Chapter 4

Social-ecological system

'everything affects everything else in one way or another, whether you are aware of that or not does not change the fact that this is what is happening'

Murray Gell-Mann

4.1 INTRODUCTION

ReGenSan nests sanitation services and products within the social ecological system (SES) of the 'place' to enhance an understanding of the systemic, holistic and integrated (SHI) interactions in the sanitation subsystems (Andries *et al.*, 2004; Binder *et al.*, 2013; Ostrom & Cox, 2010). This reinforces the established fact that to achieve adequate and sustainable sanitation services and proper institutional frameworks as well as adoption of appropriate technology requires sanitation solutions to be embedded in local physical and socio-economic, cultural, spatial and decision-making structures (Elledge *et al.*, 2002; Letema, 2012; Seghezzo, 2004; WECD, 1987). These complex-dynamic interactions have the capacity to facilitate sanitation infrastructural innovation by reinforcing technological, institutional and sociocultural transformations (Geels, 2005). The SES indicates a commitment to adopt SHI perspectives towards human and non-human elements of sanitation systems (Halliday & Glaser, 2011) intricately linked with and affected by one or more social systems and mediated through interactions with biophysical systems (Andries *et al.*, 2004). This SES dynamic shows the interactions and connections between technology and resource systems' dimensions and components of the whole sanitation system as well as the sanitation economy. Any change within the SES will affect all other aspects of the whole system. For example, technology cannot be separated from the economic and social contexts from which it evolves because issues of affordability, acceptability and willingness-to-pay should determine technology selection within an SES. A successful implementation of ReGenSan requires better understanding of the SES (Altaf, 2011; Grübler, 1998; Nilsson & Olsson, 2014) to remove the largely unknown 'black box' of interactions between the sanitation system components such as users and service

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providers. Worldwide, toilets and sanitation practices are sealed-off from the society and culturally loaded with notions of dirt, shame and waste (Curtis & Biran, 2001) and this negatively impacts improving services and expanding access to sanitation (Hegger *et al.*, 2007; van Vliet *et al.*, 2011). Therefore, a proper understanding of the interactions between sanitation entities within the SES could transform the sanitation burden into something more positive and sustainable.

Evidence has shown the inadequacy of looking at sanitation only as a matter of toilets (infrastructure) rather than the whole integrated cycle of management (including other psycho-socio-cultural factors) and this could be responsible for the slow progress experienced in sanitation service delivery. Working from within the SES ensures that infrastructure is embedded as an interactive part of the system that connects users and other SES entities (van Vliet *et al.*, 2011). Generally, even where users are knowledgeable about sanitation technology and governance, they are hardly ever considered in design and planning through the sanitation value chain; technology has been prioritised over users and the ecosystem. Some have even argued '*Let us sort out technology first; if we have proven that it works, we should implement it in society*' (Hegger *et al.*, 2007). But the implementation of sustainable decentralized sanitation technology is hampered by many non-technical barriers and it is increasingly becoming apparent that users are key to the success of technology selection, especially, when certain new well-designed sanitation technologies fail at implementation phase because they did not fit the standards of comfort that users uphold or were incompatible with cultural beliefs or religious codes. Domestic end users might be vital co-producers of change in sanitation if they are taken seriously as system users and invited to rethink sanitation practices (Hegger *et al.*, 2007; Spaargaren *et al.*, 2007; van Vliet *et al.*, 2011). This disconnection and the inadequate consideration for local contexts wherein technology is nested are largely responsible for the slow progress towards sanitation goals and targets. A classic example is presented in Box 4.1 as reported in the case of Gafumba, Karangara and Cyahi cells, Burera District, Rwanda, where traditional pit toilets upgraded to urine-diversion dry toilets (UDDT) are still used as a traditional pit toilets (Ekane *et al.*, 2012);

BOX 4.1 UDDT USED AS TRADITIONAL PIT TOILETS, GAFUMBA, KARANGARA AND CYAHI CELLS, BURERA DISTRICT, RWANDA

In Gafumba, Karangara and Cyahi cells, Burera District, Rwanda, traditional pit toilets were upgraded to urine-diversion dry toilets (UDDT), but the people still used them as pit toilets and none of these UDDTs collected urine separately. Also, in a bid to assist the UDDTs, some water was poured into both the urine and faeces compartments and sometimes urine even went into the faeces compartment in households where men are in the habit of drinking excessive amounts of alcohol (Ekane *et al.*, 2012).

This is caused by lack of understanding by the users because promoters of improved sanitation, in most cases, have completely different perspectives from the would-be users, which often results in incompatibility between technologies and the values, beliefs and experiences of the users. Also, lack of proper understanding of these dynamic interactions between the entities of the SES could lead to poor institutional and policy frameworks in the sector, which impacts negatively on issues of affordability, acceptability, willingness to pay for services and active participation in infrastructural operations and maintenance (Banerjee & Duflo, 2011; Rogers & Hall, 2003).

Furthermore, sanitation systems have been known to exert some pressures on the SES that could lead to negative impacts, especially when they are not adequately understood and incorporated early into sanitation technological design and management solutions (Golden & Earp, 2012; Stokols, 1992, 1996). For example, failed and disused infrastructures could pollute ecosystems, degrade environmental aesthetics and affect public health. Sociotechno-ecological (STE) sanitation problems facing the world today, particularly developing countries, are both systemic and managerial in character. They are systemic because they arise from deep-rooted, complex, interrelated, multi/transdisciplinary processes that cannot be resolved by technocentric approaches alone. They are management and governance problems because their solutions require sustained, integrated, coordinated and goal-driven responses across disciplines and professions and there are no quick fixes (Halliday & Glaser, 2011). Therefore, understanding specific SES (of a 'place') ensures that complementary issues such as resource recovery, psycho-socio-cultural and institutional frameworks among others are incorporated and addressed early in the design of sanitation systems to ensure fit and improve feedback mechanisms between all the subsystems, dimensions and components of the ReGenSan system. Figure 4.1 models the SES dynamics of ReGenSan and is adopted from Andries *et al.* (2004), Halliday and Glaser (2011) and Liehr *et al.* (2017). Table 4.1 shows descriptions of entities, exogenous and endogenous drivers, and Table 4.2 shows the interactions involved in the SES.

Figure 4.1 clearly depicts the fact that better understanding of other entities of SES beyond technology is a requirement to fix the infrastructural challenges of sanitation as against previous assumptions of 'fix

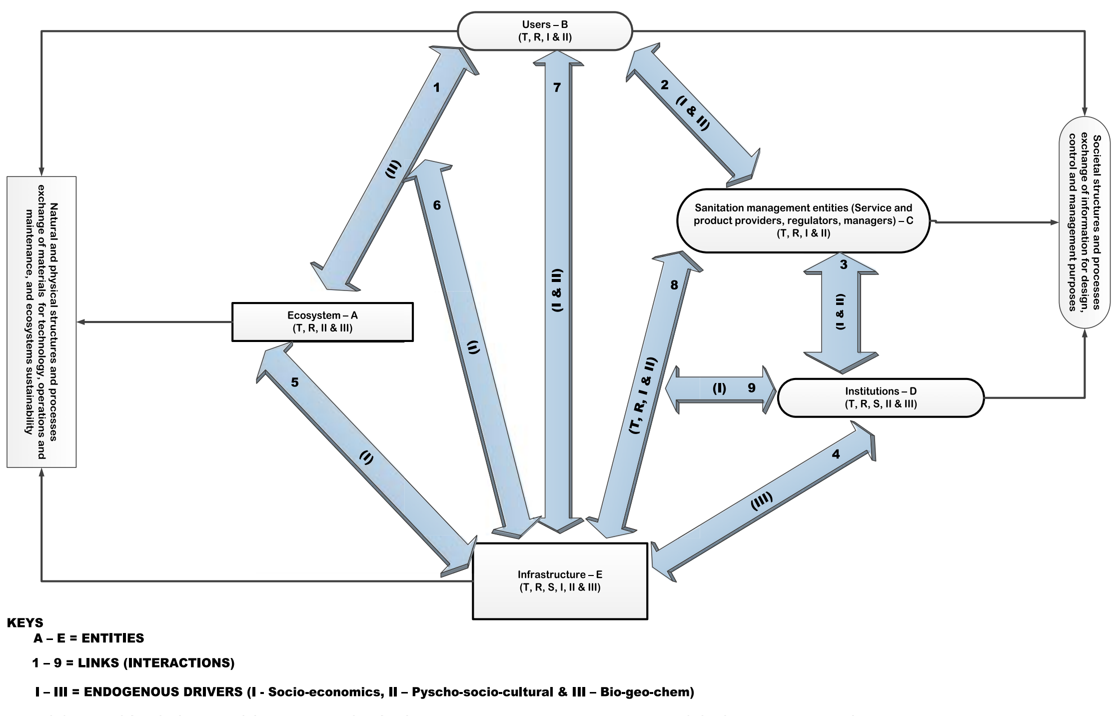

Figure 4.1 Model of social-ecological subsystem dynamics interactions of ReGenSan (Author figure inspired by Andries *et al.*, 2004.)

