	183,916
Max. produce (kg/a)	256	482	744
Compostable waste (kg)	800	1,240	1,898
Compost (kg)	241	434	759

Table 5 shows the impacts of the different CEIs modelled in the report. These represent very large potential benefits at both a municipal and household level. Benefits for households include reduced costs for water and waste and potential savings associated with local urban agriculture.

5.8 Summary of benefits

This chapter has quantified the benefits from five types of circular economy interventions and from three case studies which combine some of the CEIs. It indicates that implementing the CEIs could provide 20% of household vegetable requirements, cater for a large proportion of household water needs and create over 5,000 jobs.

However, studies were only conducted for the City of Johannesburg and the results will be different in other areas of South Africa. In addition, the modelling makes assumptions, such as the simultaneous and coordinated implementation of CEIs. If this does not happen, synergies envisaged will not be achieved.

It is therefore important that implementation plans designed to implement CEIs understand linkages and upstream and downstream impacts to ensure there is coordination and integration of initiatives that maximise the long-term sustainability benefits.

6 Conclusions and recommendations

This study aimed to explore the potential of the circular economy for human settlements in South Africa. It reviews current human settlement development pathways and draws on emerging concepts from the circular economy to identify and evaluate more sustainable alternatives. The study identifies opportunities to apply circular economy interventions (CEIs) and finds that some can generate substantial benefits.

Engagement with private and public sector stakeholders, showed a high **level of familiarity** with the identified CEIs. The three most familiar interventions were *virtualisation*, *roof gardens* and *composting*. The three least familiar CEIs were found to be *loose-fit*, *long-life design*; *equipment libraries*; and *design for disassembly*.

There was consensus amongst stakeholders, that the adoption of circular practices would be beneficial for South African human settlements. The three most **beneficial and appropriate** circular interventions to South African human settlements included: *greywater reuse; localising supply chains*; and *urban agriculture*. The three least beneficial circular interventions were seen to be *biobased construction materials*, *composting,* and *reuse of materials and products*.

In terms of **readiness to implement**, *virtualisation; smart sensors and connected technologies;* and *shared use of buildings* were scored by respondents as having the highest levels of readiness. The lowest levels of readiness were noted for *equipment libraries*, *design for disassembly*, and *biobased construction materials*.

In terms of **actual implementation**, respondents noted that all identified CEIs had some level of implementation in South African human settlements, but not all at a scale for impact. According to respondents the three most implemented CEIs in South Africa are *virtualisation; localising supply chains*; and *urban agriculture*. The three least implemented CEIs included *design for disassembly; loose fit, long-life design;* and *equipment libraries*.

For the purposes of this report, the CEIs and their potential impacts have been organised into four themes and summarised below.

6.1 Localise, diversify and enhance local access and opportunities

Examples of '*localisation, diversification, enhanced local access and opportunity*' include:

- 15-minute neighbourhoods
- Localise supply chains
- Virtualisation

The impact of a circular economy development path based on localization, diversification and enhancing local access and opportunities was explored in the study. 15-minute design principles aim to increase local access to work opportunities, education and health services and reduce transport impacts such as accidents, pollution and carbon emissions. Localising the supply chain promotes diversity and capacity within the local economy and reduces transportation impacts. A virtualisation approach reduces equipment, facilities and transport requirements and promotes increased and affordable access to government, education and health services, amongst others.

An example of the impact that can be achieved through adopting circular models is the improvement in access to facilities that can be achieved through urban development policies based on 15-minute cities. Modelling in the study estimates that an additional 100,000 households within the City of Johannesburg, would be able to access primary schools, secondary schools, health facilities and commercial buildings within a 15-minute walk by 2042, compared to the current development trend.

Recommendations

- Urban development policy and plans such as Integrated Development Plans (IDPs) and Spatial Development Frameworks (SDFs) should draw on the principles of the 15-minute city to improve spatial efficiency, access to facilities and quality of life.
- Local content policy should be developed that has a strong focus on local suppliers (i.e. within 50km) as well as suppliers from within the country. Simple procedures should be developed to enable policies to be readily applied. Local content policies should make it clear that while preference may be given to local suppliers, this does not mean that increased costs will be incurred as a result.
- Strategies for services, such as education, health, and government services, should consider drawing on the concept of virtualization to improve access and affordability and reduce transport requirements. Reviews of successful examples of e-government, knowledge economy workers, online learning and telemedicine should be undertaken, and selected models piloted. Where these are successful, models should be upscaled.

6.2 Regenerate productive ecosystems and services

Examples of '*regenerating productive ecosystems and services*' include:

- Biobased construction materials
- Onsite composting
- Roof gardens
- Sustainable urban drainage systems (SUDS)
- Urban agriculture

Findings from the study indicate that a regenerative circular economy development path has substantial benefits compared to conventional approaches. Sustainable urban drainage systems (SUDs) reduce stormwater infrastructure requirements, and by retaining moisture, enhance human comfort and plant growth. Composting reduces organic waste directed to landfill (and associated greenhouse gas emissions) and contributes to soil fertility. Urban agriculture improves food security and health by providing affordable fresh vegetables and fruit. Specifying biobased building products can be used to stimulate agriculture, including forestry, with associated benefits such as carbon sequestration and employment.

Examples of the benefits of a regenerative approach were identified through the modelling of food gardens. This showed that if food gardens were integrated into the City of Johannesburg (CoJ), 320,000 t of fresh produce per year could be targeted. Using a consumption figure of 400g of vegetables per person per day, this option would provide about 20% of the vegetable requirements for the projected urban population of CoJ of 10.3 million people (3.4 million households) in 2042.

Modelling the composting of organic waste within human settlements substantially reduces waste directed to landfill. For the City of Johannesburg, it indicates that 551 kt (about 24%) of all waste could be diverted. At the same time, it suggests that 5,050 full-time jobs could be created and carbon emissions of 165 – 330 kt avoided.

Recommendations

- Support for the development of biobased building products made from materials such as timber and hemp should be developed. Research and testing for new products should be undertaken to confirm physical properties and compliance with standards and regulations. Increased awareness of biobased building products should be created through guides and Continuous Professional Development (CPD), university and open courses.
- Non-government organisations (NGOs), community organisations, cooperatives and local entrepreneurs wishing to develop food gardens and initiate local greening initiatives such as neighbourhood composting schemes should be encouraged and supported by local government.
- Urban development policy and plans including IDPs, SDFs and building bylaws should include sustainable urban drainage systems, urban agriculture, and composting to regenerate natural systems, reduce stormwater infrastructure requirements and enhance food security.
- Technical guidance on sustainable urban drainage (SUDs), urban agriculture, roof gardens and composting systems should be developed and made readily accessible. Technical courses covering the design and maintenance of these systems should also be provided.

6.3 Harness partnerships and technologies to improve efficiency and access to services

Examples of '*harnessing partnerships and technologies to improve efficiency and access to services*' include:

- Smart sensors and connected technologies
- Energy-as-a-service
- Greywater systems
- Equipment libraries
- Shared use of facilities

The study indicates that many benefits can be secured from partnerships and the application of smart technologies. Smart sensors and controls improve the ability to manage infrastructure and buildings and increase efficiency. New business models such as product-as-service (PaaS) enable entrepreneurs to develop renewable energy, water, hot water and greywater systems and supply affordable and reliable services to building owners. Grey water systems recycle lightly soiled water, from for instance, showers. This can be used for irrigation and flushing toilets, conserving valuable potable water. This model can also be scaled up in partnerships between municipalities, communities and enterprises to provide services at a neighbourhood scale using micro-grid renewable energy and other systems.

