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RESOURCE RECOVERY FROM WASTE

Business Models for Energy, Nutrient and Water Reuse in Low- and Middle-income Countries

Edited by Miriam Otoo and Pay Drechsel

Resource Recovery from Waste

Humans generate millions of tons of waste every day. This waste is rich in water, nutrients, energy, and organic compounds. Yet waste is not being managed in a way that permits us to derive value from its reuse, whilst millions of farmers struggle with depleted soils and lack of water. This book shows how Resource Recovery and Reuse (RRR) could create livelihoods, enhance food security, support green economies, reduce waste and contribute to cost recovery in the sanitation chain.

While many RRR projects fully depend on subsidies and hardly survive their pilot phase, hopeful signs of viable approaches to RRR are emerging around the globe including low- and middle-income countries. These enterprises or projects are tapping into entrepreneurial initiatives and public-private partnerships, leveraging private capital to help realize commercial or social value, shifting the focus from treatment for waste disposal to treatment of waste as a valuable resource for safe reuse.

The book provides a compendium of business options for energy, nutrients and water recovery via 24 innovative business models based on an in-depth analysis of over 60 empirical cases, of which 47 from around the world are described and evaluated in a systematic way. The focus is on organic municipal, agro-industrial and food waste, wastewater and fecal sludge, supporting a diverse range of business models with potential for large-scale out- and up-scaling.

Miriam Otoo is a Research Economist, leading the Research Group on Resource Recovery and Reuse at the International Water Management Institute (IWMI).

Pay Drechsel is Principal Researcher at the International Water Management Institute (IWMI), leading IWMI's Strategic Program on Rural-Urban Linkages and the related Research Flagship of the CGIAR Research Program on Water, Land and Ecosystems (WLE).

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Editors and authors

Editors

Miriam Otoo holds a PhD in Agricultural Economics from Purdue University, and specialized since she joined the International Water Management Institute (IWMI) in 2011 in the economics of waste reuse, business development and entrepreneurship, agricultural markets and productivity in developing countries. Her research focuses on understanding the linkages between agriculture, sanitation and organic waste management to enhance food security via the analysis of business opportunities in the waste reuse sector in Africa, Asia and Latin America. Miriam led the development of a multi-criteria methodological framework which has formed the basis for the development and assessment of waste reuse business models for their feasibility, replicability and scaling-up potential in low- and middle-income countries. In 2008, Miriam received the Norman E. Borlaug LEAP Fellowship Award for her doctoral research.

Pay Drechsel holds a PhD in Environmental Sciences and is a principal researcher and research program leader at the International Water Management Institute (IWMI), based in Colombo, Sri Lanka. Pay worked before for the International Board for Soil Research and Management (IBSRAM) and has 25 years of working experience in the rural-urban interface of developing countries, coordinating projects and programs addressing the safe recovery of water, nutrients and organic matter from domestic waste streams for agriculture, with a special interest in wastewater irrigation, urban and peri-urban agriculture, and the cutting edge of applied inter-disciplinary research. Pay has authored over 300 publications, half in peer-reviewed books and journals. He has worked extensively in West and East Africa, and South and Southeast Asia. In 2015, Pay received the Development Award for Research from the International Water Association.

Authors

Abasi Musisi, Kampala Jellitone Suppliers (KJS) Ltd., Kampala, Uganda

Alexandra Evans, Independent Consultant, London, UK

Andrew Adam-Bradford, Coventry University, UK

Ashley Muspratt, Pivot Ltd./Waste Enterprisers Holding, Kigali, Rwanda

Binu Parthan, Sustainable Energy Associates, Kottayam, India

Charles B. Niwagaba, Makerere University, Kampala, Uganda

Doraiswamy Ramadass Naidu, Advanced Centre for Integrated Water Resources Management, Government of Karnataka, India