Table 4.1 Entities descriptions, exogenous and endogenous drivers.

Entities		Descriptions	Exogenous Drivers	Endogenous Drivers
A	Ecosystem	Provides services and functions	Technology and resource systems	Socio-economic, psycho-socio-cultural and bio-geo-chemical and hydrological
B	Users	Makes use of infrastructures and services	Technology and resource systems	Socio-economic, psycho-socio-cultural
C	Service and product providers, regulators, managers etc.	Provides infrastructures, services and products	Technology and resource systems as well as sanitation economy	Socio-economic, psycho-socio-cultural
D	Institutions	Provides the rules and regulations	Technology and resource systems as well as sanitation economy	Socio-economic, psycho-socio-cultural and bio-geo-chemical and hydrological
E	Infrastructure	Sanitation facilities/infrastructure	Technology and resource systems as well as sanitation economy	Socio-economic, psycho-socio-cultural and bio-geo-chemical and hydrological

technology first and others will follow'. Previous literature on sanitation had focused on technology, with limited interactions with users of the technology and, where users and technology were considered, the focus was on how to make users accept provided technology and not necessarily on exploring the kinds and types of technology that users will accept (see equation 4.1–4.3).

$$E \rightarrow A, B, C, D \quad (E \text{ determines all other entities without feedback}) \tag{4.1}$$

$$B, C, D, E \rightarrow A \quad (\text{All other entities impact } A \text{ without feedback}) \tag{4.2}$$

where: A = ecosystem, B = users, C = service and product providers, regulators, managers, D = institutions and E = infrastructure.

ReGenSan, therefore, proposes that real solutions to various sanitation challenges lie in better understanding and utilization of the complex dynamic interactions and linkages between the entities of the SES.

$$A \leftrightarrow B, C, D, E \quad (\text{Systemic holistic integration of entities with feedback}) \tag{4.3}$$

where: A = ecosystem, B = users, C = service and product providers, regulators, managers, D = institutions and E = infrastructure

It is indicative that one model cannot capture all potential interactions in the SES, but an attempt is made to present a broad structure with aligned processes for overall improvement of sanitation service delivery,

Table 4.2 Interactions involved in the SES.

Links		Exogenous Drivers	Endogenous Drivers
1	Ecosystem and users	Technology and resource systems	Socio-economic, psycho-socio-cultural and bio-geo-chemical and hydrological
2	Users and service and product providers	Technology and resource systems as well as sanitation economy	Socio-economic and psycho-socio-cultural
3	Service and product providers, regulators, managers and institutions	Technology and resource systems as well as sanitation economy	Socio-economic, psycho-socio-cultural and bio-geo-chemical and hydrological
4	Institutions and infrastructures	Technology and resource systems as well as sanitation economy	Socio-economic, psycho-socio-cultural and bio-geo-chemical and hydrological
5	Infrastructures and ecosystem	Technology and resource systems as well as sanitation economy	Bio-geo-chemical and hydrological
6	Users and infrastructures	Technology and resource systems	Socio-economic and psycho-socio-cultural
7	Ecosystems, users and infrastructures	Technology and resource systems	Socio-economic, psycho-socio-cultural and bio-geo-chemical and hydrological
8	Service and product providers, regulators, managers and infrastructures	Technology and resource systems as well as sanitation economy	Socio-economic, psycho-socio-cultural and bio-geo-chemical and hydrological
9	Service and product providers, regulators, managers, infrastructures and institutions	Technology and resource systems as well as sanitation economy	Socio-economic, psycho-socio-cultural and bio-geo-chemical and hydrological

product design and access expansion. The ReGenSan SES model of interactions presented in this chapter indicates the dissonance between users, service and product providers, institutions, ecosystems and infrastructure and the way it could hinder progress in global and local sanitation pursuits. In essence, all sanitation entities should work together within the given SES to determine types/kinds of sanitation technology and style/range of services suitable for the local context. This SES model will, therefore, contribute to policy, practice and research by providing information and input data for planning and design. This will also generate in-depth insight into these dynamic interactions towards evolving sanitation policies and regulations (Hinkel *et al.*, 2014; Ostrom, 2009; Ostrom & Cox, 2010; Partelow, 2016; van Vliet *et al.*, 2011; Whittington *et al.*, 1993) as well as appropriate/innovative technology provision. The five entities of this ReGenSan SES model are grouped into two dimensions: psycho-socio-ecophilia (PSEP) and governance (Figure 3.1 and Table 3.2).

4.2 DIMENSIONS OF REGENSAN SES

4.2.1 Psycho-Socio-Ecophilia (PSEP)

PSEP is a core dimension of ReGenSan whichever specific SES is being focused on. It stipulates that psychological (individual sensibilities, concerns, health, safety, privacy and preferences), social (community, status, acceptability, perception, participation/involvement, regulations, norms, behaviours, hygiene etc), cultural (traditions, customs, belief systems, religion, family/ancestry), economic (affordability, willingness-to-pay, livelihood/entrepreneurial opportunity, financing etc), physiological (urination and defecation) and geographical/geological/ecological (place, scale and ecosystem, etc) conditions should be incorporated into the design, planning and modelling of sanitation technologies and management, which could result in a most appropriate fit (van Vliet *et al.*, 2011). It recognizes that ReGenSan system is embedded within a SES (Dias, 2015; Mang & Reed, 2012b). This dimension operates from the place and scale (PaS) principle of ReGenSan, which focuses on 'sani-sheds' for sanitation management and planning that connects with the socio-ecological characteristics of local contexts (Kellert *et al.*, 2008; Mang & Reed, 2012a). It is designed to explore interlinkages between psychology, sociology, ecology, physics, political science, public administration, economics, biology, chemistry, anthropology, management, geography, geology, medical and health sciences, food production/security and engineering disciplines (among others) for multi/transdisciplinary solutions to sanitation challenges (Mang & Reed, 2012b).

PSEP is key to ReGenSan because a diversity of social and ethnic groups often exists in a locality and individual preferences cannot just be overlooked within any group (Lyle, 1984, 1994; Van der Ryn & Cowan, 2007) and all of these greatly influence acceptability, willingness to use and pay, affordability, accessibility, design, construction and usage of sanitation systems. Also, the normative contents of the human rights to sanitation (i.e. the human rights obligations of countries related to sanitation) are encapsulated in the psycho-socio-cultural and socio-economic components of PSEP (Giné-Garriga *et al.*, 2017; UNGA, 2009; UNHRC, 2011). For the economic, social and cultural rights (e.g. the right to sanitation), the content of these obligations is clarified and operationalized under the criteria of availability, accessibility, quality, affordability and acceptability (de Albuquerque & Roaf, 2014; UNESCO, 2002).

PSEP will characteristically determine system design, installation and operations in ReGenSan. In other words, user interface, collection, treatment, recovery and disposal processes should be determined by the variety of these within local situations (Chirisa *et al.*, 2017) in order to understand how the unique dynamic-potentials of a location could cardinally influence types and processes of technology (USLG, 1996). The primary intent of PSEP is to systematically integrate psychological, social, economic, cultural, health, hygiene, behaviour, environment, land use, ecosystem and natural resources concerns as well as gender equity, dignity and stakeholder management into design, technology selection and management of sanitation systems (Marshall & Farahbakhsh, 2013; Schübber, 1996).

PSEP becomes crucial as failure of technology/infrastructure due to sociocultural and socio-economic factors like lack of demand and acceptance or unwillingness/inability to pay for services is increasingly evident. This could then lead to environmental and public health risks (Starkl *et al.*, 2013) as well as negatively impacting resource recovery due to differences in social groups' values and attitudes. In this case, it is essential to drive interactions within the SES with users as the focal point rather than technology/infrastructure as was the case in the unsuccessful past (Spaaragaren *et al.*, 2007; van Vliet *et al.*, 2011).The key components of PSEP are presented in Box 4.2.

