6

CIRCULAR ECONOMY

6.1 Introduction

Circular economy approaches to sanitation services in Africa focus mainly on wastewater management. Their goal is to not only enhance sanitation services' delivery across the continent, but also to create an environment for healthy living. The main objective of the circular economic model is to eliminate waste "systematically, throughout the life cycles and uses of products and their components" (Zils 2014). The principle of circular economy is zero-waste, based on three rules:

- All durables, which are products with a long or infinite lifespan, must retain their value and be reused but never discarded or downcycled (broken down into parts and repurposed into new products of lesser value)
- All consumables, which are products with a short lifespan, should be used as often as possible before safely returning to the biosphere
- Natural resources may only be used to the extent that they can be regenerated (Stuchtey 2015)

Six types of circular economy are common to Africa, including treated water reuse for agriculture, reclaimed sewer wastewater for potable use, treated wastewater for aquaculture, recycled wastewater for agriculture, untreated wastewater for irrigation, and non-sewer wastewater recycling for agriculture and energy. Household wastewater stream caters for less than 20 per cent of the people of Africa, and there are examples of circular economy around (or with) faecal sludge and solid wastes. While there are multiple benefits of circular economy application to wastewater management in different contexts, there are also constraints such as financial, institutional, technical, social and health aspects that need to be addressed.

In Africa, a proportion of consumed water along with excreta from toilets ends up as wastewater in sewers or on-site sanitation systems (OSS) such as septic tanks or wet pits. While, to a variable extent, sewers are often developed in large urban centres, sanitation coverage with on-site sanitation systems in Africa remains one of the highest in the world. Figure 6.1 presents a typical sanitation service chain as applicable to many African countries.

Both sewer-based wastewater and non-sewer based wastewater (also called 'faecal sludge') require treatment. However, many cities in Africa still struggle to provide adequate collection and treatment systems for these materials (Andersson, Dickin and Rosemarin 2016). Main constraints along the sanitation value chain include: poor institutional arrangements for collection, high capital costs for treatment facilities, high operation costs, poor maintenance, vandalism and lack of capital. Conventional treatment follows a linear approach from collection to disposal, whereas recent emphasis has been placed on a circular economy approach in wastewater management.

6.1.1 Linear and circular approaches to wastewater management

In the past few decades, actions taken to mitigate the impacts of human activities on the Earth's ecosystems have followed the linear economy approach to resource management. With such an approach, it has been estimated that the human demand on the Earth's ecosystems will exceed what nature can regenerate by about 75 per cent by 2020 (Global Footprint Network 2019).

Conceptually, a circular economy approach implies that resources are used for as long as possible by extracting the maximum value of the resource while in use and recovering and regenerating products and materials at the end of each service life. It is an "economy that preserves the value added in products for as long as possible and virtually eliminates waste. The resources are retained when a product has reached the end of its life, so that they remain in productive use and create further value" (European Commission 2010). This is in contrast with the linear economy approach, where waste products are managed as materials that have reached the end of their lifecycle. The linear approach is premeditated on taking, making, using and disposing of resources and is extractive, often leading to waste of resources, environmental pollution and overall system inefficiency.

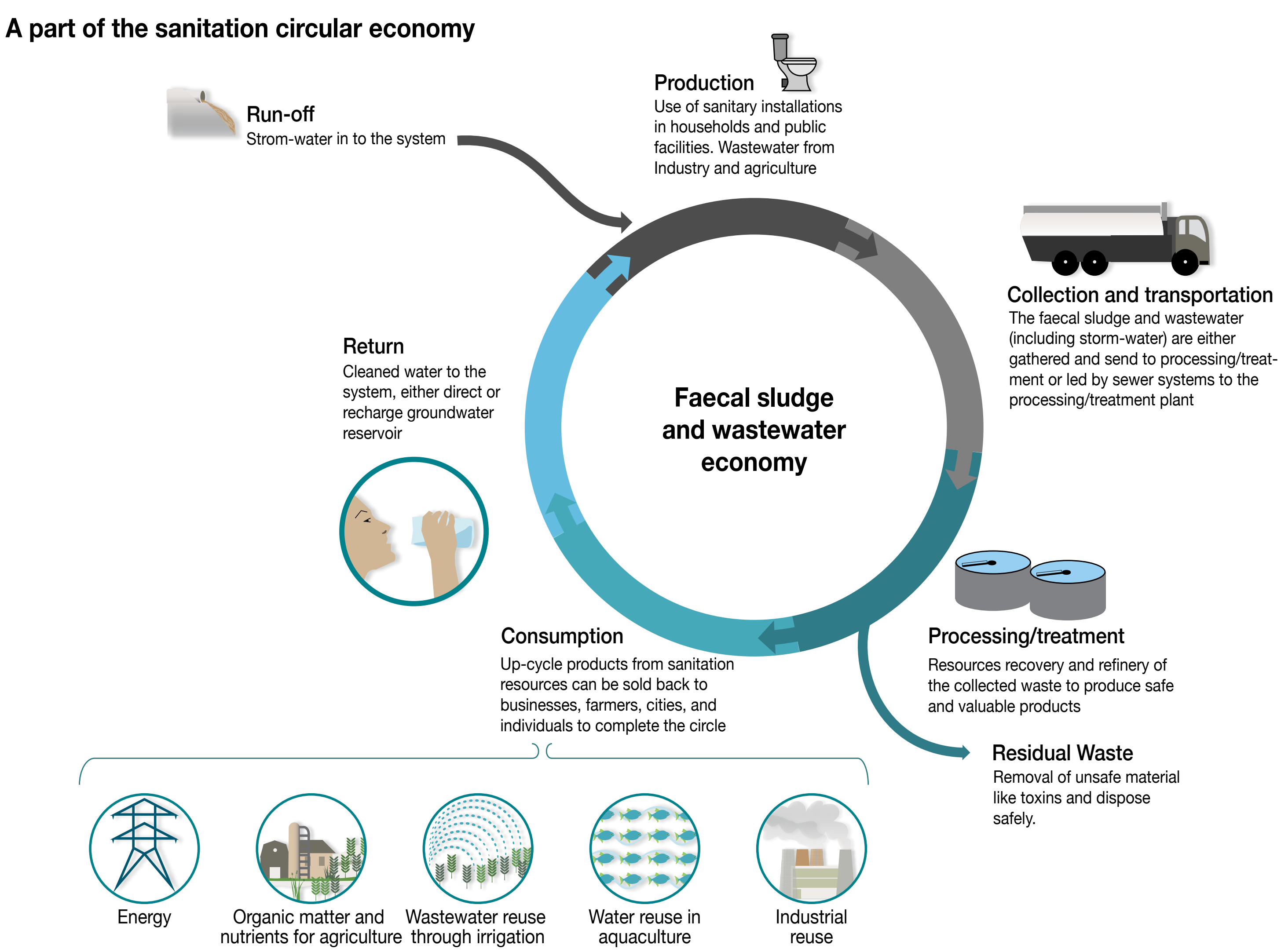


Figure 6.1. A typical example of the sanitation service chain with variation for urban and rural areas

The practice at the centre of the circular economy approach in sanitation is not new. In particular, closed loop systems linking food waste and food production have been practised for generations in many rural societies. Since 1966, there have been renewed interests and numerous publications on the importance of the circular economy approach in resource management. From Kenneth Boulding's The Economics of the Coming Spaceship Earth, published in 1966, to the European Commission's circular economy action plan of 2015, many different schools of thought condemn the linear economy approach of take, make, use and dispose, instead envisioning waste as a resource to be reused.

The circular economy is a preferred alternative to the linear wastewater and solid waste management approach of "store/collect, transport, treat, dispose". It aims at deriving value from waste streams, applying a business perspective and shifting the focus from coverage to creating value and improving resource efficiency. It implies closing cycles by turning 'waste' resources produced by the community into valuable inputs for another use, as shown in Figure 6.2. It involves not only flows of water, nutrients, materials and energy but also flows of value (such as revenues or societal benefits) and information streams, as well as cost recovery and resource efficiency. It entails adopting a holistic perspective, considering different waste streams, contexts and technologies. Although it is implemented at the local level, it goes beyond the micro-organization level of production, linking to higher levels. It also involves a multi-stakeholder approach, requiring partnerships and cooperation across sectors and stakeholder groups.

It is estimated that 60 per cent of the urban population in Africa is living in settlements where sanitation services are poor, inadequate, and unreliable (Wang et al. 2013). In a conventional sanitation delivery approach, wastewater and faecal sludge are viewed as materials that have reached the end of their lifecycle. With this approach, the annual economic loss due to poor sanitation is equivalent to between 1 and 2.5 per cent of GDP for each of the 18 Sub-Saharan African countries considered in a study (Water and Sanitation Program [WSP] 2012). By implementing the circular economy approach, these undesirable materials may be converted into goods offering multiple benefits, leading to improvement of sanitation (Drechsel et al. 2018a) and some cost recovery.

In general, the circular economy approach builds on three main principles (Ellen MacArthur Foundation 2017), namely:

- Preserving and enhancing natural capital by controlling finite stocks and balancing renewable resource flows
- Optimizing resource yields by circulating products and materials in use at the highest utility
- Fostering system effectiveness by revealing and designing out negative externalities

Prior to the emergence of the concept of circular economy, ecological sanitation ('ecosan') was in vogue. Ecosan perfectly encapsulates the idea of closing the loop, as it aims to meet socioeconomic requirements, prevent pollution of surface and groundwater, sanitize urine and faeces, recover nutrients for food production, and save water, energy and resources in a given local context (Hu et al. 2016). In the last three decades, multiple types of ecosan systems have been advanced with different user interfaces, collection and storage, treatment processes and reuse or recycling of water and nutrients for waste materials. Recycling has also been commonly practised throughout most of human history, although not to reduce waste. Its practice was historically as a result of a lack of adequate resources or the difficulty of acquiring new resources. This contrasts with the reason for the practice in the modern world, where recycling is carried out for environmental reasons and for the future.

A typical example of the sanitation service chain with variation for urban and rural areas

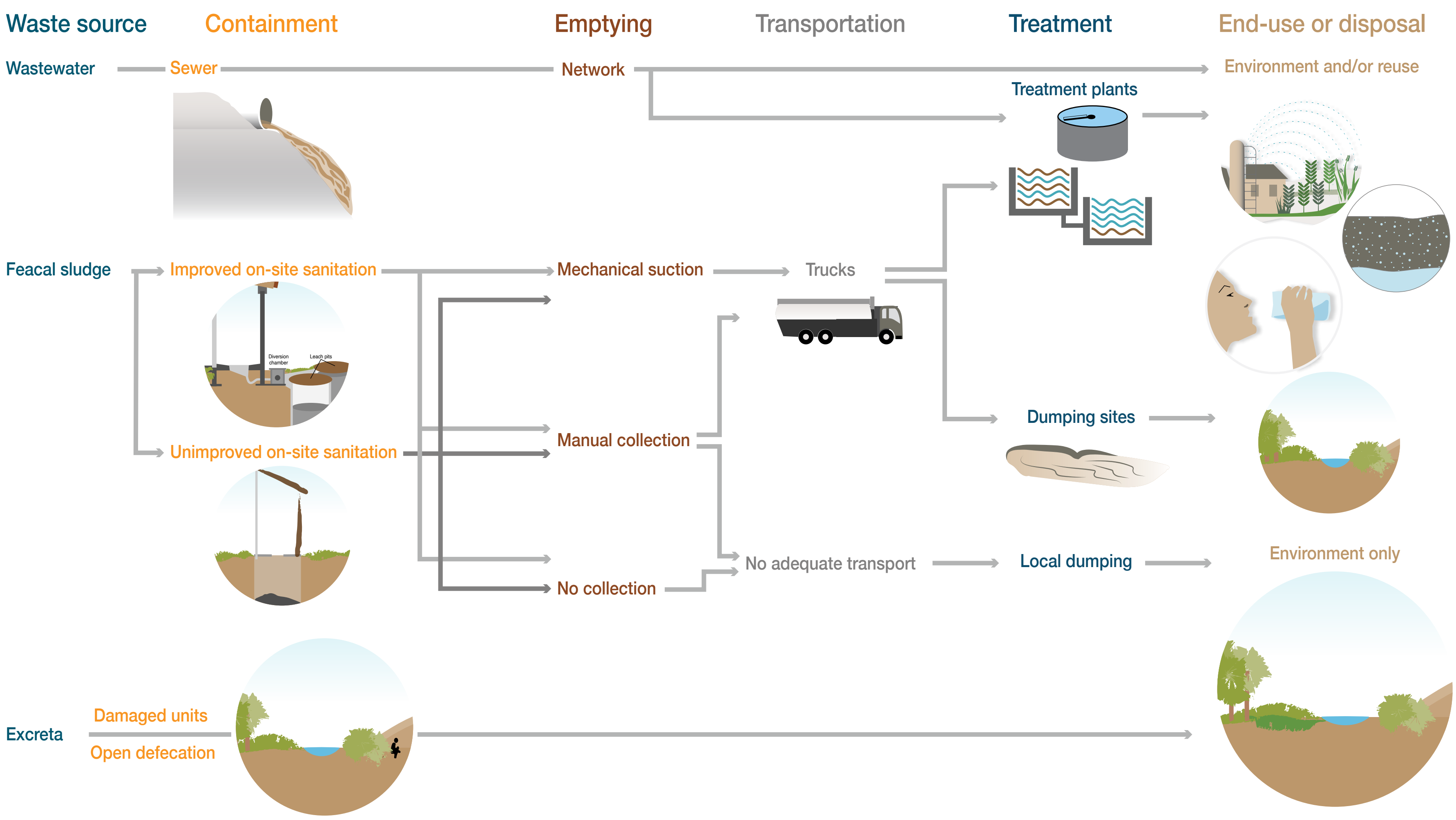


Figure 6.2. Outline of a circular economy

6.2 Driving Factors for the Application of the Circular Economy Approach in Wastewater Management

The circular economy approach in wastewater management is applied through the diverse wastewater reuse or recycling options that are being practised all over the continent. Some of the factors that drive this practice are outlined in Figure 6.3.