George K. Danso, Government of Alberta, Edmonton, Canada

Guy Hutton, United Nations Children's Fund (UNICEF), New York, USA

Hari Natarajan, Independent Consultant, Energy access, New Delhi, India

Heiko Gebauer, EAWAG: Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland

Ishara Atukorala, La Trobe University, Melbourne, Australia

Jack Odero, Gamma Systems Limited, Nairobi, Kenya

Jaideep Prabhu, Judge Business School, University of Cambridge, UK

Jasper Buijs, Sustainnovate (http://sustainnovate.nl), Arnhem, The Netherlands

Javier F. Reynoso-Lobo, Independent Consultant, Monterrey, Mexico

Joginder Singh, Punjab Agricultural University, Ludhiana, India

Kamalesh Doshi, Simplify Energy Solutions LLC, Ashburn, Virginia, USA

Katharina Felgenhauer, International Water Management Institute (IWMI), Accra, Ghana

Krishna C. Rao, International Water Management Institute (IWMI), Bangalore, India

Lars Schoebitz, EAWAG: Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland

Lesley Hope, Ruhr-Universität, Bochum, Germany

Linda Strande, EAWAG: Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland

Linus Dagerskog, Stockholm Environment Institute, Stockholm, Sweden

Louis Lebel, Unit for Social and Environmental Research, Chiang Mai University, Chiang Mai, Thailand

Luca di Mario, Asian Development Bank, Manila, Philippines

Manzoor Qadir, Institute for Water Environment and Health, United Nations University, Hamilton, Canada

Marudhanayagam Nageswaran, Independent Consultant, Pondicherry, India

Miriam Otoo, International Water Management Institute (IWMI), Colombo, Sri Lanka

Mirko Winkler, Swiss Tropical and Public Health Institute, Basel, Switzerland

Munir A. Hanjra, International Water Management Institute (IWMI), Colombo, Sri Lanka

Nancy Karanja, University of Nairobi, Nairobi, Kenya

Patrick Watson, I-Dev International, Lima, Peru; San Francisco, USA; Nairobi, Kenya

Paul Skillicorn, Lyndon Water Limited, Kingston-upon-Thames, UK

Pay Drechsel, International Water Management Institute (IWMI), Colombo, Sri Lanka

Priyanie Amerasinghe, International Water Management Institute (IWMI), Colombo, Sri Lanka

Pushkar S. Vishwanath, Tide Technocrats Private Limited, Bangalore, India

Sampath N. Kumar, Tide Technocrats Private Limited, Bangalore, India

Sena Amewu, International Water Management Institute (IWMI), Accra, Ghana

Solomie Gebrezgabher, International Water Management Institute (IWMI), Accra, Ghana

Sudarshana Fernando, International Water Management Institute (IWMI), Colombo, Sri Lanka

Surendra K. Pradhan, Aalto University, Aalto, Finland

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The here presented book or 'business model catalogue' is an output from a joint project (2011–2015) between the International Water Management Institute (IWMI), the Department of Sanitation, Water and Solid Waste for Development (SANDEC) of the Swiss Federal Institute of Aquatic Science and Technology (EAWAG), the International Centre for Water Management Services (CEWAS), the Swiss Tropical and Public Health Institute (Swiss TPH) and the World Health Organization (WHO), and follow-up studies (2016-2017) funded by WLE. The editors duly acknowledge the contribution of each partner.

The project was initiated by a landscape analysis implemented by the International Water Management Institute (IWMI) for the Bill & Melinda Gates Foundation (BMGF). The study suggested that a key factor for supporting cost recovery at scale in the sanitation sector would be the introduction and implementation of 'business thinking' along the sanitation value chain and in particular in the domain of Resource Recovery and Reuse (RRR).

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Foreword

Rapid increases in the human population and in consumption per capita threaten to stretch the planet's capacity to sustain growth beyond its limits. The time has come to move away from the 'take, make, dispose' paradigm of production and consumption, which has dominated global society since the Industrial Revolution, towards what has been termed a 'Circular Economy', which incorporates recycling into the production-consumption cycle.

The Circular Economy concept offers multiple benefits, which have gained recognition in recent decades under various guises: including ecological economics, green growth and sustainable development. The United Nations Agenda 2030 and its 17 Sustainable Development Goals (SDGs) acknowledge the environmental limits to growth and human well-being. The environment features prominently in many targets of the SDGs – particularly SDG 2 on food security and sustainable agriculture, SDG 6 on water reuse and water for ecosystems, SDG 12 on waste recycling and reuse and SDG 15 on restoring degraded soils, to name a few.