BOX 4.2 KEY COMPONENTS OF PSEP

(1) Psycho-socio-cultural: religion, norms, customs, availability, accessibility, acceptability, willingness to use, gender equity, inclusiveness, perceptions and attitude, health, hygiene and handwashing, preference, status
(2) Socio-economic: educational level (formal and informal), income level (affordability, willingness-to-get and willingness-to-pay), livelihood support (economic activities and occupational engagement), access to basic services (water supply, electricity and healthcare), access to sanitation services and types (sewer, non-sewer, shared and non-shared facilities), geographical location (urban and rural), housing/dwelling types, household sizes and head of household, age, gender and race
(3) Bio-geo-chemical (BGC): nutrients and water (C, N, P, H_2O) cycling, ecosystem services and functions, fauna and flora

4.2.1.1 Psycho-Socio-Cultural (PSC)

The psycho-socio-cultural component is the meso, macro and other contextual factors that influence sanitation design, technology, practices and management solutions. ReGenSan is framed to ensure that PSC is incorporated into sanitation infrastructural designs and management solutions increase access expansion and service improvement and help users meet their sanitation needs without any psycho-social stress (Siegrist & Marmot, 2004). PSC seeks to explore the various interactions of users with their sanitation systems to determine the willingness to accept, pay for and use the facilities provided as well as determine their level of involvement and participation (Egan *et al.*, 2008). This stems from the fact that sanitation choices are based on psycho-socio-cultural and political factors, and most service and product providers need to recognize this and include dialogue with all parties in their strategies, especially vulnerable groups (Andersson & Minoia, 2017; Jewitt, 2011) because several sanitation failures arise from poor attention to sociocultural conditions and lack of local ownership. In essence, sanitation solutions cannot be provided in uniform fashion, but should be addressed at the local level and in differentiated ways, aligned with the cultural norms and socio-economic status (Andersson & Minoia, 2017; O'Reilly & Louis, 2014).

Cultural and social sustainability is not simply an acceptance of technical propositions or even awareness-raising and capacity-building. It is important to acknowledge certain general attitudes towards faeces that are part of specific cultures and influenced by religions. Cultural acceptability in sanitation refers to pre-adaptation to behaviours, beliefs and organization of daily lives and it contributes to transformative development that impacts well-being, resource use and sustainable production (Andersson & Minoia, 2017). Culturally, humans have been known to interact with and/or relate to issues of excrement in two ways: faecophobic and faecophilic. Faecophobic cultures are common among Hindus, some South-East Asian and African sub-Saharan countries (Winblad & Simpson-Hebert, 2004). For example, Pinsem and Vinnerås (2003) observed that getting people in Thailand to accept the application of human urine as fertilizer was not easy due to sociological difficulties where human excreta is commonly viewed as being dirty and a pathway for disease transmission (Duncker *et al.*, 2007). Also, in some Nigerian ethnicities tradition prohibits collection of urine by strangers for fear that it may be used against the people through ‘black magic’ or ‘evil spirits’ (Duncker *et al.*, 2007; Sridhar *et al.*, 2005). In Rwanda, faeces are called *‘amazirantoki’*, meaning ‘do not touch’ or ‘untouchable’ and defecation inside or very close to living space is not allowed. Therefore, toilets constructed in most rural communities in Rwanda are located away from the houses and outside the household fences, usually at the exit of the compound. In addition, toilets should be constructed away from the kitchen (Ekane *et al.*, 2012; Jain, 2011).

On the other hand, faecophilic cultures are common among Chinese societies, where human excreta is seen as a valuable product and has for several millennia been used as fertilizer (Winblad & Kilama, 1985). Most world cultures occupy a position somewhere in between these two extremes (Rosenqvist, 2005) and will determine the response to sanitation choices. This fear (though somewhat rational) often hinges on the fact that human excreta is malodorous and potentially dangerous and this has proven to be one key obstacle for resource recovery and reuse of sanitation materials (Rosenqvist, 2005; Winblad & Simpson-Hebert, 2004). Of course, it is often a case of denial because most people would rather not talk about sanitation and cultures are mostly indifferent to sanitation issues – ironically seeing as every human engages in faecal and urine excretion at least four times a day (Loudon, 1977; Rosenqvist, 2005). It is vital to understand PSC issues in order to manage perception of by-products of human digestion, as is evidenced in Sweden where it became popular practice to mix cow dung with human faeces to make them less offensive and repulsive (Duncker *et al.*, 2007).

To this effect, ReGenSan shifts the focus from just building toilets to engaging the PSC component to determine the right kind of design (Devine, 2009; O’Reilly & Louis, 2014), community involvement (Kar & Chambers, 2008), involvement of the state (Black & Fawcett, 2008) and understanding people’s perceptions, ideas and values around sanitation (Drangert & Bahadar, 2011; O’Reilly & Louis, 2014; Rheinländer *et al.*, 2010; Simha *et al.*, 2017b). Therefore, the concept of PSC advocates for adequate information and communication strategies that encourage people to show interest in, talk about and act on, as well as get involved in, the management of their sanitation facilities. The trend is to ensure that ReGenSan is responsive to sanitation approaches that emphasize the physical, social and environmental needs of users. Recognizing the intimate connection between the sanitation environment and the psychological, social and mental well-being of users further underscores the need for a contextualized understanding of sanitation-related psycho-socio-cultural stress (Sahoo *et al.*, 2015). This can be clearly illustrated by the TepozEco ecological toilet project in San Juan, Mexico, where previous attempts to provide ecological toilets proved to be unsuccessful. The criticisms of this earlier project were lack of consultation with recipients in its design, scanty operation and maintenance education and no follow-up technical support; all of these resulted in a quick slide into disrepair that compromised the use of the toilets. Lessons from this earlier project were applied in the new project to increase its chances of success (Davies-Colley & Smith, 2012). Box 4.3 presents this t project, with adequate considerations for the psycho-socio-cultural, economic and governance issues.

BOX 4.3 TepozEco ECOLOGICAL TOILET PROJECT IN SAN JUAN, MEXICO

The socio-economic profile of San Juan showed a population of 2,000 predominantly rural residents, mostly earning an average income of USD 90/month and heavily involved in agriculture, particularly maize and nopal cactus (a staple vegetable crop). The mean rainfall is 1,200 mm and virtually all rain falls between May and August, with little in the remaining eight months. There is no reticulated water supply, so residents capture rainwater during the rainy season, but for the rest of the year must carry water from springs or purchase it from water-tanker trucks for around USD 60 per m^3.

This is very expensive and makes water a precious commodity and because of the lack of piped water supply, the price of water, and the absence of any form of reticulated sewerage, the community relies on waterless toilets, which have been poorly constructed and maintained (Davies-Colley & Smith, 2012). The first 12 months of the project were dedicated to planning, feasibility studies and raising the community's awareness of local environmental issues and the potential of ecological toilets. In 2002, a community meeting was held, and although many who attended initially wanted flush toilets, they conceded that they were impractical due to the lack of reticulated water and sewerage. The community accepted ecological toilets as the best potential solution. Being dissatisfied with their existing toilets and the possibility of getting toilets that did not require water (and was not a pit latrine) were important initial motives. For most recipients, knowing that their toilets would not contaminate the environment and would allow the reuse of urine and faeces on their home gardens were major additional benefits (Davies-Colley & Smith, 2012).

The governance aspect of the TepozEco ecological toilet project revolved around the formation of the community group (informal institution) and a formal letter to Morelos State Water and Environmental Commission (CEAMA) (formal institution) requesting assistance. It should be noted that state governments in Mexico are responsible for the provision of sanitation to communities: CEAMA agreed to provide a subsidy sufficient for the construction of the 30 toilets. The community itself then decided which of more than 100 interested families would get the toilets.

The education programme endeavoured to address the participants' fears and doubts and ensure they understood all aspects of the toilets. The programme included a workshop to promote proper hygiene, to provide information on the transmission of faecal pathogens, how to disinfect dehydration toilets, operation and maintenance and the value of the urine-fertilizer and faeces-compost. During this phase, project staff encouraged participants to talk about defecation, faeces and urine, which helped break their psycho-socio-cultural inhibitions. By the completion of the toilets' construction and the educational programme, the participants had become experts in the operations and maintenance of the toilets. All the toilets used urine-diverting dehydration systems, the same basic plans but specifically designed architecturally for the needs and wants of individual families; the final cost to the recipient was necessarily heavily subsidized. TepozEco trained five local youths in operations and maintenance to provide follow-up support and assist toilet recipients (Davies-Colley & Smith, 2012).

Between 2004 and 2006, 30 dehydrating-style ecological toilets were constructed in the rural community of San Juan Tlacotenco (San Juan), near the town of Tepoztlan, approximately 80 km south of Mexico City. The objective was to establish a fully functioning example of urban ecological sanitation, with a long-term goal of encouraging the adoption of ecological sanitation systems in Latin America.