6.2.1 Competition for resources

6.2.1.1 Water scarcity

Water scarcity is defined by water availability below 1,000 cubic metres per capita per year which may result from the physical absence of water or from economic factors which constrain access to available water. Physical water scarcity is common in the arid countries of northern and southern Africa (such as Egypt, Morocco and Namibia), while several other sub-Saharan African countries face economic scarcity (see Figure 6.4). Moreover, local scarcity may be due to locally specific factors. This is the case in and around many large towns where the huge population densities lead to increasing water demand for drinking and for agricultural and industrial use, putting undue pressure on available water resources and thereby generating temporal scarcity. For rapidly expanding cities in Africa, supply of safe drinking water will be a major challenge in the future. In such cases, reclamation of wastewater could contribute to increasing water availability.

6.2.1.2 Resource diversification

Compost or biogas from wastewater treatment plants are by-products with possible market value. The biogas is a source of energy which could be used on-site to reduce electricity demand for treatment processes. The compost can be used as a soil conditioner or fertilizer (nitrogen content: 1.7–5.6 per cent; 50 per cent of phosphorus in wastewater ends up in the biosolids). Despite policy support, fertilizer application rates across sub-Saharan Africa are still very low (around 8–32 kg/hectare for different sub-Saharan countries). In particular, phosphorus has been seen as a limited resource which may be depleted soon unless, for example, recycling measures are adopted. Nutrient reuse via wastewater could help reduce the leaching of mineral fertilizer (Sustainable Water Integrated Management [SWIM] Programme 2013). Access to energy is also a critical issue in many countries.

6.2.1.3 Climate variability/change

Scientists estimate that climate change will cause several impacts that can exacerbate water scarcity:
- Temperature increase will translate into higher evaporation rates for water
- Change in water availability, especially in countries that are already dry, which will become dryer (particularly in Africa)
- Sea level rise, which will increase the amounts of land lost in coastal areas and cause an increase in intensity of storms, resulting in floods (Loutfy 2011; Jimenez 2008)

As part of the mitigation strategies, adoption of new water infrastructure and water demand management solutions must be implemented. In this regard, reuse of wastewater is a water-saving measure, since it reduces the demand for freshwater sources. Wastewater reuse may also constitute a low-cost measure for mitigating impacts of short-term droughts (Van der Merwe et al. 2008; Drechsel et al 2018b).

6.2.2 Cost savings

6.2.2.1 Low-cost treatment of wastewater

Although the use of untreated wastewater in Africa could be unintentional, for example, when sewers or wastewater treatment plants (WWTPs) become dysfunctional, deliberate use of untreated wastewater for irrigation is increasing in many African cities. Capture and reuse of wastewater can be considered as a simple way of treating wastewater with minimal financial and technical input. It reduces risks of contamination of remaining water sources (Jimenez 2008) as retention of nutrients in treated wastewater results in lower risks of eutrophication of water bodies (Candela et al. 2007) while the nutrients available for agriculture constitute savings for farmers (Thebo et al. 2017; SWIM Programme 2013). Wastewater reuse may generate revenue, which can reduce treatment cost. In particular, soil aquifer treatment processes associated with the reuse of agricultural wastewater could yield similar or improved water quality compared to conventional wastewater treatment plants, such as activated sludge.

6.2.2.2 Sales of products from treatment plants

Water treatment and reuse can help sustain the operations and maintenance of treatment plants through the sale of by-products (such as compost, biogas, briquettes, electricity) from the plants. This depends on the marketability of the products and the local contexts. For example, electricity sales to the public may be constrained by imposed tariffs, while biogas and briquette sales may be

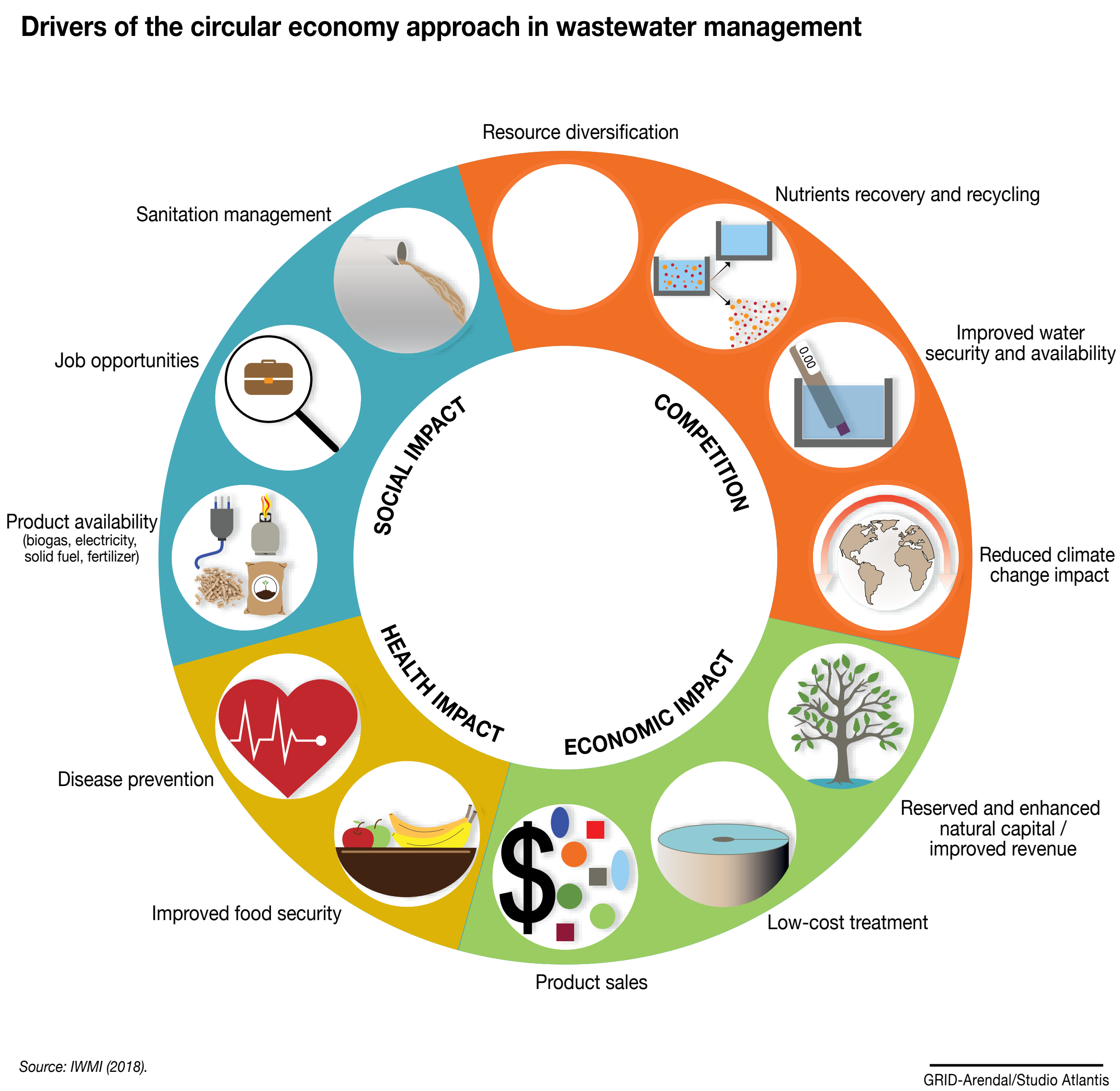


Figure 6.3. Drivers of the circular economy approach in wastewater management

Reuse of wastewster in agriculture

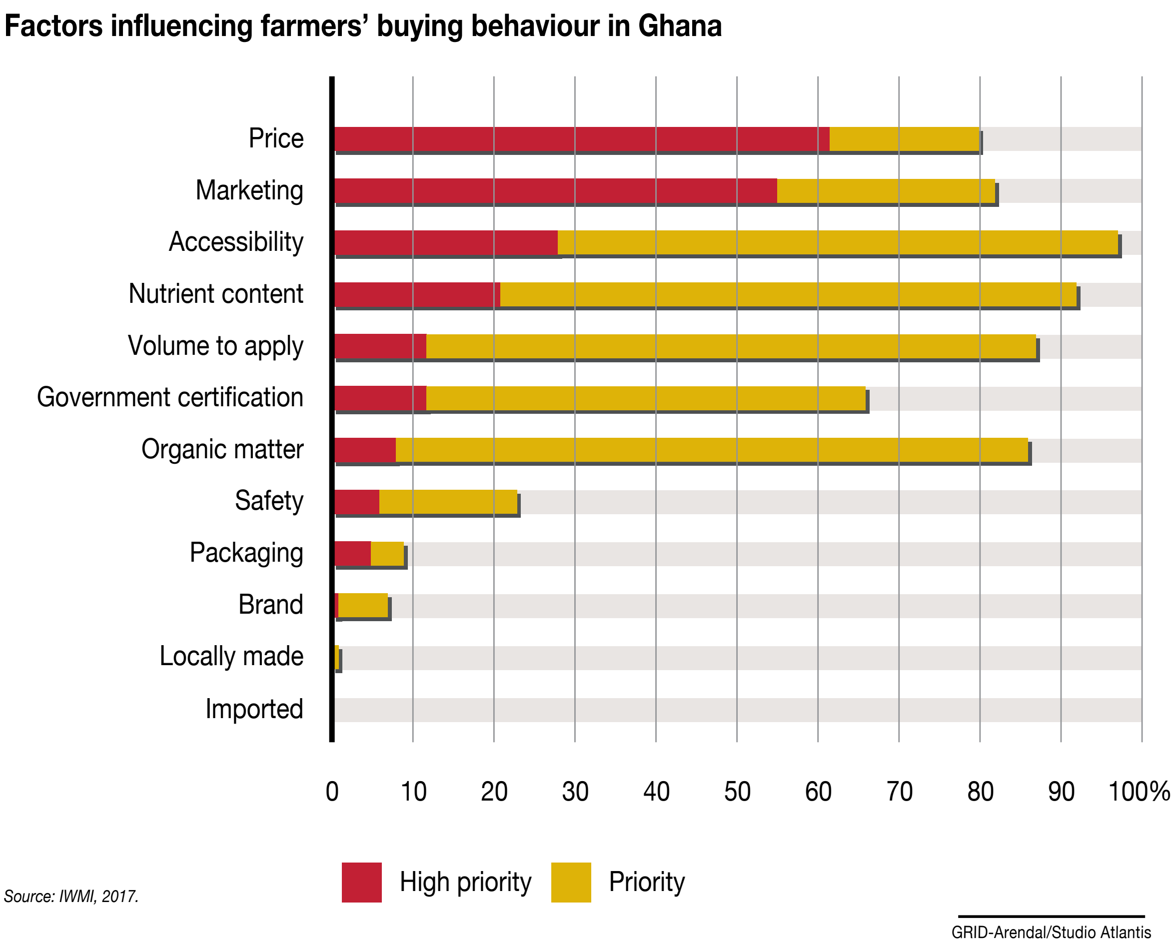


Figure 6.4. Factors influencing farmers' buying behaviour in Ghana (per cent)

constrained by the location of the plant. To benefit from compost sales, suitable credit options must apply, as indicated by buying behaviour reported in Ghana (see Figure 6.4).

6.2.2.3 Job opportunities and improved livelihoods

In the agricultural sector, wastewater is viewed as a reliable source of water and nutrients, especially when it is available near farmlands (Hanjra et al. 2018). Although the nutrients constitute a threat to the environment when wastewater is discharged into water bodies, they represent an opportunity for the agricultural sector through reducing the amount of inorganic fertilizers used (Thebo et al. 2017; SWIM Programme 2013; Jimenez 2008). Not only does this represent important cost savings for farmers, it also closes the loop for nutrients that are essential for sustainability (Hanjra et al. 2018). Treated wastewater can also be used productively in many sectors, for aquaculture production, extended farming, and more. It therefore provides a great opportunity to improve livelihoods in both rural and urban areas.

6.3 Circular Economy Approaches in Wastewater Management

There are six types of applications of the circular economy approach in wastewater management in Africa. A generic schematic of the circular economy approach (CEA) in wastewater management is presented in Figure 6.5.