Modelling grey water options for different households in the City of Johannesburg indicates that 307.7 ML of water per day could be recycled to replace municipal-supplied water for applications such as flushing toilets. This would enable large reductions in potable water consumption.

Rainwater harvesting systems capture rainfall from collection surfaces such as roofs and enable this to be used within buildings. Modelling rainwater systems within the City of Johannesburg indicates that 46,531 ML could be harvested per year. This harvested water could be used to flush toilets and for irrigation, substantially reducing requirements for potable water to be supplied by municipalities.

Equipment libraries provide affordable access to tools, such as high-cost construction equipment. This reduces the barriers for small contractors wishing to undertake larger and more complex projects. It also avoids waste as fewer items of equipment are used more intensively. Similarly, the sharing of facilities by two or more organisations increases efficiency and reduces operational costs by splitting these between multiple users.

Recommendations

- Guidance should be developed on how smart technologies can improve the operation of infrastructure and buildings. This could include guidance on how water wastage can be avoided (through leak avoidance) and how energy efficiency and renewable energy generation can be enhanced

(through energy management).
- Guidance on product-as-a-service (PaaS) models should be developed. This should draw on learning from existing applications in South Africa, for instance, for energy, and set out best practice approaches. Where necessary, government policy and regulations should be developed or modified to enable increased uptake of these models.
- Increased awareness about greywater systems should be developed. In addition, support for the design and operation of these systems should be created. This could include technical short courses for building designers and contractors.
- Human settlement policy and plans should include partnerships that draw on Municipal Service Partnership (MSP) models to enable communities and entrepreneurs to develop and operate bulk service infrastructure and provide affordable services in areas such as energy, water and waste.
- The concept of equipment libraries should be piloted and evaluated as a means of increasing affordable access to productive resources.
- The development of government service delivery strategies should draw on the concept of shared facilities, such as multi-purpose community centres (MPCC), to improve the affordability and efficiency of provision.
- Guidance should be developed to show how facilities can be successfully shared between organisations to reduce costs and enhance access to services. Learning from existing successful models such as the sharing of education infrastructure between schools and community colleges could be drawn on in best practice guidelines.

6.4 Embed circularity in new designs

Examples of strategies that can be used to '*embed circularity in new designs*' include:

- Design for disassembly
- Loose fit, long-life design
- Modular design
- Recycled content building products
- Reuse of materials and products from deconstruction

The impact of circular economy approaches is greatest when this is integrated into the early conceptualisation of infrastructure and buildings. The study confirmed the beneficial impact of adopting more circular approaches in the design and construction of projects but also finds that knowledge and adoption in this area are limited. Design approaches such as *design for disassembly*, *modular design*, *loose fit, long-life design*, the *reuse of material and products from deconstruction*, and *recycled content building products* are still new globally and will take some time to be adopted in South Africa.

Modelling the *reuse of materials and products generated during the deconstruction* of buildings options in the City of Johannesburg indicates that for a 50% adoption rate, 225.21 kt of building materials and components could be salvaged and reused. This represents about a 44% reduction in the amount of construction waste that would otherwise be directed to landfill or be fly tipped.

Recommendations

- Technical guidance on integrating circular approaches into the design of buildings and infrastructure should be developed. This guidance should be drawn on in university and Continuous Professional Development (CPD) curricula of built environment professionals.
- Local government strategies, policies and incentives should be used to encourage deconstruction and reuse of building materials and components. This could include penalties and incentives, the establishment of waste clubs and transfer depots that enable the deconstruction and reuse of building materials and components.
- Extended Producer Responsibility (EPR) policy should be developed and applied to reduce resource use and waste in the construction industry. This is increasingly being used to reduce construction waste in building materials such as glass, insulation and plasterboard in Europe (Graaf *et al*., 2024).

The study finds that circular options have the potential to make substantial contributions to the development of more sustainable human settlements. It is hoped this document can be drawn on in identifying and developing circular human settlement systems that reduce inefficiencies and waste, create new small enterprises and jobs, and improve the quality of life for all South Africans.

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Definitions

Adaptability: Is the ability of a structure to change and meet the needs of its occupants and surroundings over time.

Built environment: Human-made surroundings, such as buildings and engineering infrastructure.

Circular economy: This entails keeping materials and products in circulation for as long as possible through practices such as reuse of products, sharing of underused assets, repairing, recycling and remanufacturing (Schroder 2020).

Circular human settlement: This aims at decoupling urban development from resource consumption and at improving the quality of life for all.

Construction and demolition waste: Arises from construction and demolition (or deconstruction) activities including smaller do-it-yourself projects within private households. Wastes may include concrete, bricks, tiles, ceramics, wood, glass, plastic, bituminous mixtures, coal tar, metals, insulation and gypsum among other materials. Some wastes can be broken down into their constituent materials (downcycled) while other wastes can be recovered as whole units comprising a mix of materials, such as fixtures and fitments with historical or architectural value.

Composting: Aerobic decomposition of bio-waste.

Downcycling: The opposite of upcycling; the transformation of products and materials into lower quality and/or lower value products and materials.

Equipment library: Allows contractors and households to access equipment, such as power tools, for short periods at affordable rates. This increases access to specialist equipment, reduces waste and supports social cohesion and learning.

Flexibility: Is the ability to adapt a building to change without making significant structural changes.

Human settlement: This comprises the built environment with the natural environment (such as parks), amenities, services and people.

Linear economy: A traditional economic model that involves extracting raw materials, manufacturing products, and then discarding them as waste. It's also known as the "take, make, waste" model.

Longevity: Tailored to well-defined, long-term needs while being durable and resilient or able to cope with change with little modification/no replacement of parts due to its ‘loose fit’, generous proportions and readiness for alternative technologies, different ways of living or working and a changing climate.

Recover: Elements and materials reclaimed for reuse as they are or converted into new elements and materials and objects for use on the site or on another site nearby.

Recoverability: Designed to be deconstructed and reused or recycled on a part-by-part basis due to neither modules nor a kit of parts being desirable, feasible or viable and/or a limited future market as a result of unusual parts, dimensions or specifications.

Refurbish: Redeveloped for similar needs and uses but meeting or exceeding current regulations and standards through restoring, refinishing and futureproofing while minimising changes and avoiding replacement of any parts.

Recycle: The conversion of waste into new materials and products by remanufacturing in ways that reduce demand for extracting raw materials from the natural environment.

Reduce: The design, manufacture and use of products that use materials and other resources efficiently and effectively with consideration of waste throughout the entire life cycle including their suitability for reuse or recycling (with minimal reprocessing or remanufacturing).

Remanufacturing: To make a new or different product. Remanufacturing is more closely associated with recycling than reuse.

Reusability: Designed to be redeployed as modules or reused as a kit of parts on one or more different sites while minimising any servicing and maximising the size of the future market by using high-demand, standard dimensions and specifications.

Reuse: The use of a product in its original form with minimal reprocessing, that was originally destined for waste or recycling. Reuse depends on products and materials being recovered because recovery and reuse was designed in, or people looking for what can be reused.

Standard: A document, established by consensus and approved by a recognized body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context. NOTE Standards should be based on the consolidated results of science, technology and experience, and aimed at the promotion of optimum community benefits [ISO/IEC 2004].

Upcycling: To transform products and materials into higher quality and/or higher value products and materials.