4.2.1.2 Socio-Economic (SE)

The socio-economic (SE) component of ReGenSan (PSEP) is a complex phenomenon predicted by a broad spectrum of variables conceptualized as a combination of financial, occupational and educational influences that impact on sanitation access expansion and service improvement (Duncan, 1961; Green, 1970; Hollingshead, 1971; Mueller & Parcel, 1981; Winkleby *et al.*, 1992). Although these variables are interrelated, they reflect different individual and societal forces associated with sanitation. For example, income level reflects affordability and willingness to pay for sanitation services as well as access to other basic services; and educational level indicates willingness to use and the possibility of improving income that will enhance the ability to access other essential services due to increased opportunities to acquire positive social, psychological and economic resources (Antonovsky, 1967; Susser, 1985; Winkleby *et al.*, 1992). If users understood the economic and income-generating opportunities embedded in sanitation, especially through resource recovery and reuse, they would most likely be more interested in sanitation management even at household levels. This relates to the fact that humans are generally more actively interested in things relating to livelihood support. Studies have shown that using SE factors as incentives can be a good strategy to influence users to adopt dry toilets, especially in most water-scarce regions. This is due to cost-saving from the volume of water that it is no longer necessary to supply, treat, distribute, collect and treat again, as well as lower capital investment costs that this can imply (Anorve, 1994; Cordova & Knuth, 2005; Costner *et al.*, 1990; Del Porto & Steinfeld, 1999; Esrey *et al.*, 1998; Otterpohl *et al.*, 1997; Pollard *et al.*, 1997; Van der Ryn, 1995).

Disadvantages in SE have negative sanitation-related consequences for the society because poor sanitation has been known to cause economic losses associated with the direct costs of treating sanitation-related illnesses and lost income through reduced or lost productivity (Minh & Hung, 2011). Also, better SE conditions imply improved living situations, thus resulting in better access and improved sanitation services (Malik *et al.*, 2012; Sedhain, 2014). This could also explain the worsening sanitation situation in rural areas compared with urban areas due to variations in socioeconomic status and geographical locations (WHO/UNICEF, 2017). Therefore, ReGenSan advocates that SE factors be key drivers in sanitation policy design, development, planning and management as well as infrastructure/technology/service design, development and provision as this could affect allocation of sanitation-based resources, infrastructure provisions and sanitation pricing (Rhodes & McKenzie, 2015).

4.2.1.3 Bio-geo-Chemical (BGC)

The PSEP component of ReGenSan is designed to ensure that the elemental and molecular nutrients cycle inherent in the by-products of human digestion during degradation-stabilization and management processes is not broken. It is the main sanitation treatment process that can be enhanced to mine the elements (nutrients) converted during these cyclical processes for effective and efficient resource recovery as well as support the ecosystem services and functions of the 'place', that is, the SES. BGC draws upon the ReGenSan principles of ApT, NToB, RaSR, SHI, HS and RoDF (see Chapter 2, Section 2.4) to guarantee a system of symbiotic integration of the bio-geo-chemical cycle process within the contextual sanitation system and the ecosystem. BGC will enable appropriate technology that reduces burden transfer, encourages and supports resource recovery/reuse and operates systematically and holistically in any type of combination as well as guarantees performance quality and functionality. When sanitation systems/technology/infrastructure fail, it causes a disruption in the BGC cycling of urine and faeces whereby nutrients rich in nitrogen and phosphorous could travel on to local SES, leading to pollution and degradation of natural resources and aesthetics. To this effect, policymakers and regulators, service providers, technology designers/developers and users alike should have an understanding of how the BGC cycle concerns sanitation, its impact on technology, recovery/reuse, ecosystem protection (public health and water quality goals) and benefits as well as operations and maintenance.

Consequently, the primary concern of this component is the circulation, removal and transformation of organic and inorganic materials derived from by-products of human digestion and related activities (faeces, urine, flush/anal cleansing water and dry cleaning materials) processed in sanitation facilities. It also focuses on the operating system that regulates the physical, chemical and biological processes of the elemental (carbon, nitrogen, phosphorus and water) cycle, which supports ecosystem services and processes as well as fauna and flora diversity in the sani-shed (Reddy & Delaune, 2008). One major aim of this component is to enhance cyclical flows and continuous resource recovery/reuse of energy while ensuring that sanitation operational processes mutually integrate with natural processes to guarantee that waste volume is within the carrying capacity of the SES (Lyle, 1994). BGC cycling processes in sanitation are the result of a few major constituents of by-products of human digestion (faeces/urine) in treatment systems with controlled complex interactions of the oxidation (aerobic) and reduction (anaerobic) reactions of these organic and inorganic constituents of human digestion (Wilhelm *et al.*, 1994) leading to inactivation of pathogens and detoxification of toxic compounds (heavy metals and micropollutants) actively contributing to the global BGC elemental (C, N, P, H_2O) cycling in nature (Reddy & Delaune, 2008). The septic system is used here to illustrate the bio-geo-chemical reaction of domestic waste according to Wilhelm *et al.* (1994).

Wolgast (1993) reported that an average individual excretes around 500 kg of urine and 50 kg of faeces (dry matter content of 20%) each year, with the total nutrient composition of excreta (faeces + urine) as follows: 5.7 kg N, 0.6 kg P and 12 kg K. However, 90% of the tot-N, 60–65% of tot P and 50–80% of K is partitioned by the human body and excreted in the urine (Simha & Ganesapillai, 2017a). In relation to the ReGenSan principle of PaS, Feachem *et al.* (1983) distinguished the faecal production in developing countries (130–520 g person^{-1} d^{-1}) and North America and Europe (100–200 g person^{-1} d^{-1}) and Polprasert *et al.* (1981) estimated urine production from an average Vietnamese person at 0.82–12 kg person^{-1} d^{-1} and faeces as 130–140 g person^{-1} d^{-1}), respectively (Guyton; 1992; Jönsson *et al.*, 2005; Lentner *et al.*, 1981; Schouw *et al.*, 2002; Simha and Ganesapillai, 2017a; Strande *et al.*, 2014; Vinnerås *et al.*, 2006). This indicates that understanding the BGC cycle for sanitation management purposes should be contextual and technology/service delivery must follow suit. Ironically, several studies have explored the subsurface fate of wastewater constituent by constituent, but only a few have considered sanitation treatment infrastructure as BGC reservoirs. It could make more sense to begin to look beyond targeting specific constituents and recognize that sanitation systems (e.g. septic systems) are true BGC systems whereby wastewater constituents react with each other and with subsurface gases and porous media (Reneau *et al.*, 1989; Wilhelm *et al.*, 1994). Box 4.4 presents two major redox environments in which wastewater is transformed by the bio-geo-chemical reactions to their individual nutrient and elemental cycle.

BOX 4.4 IMPORTANT BIO-GEO-CHEMICAL REACTIONS IN SEPTIC SYSTEMS (WILHELM *ET AL.*, 1994)

Anaerobic zone (septic tank and biological mat):

Organic molecule hydrolysis:

$$\begin{aligned}&\text{Proteins} + H_2O \rightarrow \text{Aminoacids}\\&\text{Carbohydrates} + H_2O \rightarrow \text{Simplesugars}\\&\text{Fats} + H_2O \rightarrow \text{Fatty acids and glycerol}\end{aligned}\tag{4.4}$$

Ammonium release:

$$\text{Urea}\left[CO(NH_3^+)_2\right] + H_2O \rightarrow 2NH_4^+ + CO_2 \tag{4.5a}$$

$$\text{Amino acids} + H_2O \rightarrow NH_4^+ + \text{Organic compounds} \tag{4.5b}$$

Fermentation:

$$\text{Amino acids, simple sugars} \rightarrow H_2,\ \text{acetate}\,(CH_3OO^-),\ \text{other organic acids} \tag{4.6}$$

Anaerobic oxidation:

$$\text{Fatty acids} + H_2O \rightarrow H_2, CH_3OO^- \quad (4.7)$$

Sulphate reduction:

$$SO_4^{2-} + 2CH_3O^{a} + 2H^+ \rightarrow H_2S + CO_2 + 2H_2O \quad (4.8)$$

Methanogenesis:

$$CH_2OO^-(\text{acetate}) + H^+ \rightarrow CH_4 + CO_2 \quad (4.9a)$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (4.9b)$$

Aerobic zone (unsaturated zone, and saturated zone to lesser extent):

Organic matter oxidation:

$$CH_2O + O_2 \rightarrow CO_2 + H_2O \quad (4.10)$$

Nitrification:

$$NH_{4+} + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O \quad (4.11)$$

Sulphide oxidation:

$$H_2S(\text{or organic sulphide}) + 2O_2 \rightarrow SO_4^{2-} + 2H^+ \quad (4.12)$$

Carbonate buffering:

$$H^+ + HCO_3^- \rightarrow H_2CO_3 \quad (4.13a)$$

$$CaCO_3 + H_+ \rightarrow Ca^{2+} + HCO_3^- \quad (4.13b)$$

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3^- \quad (4.13c)$$

Second anaerobic zone (saturated or near-saturated conditions)[b]:

Denitrification:

$$4NO_3^- + CH_2O + 4H^+ \rightarrow 2N_2 + 5CO_2 + 7H_2O \quad (4.14)$$

[a]organic matter is simplified as CH_2O throughout. Actual organic matter contains C of various oxidation state and other elements such as N, P, and S, and therefore actual reaction products vary.
[b]Nitrate reduction can also be accomplished via oxidation of reduced sulphur compounds (Howarth & Stewart, 1992).