6.3.1 CEA 1: Treated wastewater reuse for irrigation

This CEA treats sewer wastewater (from domestic and possibly industrial sources) to meet quality standards, allowing the treated wastewater to be safely used for irrigation, taking advantage of the available nutrients. It is the most common CEA in Africa. In some cases, sewage sludge is recycled on-site, for example, for biogas production (which reduces the demand for energy of the wastewater treatment plant processes by 37–68 per cent), composting or incineration (Drechsel and Hanjra 2018-14; Weissenbacher et al. 2013).

The wastewater treatment and reuse components could be managed by the same parties. Alternatively, responsibilities for wastewater transport, treatment and reuse could be shared between different stakeholders, be they public or private.

Main resources:
Treated water for agriculture and sludge

Treatment technology:
Conventional wastewater treatment processes, such as waste stabilization ponds or activated sludge, and advanced technologies such as membranes

Typical geography:
Peri-urban, rural

The business model of CEA 1 is presented in Figure 6.6.

6.3.1.1 Case examples

Egypt has a long tradition of treated wastewater reuse dating as far back as 1911 (Loutfy 2011). Reuse of treated wastewater in irrigation is encouraged to bridge the gap between available water and demand, given the pressing water scarcity in the country, which relies on the transboundary River Nile for 97 per cent of its freshwater supply (Abdel-Shafy and Mohamed-Mansour 2013). In Egypt, as in many other African countries, two main routes for wastewater reuse coexist: direct use of treated wastewater to irrigate and cultivate the desert around urban centres (for example, in border governorates and in Upper Egypt), or indirect use by draining wastewater (treated or not) into agricultural land (for example, in the Delta governorates) (SWIM Programme 2013).

Morocco uses treated wastewater in many ways, ranging from conventional irrigation practices to landscaping, groundwater recharge and industrial use. About 25 per cent of the wastewater generated undergoes treatment in Morocco, and about 45 per cent of the treated wastewater is recycled (SWIM Programme 2013). The country's largest reuse project is in Marrakech, where reclaimed water from the municipal wastewater treatment

Generic pathways for the circular economy in wastewater management

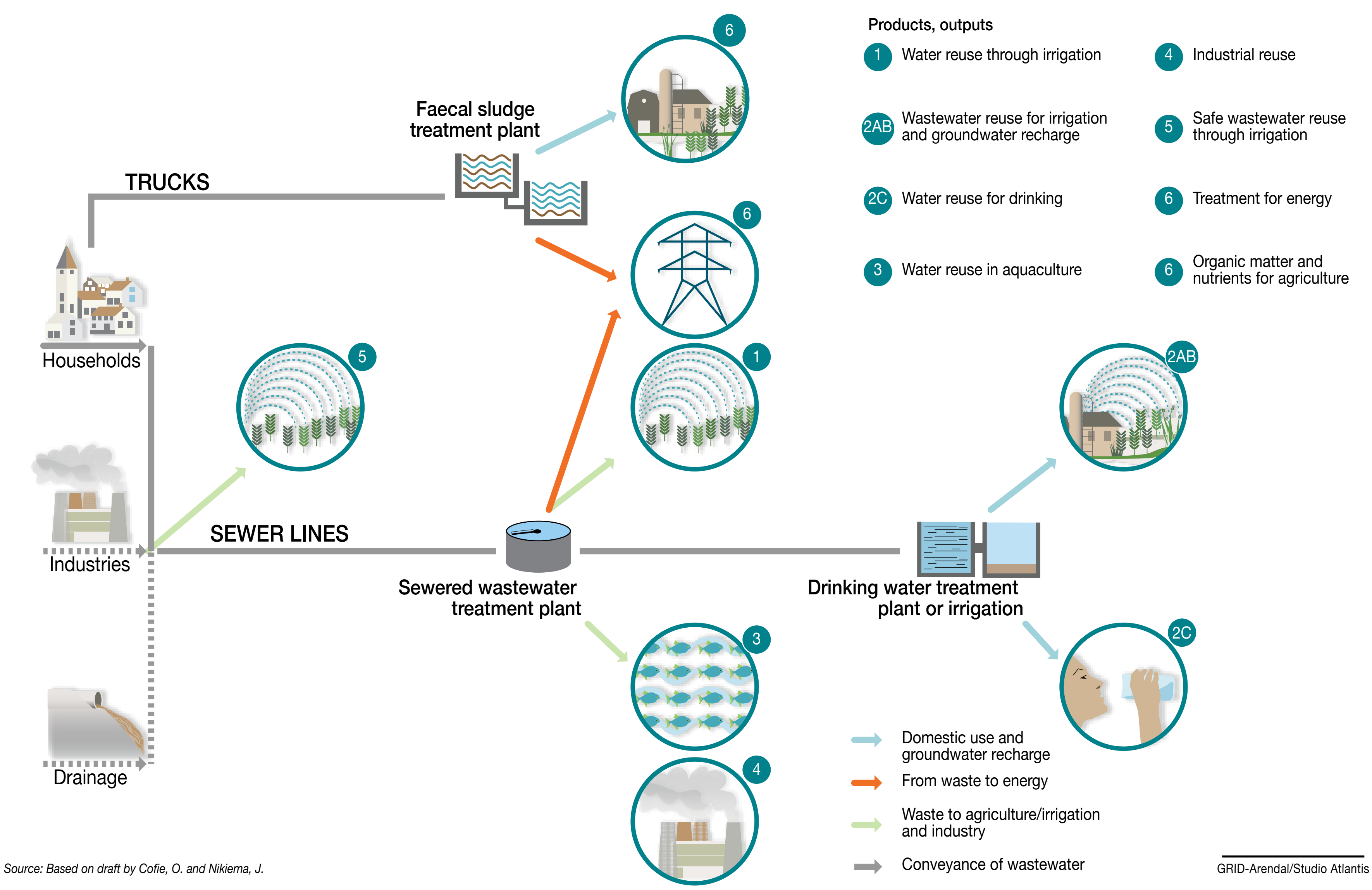


Figure 6.5. Generic pathways for the circular economy in wastewater management

Table 6.1. Wastewater treatment technologies and type of reuse

City	Treatment capacity (Mm3/year)	Treatment process	Treated wastewater reuse
Marrakech	33.1	Activated sludge + sludge digesters + tertiary treatment	Irrigation of 18 golf courses (>1,200 ha) and landscaping
Agadir	18.2	Infiltration + sand filtration	
Ben Slimane	2.0	Aerated waste stabilization ponds + quick sand filtration and ultraviolet disinfection with chlorination	
Biougra	0.5	Waste stabilization ponds + infiltration	Groundwater recharge
Tiznit[a] and Oujda[b]	16.4	Waste stabilization ponds	Agricultural crop production[c]
Khouribga, Ben Guerir and Youssoufia	11.2	Activated sludge	Industrial (phosphate extraction)

Source: Danso et al. 2018-14; Jaouhar, Bourziza and Soudi (2018); SWIM Programme (2013)

a Crops grown in Tiznit include cereals (25 per cent), forage and vegetables (25 per cent) and fruit (olive) trees (50 per cent) (SWIM Programme 2013).
b In Oujda, treated water is used by 245 farmers to grow olive trees and fodder on 1 500 ha of land (Jaouhar, Bourziza and Soudi 2018).
c Treated water is used for unrestricted irrigation.

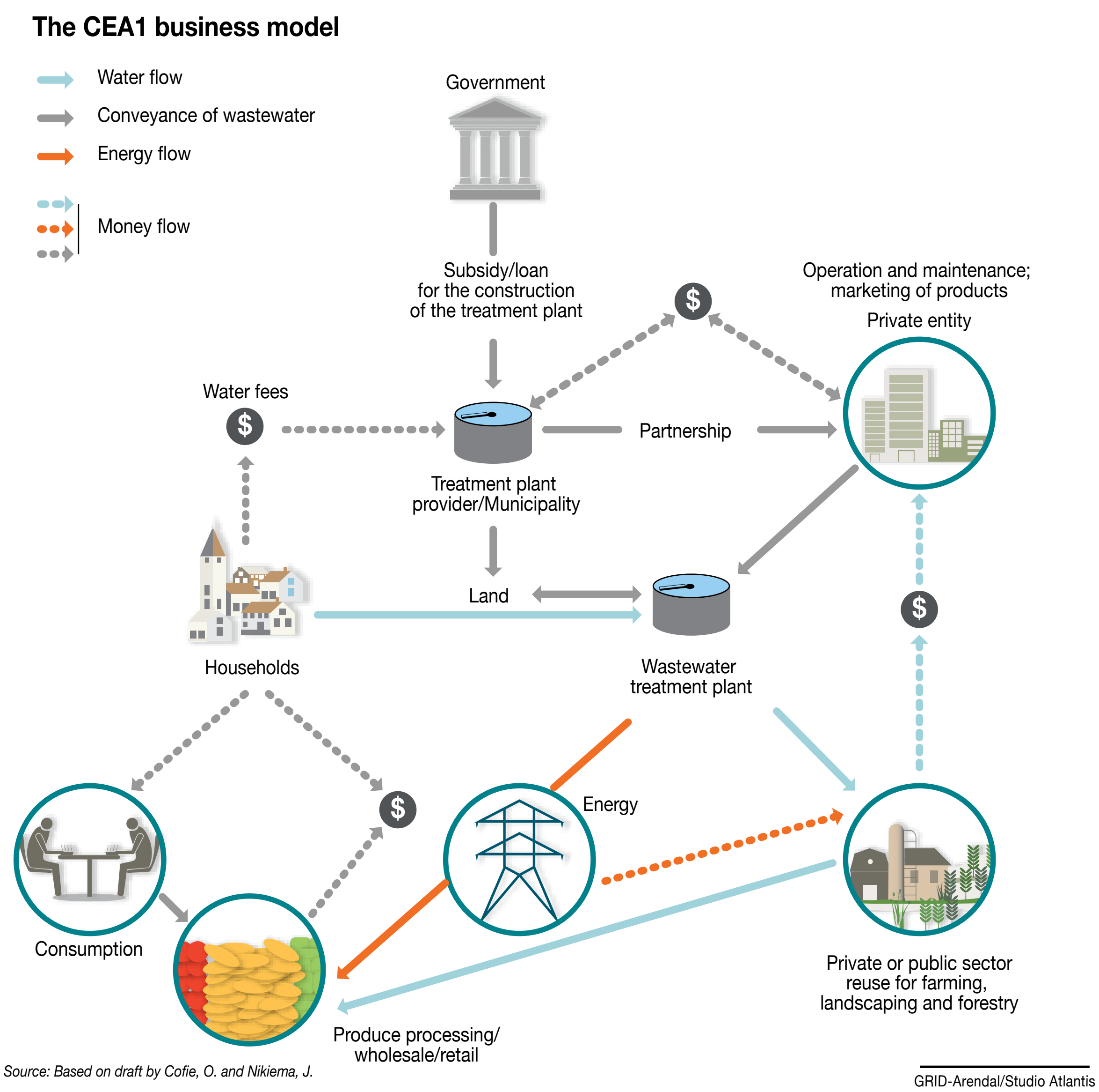


Figure 6.6. The CEA1 business model

plant with a capacity of 33 cubic megametres per year is reused, primarily to irrigate golf courses (see Table 6.1). A partnership between public and private entities has yielded positive outcomes, creating room to source part of the capital cost for wastewater treatment plants from private entities that reuse the wastewater. The same type of co-financing arrangement is replicated in other cities in Morocco. In irrigation models targeting agriculture and involving farmers, challenges such as low cost-recovery due to low willingness to pay for treated wastewater, as well as concerns regarding the quality of treated water (for example, wastewater in Morocco has been reported to have high salinity, with electrolytic conductivity of between 1.8 and 5.5 dS/m) constitute a limitation to large-scale adoption of treated wastewater reuse (SWIM Programme 2013).

Table 6.2 presents the status of treated wastewater use in selected African countries, namely Algeria, Egypt, Morocco and Senegal, as of 2018.

6.3.1.2 Sources of revenue

Treated wastewater is either free or available for a fee. If it is free, cost recovery for the reuse components will largely be impacted by the wastewater treatment plants' operation and maintenance costs, which must be reduced to be kept to a minimum. For example, in Egypt, land is leased to farmers to promote reuse of treated wastewater on allocated land (Drechsel and Hanjra 2018-14). If a large amount of wastewater is treated, sufficient volume of sewage sludge is produced. It can further be treated for biogas generation and compost or dry sludge production, adding to the sources of revenues. Another possible revenue stream could be carbon sequestration in forest plantations or orchards.

Although the reuse of treated water for irrigation does not always provide significant financial returns, it has some environmental benefits and also serves to meet demand under competing needs for freshwater resources, as presented in Appendix 6.1 (Tables 6.12 to 6.16).

Box 6.1. Sources of revenue, conventional and non-conventional

Conventional sources of revenue:
- Household sanitation fees
- Government subsidies
- Treated wastewater use charges

Non-conventional sources of revenue:
- Sales of forest/tree-crop products
- Sludge recycling
- Land charges
- Carbon credits

Sources: Drechsel and Hanjra (2018-14); Danso et al. (2018-14).