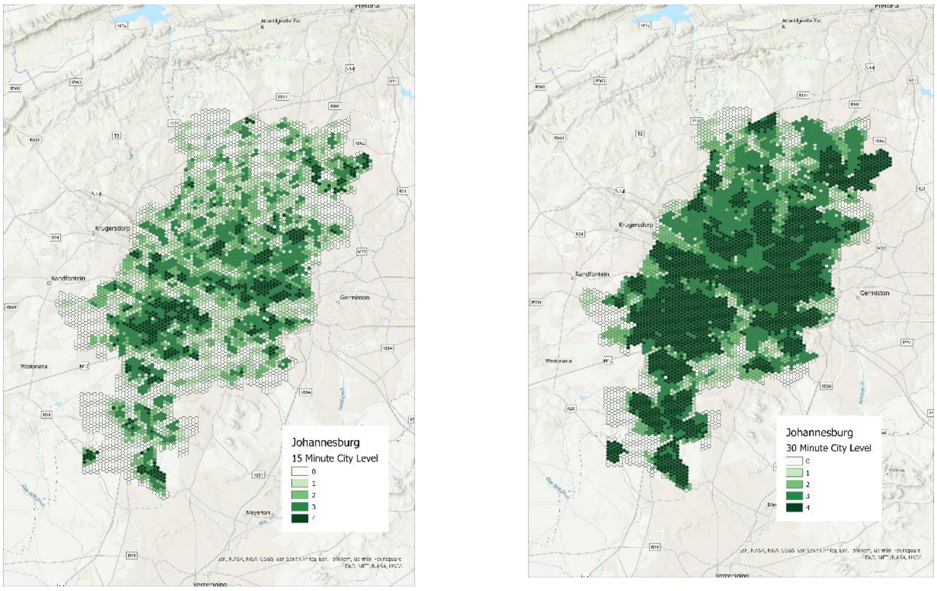
Annexure 1
Detailed modelling of circular interventions

This section provides the detailed modelling of the circular economy interventions as stated in Chapter 5 of the document. Several circular economy interventions have been identified for urban settlements. The modelling team selected a few to assess their impact, focusing on composting, greywater systems, urban agriculture, 15-minute cities, and the deconstruction and recycling of houses. The City of Johannesburg (CoJ) was chosen as the case study due to the existing urban growth model that provides access to current and projected data such as households, jobs, and buildings. For the modelling exercises, households were divided into three income groups, with two housing types for each group (Table 4).

7.1 15-minute city

The 15-minute city is an urban planning concept in which most daily necessities and services, such as work, shopping, education, healthcare and leisure, can be easily reached by a 15-minute walk or ride (bike, public transit).

This section aims to determine to what extent CoJ meets the requirements of the 15-minute city and to what extent the city can be aligned with the requirements by implementing the Spatial Development Framework (City of Johannesburg, 2021). To do this, CoJ was subdivided into hexagonal analysis units as shown in Figure 8. Data were obtained for four types of points of interest. These points of interest include primary schools, secondary schools, health facilities and commercial buildings. The primary school, secondary school and health care facilities data was provided by CoJ. The commercial building points were obtained from GeoTerraImage's "Building Based Land Use" database (GeoTerraImage, 2024).



a.) 15-minute access

b.) 30-minute access

Figure 8. Access level to primary schools, secondary schools, health facilities and commercial buildings.

Once the data had been obtained, the CSIR's social facilities toolkit was used to determine the access of analysis units (hexagons) to the various types of points of interest (CSIR, 2024). The social facilities toolkit allocated analysis units to their nearest facilities using distances based on the road network. The toolkit makes use of a maximum cut off distance after which no allocations will be made. Using an average walking speed of 5 km/h the cut-off distance for a 15-minute walking distance is 1.25 km, and 2.5 km for a 30-minute walking distance (Browning, 2006). The access level is then defined by the number of points of interest types reachable by the analysis unit for the given distance. For example, if an analysis unit only has access to primary and secondary schools, but not health facilities and commercial buildings then the 15-minute city level for this analysis unit is two, since it has access to two out of the four specified points of interest. If the analysis unit has access to all the facility types, the 15-minute city level for the analysis unit is four.

The results of this investigation are shown in Figure 8. Figure 8 indicates most of the land area in CoJ does not comply with the 15-minute city criteria. Only 9.3% of the analysis units have access to all four points of interest types. The figure also shows that the accessibility coverage for a 30-minute walkable distance is much better (as would be expected). When using a 30-minute walkable distance much of CoJ (42% of the analysis units) has access to primary schools, secondary schools, health facilities and commercial buildings. Government can alter the spatial characteristics of a city by implementing policies that can densify specific areas and thereby increasing access to services.

To quantify to what extent the SDF would have an impact on the 15-minute city, two simulation runs were done using the CSIR UrbanSim platform (CSIR, 2024). One simulation determines the location of household if the current urban trends in CoJ continue. The other simulation determines the household locations if the SDF is successfully implemented. The results of these simulations are translated from the UrbanSim analysis units to the hexagons used in this analysis by using the proportion overlap between the units. The results of this analysis are given in Table 6. The levels in the table, refer to the levels of access as described in the previous paragraphs.

Table 6. The total number of households by access level for a case study in CoJ.

Level	15 Minutes			30 Minutes		
	Trend 2042	SDF 2042	% Change	Trend 2042	SDF 2042	% Change
0	752,774	486,213	-35.4	264,112	143,117	-45.8
1	751,478	669,113	-11.0	251,170	143,030	-43.1
2	561,577	618,430	10.1	287,331	215,782	-24.9
3	746,765	938,982	25.7	652,563	653,227	0.1
4	593,585	693,442	16.8	1,951,003	2,251,023	15.4

The table shows the number of households with certain access levels for both the SDF and trend scenarios. As can be seen in the table, there is a noticeable improvement in the number of households with level four access in the SDF scenario. The number of households with access to all four points of interest increases by 17% for the 15-minute access distance and is improved by 15% for the 30-minute access distance. This equates to 99,857 households for the 15-minute access distance and 300,020 households for the 30-minute access distance.

The results show that CoJ's current SDF supports the 15-minute city and, if followed, is estimated to enable about 100,000 additional households with access to primary schools, secondary schools, health facilities and commercial buildings within a 15-minute walks by 2042 compared to the current trend. This number increases to about 300,000 households if a 30-minute walk criteria is used.

7.2 Urban agriculture

Urban agriculture refers to the practice of cultivating, processing, and distributing food within urban areas. This case study aims to determine the amount of food that can be cultivated within CoJ. This was done by determining the amount of available land in the city and multiplying this number with crop yields to reach the final number of t produced.

Table 7 provides the expected crop yields for a given area in commercial farming operations (KZN Agriculture & Rural Development, 2024). The adjusted output is the number of t of produce per hectare that can be produced for a given crop. The mixed output provides the number of t of crops that can be produced for a given hectare of land when the hectare is divided to produce a variety of different crops. The percentage land used indicated how much of the hectare is allocated to each crop type.

Table 7. Expected crop yields for a given area in commercial farming operations (KZN Agriculture & Rural Development, 2024)

Crop	% Land use	Adjusted Output (t/year)			Mixed output (t/year)		
		Conservative	Likely	Target	Conservative	Likely	Target
Beetroot	10	14	18	25	1.4	1.8	2.5
Butternut	10	12	16.5	27.5	1.2	1.65	2.75
Carrot	5	20	30	40	2	3	4
Cauliflower	5	7.5	11	17.5	0.75	1.1	1.75
Cucumber	10	12	16.5	27.5	1.2	1.65	2.75
Lettuce	10	13.5	22.5	35	1.35	2.25	3.5
Onion	10	17.5	27.5	40	1.75	2.75	4
Potato	10	10	17	28	1	1.7	2.8
Pumpkin	10	13.5	19	30	1.35	1.9	3
Sweet potato	10	17.5	27.5	40	1.75	2.75	4
Tomato	10	30	47.5	70	3	4.75	7
Total	100				**15.38**	**23.25**	**35.18**

Table 8. Expected crop outputs generated from available open land in CoJ.