BGC interactions could improve the quality and performance of the next generation of resource recovery/reuse facilities and technology to boost the sanitation economy. A whole world of research is urgently needed in this area. In essence, BGC processes in urine separation technologies could learn from human physiology (which excretes faeces and urine separately) to design an engineered system that captures nutrients for return to the soil, thereby improving sanitation (Elser & Bennett, 2011; Simha & Ganesapillai, 2017a). In another light, pit latrines (used by an estimated 1.77 billion people concentrated primarily in rural areas of developing- and middle-income countries) pose huge environmental challenges through global methane (CH_4) emissions and groundwater contamination (Graham & Polizzotto, 2013; Reid *et al.*, 2014). Meanwhile, a better understanding of the BGC reactions within pit latrine systems could provide much-needed solutions: for example, pit latrines are estimated to emit ~14 Tg CH_4 y^{-16}, or >4% of global anthropogenic emissions, but mitigations for wastewater treatment technologies do not apply to them (Reid *et al.*, 2014). The limited studies on pit latrines and groundwater only focus on a few indicator contaminants; much is not known about the relevant elemental nutrients and molecular BGC cyclical interactions and their behaviours. Furthermore, although groundwater is frequently observed downstream of latrines, contaminant transport distances, empirically based recommendations and guidelines are varied and not well aligned (Graham & Polizzotto, 2013). The ability to effectively predict the behaviours of BGC constituents' cycles and the changes that take place in the systems can help to boost resource recovery and reuse in ReGenSan.

ReGenSan further advocates that the BGC cycle could play a critical role in buffering the impacts of nutrients and other contaminants through the process of biodegradation, transformation and assimilation and ultimately contribute to ecosystem services and functions as well as fauna and flora diversity. Further studies in this regard are crucial because a well-functioning BGC process can enhance exchange of materials between living and non-living components of the sanitation system, while also supporting systems biodegradation processes, preventing system failures and improving resource recovery/reuse (Wilhelm *et al.*, 1994). Consequently, overlooking the specific BGC operations and mechanisms in different sanitation facilities and contexts could cause 'broken bio-geo-chemical cycles' and could then lead to large release of nutrients from failed sanitation systems to air, soil and water, causing enormous devastation to ecosystem services and functions (Elser & Bennett, 2011).

These major BGC interactions show the behaviour of specific contaminants and the impact of these changes in septic systems (sanitation systems) (Wilhelm *et al.*, 1994).

4.2.2 Governance Function (GoF)

The ReGenSan dimension of governance function (GoF) is predicated on the fact that adequate intervention and service/solution provision in any local context is predominantly dependent on prevailing policy, legislations, regulations and acceptable standards. As acknowledged in the 2006 United Nations World Water Report, the 'global water crisis' and by extension the 'sanitation crisis' is primarily a 'crisis of governance' (UNESCO–WWAP, 2006), a fundamentally ethical challenge that the sector faces in the twenty-first century (Castro & Heller, 2009; Davis & McGinn, 2001; Delli Priscoli *et al.*, 2004; EUWATER Network, 2005). According to the World Bank, governance includes public sector management, accountability, legal framework, transparency and information availability as well as equitability and responsiveness to people's needs (Larmour, 1998). Governance should also be seen as the enforcement of law, accountability, transparency and implementation of government policies (Mwanza, 2005). Without adequate governance backing, sanitation management will be weak and the SDG targets a pipe dream. Governance is the structure and process that society uses to make decisions and share power. It is also the interaction of laws, norms, institutions and processes through which society exercises powers and responsibilities to make and implement decisions and ensure accountability, as well as set the rules under which management operates (Cookey *et al.*, 2016; Folke *et al.*, 2005; Moench *et al.*, 2003; Moore & Unsworth, 2006; Pahl-Wostl, 2009; Pahl-Wostl *et al.*, 2012; Rogers & Hall, 2003; Tropp, 2007). Balancing competing interests about who is entitled to what services, how services are provided, who pays and how competing interests are balanced, as well as decisions about how to recover resources and reuse from sanitation, are governance responsibilities (Moriarty *et al.*, 2007).

The ideal governance takes account of the different actors and networks that help formulate and implement sanitation policies. Therefore, sanitation governance entails the ongoing dialogue between public and private sanitation stakeholders to discern expectations for what results to achieve; translating these expectations including other information as well as perspectives and values of stakeholders into written criteria that is institutions and policies; and checking to see that criteria are met, that is through monitoring (Ekane *et al.*, 2013). GoF of sanitation is multi-level in nature because decision-making and service delivery involve different actors via multi-level processes within which different roles and powers are dispersed among different actors (Ekane *et al.*, 2014; Pahl-Wostl, 1995; Rotmans *et al.*, 2001). In between national policies (at the macro level) and individual households (the micro level) is the meso level, which includes the web of actors ranging from government employees (e.g environment and health inspectors) to private sector formal and informal service providers, civil society organizations and homeowners. The basic functions of ReGenSan governance are presented in Box 4.5.

BOX 4.5 BASIC FUNCTIONS OF ReGenSan GOVERNANCE

(1) Provision of enabling environment, political will and effective management, essential for long-term provision of sanitation services as well as ensuring good administration, planning and decision-making systems (ISF & Stone Environmental, 2009; Yeager *et al.*, 2006),
(2) Provision of institutional and regulatory framework for adequate and appropriate guidelines and standards for sanitation facilities operations and performance, with strict enforcement to ensure compliance (IWA 24:2016; Rodic, 2015),
(3) Institutional arrangements that support technological innovative interventions, operational and maintenance responsibilities of physical systems, make provisions for restoration of dysfunctional and unimproved sanitation technologies (Crous *et al.*, 2012; Eales *et al.*, 2012/2013; Roma & Jeffrey, 2010; Washcost, 2012) as well as technological institutional arrangement that clearly defines roles and responsibilities for service delivery (Montgomery *et al.*, 2009; Oosterveer & Spaargaren, 2010; Parkinson & Tayler, 2003; Roma & Jeffrey, 2010; Sansom, 2011),
(4) Provision of financial arrangements for infrastructural components and cost recovery from service delivery as well as financing operational and maintenance responsibilities (ORs) and institutional arrangements (IAs) (Fonseca *et al.*, 2011; Fonseca & Verhoeven, 2013; IRC & WSUP, 2012; Trémolet & Rama, 2012), and
(5) Psycho-socio-cultural acceptance such as ensuring that prevailing attitudes are compatible and match users' perceptions, preferences and level of commitment with the technologies or practices to be implemented (Lüthi *et al.*, 2011a, b; Tilley *et al.*, 2014).

These multi-level actors, their roles and interactions constitute sanitation governance. The meso-level actors operate in relation to the (macro-level) policies, plan and strategies of the national government and donor agencies. The micro-level actors de facto have much responsibility in realizing sanitation (Ekane *et al.*, 2014). GoF provides the effective and efficient sanitation operational responsibilities (ORs) (i.e. the day-to-day functionality of the service delivery) and fit-for-purpose institutional arrangements (IAs) (i.e. the formal and informal institutional contexts that help or hinder the successful delivery of the day-to-day activities) (Kooiman, 2003; Ross *et al.*, 2014; Starkl *et al.*, 2013).

GoF is a foundational component of ReGenSan in that it provides the enabling environment for effective and efficient service delivery, technology selection, financing and sustainability of sanitation systems and technologies (Maurer *et al.*, 2012; Schertenleib, 2005). This PSEP component draws extensively on the PaS principle as well as the PaP, SHI and NToB principles. It is required to define boundaries of sani-sheds and scale levels as well as set targets for source separation and resource recovery. Generally, sanitation governance encompasses arrangements for ownership, management and operations, institutional contexts and regulatory frameworks (i.e. requirements on service standards, resource recovery, emission standards, pricing guidelines and cost recovery) within 'place' and 'scale' (sani-sheds) of SESs (Ross *et al.*, 2014). It also provides strategic goals, guiding principles, policy instruments, institutional arrangements and capacities, stakeholders' interactions, financial mechanisms and technology selections towards sanitation management (Rodic, 2015). The key components of GoF are presented in Box 4.6.