Table 6.2. Status of treated wastewater (TW) reuse in selected African countries as of 2018

	Algeria	Morocco	Senegal	Egypt
Number of treatment plants in the country	188 (including 8 with tertiary treatment and 17 applying wastewater reuse [WR])	121 (66 per cent WSP, 14 per cent activated sludge)	14 wastewater treatment plants (WWTPs) and 14 faecal sludge treatment plants	358 (as of 2013) (11 per cent WSP, 75 per cent activated sludge)
Volumes treated	123 Mm3/year	314 Mm3/year	7 Mm3/year (in 2012)	3,000–3,650 Mm3/year
Per cent reused directly	7 per cent	15 per cent of wastewater generation or 45 per cent of treated fractions	0.50 Mm3/year in Thiès; 0.46 Mm3/year in Dakar	19–23
Irrigated surface – Actual (potential)	11,062 ha (target to reach by 2030: 100,000 ha)	2,000 ha for agriculture	60 ha	4,478 ha (public forestry only) (potential is up to 37,000 for public-sector initiatives)
Implementing institution(s)	National Sanitation Utility	National Water and Electricity Utility; Ministry of Energy, Mining, Water and Environment; Municipalities	National Sanitation Utility	Holding Company for Water and Waste Water and its affiliates: Ministry of Water and Wastewater Utilities and Ministry of Agriculture and Land Reclamation
Guiding regulations	• Law 05-12 (2005) permits treated water use in irrigation • Decree 07-149 (20/05/2007) defines conditions for treated water use in irrigation; supported by the Ministerial Decree of 02/01/2012 • Algerian Standard 17683 defines specifications of physical, chemical and microbial quality of treated wastewater (TW)	• Decree 2-97-875 defining conditions of TW use • Ministerial Decree in 2002 on standards on TW quality (physical, chemical and microbial) for irrigation • Restrictions on irrigation systems for different water qualities and crops	• Article R30 sets conditions of reuse of water • Standard inspired by World Health Organization (WHO) guidelines	• Egyptian Code (Ministerial Decree No. 171/2005) defines conditions of TW use in agriculture (for example, it prohibits the use of raw wastewater) • Law 48/1982 defines TW quality for discharge and imposes limits on agricultural uses of TW
Financing of WWTPs (operation and maintenance)	Public sector	Public and private (mostly golf courses) sectors	Public sector	Public sector
Challenges with TW use	• Disconnect between plans of TW producers and users; unclear roles and responsibilities for many actors; non-alignment of treatment standards with reuse standards (i.e. financing of additional resources required for TW safe use) • Limited awareness of safety measures, standards and best use practices; incomplete or constraining regulations on TW use beyond WHO standards • Competition with conventional water; insufficient TW availability during summer due to lack of adequate storage facilities • Cost of O&M of WWTPs and irrigation systems (insufficient cost recovery); management of treatment plant by-products; low willingness to pay for TW (prices must be subsidized) • Poor/inadequate TW quality (for example, odour in the water); limited monitoring of TW quality due to high costs required or lack of capacity • Low willingness to pay for TW versus high O&M costs of networks • Inadequate/insufficient water quality (salinity, pathogens) potentially leading to reduced soil fertility • Poor linkage between treatment and reuse • Land availability for irrigation; inadequate localization of the WWTPs (away from farming areas)			
Use of TW	• Tree irrigation • Agriculture	• Mainly: Irrigation of green parks and golf courses • Agriculture (farmers' fee: 0.056 USD/m^3, half the price for agricultural water) • Industrial use (transport of phosphates) • Groundwater recharge	• Agriculture (water reuse tariffs set at €0.076/m3)	• Tree irrigation • Landscaping • Indirect reuse is very prominent
References	Hartani 2018	Danso et al. 2018-14; Jaouhar, Bourziza and Soudi 2018; SWIM Programme 2013	Niang 2018; Waterbiotech 2012	Moussa 2012; Drechsel and Hanjra 2018-14; SWIM Programme 2013

6.3.2. CEA 2: Reclaimed sewered wastewater for direct and indirect potable use

In this CEA, sewered wastewater is treated to meet quality standards for drinking. There are three possible pathways to convert wastewater into drinking water, as shown in Figure 6.7.

Main resources:
Treated water for drinking or storage

Treatment technology:
- Advanced wastewater treatment processes (for example, membrane filtration) for direct reuse as potable water
- Conventional wastewater treatment processes for indirect reuse through groundwater recharge
- Untreated wastewater use in agriculture with indirect groundwater recharge

Typical geography:
Peri-urban, rural

Rivers flowing through towns are at a great risk of pollution

6.3.2.1 Case examples

Reclaimed sewered wastewater for direct and indirect potable use has not yet been extensively explored in Africa. Examples of groundwater recharge initiatives are reported in Morocco (Jaouhar, Bourziza and Soudi 2018) and are being explored in other parts of Africa such as Egypt (El Arabi 2012), albeit with several challenges in demonstrating positive impacts. Box 6.2 presents a brief overview of the most promising example reported of this case, in Windhoek, a city with about 350,000 inhabitants located in Namibia, which is the most arid country in sub-Saharan Africa. Annual rainfall is 370-450mm and there are no perennial rivers in the country (van der Merwe 2008; Lahnsteiner and Lempert 2007). For many decades before the 1960s, Windhoek relied solely on groundwater for drinking. Later on, dams were constructed but the water supply was insufficient, especially during extended periods of drought (Biggs and Williams 2001). The first plant to process domestic wastewater for drinking purposes was constructed in 1968 and subsequently replaced in 2002 with a new system.

In Windhoek, operational barriers are essential aspects of the treatment processes (van der Merwe 2009). The following non-treatment barriers are also being used for the city water management:
- Strict control of wastewater release into sewers for treatment and drinking, including diversion of all industrial effluents to other treatment plants
- Strict control of raw and treated wastewater, to ensure early detection and correction of any public health issue
- Implementation of good solid waste management practices (van der Merwe 2009)

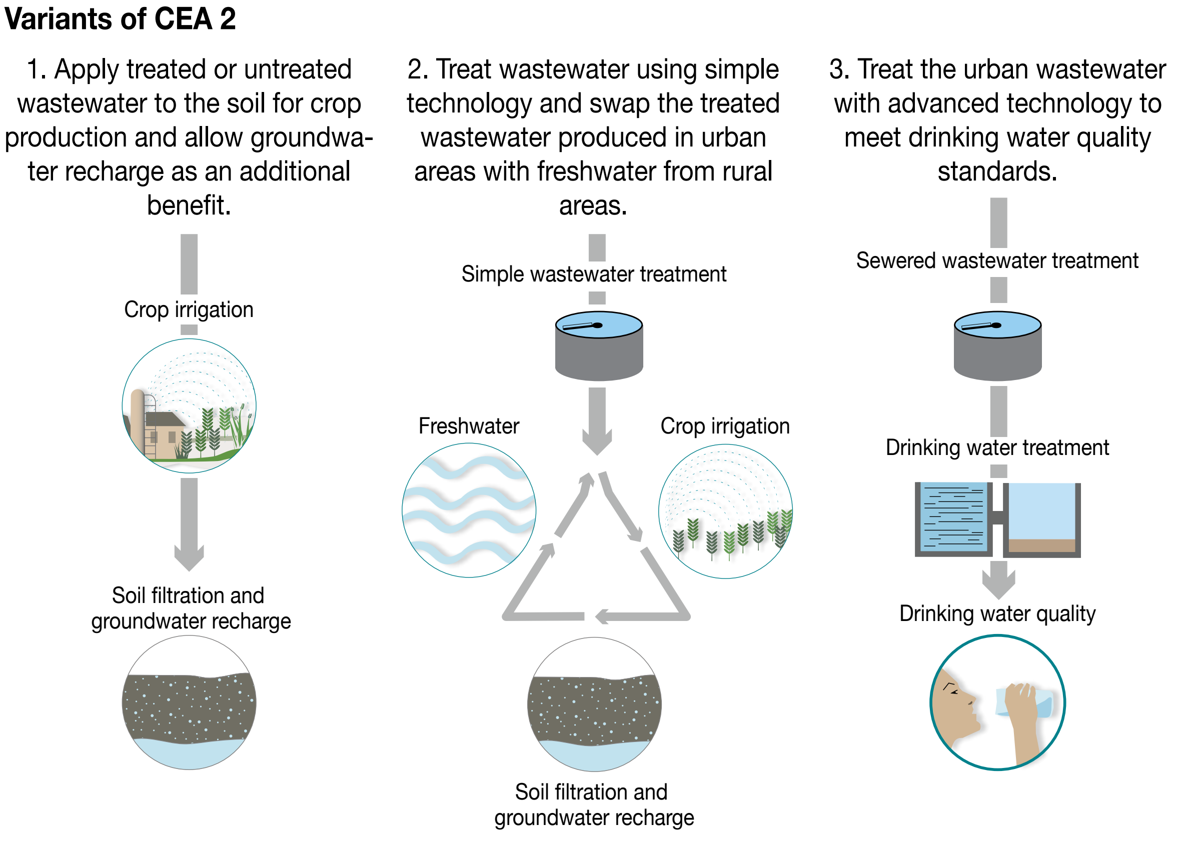


Figure 6.7. Variants of CEA 2

Box 6.2. CEA 2: Existing plant in Namibia

Volumes of wastewater treated:
9.1 Mm^3/year in one plant

Implementing institution(s):
Windhoek Goreangab Operating Company

Guiding regulations:
Quality compliance guidelines are stipulated under the Private Management Agreement

Financing of wastewater treatment plants operations and maintenance:
Public

Use of treated water:
- Only a maximum of 35 per cent of treated wastewater blended with conventional drinking water sources can be supplied to residents;
- Surplus treated wastewater is used for aquifer recharge and irrigation

Since these (treatment and non-treatment) risk-mitigation measures have been put in place, no health problems have been encountered in the city (Onyango, Leslie and Wood 2014; Lahnsteiner and Lempert 2007). To improve acceptance of wastewater reclamation, several awareness campaigns are organized with the media and in schools (Onyango, Leslie and Wood 2014). There are also policy measures for water conservation such as water-efficient equipment and strict rules for gardens and swimming pool water management (Lahnsteiner and Lempert 2007).

The business model of this CEA is presented in Figure 6.8.

6.3.2.2 Sources of revenue

Sources of revenue include household sanitation fees for wastewater discharged into sewers and government subsidies (van der Merwe 2009), as well as drinking water charges and groundwater abstraction fees (Drechsel and Hanjra 2018c; Van der Merwe 2009; Jimenez 2008; Danso et al. 2018-17). In Windhoek, financial savings from wastewater reclamation are between US$2.16/m^3 (if a nearby groundwater supply has been adopted) and US$25.81/m^3 (if the drinking water was sourced from the closest surface-water source) (Van der Merwe et al. 2008). However, to obtain drinking-quality water, the operation and maintenance costs per cubic metre are double those of treating wastewater for irrigation (i.e. US$1.05 against US$ 0.52).

Reuse of wastewater to water lawns

The main advantages of reclaimed sewered wastewater for direct and indirect potable use are the high social impacts. For farmers, increased water availability and nutrients means higher yields and better livelihoods, while for citizens, sufficiently available drinking water is essential for a good quality of life.

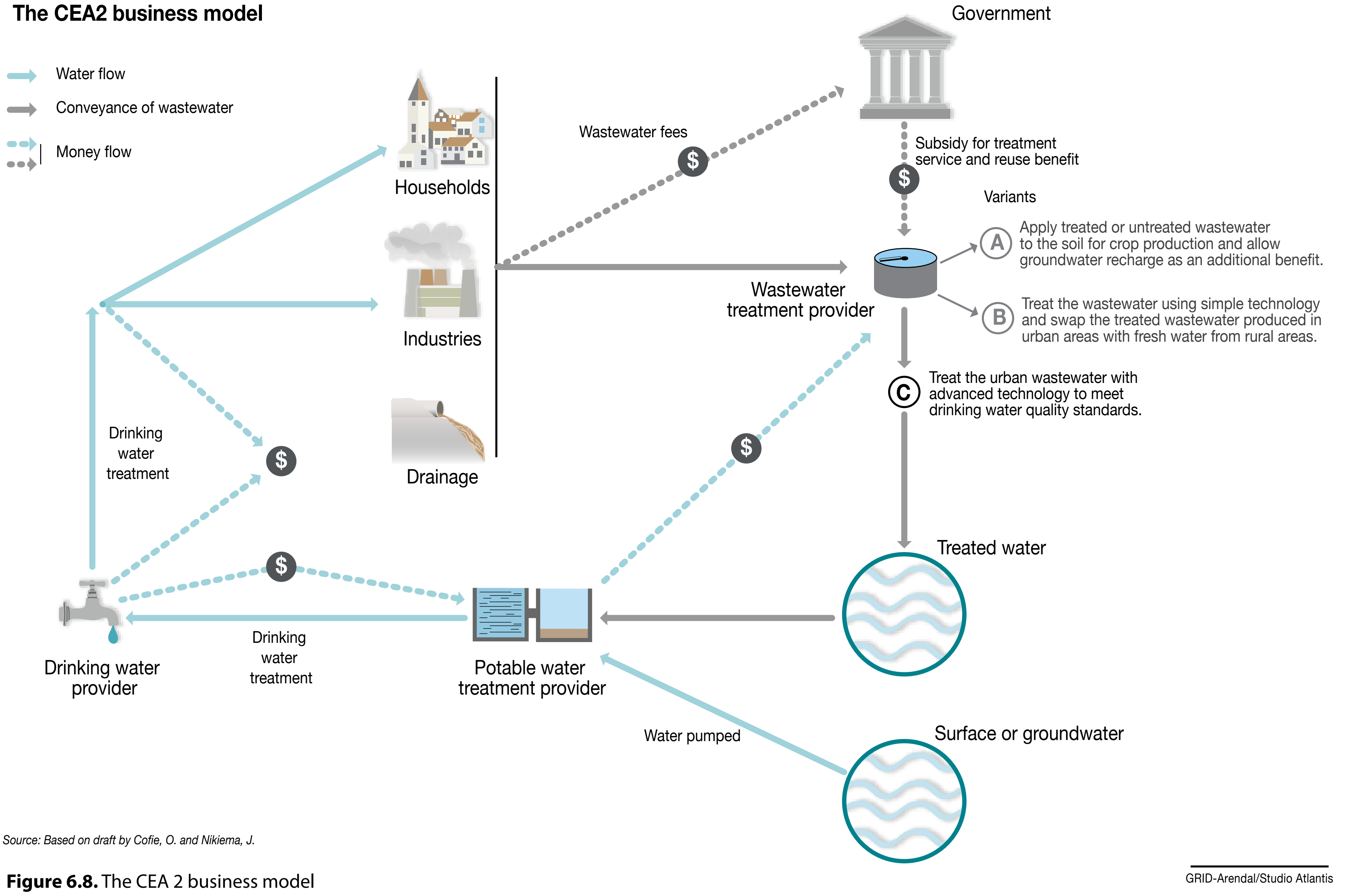


Figure 6.8. The CEA 2 business model

6.3.3. CEA 3: Treated wastewater for aquaculture

In this CEA, sewered wastewater is treated to quality standards suitable for fish, fingerling and livestock feed production.