Land Class	Total Land (ha)	Used (%)	Land Used (ha)	Conservative (t/year)	Likely (t /year)	Target (t /year)
Contiguous low forest & thicket	594.24	10	59.42	913.64	1,381.60	2,090.23
Natural grassland	28,785.48	10	2,878.54	44,257.67	66,926.24	101,252.92
Open woodland	1,088.2	10	108.82	1,673.10	2,530.06	3,827.74
Sparsely wooded grassland	9.84	10	0.984	15.12	22.87	34.61
Urban recreational fields (bare)	272.8	10	27.28	419.43	634.26	959.57
Urban recreational fields (bush)	28.04	10	2.804	43.11	65.19	98.63
Urban recreational fields (grass)	1,530.44	10	153.04	2,353.05	3,558.27	5,383.32
Backyards	58,167.15	5	2,908.35	89,431.99	135,238.63	204,602.96
Total	**90,476.19**		**6,139.26**	**139,107.14**	**210,357.15**	**318,250.01**

Table 8 shows the amount of open land in CoJ. All of the land values were derived from the green space dataset provided by the CoJ, except for the backyard values.

The backyard areas were determined by performing a spatial join with the Google residential buildings footprint data and the cadastre data. From this the total backyard area could be determined by subtracting the cadastre area from the building footprint area. The table also assumes that only 10% of the green spaces are used for urban agriculture and only 5% of the backyard area. These areas are then multiplied by the mixed output values provided by Table 7.

Urban agriculture also tends to produce higher yields than commercial agriculture. According to Rosset (1999) small scale farming activities can produce 2 to 10 times greater yields than large scale farming activities. To account for this, the backyard outputs were multiplied by a factor of two. Two was selected as it is on the conservative end of the range of values stated.

Healthy adults require approximately 400 grams of fruit and vegetables per day to be healthy. Using the UrbanSim 2042 population forecasts for CoJ the total amount of produce required is estimated at 1,498,869 t per year. With the estimates in Table 8, a total of 14% of CoJ's vegetable requirements can be met with urban agriculture in the likely scenario and 21% in the target scenario.

The results of the modelling show that approximately 6,100ha of land could be used for urban agriculture. If this was intensively farmed, a target of 320,000 t of fresh produce could be aimed for. Using a figure of 400g of vegetables per person, this would provide about 20% of vegetable requirements for a projected urban population for the CoJ of 10.3 million people (3.4 million households) in 2042.

7.3 Composting

Composting involves processing organic waste from households to produce compost, which can be used to fertilise gardens or nearby green spaces. This approach prevents organic waste from ending up in landfill sites and supports local food production. Composting can be done on-site or at centralised community composting facilities.

The following assumptions were used to model the potential impact of diverting organic waste from landfills to composting:

- All calculations are based on the 2024 CoJ urban growth model outputs.
- The number of persons per income group and housing type was derived from the household dataset from the UrbanSim output.
- An average total waste per person per day was used is shown in Table 9 (Haywood, 2021; Department of Environmental Affairs, 2018).
- An average compostable waste per person per day was used is shown Table 10 (Haywood, 2021; Department of Environmental Affairs, 2018).
- Minimum and maximum composting rations were obtained from (Haywood, 2021; Department of Environmental Affairs, 2018). Both the composting materials as well as the composting method impact the ratios. Table 11 below provides the ratios used for centralised and decentralised composting for the various income classes and housing types, with freestanding high-income households having the highest ratio.
- Jobs created by centralised composting facilities were obtained from (Ribeiro-Broomhead, 2021; Platt, 2023). The yearly processing capacity was also obtained to determine the number of these facilities required. The jobs and processing capacity is provided in Table 12.

Table 9. Total waste per person per day per income and housing type

Household income	Housing type	Total waste per person per day (kg)		Total waste per person per day (kg) used
		min	max	
Low	Informal	0.3	1	0.65
	RDP	0.5	1.5	1
Middle	Freestanding	1	2.5	1.75
	High-rise	1	2	1.5
High	Freestanding	2.5	4	3.25
	High-rise	2	3	2.5

Table 10. Compostable waste per person per income and housing type

Household income	Housing type	Compostable waste per person per day (kg)		Compostable waste per person per day (kg) used
		min	max	
Low	Informal	0.2	0.6	0.4
	RDP	0.3	0.8	0.55
Middle	Freestanding	0.5	1.2	0.85
	High-rise	0.4	1	0.7
High	Freestanding	1	1.6	1.3
	High-rise	0.7	1.2	0.95

Table 11. Centralised and decentralised compost ratio per income and housing type

Household income	Housing type	Compost ratio		Compost ratio used centralised	Compost ratio used decentralised
		min	max		
Low	Informal	0.3	0.5	0.4	0.3
	RDP	0.3	0.5	0.4	0.3
Middle	Freestanding	0.3	0.5	0.45	0.35
	High-rise	0.3	0.5	0.45	0.35
High	Freestanding	0.3	0.5	0.5	0.4
	High-rise	0.3	0.5	0.48	0.38

Table 12. Jobs created by a centralised composting facility and processing capacities

Centralised facility type	Jobs per facility	Waste processing capacity (ton/year)
Neighbourhood	5	500
Small city	15	5,000
Large city	20	20,000

- Carbon emission reductions due to composting organic waste rather than directing it to a landfill can range from 0.3 to 0.6 kt/year (Ribeiro-Broomhead, 2021; Platt, 2023).
- An adoption of 50% was assumed.

To show the impact of composting organic waste the following indicators were calculated:

- Waste removed from landfill per year

$$Let\ \boldsymbol{I}\ be\ the\ set\ of\ income\ classes$$
$$Let\ \boldsymbol{B}\ be\ the\ set\ of\ of\ housing\ types$$
$$Total\ waste = \sum_{ib} persons_{ib} * \text{ total waste per person per day}_{ib}$$
$$Compostable\ waste = \sum_{ib} persons_{ib} * \text{ compostable waste per person per day}_{ib}$$
$$Waste\ removed\ from\ landfill = \sum_{ib} compostable\ waste_{ib} * \ adaptation_{ib}$$

- Compost that can be created through onsite of centralised composting per year

$$Centralised\ compost\ created = \sum_{ib} waste\ removed\ from\ landfill_{ib} * \text{ centralised composting ratio}_{ib}$$
$$Decentralised\ compost\ created = \sum_{ib} waste\ removed\ from\ landfill_{ib} * \text{ decentralised composting ratio}_{ib}$$

- Jobs that can be created through centralised composting

$$Let\ \boldsymbol{F}\ be\ the\ set\ of\ centralised\ composting\ facility\ types$$

$$Jobs\ created = \frac{Waste\ removed\ from\ landfill}{capacity_f} * jobs_f$$

- Reduced Carbon emissions per year

$$Reduced\ carbon\ emissions = \ carbon\ reduction\ coefficient * \sum_{ib} waste\ removed\ from\ landfil_{ib}$$

The results of the CoJ modelling case study are provided in Table 13 and Table 14. Through the modelling it is estimated that the households in CoJ will create an estimated waste of 2,273 kt of waste. Of this waste approximately 1101 kt are compostable. With a 50% adoption rate of composting across all households 24.23% of the total waste or 551 kt will be removed from the landfills through composting.