BOX 4.6 KEY COMPONENTS OF GoF

(1) *Institutions: policies, legislation and regulations, informal institutions, international treaties and protocols*
(2) *Management: sanitation management entities (SMEs), planning and implementation, asset management, clearly defined roles of actors, stakeholders' information and communication, regulatory compliance and enforcement, monitoring and evaluation*
(3) *Sustainable financing: blending public and private funding sources, resource leveraging, cost recovery and lifecycle costing, supplementary income and social marketing, and utilization of local/domestic private sector.*

But, sanitation is really more about service delivery than technology provisions and deals with complex systems of interactions between social (intra and inter), institutions, ecosystems and physical infrastructure – all operating at various governance levels (Galli *et al.*, 2014), therefore, GoF of ReGenSan embodies particularly contextual institutional/policy frameworks (direct regulation, standards and guidelines, supportive economic and social instruments and guidelines for technology selection/sani-shed description and delineation), stakeholders' engagement and involvement, planning and management, operations and maintenance, financing and full cost recovery and compliance and enforcement (Kooiman, 2003; Lüthi *et al.*, 2011a, b; Ross *et al.*, 2014; Starkl *et al.*, 2013; Tilley *et al.*, 2014). For instance, Japan's achievement of universal access and coverage in sanitation thrived on an enabling environment characterized by the enactment of legislative instruments prioritizing sanitation; a robust regulatory regime; establishment of institutional arrangements and coordination mechanisms among stakeholders, where functions and responsibilities are clear-cut and delineated; and initial financing from governments at the forefront of allocating funds for sanitation interventions of varying complexities and scale (ADB, 2016).

4.2.2.1 Institutions

Institutions are rules, constraints and norms of behaviour, conventions and self-imposed codes of conduct and their enforcement characteristics (North, 1990; Obeng & Agyenim, 2011) as well as regularized behaviours that have turned into standard routines (Cookey *et al.*, 2017; Ekane *et al.*, 2012; North, 1990, 1998; Ostrom, 2005). Sanitation institutions are the configurations of various legal, policy and organization elements involved in sanitation technological design and development, ownership, resource allocation, recovery and use as well as management (Saleth, 2004, 2010; Saleth & Dinar, 2004). There are sets of rights, rules and decision-making procedures (Young *et al.*, 1999), which are often referred to as the rules of the game in a society, and the humanly devised constraints that shape human actions (North, 1990). These rules provide information about how agents (actors) are expected to act in certain situations and around rules to which others conform (Amable, 2003; Ekane *et al.*, 2012). Agents/actors (i.e. individuals and organizations) use institutions as instruments for coordination, reducing uncertainty and implementing sanitation programme strategies as well as responses to various challenging situations. Cases abound, where large public and private investments are made in off-site and on-site sanitation solutions, that are seldom backed by adequate institutional and regulatory frameworks at the critical stages of operations, maintenance and monitoring, thereby allowing service deficiencies to persist (Srinivasan, 2015). Thus, sanitation institutions must be relevant to all actors, providing them with an enabling environment and a common understanding of how the tasks are performed (Ekane *et al.*, 2012).

North (1990) separates institutions into two sets of rules or norms: formal or informal. Formal institutions are linked to the official channels of governmental bureaucracies. They are codified in regulatory frameworks or any kind of legally binding documents and they can be enforced by legal procedures; informal institutions refer to socially shared rules such as social or cultural norms. In most cases, they are not codified or written down. They are enforced outside of legally sanctioned channels (Pahl-Wostl, 2009). Government have the legal powers to use formal institutions to adopt, tolerate or outlaw informal laws and/or constraints based on their cultural acceptability, technical feasibility, suitability and practicability. For example, many developing countries have enacted laws to ban the use of the pan or bucket latrine, which has been practised by some communities for several years (See Box 3.2 – Obeng and Agyenim, 2011). In the sanitation sector, informal institutions and constraints are major determinants of the commitments of various stakeholders to the enforcement of and compliance with formal institutions (Vogler, 2003). They influence such critical factors as attitudes, willingness to get and pay for services, compliance with sanitation laws and participation in resource recovery/reuse.

The impact of informal institutions and constraints on the sanitation sector are generally more pronounced in developing countries (Obeng & Agyenim, 2011). For example, in the Burera District, Rwanda, a mismatch was found between the prevailing sanitation behaviour practices and the provisions of the national guidelines and standards for hygiene and sanitation (Ekane *et al.*, 2012; Ekane, 2013 – see Box 4.8). Therefore, it is worth noting that the functionality of institutions depends on the degree of match/fit between the formal and informal institutions (Khan, 1995; Kjellén, 2006) because in many developing societies informal rules have a tendency to override formal rules, making the enforcement of formal rules very difficult and thereby affecting performance (Bandaragoda & Firdousi, 1992). Sanitation institutions have their own institutional structure and environment (Saleth & Dinar, 1999, 2000) and are characterized not only by factors determining the overall institutional environment, but also by those related to the conditions of infrastructural and management solutions, as well as to other sanitation-related sectors such as water, health, agriculture, environment, forest and urban development. The sanitation institutional structure is defined interactively by three institutional components: sanitation law, policy and administration (or sanitation-related organizations) (Ekane *et al.*, 2012, 2013; Saleth & Dinar, 1999). The important role of institutions could best be illustrated in the case of Thailand presented in Box 4.7; in 1897 the country promulgated its first specific sanitation law, which was responsible for the remarkable success of Thailand attaining 91.94% sanitation access coverage as long ago as 1999 (Luong *et al.*, 2000).

The biggest governance challenge of most countries that retard sanitation coverage and service improvement is absence of policy. Elledge *et al.* (2002) described the absence of supportive policies for planning and implementing sanitation projects and programmes as a missing link to improving sanitation coverage. ReGenSan advocates that specific and contextual fit-for-purpose policies, statements, guidelines and standards should make provisions and accommodate all the subsystems of sanitation

BOX 4.7 THAILAND'S FIRST SANITATION LAW

The Bangkok Sanitation Law of 1897 was aimed at curbing the spread of communicable diseases due to poor environmental sanitation. The campaign then targeted garbage collection and building public latrines. A hookworm eradication project initiated in 1918 emphasized using pit latrines. In 1926, the Ministry of the Interior issued regulations banning defecation in rivers and canals. All the ramshackle latrines along the banks of rivers/canals were destroyed. Establishment of the Ministry of Public Health in 1942 led to the integration of Environmental Sanitation into overall health development in the country. The Village Health and Sanitation Project initiated in 1960 to combat the prevalent water/faecal borne diseases gave impetus to expand the sanitation programme nationwide. Rural Environmental Sanitation programmes of the National Health Development Plan were incorporated into successive governments' five-year National Economic and Social Development Plans starting from the first five-year plan in 1961 (Luong *et al.*, 2000).

(SES, TeS and ReS). This could correct the current technocentric institutions responsible for poor performance of sanitation goals and targets. Moving forward will also require modifications to the current institutions of sanitation, which are more focused on micro-level (site and household) and counting of toilets (technology) without adequate attention paid to functionality (Kvarnström *et al.*, 2011).

There will be a need to extend the scope of institutions to cover the meso and macro-levels (sani-sheds) since it has already been established that sanitation solutions cannot be comprehensively provided at household level (Zurbrügg & Tilley, 2009). Thus, extending the scope will cover the neglected aspect of faecal sludge management (Graham & Polizzotto, 2013; Reid *et al.*, 2014) and adequate provisions for resource recovery and reuse for all categories of sanitation infrastructure.

4.2.2.2 Management

The management component refers to the actual operational and institutional responsibilities of organizations to provide sanitation services based on adopted business, legal and sociocultural orientations. The commonly applied approaches are public-sector management with emphasis on the role of local authorities/municipalities, private-sector management and cooperative and community-driven approaches for implementation of sanitation programmes at the local, regional or national level (Castro & Heller, 2009). Currently, sanitation management in most countries is unclear and lacks an organizational home and a champion for investment and service delivery, particularly regarding institutional mandates to decentralize activities that support promoting consumer demands. This lack of a responsible home-base can add to the complexity of the sector-management and resource-allocation processes while limiting organizational accountability for progress (Mehta & Knapp, 2004; WSP, 2011). Presently, sanitation service delivery is overseen by different government ministries, departments and agencies based on their priorities (e.g. health, environmental protection) with administrative decentralization for project implementation at regional and local government levels (Rouse, 2007). This often results in conflicts of the roles and responsibilities of different actors and weak coordination of projects and programmes among different levels of government (Ekane *et al.*, 2014). Different management structures and many layers of policy interpretation usually make it difficult to ensure that clear messages are conveyed, in particular to the local or household levels where the implementation of sanitation mainly occurs (Ekane *et al.*, 2016; Morella *et al.*, 2008). In most parts of the world, responsibilities for sanitation management generally fall on local governments/municipalities, communities and households (Gutterer *et al.*, 2009; Ross *et al.*, 2014), who more often than not have little or no capacity for effective implementation or monitoring of sanitation access expansion and service improvement. Box 4.8 presents sanitation organizational management in Rwanda (Ekane *et al.*, 2016).