6.3.3.1. Case examples

Table 6.3 presents the status of treated wastewater reuse for aquaculture in selected countries. Waste stabilization ponds are transformed into fish ponds for fish species that can survive under such conditions (Drechsel and Hanjra 2018a; Drechsel and Hanjra 2018b). Studies (IWMI 2018) show that pathogens may accumulate on the skin and in the gut of the fish, so it is important that fish ready for harvesting spend the days prior to the harvest in clean water. Post-harvest processing techniques such as smoking should be carried out on the fish harvested from wastewater ponds. The preferred fish-processing method depends on the local context and market demand. Rearing of broodstock for fingerling production helps to minimize the negative perception of using wastewater for aquaculture. Since the use of treated wastewater for aquaculture is not consumptive, it can still be used for other activities, such as irrigation of crops or fruit trees (Drechsel and Hanjra 2018d).

6.3.3.2. Sources of revenue

Conventional revenue sources (Box 6.3) include household sanitation fees for wastewater discharged into sewers, either collected as part of the water bill or separately, and government subsidies reflecting the treatment service benefits for society and nature. Another key revenue source comes from fish and fish feed sales. In some cases, fingerlings are also produced and sold.

Main resources:
Treated water for aquaculture

Treatment technology:
Pond stabilization systems or any process involving the use of ponds or enabling the construction of fish ponds

Typical geography:
Urban, peri-urban

Table 6.3. Status of wastewater treatment and reuse for aquaculture in Ghana and Bangladesh

Country and wastewater treated	Main wastewater treatment pond processes in the country	Products
Ghana 225 m^3/d	Waste stabilization ponds (1 ha)	• 40 tons of African catfish • Fingerlings • Broodstock
Bangladesh 300 m^3/d	Waste stabilization ponds (1ha) + duckweed canals (0.6 ha)	• 6.5–15 tonnes carp • Fish feed • Fruit

Source: Amoah et al. (2018); Drechsel et al. (2018)

Box 6.3. Sources of revenue, conventional and non-conventional

Conventional sources of revenue:
- Household sanitation fees
- Government subsidies
- Fish sales
- Fish feed and fingerling sales

Non-conventional sources of revenue:
- Sludge recycling
- Reuse of treated wastewater for irrigation
- Carbon credits

Figure 6.9 presents the typical financial flow from a recently implemented model in Kumasi, Ghana. The main sources of revenue are from sales of African catfish, which exceed the operation and maintenance costs of the wastewater treatment plant.

Treated wastewater can also be reused on-site to irrigate crops and fruit trees or for several other purposes. The volumes of sludge in small plants may not be attractive enough to engage in sludge recycling and commercialization. Also, carbon credits may be considered if the scale of implementation of this CEA and related savings are sufficient.

The main benefit of using treated wastewater for aquaculture is the high profitability potential of fish farming and the low operation and maintenance costs of the treatment plant. The environmental impact of treated wastewater for aquaculture is moderate compared with other CEAs, as the addition of fish feed to treating ponds may increase the nutrient content of the treated wastewater.

6.3.4. CEA 4: Recycling of wastewater for industrial use

Recycling wastewater for industrial use is critical in regions affected by high water stress. In Durban, South Africa, a private company treats the city's wastewater for local industries to reuse.

Main resources:
Wastewater

Treatment technology:
Multiprocess treatment of municipal waste-water with activated sludge and ozonation

Typical geography:
Urban, peri-urban

6.3.4.1. Case example

Durban is the third biggest city in South Africa, a water-scarce country. During the 1990s, Durban faced constraints in its sewage capacity and management. The existing infrastructure could not cope with the city's growing population and economic development. The municipality therefore had to invest in new infrastructure to increase wastewater collection in order to avoid negative impacts on its citizens and the environment. Durban's first option was to invest in a new marine outfall pipeline to discharge the treated wastewater

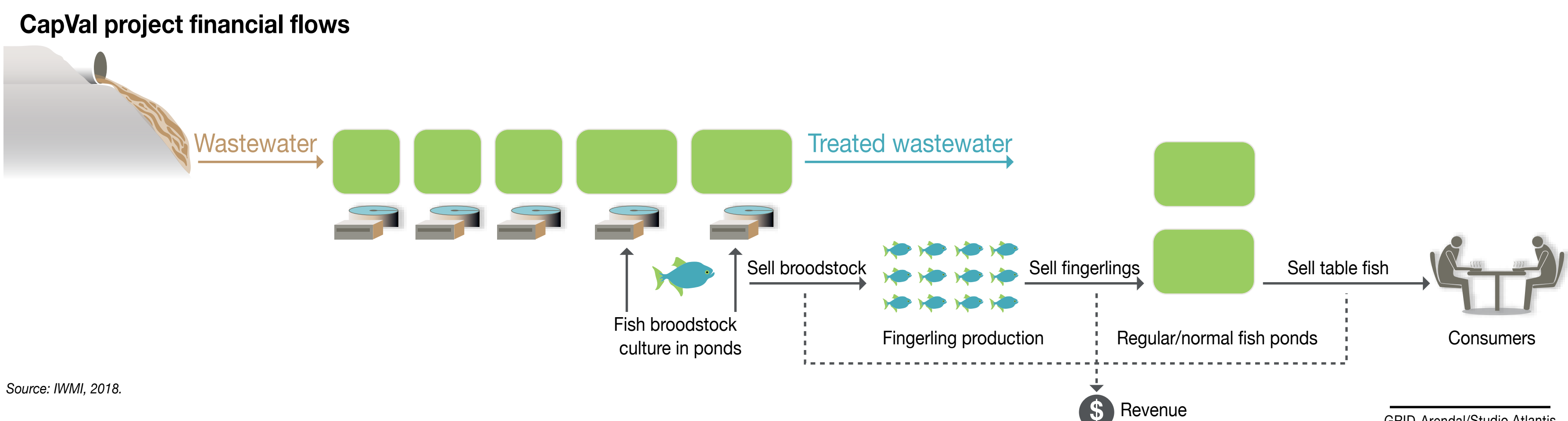


Figure 6.9. CapVal project financial flows

into the Indian Ocean. The costs of this infrastructure were very high, leading the city to consider alternative solutions to prevent large increases in the costs of wastewater disposal in the area. Through a public-private partnership, the municipality successfully implemented a wastewater recycling project for industrial purposes. This project is an example of sustainable wastewater management that also has multiple environmental, economic and social benefits for the region. In addition, the project is the first of its type in South Africa and is an example of a solution that does not dispose of wastewater, but considers it an asset.

Instead of increasing the capacity of the existing marine outfall pipeline in the city's Southern Wastewater Treatment Works to discharge primary treated wastewater into the ocean, Durban explored the possibility to further treat it for industrial reuse. A paper company and an oil refinery expressed interest in receiving the treated wastewater. The aim of the project was to treat around 48,000 m³ per day (approximately 10 per cent of the city's municipal wastewater) and achieve an acceptable quality for industrial reuse, with 85 per cent of the treated wastewater going to the paper company and 15 per cent to the oil refinery. In order to be able to supply recycled water to these two industrial users, the municipal water utility (eThekwini Water Services) needed to upgrade the existing activated sludge process, build a new tertiary wastewater treatment plant, refurbish the high-level storage tank and install a reclaimed water reticulation system. One of the project's complexities was that the paper company required high-quality water, given that it is used to produce fine paper (World Bank Group 2018).

6.3.4.2. Sources of revenue

The revenue from the sale of the treated wastewater for industrial use covers almost all operation and maintenance costs of the treatment plant as shown in Figure 6.10. After an international biding phase, Durban Water Recycling, a consortium of private companies led by Veolia (formerly Vivendi Water) was chosen to finance, design, construct and operate the tertiary wastewater treatment plant at Southern Wastewater Treatment Works under a 20-year concession contract. Durban Water Recycling funded the entire project and also undertook the risk of meeting the two industrial users' water quality needs, meaning the municipal utility did not incur any extra costs for taxpayers.

Figure 6.11 presents a stakeholder diagram for the Durban wastewater recycling project. The total investment in the project was R72 million (US$4.858 million). Equity from Durban Water Recycling company was 19 per cent of the investment cost. After signing a 20-year concession contract with the eThekwini Water Services (municipal utility), the Durban Water Recycling consortium approached the Development Bank of Southern Africa and the Rand Merchant Bank for loans of R34 million ($2.295 million) and R24 million ($1.62 million).

The guaranteed demand for treated wastewater from the two industrial users made the project economically attractive. The Durban Water