At home or decentralised composting can create 186.50 kt of compost. If a centralised composting approach is followed the amount of compost create can increase to 241.56 kt as more sophisticated methods are used. Centralised composting also allows for job creation. Small (neighbourhood) composting sites can create up to 5,050 jobs and will require 1,101 facilities. Medium (small city) composting sites will create 1,650 jobs and will require 110 facilities. Large (large city) composting sites will create 560 jobs and only require 28 sites. The reduced carbon emissions form removing this compostable waste from landfills range between 165.17 kt and 330.33 kt depending on the composting method used and the materials composted.

The results show that composting organic waste could substantially reduce waste being directed to landfill and indicate that 550 kt (about 24%) of all waste could be diverted with a 50% adoption rate. A composting scheme could also potentially create significant numbers of jobs. It suggests that local schemes, were composting was done in each neighbourhood could create 5,050 full time jobs. Composting also has a significant impact on carbon emissions and could reduce these by between 165 and 330 kt per year. Having local composting schemes will in turn also reduce the carbon emissions to get the organic waste from the households to the composting site.

Table 13. Waste removed from landfill through composting and compost created for CoJ in 2024

Household income	Housing type	Total waste (kt/ year)	Total compostable waste (kt/ year)	Waste removed from landfill with adoption (kt/ year)	Waste removed from landfill per year (%)	Decentralised compost created (kt/ year)	Centralised compost created (kt/ year)
Low	Informal	277.10	170.52	85.26	30.77	25.58	34.10
	RDP	567.78	312.28	156.14	27.50	46.84	62.46
Middle	Freestanding	380.45	184.79	92.39	24.29	32.34	41.58
	High-rise	317.67	148.25	74.12	23.33	25.94	33.36
High	Freestanding	400.19	160.08	80.04	20.00	32.02	40.02
	High-rise	329.45	125.19	62.60	19.00	23.79	30.05
		2,272.63	**1,101.10**	**550.55**	**24.23**	**186.50**	**241.56**

Table 14. Jobs that can be created through centralised composting and reduction in carbon emissions

Household income	Housing type	Jobs created through centralised composting			Reduced carbon emissions (kiloton/year)	
		Neighbourhood	Small city	Large city	min	max
Low	Informal	5505	1650	560	25.58	51.16
	RDP				46.84	93.68
Middle	Freestanding				27.72	55.44
	High-rise				22.24	44.47
High	Freestanding				24.01	48.02
	High-rise				18.78	37.56
					165.17	**330.33**

7.4 Greywater

Greywater recycling is defined as the process of reusing untreated domestic wastewater other than toilet water and discarded kitchen water (Chemtronics, n.d.). Greywater is thus the wastewater from bathtubs, basins, showers, and washing machines. Greywater recycling has many purposes and benefits, such as:

- Relieves the pressure on municipal potable water supply.
- Relieves the pressure on wastewater treatment facilities.
- Serves as a water-saving measure for some household water uses.
- Saves households money on water usage.
- Replenishes ground water levels.

Although the reuse of greywater has many benefits, it should be noted that these systems have their limitations/risks. The Department of Human Settlements (2019) warns that care should be taken in the way greywater is reused inside homes. Greywater can be used for irrigation and flushing toilets. Greywater should also be used within 24 hours before bacteria start to grow and the water acquires an odour (City of Cape Town, 2024).

Water saving is extremely important for a water-scarce country such as South Africa (Cape Nature, 2024). Water saving contributes to the support of a sustainable water supply for the future of South Africa. To save potable water for indoor use, rainwater harvesting and storing can be used. Rainwater is a less contaminated source (food and pathogenic) that can also be stored for longer periods of time (Smart Water, 2024) than greywater. If rainwater is collected and stored correctly, it can be used for toilet flushing, dish washing, laundry, showers/bathing, and even drinking water. These uses will depend on the sophistication of the harvesting and filtering system. It should be kept in mind that rainwater harvesting is seasonal and not as consistent as the supply of greywater. The potential impact of greywater and rainwater use was modelled separately, since the harvesting, usage and storage of these systems differ.

To determine the water usage per household, the following table from the WRC (2020) was used. Table 15 lists the estimated water usage per person per day for different levels of service (LOS).

Table 15. Water usage per household and LOS

		Estimated water use (l/p/d)			
		Number of persons per household			
Level of service		**1**	**2**	**3**	**4**
LOS 1	Standpipes	22	22	22	22
LOS 2	Communal ablution blocks	54	42	37	34
LOS 3	Yard connections	85	62	52	46
LOS 4	Low-cost housing - limited fixtures	163	111	89	76
LOS 5	Full house connections (indoor)	275	198	163	143
LOS 6	Full house connections (including outdoor)	407	300	251	221

The UrbanSim 2024 CoJ output data stipulates the number of households per number of persons per building type as shown in Table 16, below.

An assumption was made that a household with 4 or more persons per household will use the same amount of water per person per day. This simplifies the calculations and makes it easier to align the UrbanSim data with the documented household water usage.

Determining the amount of greywater produced per household can be complicated since households use water very differently, especially when they fall into different income classes. The harvesting/collection method also has an impact on the amount of greywater a household will have access to since sophisticated harvesting systems can collect more water than, for example, a bucket placed in a shower. It is estimated that 50-70% of wastewater in households is classified as grey water and can be recycled (Friedler, 2004 Oteng-Peprah *et al.*, 2018). Thus, assumptions had to be made for the amount of greywater produced by each income class and household type. The assumption was that an average of 60% of household water use would be converted to greywater. It should be noted that the water used by toilets and kitchens are excluded in this percentage.

After combining Table 15 and Table 16, the amount of greywater was calculated by using the following formula:

$$Greywater\ (l) = Number\ of\ persons\ \times Number\ of\ households\ \times Water\ usage\ \times 0.6$$

The result is the following Table 17 below.

Table 16. Number of households and persons per housing type and income

Household income	Housing type	Number of persons	Number of households
Low	Informal	1	237,533
		2	146,558
		3	104,395
		4+	147,949
	RDP	1	99,144
		2	90,625
		3	78,853
		4+	185,792
Middle	Freestanding	1	36,288
		2	44,402
		3	34,214
		4+	72,967
	High-rise	1	39,472
		2	42,154
		3	33,444
		4+	66,022
High	Freestanding	1	21,407
		2	27,930
		3	19,533
		4+	41,051
	High-rise	1	24,013
		2	28,240
		3	20,641
		4+	43,057

Table 17. Amount of greywater produced per household income and type.