BOX 4.8 SANITATION ORGANIZATIONAL MANAGEMENT IN RWANDA

Sanitation main management responsibilities in Rwanda are shared between five ministries, central government service management and regulatory agencies as well as other private-sector and local-level actors. The Ministry of Infrastructure (MININFRA) is responsible for national policies, guidelines and strategies, enhancing human resource capacity at the district level and the monitoring and implementation of government policies. The Ministry of Health (MINISANTE) leads primarily on the promotion of sanitation at the community level and provides preventive, curative and rehabilitative services as well as promoting behaviour change. The Ministry of Education (MINEDUC) is involved in the implementation of hygiene programmes at the local level. The Ministry of Finance and Economic Planning (MINECOFIN) is responsible for budgeting and financing as well as coordination of sanitation external funds and aid and the Ministry of Local Government (MINALOC) is responsible for the coordination of local actors for effective service delivery as well as funding small-scale sanitation projects. The Water and Sanitation Corporation (WASAC), a profit-making company owned by the government, is responsible for managing and regulating water and sanitation services. The districts (local government) and community-based organizations (CBOs) are responsible for providing access to basic sanitation services at the local level. Private-sector actors operate under contracts with the district government and play a major role at the local level. Thus, coordination of actors and other key stakeholders at different levels of the society becomes a major challenge in transforming the sanitation sector and translating policies into practice (Ekane *et al.*, 2016).

Apart from the problem of service coverage, especially in developing countries with low access and poor service delivery, the sanitation sector has long suffered from inadequate management and in most cases total absence of management (Mwanza, 2005; Schwartz, 2008; WHO/UNICEF, 2006). Previous attempts designed to address poor sector performance occasioned by inadequate management was focused on providing ‘hardware’ because it was thought that if service providers were technically equipped it would improve service delivery.

Unfortunately, the results of the last two decades of sanitation development (Drinking Water Decade, 1981–1990; MDG, 1990–2015) proved disappointing, with almost as many people still without access or improved service delivery (Schwartz, 2008). It has become obvious that providing improved and sustained services is not limited to technical capabilities, but requires more managerial and institutional strengthening because sustainability of sanitation services cannot happen in the absence of credible sanitation management systems (Spiller & Savedoff, 1999; Pahl-Wostl, 2007). This necessitates a shift from project-based approaches to planning, construction and management as well as changes in the role of the government from service provider to policymaker and decentralized service deliverer (Ekane *et al.*, 2016). A lack of a supportive institutional framework that establishes effective and efficient management systems has often resulted in fragmented organizational and conflicting mandates, poor coordination of actors and activities and much emphasis on technological solutions (hardware).

Sanitation management is essential to enable long-term service improvement and access expansion through effective and efficient administration, planning, organizing, directing, controlling and decision-making processes (Grigg, 1986; ISF and Stone Environmental, 2009; Ross *et al.*, 2014; Yeager *et al.*, 2006). Effective management should address all aspects of sanitation subsystems (SES, TeS and ReS) and not focus only on infrastructure, to ensure comprehensive system standardization for cost-effective solutions. It could also be a key to achieving best performance of sanitation facilities, from the simplest 'traditional pit toilets and septic systems' to the most complex treatment and recovery systems (WERF, 2009). This is best illustrated in Box 4.9, on sanitation management in Japan (ADB, 2016).

BOX 4.9 SANITATION MANAGEMENT IN JAPAN

Japan's Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) is responsible for the management of off-site sanitation (sewer systems), while the Ministry of the Environment (MOE) handles on-site sanitation (i.e. Johkasou, septage management with scheduled desludging and sludge treatment facilities) and both ministries are expected to work together. To properly promote sewerage works subsidized by the national government, the Sewerage Law of Japan stipulates structural criteria and standards for effluent quality; guidelines for planning, construction and installation of pre-treatment facilities; household connections; user fees; national government financial support; and the respective roles of national and local governments. In areas where construction of a sewerage system is difficult, the households or small communities, located mostly in rural or peri-urban areas, use an on-site treatment system called Johkasou (a packaged aerated wastewater treatment plant installed in individual houses, buildings or small communities for collection and treatment of night soil and domestic greywater). The Johkasou Law mandates the owner to engage a desludging contractor for the facility at least once a year, with the owner paying the associated charge. The effluent water quality of the Johkasou is monitored by the authorized inspection agency once a year in accordance with the law. The Waste Management and Public Cleaning Law mandates local governments to create household wastewater treatment plans for their municipalities, including sludge disposal plans. Sludge treatment facilities are constructed, operated and maintained by municipalities and cities (ADB, 2016).

Sanitation management in the context of ReGenSan is sets of actions taken to guide the overall sanitation systems towards achieving desired goals and targets for the day-to-day operational and institutional responsibilities of the SMEs; within the context of the strategies, policies, processes and procedures that have been established by governance instruments (Lertzman, 2009; Pahl-Wostl, 2007). Its deals with the implementation of a comprehensive lifecycle series of elements and activities that address the structure of SMEs, public education and participation, planning and financing, facility standardization, construction, operations and maintenance, compliance/enforcement, asset management, monitoring and evaluation as well as establishing distinct roles and responsibilities of actors involved in ensuring proper sanitation system management (USEPA, 2003).

ReGenSan advocates for an integrated hybrid management system that provides opportunities for coordination of multi-technological systems, scales, institutional arrangements and multiple providers of sanitation services in sani-sheds (Letema, 2012). It aligns with the principle of decentralized flexible SMEs' organizational/operational structures with active engagement of stakeholders to decide on the types of business and management models to be adopted in sani-sheds. This approach will ensure that SMEs are structured to conform to the sociocultural norms within sani-sheds. The purpose is to adequately and appropriately integrate existing technological scales and types as well as using different management and institutional arrangements to ensure a synergy for effective and efficient access expansion and service improvement.

4.2.2.3 Sustainable Financing

The sustainable financing component of the GoF dimension provides innovative funding strategies that support sanitation institutional arrangements, technology and resource recovery as well as creating a sanitation economy (Badu *et al.*, 2015; Lerner & Tufano, 2011), with the ultimate goals being to improve services and expand access. The investment needed to generate these benefits is enormous because of sector under-funding that results in huge financing gaps, particularly in developing countries where the challenge of increasing access is substantial (OECD, 2011). Studies have identified major financial challenges impacting the sanitation sector as being inadequate resources for sanitation service improvement and expansion, low or non-existent cost recovery from service delivery and lack of financial sustainability of existing solutions (ADB, 2007; van Dijk *et al.*, 2014). These challenges arise from inappropriate institutional frameworks, ineffective and inefficient financing policies and public resources inadequate to meet the costs of sustained, enhanced coverage and improved service delivery (Badu *et al.*, 2015; World Bank, 2003). Previous experiences have shown that investments tended to concentrate on the construction of infrastructure (capital expenditure) with insufficient attention paid to the systems needed to make sanitation function properly, such as regulations, policies, monitoring, institutions and the human resources that provide and deliver services. For instance, having clear institutional roles and legal frameworks that define assets ownership is a major component of attracting private and public finance. If assets ownership is not legally defined, no comprehensive maintenance and rehabilitation can take place and no loans will be provided due to a lack of guarantee (IRC & Water.org, 2017).

Financial flows in the sanitation sector are derived from a large range of sources including overseas development assistance, loans, grants, international private-sector investments, domestic small-scale private service providers' investments, public-sector expenditures, individual households and community investments. In practice, there are only a few options that are actually available and used to finance sanitation investments. Much funding is required to finance the operational responsibilities and institutional arrangement activities critical for upgrading sanitation services and expanding access (Ross *et al.*, 2014). According to Hutton and Varughese (2016) an estimated figure of USD 68.5 billion per year, exclusive of costs to reach the unserved and sustain the gains, is required to meet sanitation SDG no. 6. Sustainable financing also requires proper understanding of lifecycle perspectives on sanitation costing, a vital key to determining recurrent costs and necessary planning for adequate resources to fund long-term operations (Fonseca *et al.*, 2011; IRC & WSUP, 2012; Trémolet & Rama, 2012).