What the green development has lacked so far, however, thus limiting its success, are workable business models that incentivize economic agents to act on the basis of social and environmental concerns, and consider these as concrete bottom lines in their business decisions. As a result, efforts to mainstream Corporate Social Responsibility (CSR) have relied mainly on the conscience of business leaders, appealing to their sense of responsibility for social and environmental concerns. The proponents of CSR policies have rarely justified them in terms of their most important bottom line, the financial one. The goal of the Circular Economy, on the other hand, is for business leaders to assess business viability not only in the short term but for the future generations who will demand their services. The idea is for businesses to internalize the wider environmental costs and benefits in their production decisions and to make consumers complicit in these decisions.

This publication showcases real examples from around the world, demonstrating how plant nutrients, energy and water can be recovered from what is currently viewed as 'waste' – avoiding their unregulated disposal into the environment and associated costs (e.g. health costs, clean-up costs), while also capturing the financial value associated with reuse of the treated or recycled resource. Like a catalogue, compiled mostly from low- and middle-income countries, the book covers a wide range of value propositions to maximize cost recovery and social or financial benefits. It is impossible to underestimate the importance of recovering resources, particularly from food waste in growing urban centers, for the benefit of the water, energy, nutrient and carbon cycles. If these case studies and the models derived from them can inform broader programs aimed at scaling up good practices, they will contribute importantly to the achievement of many SDG targets, including SDG 11 on more resilient cities.

What these case studies demonstrate is that businesses working towards a Circular Economy can create social and financial value beyond cost recovery. However, the success of these business models relies on the presence of an enabling environment, such as laws and regulations, strong capital markets, consumer advocacy, and so on, to attract private capital and expertise. These findings underline the critical role of governments in making the Circular Economy a reality.

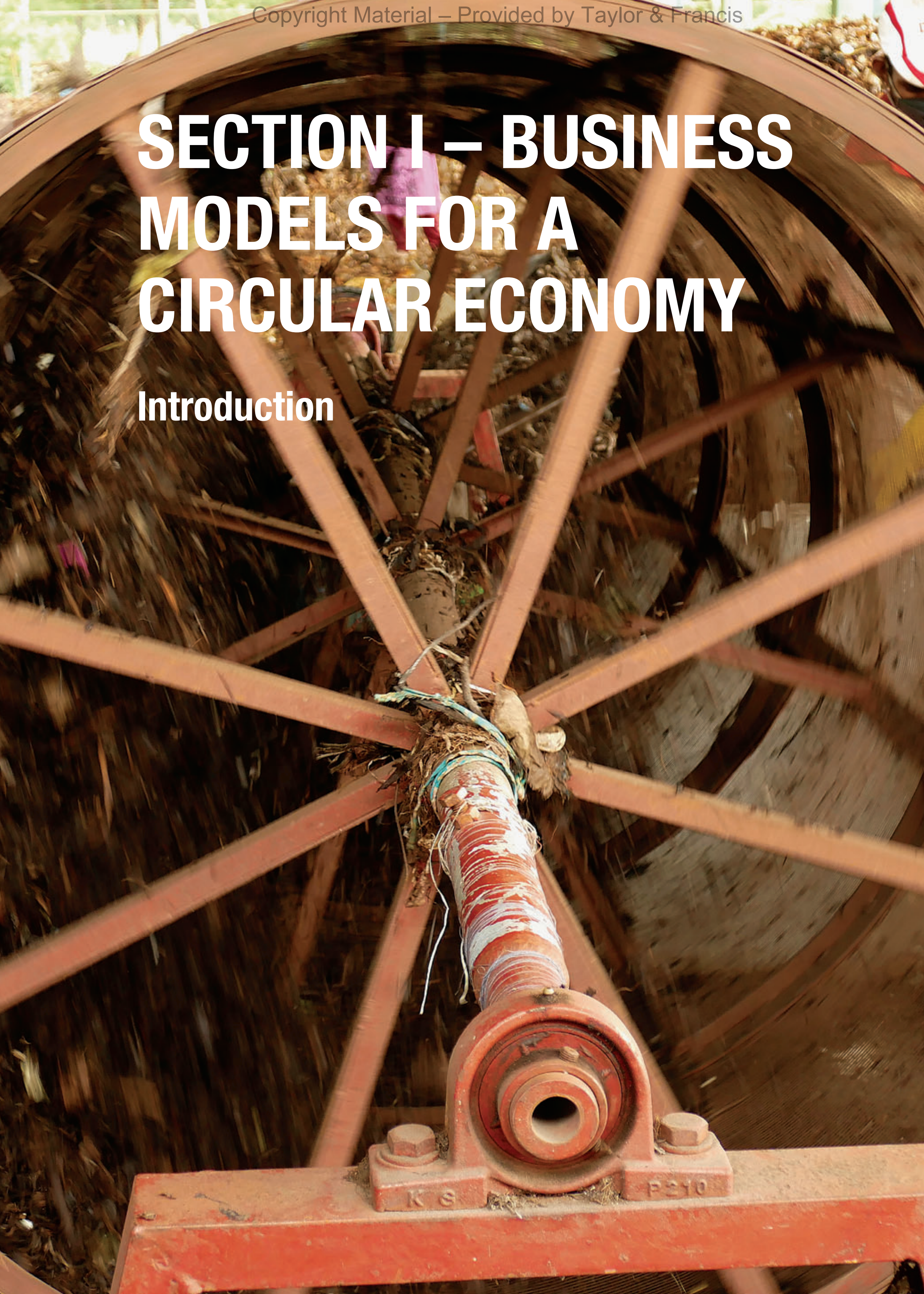
The catalogue fills a significant gap in the literature and should prove useful not only for today's investors and policy makers but also for the curricula of engineering, economics, environmental and business schools. This will help sensitize the next generation of decision makers to the opportunities inherent in the Circular Economy.