Household income	Housing type	Number of persons	Number of households	Water use (l/p/d)	Water use for households (l/d)	Greywater (l/d)
Low	Informal	1	237,533	53.67	12,747,604.33	7,648,562.60
		2	146,558	42.00	12,310,872.00	7,386,523.20
		3	104,395	37.00	11,587,845.00	6,952,707.00
		4+	147,949	34.00	20,121,064.00	12,072,638.40
	RDP	1	99,144	163.00	16,160,472.00	9,696,283.20
		2	90,625	111.00	20,118,750.00	12,071,250.00
		3	78,853	89.00	21,053,751.00	12,632,250.60
		4+	185,792	76.00	56,480,768.00	33,888,460.80
Middle	Freestanding	1	36,288	407.00	14,769,216.00	8,861,529.60
		2	44,402	300.00	26,641,200.00	15,984,720.00
		3	34,214	251.00	25,763,142.00	15,457,885.20
		4+	72,967	221.00	64,502,828.00	38,701,696.80
	High-rise	1	39,472	275.00	10,854,800.00	6,512,880.00
		2	42,154	198.00	16,692,984.00	10,015,790.40
		3	33,444	163.00	16,354,116.00	9,812,469.60
		4+	66,022	143.00	37,764,584.00	22,658,750.40
High	Freestanding	1	21,407	407.00	8,712,649.00	5,227,589.40
		2	27,930	300.00	16,758,000.00	10,054,800.00
		3	19,533	251.00	14,708,349.00	8,825,009.40
		4+	41,051	221.00	36,289,084.00	21,773,450.40
	High-rise	1	24,013	275.00	6,603,575.00	3,962 ,45.00
		2	28,240	198.00	11,183,040.00	6,709,824.00
		3	20,641	163.00	10,093,449.00	6,056 ,69.40
		4+	43,057	143.00	24,628,604.00	14,777,162.40
					512,900,746.33	**307,740,447.80**

Step 3: The amount of greywater that can be harvested and/or reused is dependent on the greywater harvesting as well as the reticulation system. As stated above, a sophisticated greywater collection and filtering system will be able to collect a higher percentage of wastewater, as well as be able to store the greywater for an extended period of time. Also, if the reticulation/irrigation system has leaks or gets contaminated with biological materials (such as bugs or chemicals), a smaller percentage of the greywater will be reusable as irrigation water (Oteng-Peprah, *et al.*, 2018).

Greywater systems have the potential to relieve the municipal potable water supplies for uses that require less purified water, such as irrigation. These systems can also save households money and assist in the goal for municipalities to save water. However, greywater should be collected and used with care. The City of Cape Town (2024) advises households to use greywater within 24 hours, before bacteria start to grow and cause unpleasant odours. Limits on volumes of greywater storage are also important to keep in mind, since this can influence the type of greywater system the households will make use of. Greywater also has the potential to contaminate natural underground water sources if it is not correctly filtered and reticulated (City of Cape Town, 2024).

Since households produce vastly different amounts of greywater depending on their size and type, it is challenging to generalise how much potable water they are able to save when using greywater. This is also dependent on what the greywater is used for. Section 7.6 focuses on very specific case studies to demonstrate how much greywater usage can save on a household's potable water use.

7.5 Rainwater

Like greywater recycling, the collection and utilisation of rainwater for household use has many advantages that are focused on potable water and cost savings. Unlike greywater, rainwater is often a cleaner alternative to greywater, since greywater may contain chemicals such as detergent, soap, and other chemicals (GRAF, n.d.). This means that it can be used for more indoor water needs such as showering, dish washing, toilet flushing, and cleaning. A disadvantage of using rainwater is the fact that it is seasonal and less constant than the supply of greywater.

Following the methodology of Gibberd (2022), the amount of rainwater that can be harvested for household use is calculated using the following formula:

$$Potential\ rainwater\ captured\ (l/year) = Roof\ area\ (m^2) \times Rainfall\ (mm/year) \times Runoff\ factor$$

The total roof area of residential units in CoJ was calculated using a combination of Google Footprint data, together with the UrbanSim household classification data. The roof areas of residential units were summed to get the total roof area of all the residential units in CoJ. The runoff coefficient was determined by referring to Table 18 (Farreny, *et al.*, 2011).

Table 18. Runoff coefficients

Roof type/surface	Runoff coefficient
Sloping corrugated metal roof sheeting and tiled roofing	0.9
Flat concrete roofing with gravel topping	0.8
Level cement surfaces, such as driveways and tennis courts	0.8
Pavements and roads	0.7 – 0.95
Parks and pastures	0.05 – 0.3

The following assumptions were made with regards to the runoff coefficient of each building type:

- Informal buildings were determined to have a runoff coefficient of 0.85. This is supported by StatsSA (2024), which states that corrugated iron and roof tiles are the most used roofing materials in informal settlements. A coefficient of 0.85 was determined to be suitable since it is not stated that the roof panels are sloped.
- RDP houses must adhere to strict building guidelines as stated by the National Housing Code (2009). This states that minimum roofing requirements are galvanised roof sheets. It is not specified whether these sheets need to be sloped. Thus, a runoff coefficient of 0.85 was determined to be suitable.
- Middle- and high-income freestanding roofs were assigned a runoff coefficient of 0.9. This is supported by national building regulations (SABS, 2011a). These regulations state that a roof must be at a minimum incline, which allows it to slope. The type of roofing material does not influence the coefficient too much, since the sloping has a bigger influence on the runoff.
- Middle- and high-income flats were assigned a runoff coefficient of 0.8, since the most common roof type for high-rise residential buildings are flat roofs (Spencer, 2023).

The average monthly rainfall (Weather and Climate, 2024) was summed to get the yearly rainfall. By using the formula to calculate the potential rainwater to be captured, the following results were obtained for CoJ (Table 19).

Table 19. Potential rainwater captured for CoJ

Household income	Household type	Total roof area (sqm)	Runoff factor	Rainfall (mm/year)	Potential rainwater harvested (l/year)
Low	Informal	15,899,880.18	0.85	779.30	10,532,160,132.22
	RDP	31,170,572.66	0.85	779.30	20,647,543,183.95
Middle	Freestanding	12,625,835.35	0.90	779.30	8,855,382,141.03
	High-rise	868,734.02	0.80	779.30	541,603,539.38
High	Freestanding	7,938,275.23	0.90	779.30	5,567,668,095.82
	High-rise	620,306.13	0.80	779.30	386,723,651.05
					46,531,080,743.45

The results in Table 19 show that rainwater harvesting systems, if installed at a household level, have the potential to save large amounts of water. It is estimated that around 46,531,080,743 Litres could be generated by rainwater harvesting systems, which if used to reduce potable water consumption by for instance being used to flush toilets could reduce water requirements by around 24.86%. These savings have the potential to save and/or supply households with additional water that can be used for toilet flushing as well as irrigation. Rainwater collection tanks limit the amount of rainwater that can be collected by households. This component is accommodated in the case study, where more informed assumptions can be made to demonstrate how each system discussed can contribute to a circular economy. The amount of rainwater that can potentially be collected over CoJ from residential use alone, has the potential to noticeably impact the current municipal potable water supply system. If rainwater can be substituted for (less purified) indoor household water requirements, it might relieve a large amount of stress on the current water supply systems in CoJ.

7.6 Circular system case study

To demonstrate a circular economy on a household level, 3 case studies were conducted. Figure 9 demonstrates how each of the above indicators flow into the circular system on a household level. The connection between these components will be discussed in more detail.

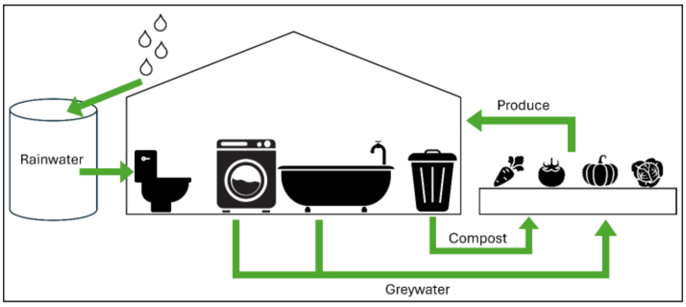


Figure 9. Process of circular economy on a household level.