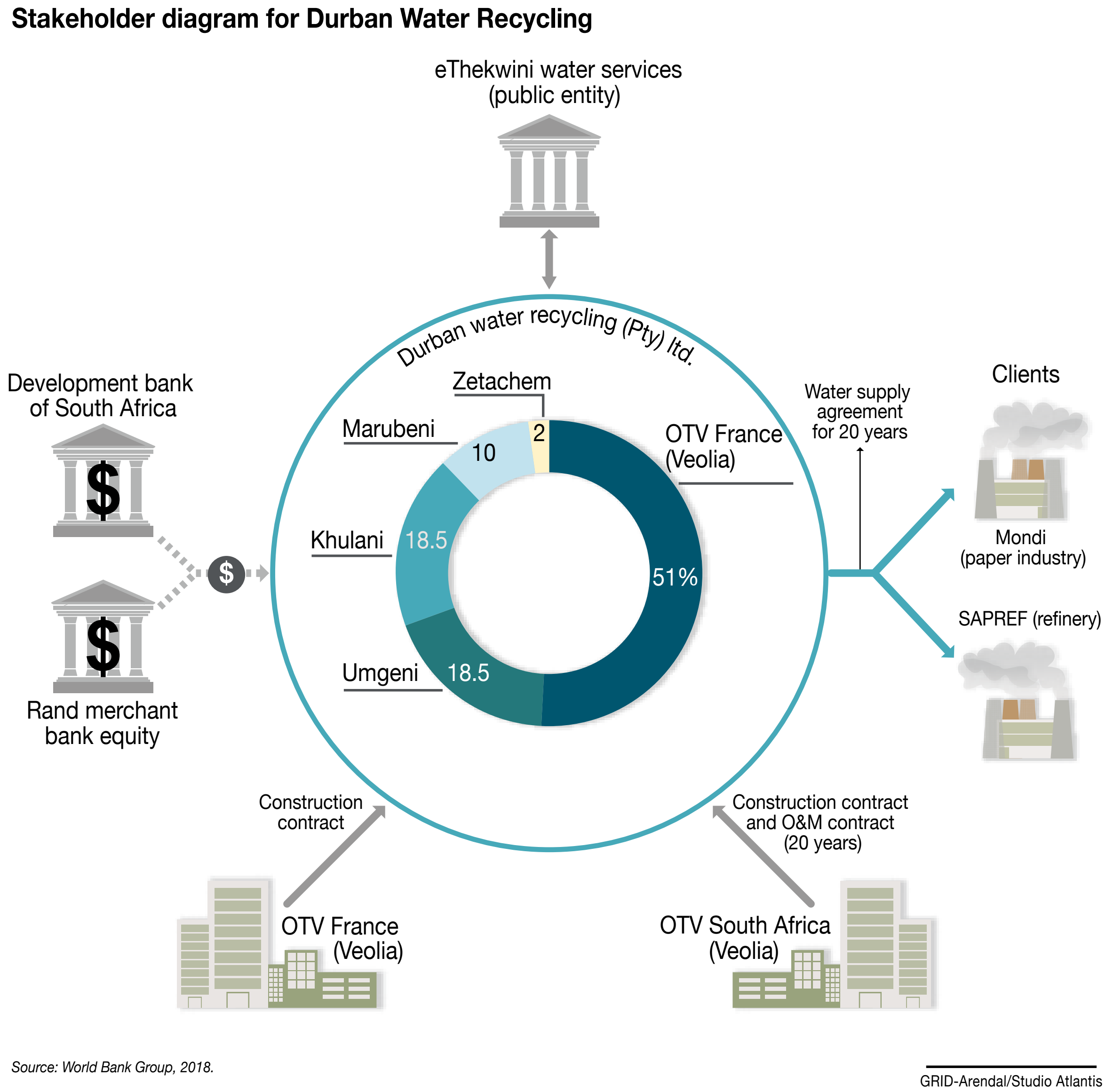


Figure 6.11. Stakeholder diagram for Durban Water Recycling

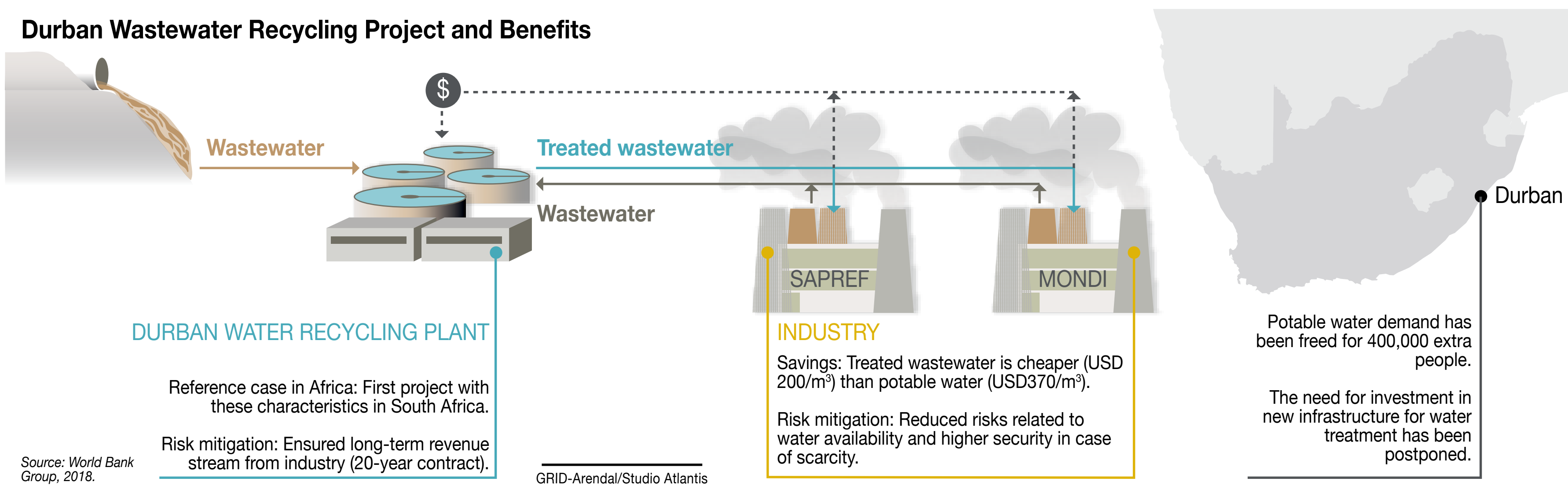


Figure 6.10. Durban wastewater recycling project and benefits

Recycling consortium pays fees to the municipal utility, including an annual management fee, a land-leasing fee and a levy per cubic metre to reflect the cross-subsidization income from the industrial users. The sales price of treated wastewater is now cheaper than potable water, at R28/m^3 (\$1.89/m^3) compared with R54/m^3 (\$3.65/m^3).

The model of recycling wastewater for industrial use is an example of a successful and innovative public-private partnership agreement that improves the sustainability of wastewater management, minimizes environmental impacts and generates multiple benefits for the community. The city of Durban was able to convert a challenging situation into an opportunity, leveraging local conditions and innovative thinking into a win-win solution for all stakeholders. Though the wastewater treatment technologies implemented for the project are quite standard, the innovative combination of the different steps makes the project unique, as the treatment technology has been customized to ensure that the recycled water meets the quality standard of the industrial clients.

Untreated wastewater for irrigation

6.3.5. CEA 5: Safe use of untreated wastewater for irrigation

Untreated wastewater is used for crop irrigation, usually in an uncontrolled and unregulated manner. This practice can be made safe by setting up risk barriers at different critical points, including appropriate strategies to enhance public risk awareness and improve safety (Drechsel 2018). Countries such as Mauritius or Tunisia have shifted away from reusing wastewater in an informal or indirect manner towards more formal and safer practices.

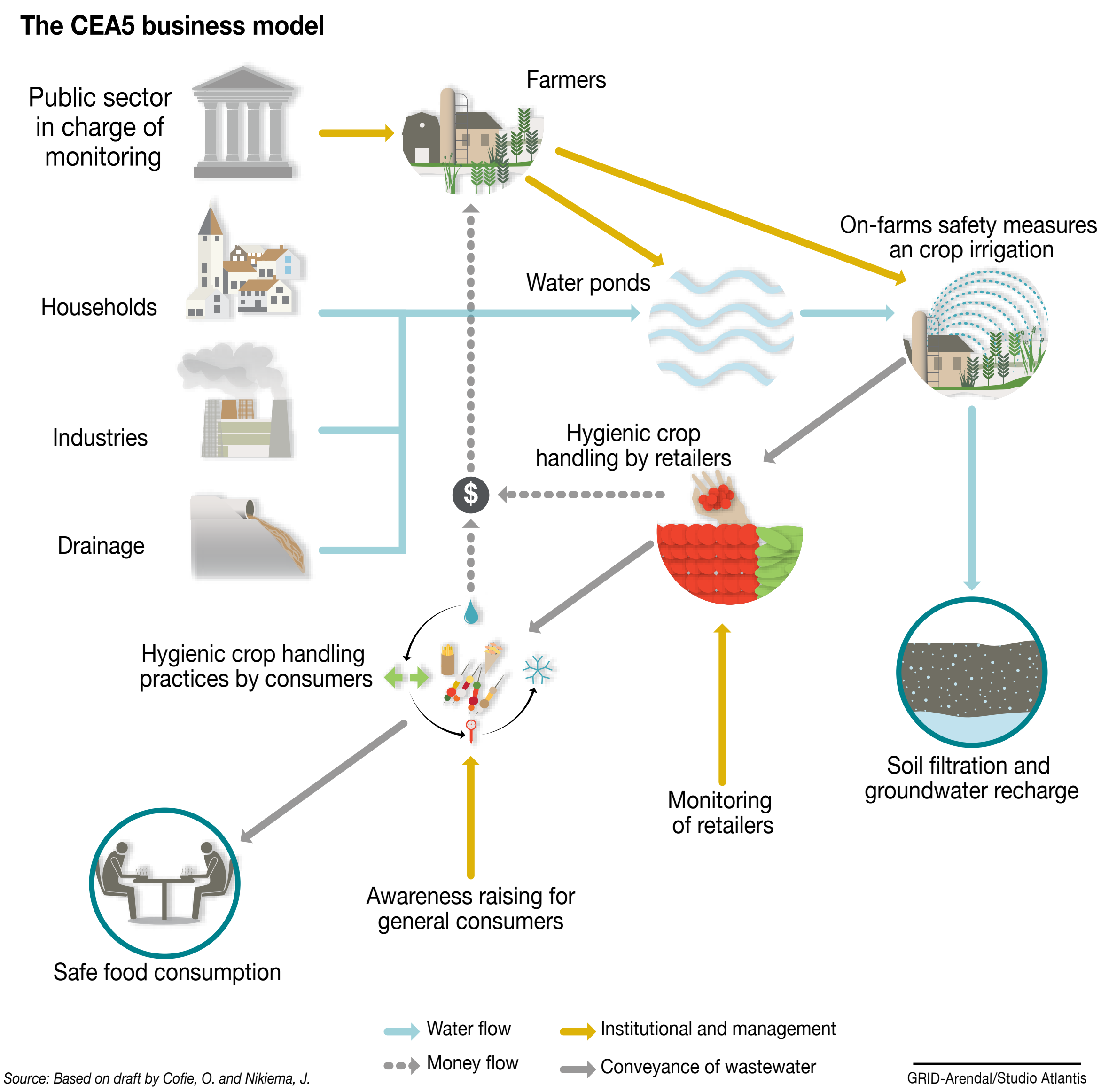


Figure 6.12. CEA 5 business model

Main resources:
Untreated wastewater for irrigation

Treatment technology:
On-farm safe irrigation practices combined with hygienic handling practices and safety awareness

Typical geography:
Urban, peri-urban

The business model of CEA 5 is presented in Figure 6.12.

6.3.5.1. Case examples

In general, only 10 per cent of the wastewater generated in the world receives some form of treatment (Thebo et al. 2017). Africa has particularly low coverage of wastewater treatment. The use of untreated, partially treated or diluted wastewater occurs downstream of urban areas in four out of five cities in the developing world and is usually driven by farmers' lack of alternative water sources and/or search for nutrients (Thebo et al. 2017). This often informal reuse of wastewater benefits farmers and the local economies and contributes to increasing the food supply. To mitigate associated risks and protect public health, it is important to apply the multiple-barrier approach as recommended by the World Health Organization (WHO) in 2006 (see Figure 6.13).

Many low-cost technologies and practices can significantly reduce health risks on- and off-farm. As part of on-farm measures, use of ponds (Figure

Washing vegetables with clean water can help reduce the germs and contaminants on food

Table 6.4. Examples of incentives to encourage farmers and consumers to adopt safety measures in the use of untreated wastewater for irrigation

Incentive	Description
Tenure security	Many farmers who use wastewater in peri-urban areas are challenged with land tenure security. This could therefore be used as an incentive for adopting good on-farm practices.
Credit on condition	Low-interest credit could be provided to farmers applying safe irrigation methods. In this case, there is need for monitoring farmers' compliance with their contractual obligations.
Fear of exposure	Media exposure (e.g. naming and shaming) can be a powerful alternative to steer compliance. Urban farmers and food restaurants often fear media exposure which could trigger eviction from the land or business closure.
Social values	Social marketing can encourage households to adopt safety measures. Possible triggers and drivers for change need to be identified for key target groups.

Source: Drechsel (2018)

6.14), weirs and reservoirs (Figure 6.15), changes in irrigation methods, timing, and adequate selection of crops grown are commonly suggested risk-mitigation measures. Figure 6.16 shows the pathogen concentration as a function of the water retention time in a pond, though these solutions may not always be financially attractive for farmers (Drechsel 2018). Table 6.4 shows the benefits of adopting safety measures when using untreated wastewater.

Implementing good post-harvest handling practices, such as washing by traders and processors (restaurants or households), can further improve the quality of farm produce. Experiences in Ghana showed that the cumulative effect of the multiple-barrier approach can completely address the health risks associated with using poor quality water for irrigation (Figure 6.17).