On behalf of the editors and authors, we strongly recommend the catalogue to readers working at the interface between waste management, sanitation and other sectors, such as agriculture, and urge them to make good use of this timely and valuable publication.

Guy Hutton
Economist
Senior Adviser, UNICEF

SECTION I – BUSINESS MODELS FOR A CIRCULAR ECONOMY

Introduction



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1. BUSINESS MODELS FOR A CIRCULAR ECONOMY: LINKING WASTE MANAGEMENT AND SANITATION WITH AGRICULTURE

Pay Drechsel, Miriam Otoo, Krishna C. Rao and Munir A. Hanjra

Business models for a circular economy: Linking waste management and sanitation with agriculture

Urbanization is the pre-eminent global phenomenon of our time. Currently, urban areas account for 75% of the world's natural resource consumption, while producing over 50% of the globe's waste on just 2–3% of the earth's land surface (UNEP, 2013). Without recycling, cities will continue to constitute vast sinks for food waste including valuable crop nutrients and organic matter, while millions of rural, peri-urban or urban farmers struggle with depleted soils to feed the growing urban population. Yet, it is not only the loss of valuable, and in part, finite resources, but also the costs of poor waste management, i.e. environmental pollution and the production of avoidable greenhouse gases (GHG) which threatens sustainable urban growth. Halving, for example, the current rate of food wastage would greatly support waste management while reducing GHG emissions by 22–28% (WEF, 2016). So far, the environmental costs of poor waste management are usually externalized and the market incentives to reduce waste are minimal.

While global demand projections for water, food and energy predict continuous and significant growth, the declining reserves of the non-renewable phosphorus, copper and zinc resources (Holmgren et al., 2015) reinforce the need for more investments in resource recovery and reuse across the food, waste and sanitation sectors (Ellen MacArthur Foundation, 2017; TBC, 2016).

While Europe continues setting an example with the implementation of a first action plan on the circular economy (EC, 2016), more attention should be given to natural resource loops in low- and middle-income countries, especially in the tropics where soils are poor and nutrient depletion is high and commercial fertilizer is basically unaffordable. Minimizing resource loss and returning resources into the food production process is essential in particular in drier climates where every drop of water counts and organic matter is needed for sustaining soil fertility as natural biomass production is low.