Lifecycle costs approach (LCCA) is particularly important in clarifying the cost of service delivery to be able to arrive at a unit cost for each socio-economic status of the society (IRC & WSUP, 2012). Adequate financing requires adequate costing because when reoccurring and capital costs including maintenance, capacity-building and policy development are not accounted for in budgets, then systems cannot be properly maintained, replaced or expanded (Badu *et al.*, 2015; Dijk, 2003, 2008). This is fundamental, since existing data on costs often refer to the service as designed, with no exploration of the real costs that people actually pay for real services received (IRC & WSUP, 2012). Determining the real funding gaps and service quality that can be delivered at particular funding levels will help to facilitate the supply of adequate funding to service providers and households for optimum services. Recent World Bank studies to track expenditure in seven infrastructure sectors found that households were actually the largest source of finance in the sanitation sector, ahead of governments and international donors, in sub-Saharan Africa (Banerjee *et al.*, 2011). Sustainable financing is designed to provide a proper mix of funding sources that will deliver the required level of services as well as considering sanitation activities as a value chain where private actors play an important role (WSP, 2004; van Dijk, 2012). These strategies are as follows:

(I) Blending public and private funding sources to finance capital expenditure, repairs, renewal and expansion of infrastructure and service improvement. This mechanism addresses affordability constraints at household levels and expansion constraints for service providers (IRC & Water.org, 2017; OECD, 2011);
(II) Resource leveraging from additional sources such as private/domestic and public-sector participation, local investment through local credit markets (microfinance) and resource enhancement from households and community sources;
(III) Cost recovery through service delivered to finance operational and institutional responsibilities as well as life cycle costing approaches to ensure comprehensive costing of sanitation service delivery;
(IV) Supplementary income and social marketing, especially from the sales of materials recovered from sanitation systems and participation in carbon trading; and
(V) Utilization of local/domestic private businesses to provide a range of services such as latrine construction, emptying and management (Badu *et al.*, 2015; IRC & Water.org, 2017; IRC & WSUP, 2012; OECD, 2011; Ross *et al.*, 2014).

The main objective is to attract funds that would otherwise not be attracted by ensuring that basic public policy goals, such as increasing access and service improvement, are met (OECD, 2011). ReGenSan advocates for the use of mixed financing strategies to stimulate the growth of the sanitation sector and encourage local sanitation private-sector service providers to adopt policies and business models that would enhance affordable service delivery. Public finance and development aid alone will not be sufficient to achieve the ambitious targets of SDG no. 6. The sector requires significantly more funding to ensure that sanitation infrastructure investments are properly maintained to deliver quality services (IRC & Water.org, 2017). ReGenSan supports financing solutions that take a blended approach – strategically and intentionally combining aid, public and private finance – because universal access to sanitation cannot be achieved without increased resources to the sector. Classical examples are presented in Box 4.10.

BOX 4.10 BLENDED FINANCIAL APPROACHES

Bangladesh market-based instrument: National social mobilization campaigns combined with market creation approaches supported the emergence of more than 4,000 private workshops producing over one million latrines per year in response to demand promotion and gradual government withdrawal from direct subsidy and production. This led to an annual household investment of USD 10 million in sanitation improvement (Froehlich, 1999; Mehta & Knapp, 2004; SDC, 2003; Urs & Polak, 2000; WSP-SA, 2000).

Lesotho experiences in scaling up sanitation promotion: The National Sanitation Programme in Lesotho dates back 20 years and shows that determined government leadership, limited subsidies and involvement of the local private sector can lead to large increases in national latrine coverage, from approximately 20% to 53% of the population. It focuses on demand and supply and is basically not subsidized. Outstanding features of the programme are that it is an established item on the government budget independent of external support and has simple and clear financing rules including zero direct subsidies for building individual household latrines. Households directly employ private-sector latrine builders while the government concentrates on promotion and training (Pearson, 2002; Mehta & Knapp, 2004).

Ghana's revolving funds for sanitation: Significant challenge for increased coverage of sanitation in Ghana's rural communities is insufficient up-front cash to pay for latrine construction materials. Previous credit funding schemes for latrines offered by local banks or microfinance banks proved unsuccessful. Simavi and its local partner INTAGRAD developed an innovative loan structure where one-third was meant for the construction of a latrine and the remaining two-thirds for income-generating activities at an affordable interest rate. To ensure that funding was actually spent on latrine construction, the credit was disbursed in three tranches; the second tranche was released only after the latrine was built. To improve the financial viability of the loans, they were provided to community savings groups. The profit from the income generation activities allowed latrine loan repayment. The payback rates were as high as 98% over a period of one and a half years. The credit scheme offered adequate sanitation to 1,400 people with a net investment of USD 1,200 (https://rsr.akvo.org/en/project/4279/#report in IRC and Water.org, 2017).

4.3 SES APPROACH TO REGENSAN SOLUTIONS

Solving global sanitation challenges requires system thinking, partnership and the use of transdisciplinary skills. Transdisciplinary approaches can improve sanitation infrastructural and management solutions by reducing discrepancies and mismatch between the SES entities of ReGenSan. Nevertheless, transdisciplinary approaches are often difficult and challenging to perform in the real world because integration efforts are complex to facilitate due to human resource limitation, institutional biases and lack of adequate networking and communication among SES entities (Virapongse *et al.*, 2016). However, it could be critical to fostering better relationships between social, natural sciences, engineering, technology and governance issues as well as providing complex feed-back systems and dependencies.

SES enables proper understanding of the complex interactions between the users, service providers, institutions, infrastructure and the ecosystem (Figure 4.1). The ReGenSan SES subsystem will help address the 'sanitation system blindness' – which describes the focus on tangible infrastructure without attention to the support systems needed to ensure functional adequacy (IRC & Water.org, 2017). The SES consideration has broadened previous definitions of sanitation problems; this implies that they can always be fixed by technology, which has been shown, in case studies both presented in this book and found everywhere around the globe, to be inadequate.

The interactive interconnectedness of the SES entities is a fundamental trait of ReGenSan; no system can be managed effectively and efficiently by focusing on only a few entities, as no problem exists in isolation. All entities are part of the larger system's interacting networks of social, biogeophysical-chemical, political and economy considerations. This perspective provides better insights into infrastructure as an entity that links users, service providers, institutions and the ecosystem, thus providing an avenue to think about sanitation as a whole system. It proves that a sanitation system is more than a chain of actions that starts with faecal matter and urine with its organic and mineral compounds, flush water, wastewater, washing machines and showers. A sanitation system includes psycho-social-cultural, economic and ecological systems as well as the biogeophysical-chemical processes of converting faecal matter and urine into valuable resources to support livelihood and it also needs supportive institutional arrangements that provide the enabling environment (van Vliet *et al.*, 2010).

Users' engagement is well emphasized in the SES of ReGenSan because the isolation of users from different sanitation initiatives is often the underlying cause of many current challenges in achieving successful, sustained results in service improvement and access expansion. Providing a sanitation framework that integrates both social and biophysical components into one management approach ensures that SES of ReGenSan offers great potential for sustainable sanitation interventions and solutions.

4.4 EXERCISES

(I) How could understanding the SES in ReGenSan improve service and expand access?
(II) How do the SES entities and their interactions affect technology selection?
(III) In what ways can understanding the ReGenSan SES affect the success of sanitation infrastructure provisions and wastewater/faecal sludge management?
(IV) Why is governance key to ReGenSan?
(V) Design a sani-shed with a hybrid sanitation system and proffer adequate and appropriate financial and management strategies.
(VI) Describe the institutional arrangement and organizational system of sanitation in your country.
(VII) What are the stages of BGC reactions in septic systems and their corresponding chemical reactions and equations?

4.5 RECOMMENDATIONS FOR FUTURE RESEARCH

(I) Explore three scenarios in sani-management whereby users are the central focus in a systemic and cyclical relationship.
(II) Explore three scenarios where users are not consulted and infrastructure is the focus.
(III) From the perspective of this SES, how is the ecological systemic worldview preferred over the mechanistic-reductionist worldview?
(IV) Explore the BGC recycling process of human digestion by-products in sanitation systems.
(V) Explore the governance challenges of coordinating different stakeholders and actors across societal levels.
(VI) Explore the challenges of integrated hybrid management system in the coordination of multi-technological systems, types, scales, institutional arrangements and multiple providers of sanitation services.
(VII) Explore and advance the concept of sani-sheds as the most appropriate scale of sanitation management.
(VIII) Explore the appropriate mix of blending various financial sources based on systems, types, scales, management and institutional arrangements.

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