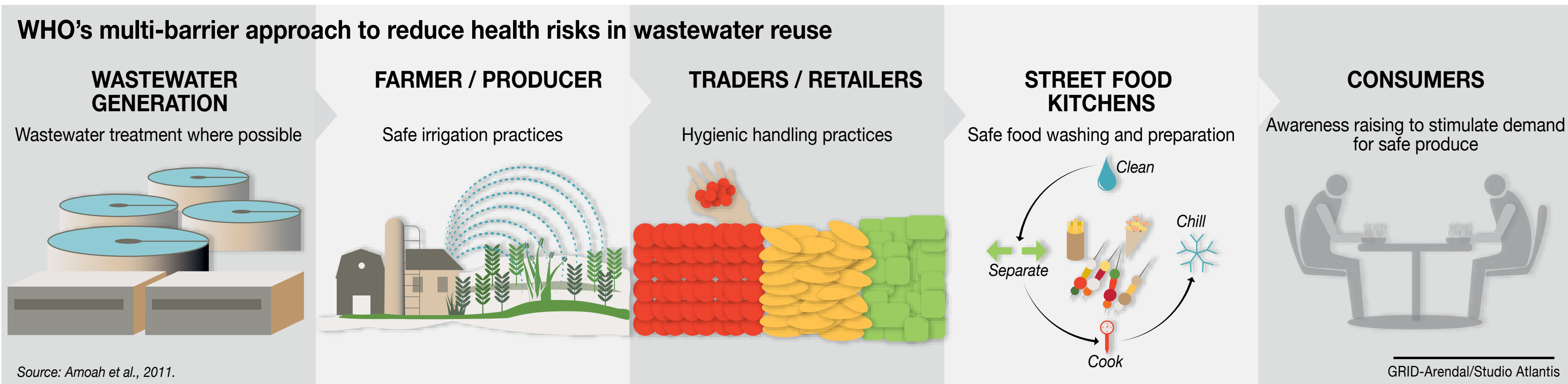


Figure 6.13. WHO's multi-barrier approach to reduce health risks in wastewater reuse

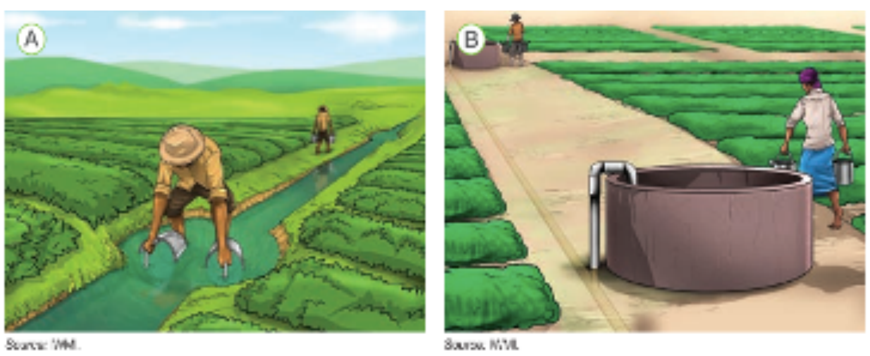


Figure 6.14. Common on-farm ponds use in West Africa

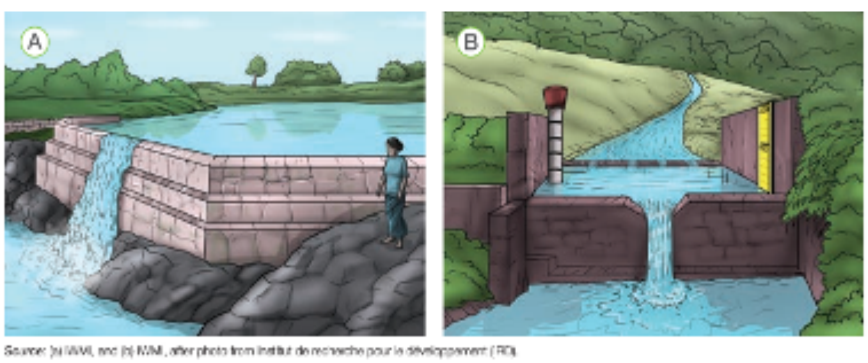


Figure 6.15. Use of weirs and reservoirs

Safe use of wastewater is a challenge for poor farmers

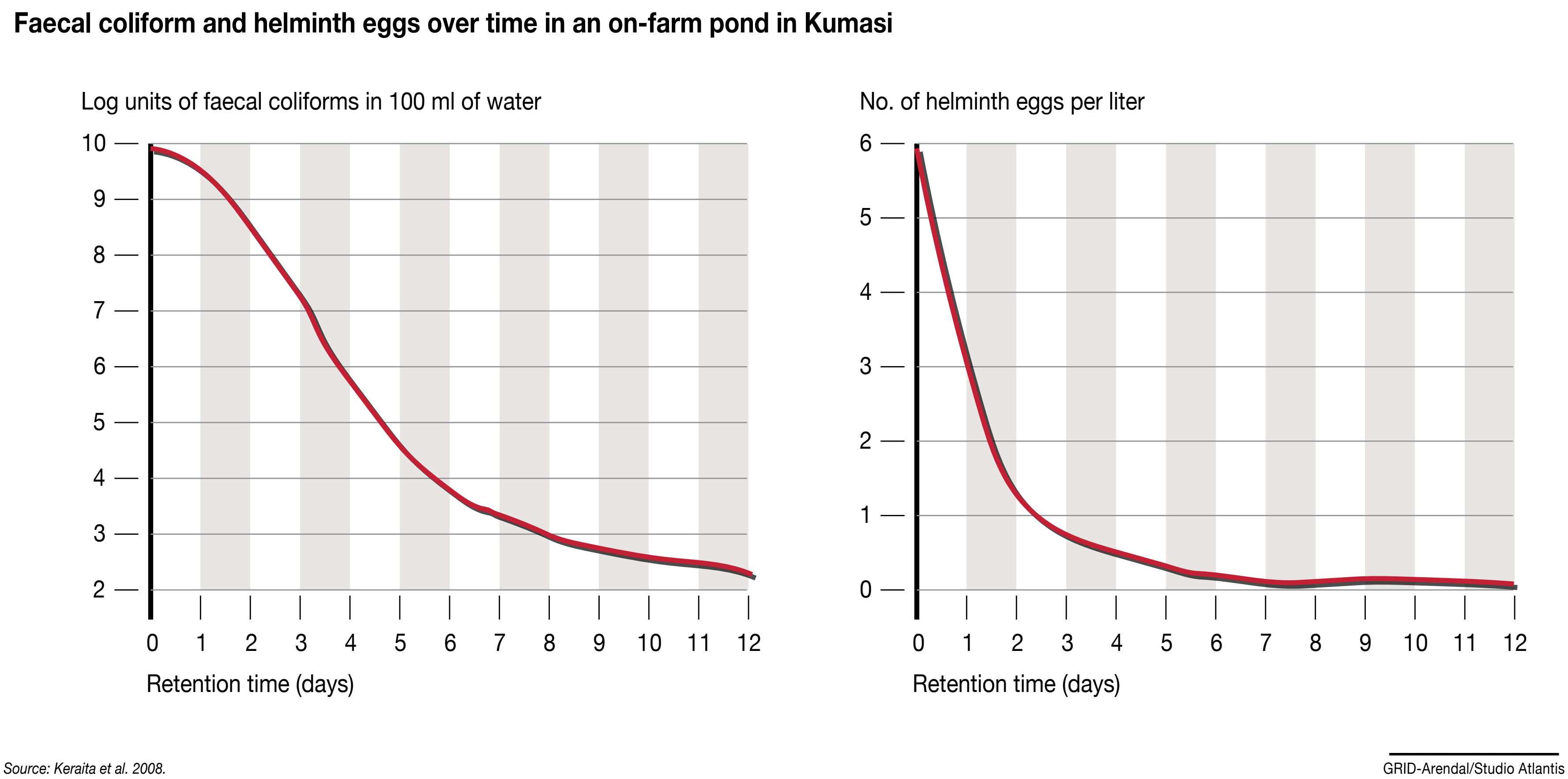


Figure 6.16. Faecal coliform and helminth eggs over time in an on-farm pond in Kumasi

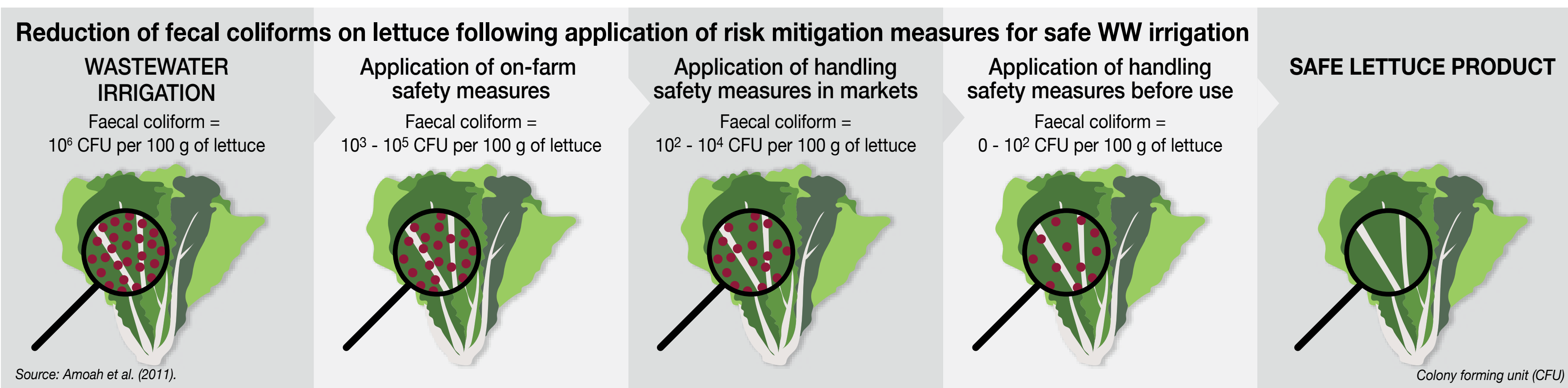


Figure 6.17. Reduction of faecal coliforms on lettuce following application of risk-mitigation measures for safe wastewater irrigation

Small-scale irrigation

6.3.5.2. Sources of revenue

The main advantage of using untreated water for irrigation is increased food production. Studies confirm that for every dollar spent on risk reduction from 'farm to fork' will return US$5 in consumer health care savings (Drechsel 2018). The social nature of these costs justifies the relevance of public investments in incentives to promote safe reuse of wastewater and minimize risks along the entire crop value chain. However, risk awareness and the incidence of costs and benefits do not fall evenly across stakeholders along the value chain, which creates difficulties in terms of financing the implementation of this approach.

Overall environmental impacts are minimal due to the use of untreated wastewater for irrigation. It also reduces expenditure on public health while supporting the informal irrigation sector (often dominated by rural migrants or minority groups).

Table 6.5. Mechanisms for financing the needed changes

Driver of change	Means of achievement	Measures adopted for improved safety	Examples
Corporate social responsibility	Support of wastewater treatment	Conventional wastewater treatment plant	Industrial companies such as Nestlé invest in wastewater treatment plants to treat their wastewater in areas where there are no such facilities. Wastewater therefore becomes available for irrigation.
	Support of farm-based interventions	Drip irrigation used on-farm	In Botswana or South Africa, some supermarkets or wholesale companies opt for compliance with a 'responsible sourcing policy' to meet international quality and sustainability standards. These companies source their crops from farmers applying safe on-farm irrigation practices.
	Support of post-harvest interventions	Awareness-raising campaigns	As part of its consumer service programme, Nestlé initiated the establishment of trader associations, such as the Maggi™ Fast Food (Seller) Association (MAFFAG), in Ghana, which is now the strongest association in the country's street food sector. MAFFAG regularly provides training in food preparation, cooking, environmental hygiene and food safety across the country. Their training programmes are able to address food safety issues throughout the sector.
Quality assurance	Branding certificate	Branding	A recognized certification body could help in attesting compliance with food safety standards. This could increase customers' willingness to pay a premium for better quality products.
Farmer innovations		Investments to secure water	The Water Resources Users Association is a commercial farmers group in Ghana that produces crops for the local market. With a private-sector non-governmental organization (NGO), the group co-invested in a pond and canal system, which supports natural water remediation and can easily be combined with further safety enhancing features.

Source: Drechsel (2018)

6.3.6. CEA 6: Non-sewered sanitation recycling for agriculture or energy

In many African urban and rural areas, people rely on on-site sanitation installations, such as pit latrines and septic tanks, to capture human excreta either at the household level or through shared facilities. Occasionally, these on-site sanitation installations must be emptied with the collected waste (faecal sludge) sent for treatment. Unfortunately, a high proportion of the faecal sludge is released into the environment untreated or only partially treated, which contaminates coastal areas, waterways and land. Faecal-borne pathogens are also released, which can affect food supplies. However faecal sludge has some benefits, such as, for example, its nutrient content, which can be used in agriculture, as well as its carbon, which can be used for soil remediation or converted into energy. The use of non-sewered wastewater recycling for agriculture or energy generation allows compost or energy to be produced from faecal sludge.

6.3.6.1. Case examples

The Fortifer production plant in Tema and the Safi Sana production plant in Ashiaman, Ghana, are examples of non-sewered wastewater that is recycled for agriculture or energy. Both examples involve a public-private partnership arrangement. Jekora Ventures converts faecal sludge into compost fertilizer called Fortifer. The production process (Figure 6.18), which was developed by IWMI, does not demand sophisticated technology. Rather, sufficient space is needed for faecal sludge drying beds and heap composting. Electricity supply is only needed for the post-processing of the compost, if desired. The compost obtained at this plant contains both nutrients and organic matter, which are essential for plant growth and soil health. The compost can be processed further through pelletization and/or enrichment, which increases its quality and market value.

Bulk water delivery

Under the public-private partnership arrangement, Jekora Ventures agreed the following implementation conditions with the Tema Metropolitan assembly:

- the private entity bears the operation and maintenance costs
- the public sector and other donors are to finance the capital cost
- profits from the plant operation are to be shared as follows:
  - municipality/private entity: 20 per cent/80 per cent after breakeven and until the private entity recovers the working capital investment
  - municipality/private entity: 50 per cent/50 per cent thereafter
- profits generated by the municipality will finance community sanitation projects (see Figure 6.19 for the business financial flows).

As regards the second company, Safi Sana, faecal and organic waste are collected from urban slums and treated in a biodigester to create compost fertilizer called Asase Gyefo, irrigation water and biogas, which is generated into electricity that feeds into the national electricity grid. The sale of these products can cover operational costs, thus making the company independent of government subsidies support. Irrigation water and a percentage of the compost fertilizer are used in a greenhouse for seedling and herb production (where compost is used as a substrate). Safi Sana provides employment for the local community, improves quality of life through better hygiene at central toilets and better waste management and improves local food security through high-yielding compost. Fortifer and Asase Gyefo have been tested for other contaminants, in particular heavy metals.