Aside from the reduction of food waste along the food chain, resource recovery allows to capture value even from apparently 'wasted' resources (FAO, 2011). In particular, domestic and agro-industrial waste is rich in water, nutrients, energy and organic compounds. Yet, in most parts of the world, this waste is not being managed in a way that permits us to derive value from its reuse, although resource recovery is nothing new. Closed loop systems linking food waste and food production have been practiced for generations in many rural societies. However, population growth and urbanization in particular have increased distances and polarized food flows towards urban centres where agricultural reuse opportunities for food waste are limited.

But cities are not only 'hungry'; they are also 'thirsty'. Van Rooijen et al. (2005) crafted the term 'Sponge City' to visualize the **urban metabolism** which is absorbing freshwater from its periphery while discharging wastewater which has a high potential to support ecosystem services and food production in water-scarce regions, if wastewater treatment and safe reuse can be achieved. If not, this water will be a threat to food safety and public health.

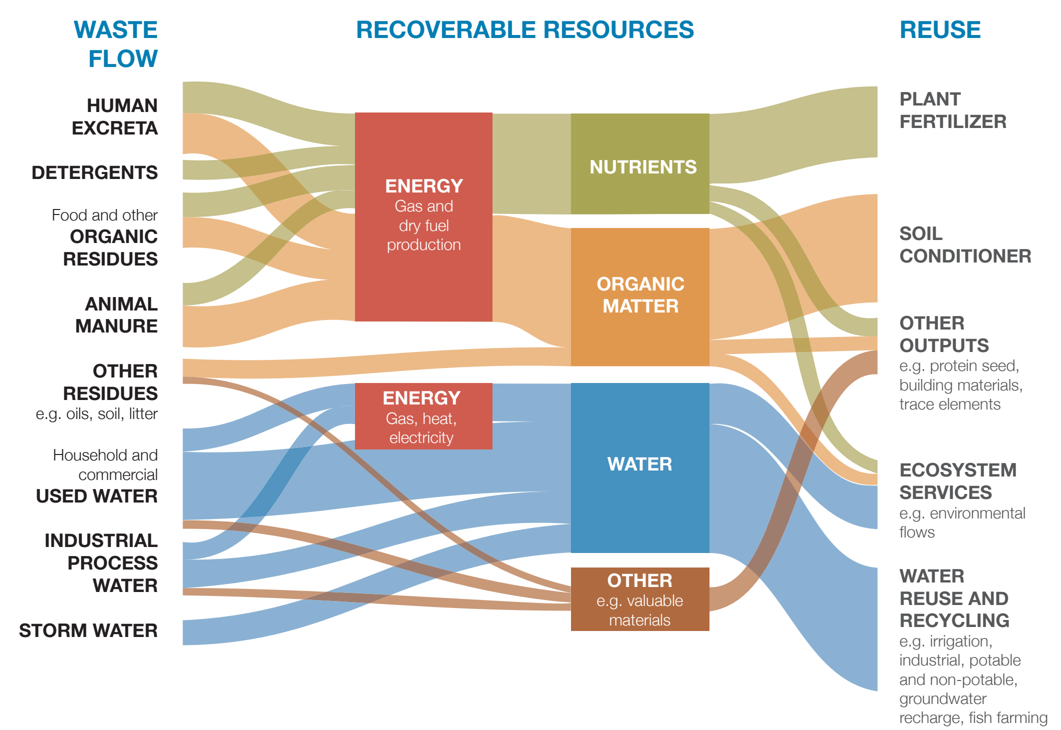
In fact, due to limited treatment capacities, the various domestic waste streams, solid as well as liquid, form a significant part of the unwanted urban footprint. The resulting pollution constitutes not only the paramount environmental and health challenges that today's exploding cities and their surroundings are facing, but also a significant economic challenge in countries where waste collection and treatment cannot be financed through taxes and fees (Kennedy et al., 2007; Le Courtois, 2012). This mismatch

puts into question the sustainability of urban growth where it is the fastest unless alternative business models are put in place (Muradian et al., 2012; Villarroel Walker et al., 2012).