The purpose is to quantify each of the abovementioned indicators and their impacts for 3 different household types. Each case study will focus on a 4-member household in different income groups as a constant, with the assumptions (Table 20).

Table 20. Assumptions for the case studies.

Assumption	Case Study A	Case Study B	Case Study C
Housing income	Low income	Middle income	High income
Housing type	RDP house	Freestanding house	Freestanding house
Adoption (%)	100	100	100
Grey water percentage (%)	60	60	60
Water usage/person/day (l)	76	143	221
Useful grey water percentage (%)	95	95	95
Runoff coefficient	0.85	0.90	0.90
Roof area (m^2)	40	170.5	310.5
Flush/person/day	4	4	4
Litres/flush	11	11	11
Tank size (l)	1,000	2,000	5,000
Tank start level (l)	500	1,000	2,500

For these case studies, the following process was assumed for the use of rainwater. Rainwater is collected from the roof of each building, stored in a tank, and fed into the toilet flushing system of the household. The goal is to eliminate potable water for toilet flushing and use rainwater as the alternative to relieve the strain on municipal water supply, specifically for toilets. As warned by the Redbook (2019), untreated greywater should not be used inside a house. Thus, rainwater would be a more suitable alternative. **Table 21** is an excerpt from the larger analysis of rainwater collection for the 3 case studies. It starts with the daily rainfall for CoJ for 2023 (AfriWX, 2023). The equation below is then used to calculate the total potential rainfall captured in litres per day. It then needs to be determined whether the rainwater is enough for the toilet use of the entire day. This is determined using the following formula:

$$Toilet\ water\ supplied\ by\ rainwater\ (l/day) = [Tank\ level\ (l) + Rainfall\ captured\ (l/day)] - Toilet\ use\ (l/day)$$

This equation considers the storage possible for each day. The analysis also considers the size of the collection tank, which limits the amount of rainwater that can be stored for each house. This makes the analysis more realistic, since unlimited storage is not possible.

In all 3 cases, the rainfall harvesting was limited by the size of the tanks. Some days, the tank was full and could not capture more rainwater. In these cases, the household can use the rainwater for uses other than toilet flushing. If rainwater is stored and filtered correctly, it can be used for showers, baths, laundry, dishes and even drinking water. Depending on the sophistication of this system, the household may decide to utilise unused rainwater for these activities. This can lead to even more water savings.

To calculate the amount of greywater for each case study, the process discussed in greywater section above was followed. Water usage per day is calculated by multiplying the number of people in the household by the water usage per person per day. This number is multiplied by 30 (average number of days in a month) to get the water usage per month for the household. The amount of greywater is calculated as 60% of the households' water usage per day and per month. The greywater saving is the amount of greywater vs the amount of household water use. This percentage gives an idea of how much of the water used in a household can be reused as irrigation water. It is assumed that all greywater is supplied to the vegetable garden and yard. The cautions and considerations discussed in the above greywater section should be considered when implementing a greywater system for agricultural use, especially if vegetables are grown for human consumption.

Based on above urban agriculture section, the following analysis was done to determine the impact of urban agriculture for the 3 case studies. Irrigation requirements were determined by Stark Ayres (2019) and various other sources (n.d.), and are listed in Table 22. The amount of water required by each crop was used to determine the area that can be planted of each crop type, with the supplied amount of greywater.

To calculate the compost for each case study, the process discussed in the above composting section was followed. The full implications of these circular system households are discussed below.

Results

The results are provided in Table 23 and discussed below. The results show that households can save between 40% to 80% on their water usage for toilets, if a rainwater system with the previously specified characteristics is installed. Since the tanks limit the amount of rainwater that can be stored, these water savings might increase if "surplus" rainwater is used for other household activities such as bathing, laundry, dishes, etc. The case studies also show the impact of roof and tank size in the storage of rainwater. Larger roof areas and tanks can capture more rainwater.

Table 21. Rainwater model for case studies.

Month	**Day**	**Rainfall/ day (mm/day)**	**Potential captured A (l/day)**	**Potential captured B (l/day)**	**Potential captured C (l/day)**	**Flush/ person/ day**	**Toilet use/day (l/day)**	**Tank level rainwater A (l)**	**Tank level rainwater B (l)**	**Tank level rainwater C (l)**	**Water saved by rainwater per day A (l/day)**	**Water saved by rainwater per day B (l/day)**	**Water saved by rainwater per day C (l/day)**
								500	**1,000**	**2 500**			
Jan	1	2.00	72.00	306.90	558.90	4	176	396.00	1,130.90	2,882.90	176	176	176
Jan	2	1.00	36.00	153.45	279.45	4	176	256.00	1,108.35	2,986.35	176	176	176
Jan	3	-	-	-	-	4	176	80.00	932.35	2,810.35	176	176	176
Jan	4	13.00	468.00	1,994.85	3,632.85	4	176	372.00	2,000.00	5,000.00	176	176	176
Jan	5	24.00	864.00	3,682.80	6,706.80	4	176	1,000.00	2,000.00	5,000.00	176	176	176
Jan	6	12.00	432.00	1,841.40	3,353.40	4	176	1,000.00	2,000.00	5,000.00	176	176	176
Jan	7	-	-	-	-	4	176	824.00	1,824.00	4,824.00	176	176	176
Jan	8	2.00	72.00	306.90	558.90	4	176	720.00	1,954.90	5,000.00	176	176	176
Jan	9	-	-	-	-	4	176	544.00	1,778.90	4,824.00	176	176	176
Jan	10	-	-	-	-	4	176	368.00	1,602.90	4,648.00	176	176	176
Jan	11	-	-	-	-	4	176	192.00	1,426.90	4,472.00	176	176	176

Table 22. Possible urban agriculture areas linked to grey water supply.

Crop	Water required (mm/day)	Fraction	Grey water supply A (l/day)	Grey water supply B (l/day)	Grey water supply C (l/day)	Area planted A (sqm)	Area planted B (sqm)	Area planted C (sqm)
Beetroot	4.00	0.10	17.33	32.60	50.39	4.33	8.15	12.60
Butternut	4.64	0.10	17.33	32.60	50.39	3.73	7.02	10.85
Carrot	6.43	0.05	8.66	16.30	25.19	1.35	2.54	3.92
Cauliflower	4.29	0.05	8.66	16.30	25.19	2.02	3.80	5.88
Cucumber	3.63	0.10	17.33	32.60	50.39	4.78	8.99	13.89
Lettuce	3.93	0.10	17.33	32.60	50.39	4.41	8.30	12.83
Onion	3.57	0.10	17.33	32.60	50.39	4.85	9.13	14.11
Potato	5.40	0.10	17.33	32.60	50.39	3.21	6.04	9.33
Pumpkin	4.64	0.10	17.33	32.60	50.39	3.73	7.02	10.85
Sweet potato	4.14	0.10	17.33	32.60	50.39	4.18	7.87	12.16
Tomato	5.44	0.10	17.33	32.60	50.39	3.18	5.99	9.26
Total	**50.11**	**1.00**	**173.28**	**326.04**	**503.88**	**39.78**	**74.85**	**115.67**

Table 23. Case study results.