Sanivation, a social enterprise, is another case example. The enterprise operates container-based sanitation services in the Kenyan town of Naivasha since 2012. Naivasha has a population of almost 200,000 people and is located about 90 km north-west of Nairobi, the capital city of Kenya. The container-based toilets provided by Sanivation are urine diversion dry toilets (UDDTs) in which the urine and faeces are collected in separate containers at the site where the toilets are located. As of late 2018, around 130 container toilets had been installed in the areas served by Sanivation. Twice a week, the excreta is collected by Sanivation from all their clients and transported to a factory where the faeces are sterilized through thermal treatment, mixed with other local biomass materials and then compressed into briquettes while the urine is drained into a soak pit. As of April 2019, Sanivation had sold over 1,000 tonnes of briquettes to a variety of clients including households, restaurants, supermarkets and poultry farms, all of whom use the briquettes as solid fuel for cooking and heating.

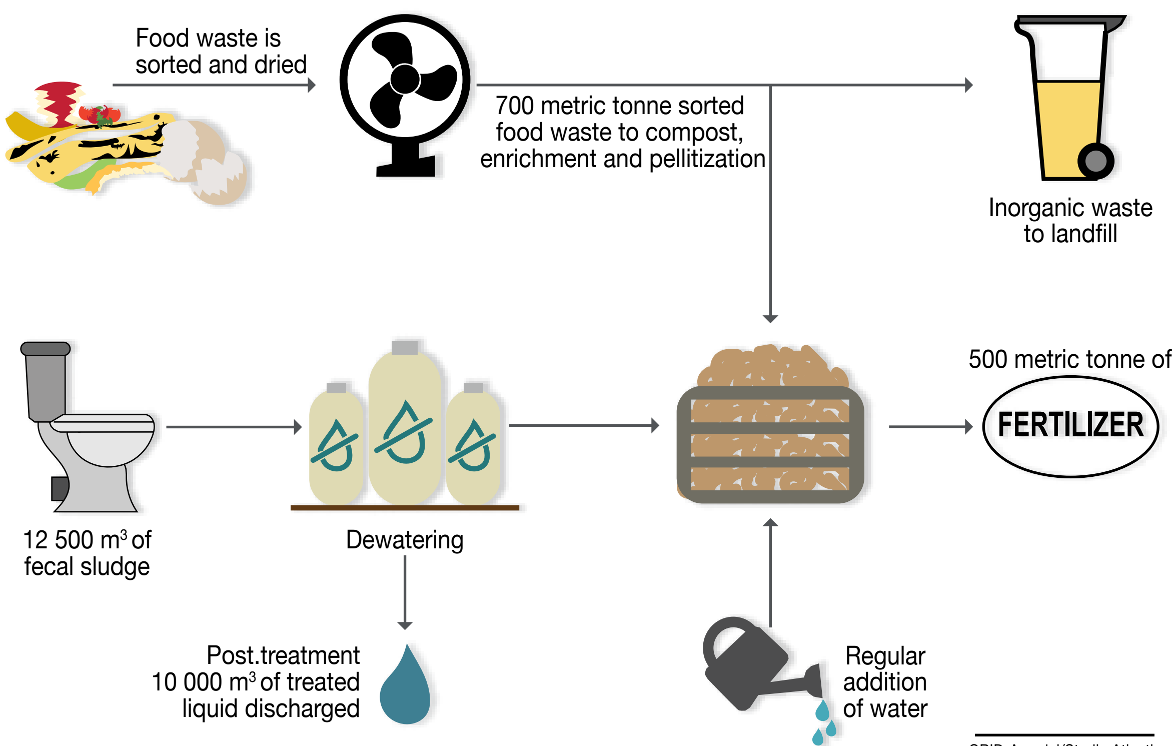
In late 2018, Sanivation in partnership with the Naivasha Water and Sanitation Company, a local utility, established another factory that produces solid fuel from faecal sludge in the form of super logs. The super logs are made from a mixture of faecal sludge and other biomass types like saw dust, with the faecal sludge acting as a binder. Just like briquettes, the super logs will also be used for energy although they are suited for industrial and commercial applications due to their bigger size in comparison with briquettes.

6.3.6.2. Sources of revenue

The key sources of revenue for non-sewered wastewater recycled for agriculture or energy as presented in Box 6.4 and include conventional sources such as tipping fees, which are paid by the sludge collecting/desludging body at the treatment plant gate and taken from charges paid by households that demand emptying of their on-site sanitation systems. The CEA also depends on the sale of its key recycling products, i.e. compost, electricity or biogas. When compost is produced, it may be sold to farmers or used in-house to produce seedlings or enhance agricultural productivity of company farms. In the latter case, the compost becomes an indirect source of revenue to the CEAs.

Other revenue sources may include governmental subsidies reflecting the treatment service benefits for society and nature, paid as part of an off-take agreement for the compost (applied on municipal parks and landscapes) and energy (based on tariffs for feeding the national electricity grid) or as a subsidy for the treatment process.

Steps in the Fortifer production process

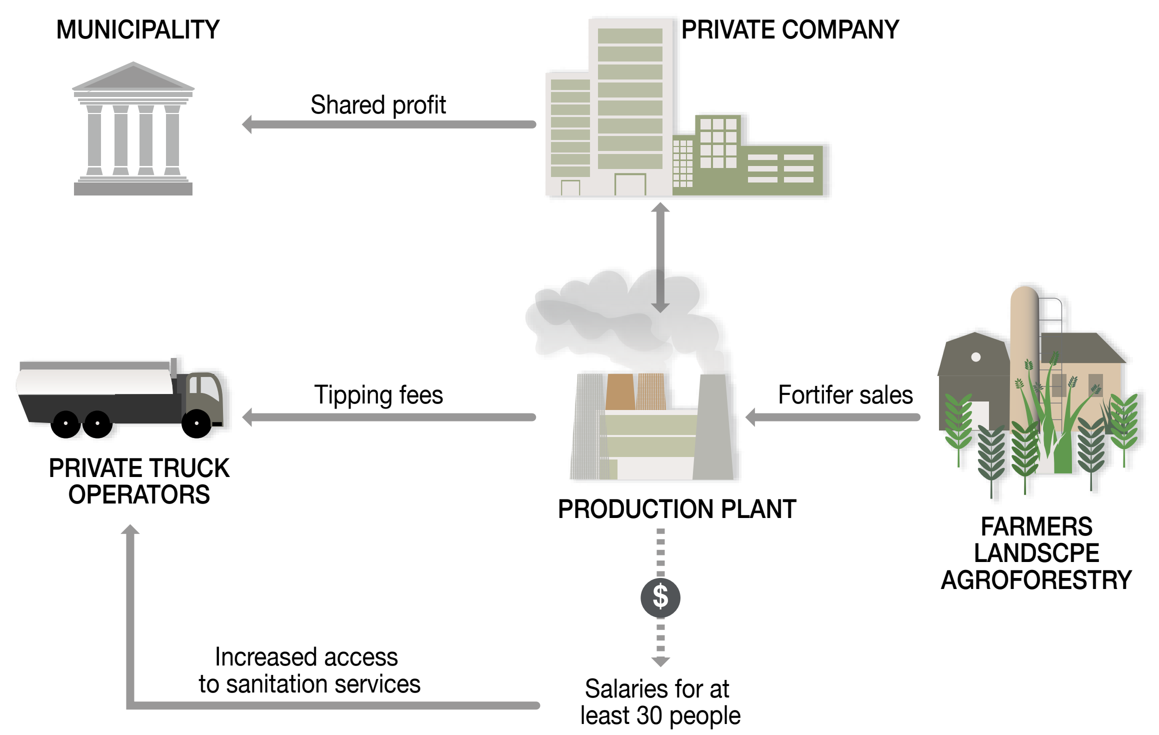


Source: IWMI, 2018.

GRID-Arendal/Studio Atlantis

Figure 6.18. Steps in the Fortifer production process

Financial flows in the Fortifer Business



Source: IWMI, 2018.

GRID-Arendal/Studio Atlantis

Figure 6.19. Financial flows in the Fortifer business

Box 6.4. Sources of revenue, conventional and non-conventional

Conventional sources of revenue:
- Tipping fees
- Sales of compost/electricity/biogas/dry fuel
- Savings from solid waste management
- Sales of seedlings or crops

Non-conventional sources of revenue:
- Governmental subsidies
- Carbon credits

6.4 Constraints to the application of a circular economy approach in wastewater management in Africa

Although the aforementioned circular economy concepts sound attractive and promising in many ways, there are important challenges that have, through the years, negatively affected the successful adoption of these solutions. Table 6.6 presents key essential elements required for sustainable CEAs in terms of financial, institutional, environmental, technical, and social and health aspects. One of the key factors it highlights is to set adequate financing and cost recovery mechanisms to sustain the CEA. Although the environment often benefits from the implementation of circular economy concepts, it is important to manage public health risks in a rigorous way, which demands three sets of interventions:

- policy, regulation and institutional initiatives, such as defining guidelines for practices (e.g. water quality standards, crop restrictions, if any, and immunization requirements for farm workers);
- engineering solutions (for treatment of water, irrigation and more);
- suitable end-user practices (crop selection, product use and application rates, harvesting measures, etc.) (Lazarova et al. 2013).

Use of wastewater on root crops is often discouraged

All CEAs must build on stakeholders' needs and preferences to promote acceptance and buy-in in the long term. When necessary, the public sector needs to create a conducive policy environment, which will help attract and retain the private sector. This is especially critical given that uncertainties concerning the impacts of treated wastewater or wastewater use may be difficult to evaluate in the shorter term.

Table 6.6. Financial, institutional, environmental, technical, social and health requirements for sustainable CEAs in wastewater

Requirements	Essential factors
Financial	• Existence of financing opportunities for public-private partnership ventures. • Adequate or sufficient market opportunities for public-private partnership products. • Securing of financial viability for reuse, reduce and recovery projects
Institutional	• Existence of mechanisms for monitoring and managing plants. • Setting of procedures for managing conflicts between stakeholders. • Strong and capable players/stakeholders. • Favourable policy environment for products and processes. • Adequate/smart and timely protocols. • Political acceptance of reuse, reduce and recovery products and solutions.
Environmental	• Clear protocols with standards and benchmarks. • Existence of a water law, regulating bodies and guidelines, and/or criteria for treated wastewater use or management of by-products (crop selection, irrigation and soil-based practices). • Proper enforcement of by-laws, etc. • Responsible environmental management
Technical	• Capacity to access the wastewater or faecal sludge through adequate collection infrastructure. • Capacity to operate and maintain treatment and recycling systems. • Technology availability. • Capacity to adapt to environmental and health standards. • Innovative and cost-effective technologies. • Access to land for the construction of treatment plants at a convenient location. • Quality of treated water and by-products guaranteed continuously
Social and health	• Food safety guaranteed. • Proper management of public perception. • Treated water quality guaranteed. • Low/no pathogens in human excreta, i.e. worm eggs, protozoa, bacteria and viruses. • Co-treatment of industrial and domestic wastewater (which leads to changes in pH levels or the inflow of high levels of heavy metals, salts or various other synthetic and recalcitrant compounds) avoided. • Potential impacts from emerging pollutants, such as pharmaceutical and personal care products (e.g. painkillers, antibiotics, contraceptives) or other contaminants, understood and mitigated. • Enhanced public/social awareness of health risks associated with treated wastewater or wastewater use

Sources: Loutfy, 2011; Lazarova, et al., 2013; IWMI, 2017.

6.5 Conclusion

Due to urbanization and population growth, there is growing pressure on freshwater reserves in cities. Available water is used for multiple purposes and substantial wastewater is generated. Many wastewater treatment projects depend on subsidies and barely survive over time. In Africa, viable wastewater-based resource recovery initiatives are emerging. These initiatives are founded on public-private partnerships that leverage private capital to finance large treatment infrastructure or cover the costs of operating and maintaining the plants. In this way, the focus is being shifted from 'treatment for disposal' to 'treatment for safe reuse', which is not only yielding valuable resources such as water, food and energy, but also improving livelihoods and the environment.

Considering that wastewater has been reused in irrigation for over a century, other reuse solutions have great prospects for the continent, including treated wastewater for drinking, aquaculture and energy, as well as sludge recycling for soil management. Reuse of untreated wastewater is still common and mostly uncontrolled. New solutions that are yet to be tested at scale could help Africa mitigate possible health risks that may result from such practices.

An advantage of the circular economy approach is that it helps increase the volumes of wastewater treated. The impacts are then multiplied, since water is central to life and therefore simultaneously impacts several SDGs and their targets. In fact, the SDGs – enshrined in the United Nations 2030 Agenda – are a testament to the key role that sustainable environmental management plays in terms of economic growth and human well-being. Current experiences attest to the fact that the various wastewater-based circular economy approaches could contribute to achieving SDG 2 (Zero hunger) and SDG 6 (Clean water and sanitation) and should constitute a key component of climate change mitigation strategies (SDG 13) in many countries. The circular economy for sanitation can help increase revenue from additional product streams, increase efficiency through the circular provision of equipment and facilities, and build shared best practices to monetize some of the externalities.

Plastic is increasingly becoming a major component of waste