In the context of resource poor countries, it is more than opportune to argue for a circular metabolism, as increasingly promoted in many developed nations, where waste segregation and recycling contribute to overall system resilience (UNEP, 2017) and the values of *green growth*, i.e. an economy without degrading the environment. In this regard, the urban waste challenge – including fecal matter generation – can offer immense and scalable opportunities for entrepreneurs through transforming waste from domestic and agro-industrial sources into low-carbon assets for use in agriculture and other sectors (Figure 1). This is strongly supported by the Sustainable Development Goals (SDG) targeting for example water reuse (SDG 6), renewable energy (SDG 7) and waste recycling and reuse (SDG 12), which can help to restore degraded soils (SDG 15) for sustainable agriculture and food security (SDG 2) and resilient cities (SDG 11). Especially wastewater and the different organic fractions of municipal waste streams offer a significant potential for the support of a 'biocycle economy' (Ellen MacArthur Foundation, 2017).

These opportunities for value creation from resources that would otherwise be irretrievably lost also allow for cost savings and/or cost recovery in the sanitation sector; for example in the case of composting which, depending on scale, reduces municipal solid waste volumes and transport costs with the potential to enhance the lifetime of landfills with less GHG emissions. Furthermore, by moving increasing amounts of biological material through anaerobic digestion or composting back into the soil, a circular economy approach will reduce the need for chemical fertilizers and soil amendments (Box 1).

FIGURE 1. OVERVIEW OF WASTE STREAMS AND RESOURCES WITH POTENTIAL FOR THE RECOVERY AND REUSE OF NUTRIENTS, ORGANIC MATTER, WATER AND ENERGY



Source: Andersson et al., 2016, modified.

Box 1. The potential of organic waste for the circular economy

The World Economic Forum has estimated potential global revenues from the biomass value chain (production of agricultural inputs, biomass trading and biorefinery outputs) as high as USD 295 billion by 2020. Cities, as major concentrators of materials and nutrients, and the power of generating over 80% of the global Gross Domestic Product (GDP), will play a major role on the 'biocycle economy'.

Return of food waste: If 100% of consumption-related food waste and 50% of other food waste generated today were returned to the soil, it could replenish 5 million tonnes of nitrogen, phosphorus and potassium (N, P, K) reserves, substituting for 4% of current N, P, K consumption.

Return of animal manure: If all the nutrients from the current stocks of cattle, chicken, pig and sheep manure were captured, they would yield an astounding 345 million tonnes of N, P, K annually – more than twice the world's current consumption. Using animal manure also improves soil structure and organic content and reduces commercial fertilizer loss.

Return of human waste: Human waste also contains significant amounts of N, P, K. If nutrients contained in the waste of the world's population were captured, they would amount to 41 million tonnes, representing 28% of the current N, P, K consumption.

In theory, the organic sources of N, P, K fertilizer recovered from food, animal and human waste streams could on a global scale contribute up to 2.7 times the nutrients contained within the volumes of chemical fertilizer currently used.

Further analysis is needed to assess what share of organic fertilizers could be returned to the soil in a cost-effective way. In OECD countries, for example, an estimated 177 million tonnes of municipal organic waste are produced annually, of which 66 million tonnes are so far valorized in composting or anaerobic digestion. The market value of N, P, K in this fraction is estimated at USD 121 million per year, and adds an estimated 5 million tonnes of stable carbon (and 10 million tonnes of carbon in total) to OECD soils every year in the form of compost/digestate. ISWA (2015) estimate that around 58 million tonnes additionally could feasibly be collected and valorized.

Source: Ellen MacArthur Foundation, 2013, 2017; ISWA 2015.

As farm soils need organic material, especially on highly weathered tropical soils, closed loop processes appear to be a win-win situation (Drechsel and Kunze, 2001). It is estimated that halving the current rate of food wastage could meet over a fifth of caloric needs by 2050, reducing required cropland by 14% (WEF, 2016). The reality is however, that resource recovery and reuse (RRR) has been until now more theory than practice. RRR remains challenged where awareness for 'green' values and opportunities is less developed, public perceptions do not favour reuse or municipal capacities are too constrained to make the required investment. Developing countries spend around USD 46 billion annually on waste management, and it is estimated that they should spend another USD 40 billion to cover the current service delivery gap (Le Courtois, 2012). The total costs are expected to surpass USD 150 billion by 2025. The additional capital investments required for safe fecal waste management in support of the SDGs target 6.2 amount to about USD 49 billion per year (Hutton and Varughese, 2016).