Category	Indicator	Case Study A	Case Study B	Case Study C
Rainwater	Total potential rainfall (mm/year)	844.00	844.00	844.00
	Total toilet water use (l/year)	64,240.00	64,240.00	64,240.00
	Total water saved by using rainwater (l/year)	24,848.00	44,292.30	51,255.75
	Total water saved by using rainwater (%)	38.68	68.95	79.79
Greywater	Water usage (l/d)	304.00	572.00	884.00
	Water usage (l/mo.)	9,120.00	17,160.00	26,520.00
	Greywater (l/d)	182.40	343.20	530.40
	Greywater saving (l/d)	173.28	326.04	503.88
	Greywater (l/mo.)	5,198.40	9,781.20	15,116.40
	Greywater saving (%)	57.00	57.00	57.00
Urban agriculture	Area planted (sqm)	39.78	74.85	115.67
	Area planted (Ha)	0.00397789	0.00748471	0.01156728
	Backyard production factor	2.00	2.00	2.00
	Yield per year conservative (ton/Ha)	15.38	15.38	15.38
	Yield per year likely (ton/Ha)	23.25	23.25	23.25
	Yield per year target (ton/Ha)	32.18	32.18	32.18
	Yield per year conservative (kg/year)	122.32	230.15	355.69
	Yield per year likely (kg/year)	184.97	348.04	537.88
	Yield per year target (kg/year)	255.98	481.64	744.35
Compost	Total waste (t/year)	1.46	2.555	4.745
	Total compostable waste (t/year)	0.80	1.24	1.898
	Compost created (t/year)	0.2409	0.43435	0.7592
	Reduced carbon emissions (t/year)	0.24	0.37	0.57

For Case Study A, the rainwater was able to cover the use of the toilet flushing until mid-January. From this date, municipal water was required to flush the toilets for some intervals where the rainfall was not sufficient. For the entire study, 24,848l rainwater was used to flush the toilets, saving 38.68% of water for flushing toilets. Using the 63,247l of greywater per year, this household will be able to produce between 122.32kg and 255.98kg of produce per year. This is equivalent to between 10.19kg and 21.32kg of produce per month. This household will produce 800kgn of compostable waste and 240.9kg compost in a year that can then be used to fertilize the produce garden.

For Case Study B, the rainwater was able to cover the use of the toilet flushing until mid-April. For the entire study, 44 292.30l rainwater was used to flush the toilets, saving 68.95% of water for flushing toilets. Using the 119,004.6l greywater per year, this household will be able to produce between 230.15kg and 481.64kg of produce per year. This is equivalent to between 19.18kg and 40.14kg of produce per month. This household will produce 1.24tonne of compostable waste and 434.35kg compost in a year that can then be used to fertilize the produce garden.

For Case Study C, the rainwater was able to cover the use of the toilet flushing until the first week of July. Less intervals of municipal water use were required for this case study. For the entire study, 51,255.75l rainwater was used to flush the toilets, saving 79.79% of water for flushing toilets. Using the 183,916l greywater per year, this household will be able to produce between 355.69kg and 744.35kg of produce per year. This is equivalent to between 29.64kg and 62.03kg of produce per month. This household will produce 1.90tonne of compostable waste and 759.20kg compost in a year that can then be used to fertilize the produce garden.

These case studies show how households of various sizes and income classes are able to support a circular economy to some extent. This can lead to improvements in quality of life, seeing that households are enabled to grow their own produce using wastewater that would normally be discarded. They are also able to save on the use of potable water where rainwater capturing systems are implemented. Together with this, waste from the agricultural processes can be invested back into the system which would also normally be discarded. Although these examples of circular economy households might require some monetary investment at the start, it has the potential to save households a lot of money in the longer term.

7.7 Deconstruction and reuse

Construction and demolition waste is one of the largest waste streams in South Africa at around 8.1% (Department of Environmental Affairs, 2018). A way to reduce the construction and demolition waste is to deconstruct buildings and reuse materials instead of demolishing them (Gibberd, 2024). Though this deconstruction process various materials can be recycled or re-used in future projects instead of ending up in landfills.

The team decided to model deconstruction of freestanding houses for densification purposes. For this reason, the SDF scenario urban growth model output was used. The employment figures for recycling construction waste presented in Table 24 were derived by integrating data from a number of sources, including reports by the Department of Forestry, Fisheries and the Environment, the International Labour Organisation and Chatham House. These sources offer comprehensive insights into the job creation potential of circular economy practices, particularly recycling, across various waste streams. The ranges were determined through a synthesis of sector-specific analyses and global benchmarks, ensuring relevance to circular economy interventions in the construction sector (Department of Forestry, 2023; Mitchell & Morgan, 2015; Van der Ree, 2019).

The following assumptions were made for the model.

- All freestanding houses demolished between 2024 and 2042 to develop high density housing was included in the calculation. A total of 754 houses are predicted to be demolished in that period.
- Depending on the size of the house the minimum waste create is 75 tonne and the maximum is around 1200 tonne. An average of 675 tonne of waste per house was used.
- The composition of construction and demolition waste was obtained from the 2018 State of waste report. Concrete and masonry account for around 69% of the waste, asphalt for 16.3%, metal for 2.1% and plastic for 1.1% (Department of Environmental Affairs, 2018).
- An adoption rate of 50% is assumed in the deconstruction and recycling of construction waste.
- The yearly processing capacity for a recycling facility is 10 000 ton.
- Jobs created through recycling each of the waste types is provided in Table 24 below (Van der Ree, 2019).

Table 24. Jobs created per construction waste type.

Waste type	Jobs (per 10,000 t)	
	min	max
Concrete and masonry	3	13
Asphalt	3	13
Metal	4	8
Plastic	6	11

To show the impact of deconstructing old freestanding homes where densification takes place and recycling the waste the following indicators were calculated:

- Deconstruction waste recycled

$$\text{Let } \boldsymbol{T} \text{ be the set of waste types}$$
$$Total\ deconstruction\ waste = waste\ per\ house * numer\ of\ houses\ deconstructed$$
$$Deconstruction\ waste\ recycled = Total\ deconstruction\ waste * waste\ composition_t * adaptation$$

- Jobs created per year

$$Jobs\ created\ per\ year = \frac{\left(\frac{Deconstruction\ waste\ recycled_t}{10\ 000} * jobs_t\right)}{18}$$

Table 25 provides the results of the deconstruction and recycling of freestanding houses for densification over an 18-year period from 2024 to 2042. Over the 18 year per period a total of 508,950 kt of construction waste will be generated from deconstructing freestanding houses to build density housing. With a 50% reuse and recycling adoption rate 225,210 kt of this waste will be recycled instead of ending up in landfills, which is around 44%. The jobs created through the recycling of these construction waste materials can range from 4 to 16 jobs per year. With the 50% adoption of recycling for the deconstruction waste the metal and plastic is not enough to open a recycling site for it, therefor no explicit jobs are created for it, however there is a possibility that it will create more jobs at existing sites.

Table 25. Construction waste from deconstruction for densification from 2024 to 2042

Waste type	**Composition**	**Adoption**	**Total deconstruction waste (t)**	**Deconstruction waste recycled (t)**	**Waste removed from landfill (%)**	**Total jobs created per year**	
						min	**max**
Concrete and masonry	69.00%	50%	508,950	175,588	44%	3	13
Asphalt	16.30%	50%		41,479		1	3
Metal	2.10%	50%		5,344		0	0
Plastic	1.10%	50%		2,799		0	0
				225,210		**4**	**16**

The results show that a deconstruction and reuse intervention could result in substantial amounts of waste being reused or recycled. With a 50% adoption rate, it shows that 225,210 t of building materials and components could be sourced and reused, this represents about a 44% reduction in the amount of construction waste that may be diverted to landfill or fly tipped. It is estimated that between 72 and 288 additional jobs can be created between 2024 and 2042 though deconstruction and reuse related activities where low-density buildings are deconstructed to build high density housing.

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