In their daily struggle with the service delivery gap, many municipalities consider RRR a task for the future, once their current challenges are under control. What Onibokun (1999) called 'Managing the

Monster' is in fact often absorbing as much as half of the municipal budget in many low-income countries (Le Courtois, 2012).

Accepting the limitations of the public sector, an opportunity is to leverage private capital based on the value of the recovered resources (Otoo et al., 2012; Le Courtois, 2012). This could also support a conceptual transition from 'treatment for safe disposal' to 'design for reuse' (Murray and Buckley, 2010; Huibers et al., 2010). In such a postmodern sanitation system (Ushijimaa et al., 2015), incentives for financing sanitation could be shared between 'front-end users' and 'back-end users' building on demand for the products of sanitation and waste management to motivate a combined finance model and more robust operation and maintenance of complete sanitation systems (Murray and Ray, 2010). This would require a supportive regulatory and finance environment and well-designed partnerships agreements.

However, the lessons learned so far have also shown that closed loop processes do not manifest themselves through the promotion of composting, water reuse or – for example – *ecological sanitation*. What is often described as an engineering challenge (*'Reinvent the Toilet'*) and in fact is often driven by technology development, like for the removal of unwanted struvite in wastewater treatment plants ('phosphorus recovery'), is increasingly understood as an institutional, social and economic challenge. There is significant need for investments in market research, bankable business models for cost recovery, stakeholder buy-in and innovative partnerships, especially if scalability and sustainability are targeted (Guest et al., 2009; Le Courtois, 2012; Beltramello et al., 2013; Hanjra et al., 2015; Verstraete and Cornel, 2014). Countless failed composting projects began with significant amounts of grant funding but eventually collapsed due to their inability to support their operational costs (World Bank, 2016).

Given the common situation of the waste and sanitation sectors, especially in Africa and Asia, the term 'business models' might appear to be out of place. However, exactly where every step towards cost recovery counts, the thinking has to change (Koné, 2010). While for example wastewater treatment was and is first of all a 'social business model' with a strong economic justification and returns on investments through safeguarding public health and the environment, a second (reuse-based) value proposition can offer incentives for private sector engagement, that leverage private capital to help realize commercial or social value. However, what sounds in theory promising often faces fundamental structural barriers. In fact, 88% of developing country governments have no cost recovery efforts at all for water and sanitation (Muspratt, 2016a).

There are multiple bottlenecks faced by both the public sector and/or the emerging private sector across most low- and middle-income countries. These include financing challenges, unsupportive regulations and slow approval processes, but also missing the capacity to present viable business plans for penetrating the reuse market. In particular, organic waste composting is often more driven by cost savings than revenue generation (Box 2) which can potentially undermine those SDG targets, which will count actual 'reuse'. Thus, private sector participation in waste management is not a panacea for success in promoting Resource Recovery *and Reuse* unless the companies understand how to approach the reuse market (e.g. Rouse et al., 2008) and can count on an enabling environment (see Chapter 19). In particular in Africa, smaller start-ups struggle with bureaucracies and financing (Muspratt, 2016ab), while larger companies, that can accommodate delays, succeed. In India, for example, several firms have emerged that treat today the waste collected by municipalities without any charge, while revenue is generated exclusively by recycling the waste collected (Furniturwala, 2012). In this regard, urbanization is not only posing challenges but also opportunities compared with rural areas, such as market proximity, shorter transport distances, higher purchasing power, export hubs and economies of scale that can attract private capital, if the enabling policy environment is in place and *de facto* functional.

Box 2. Cost savings as a driver for resource recovery (and reuse)

Where land prices go up in urban vicinity, communities do not accept hosting a landfill. This is resulting in increasing transport costs for municipal waste disposal to remote areas where land is still abundant. As transport can be their major cost factor, many waste managers show a strong interest in composting as a means to reduce waste volumes and transport costs (Drechsel et al., 2010). If the compost is eventually 'burned', distributed for free, or becomes a revenue stream, from the waste management perspective this is often of lower relevance, especially where (i) contracts are based on the processed waste volume, but not on the sale or reuse of the recovered resource, or (ii) the gains from volume reduction outweigh any expected returns from compost marketing.

The same applies to those waste-to-energy projects, which are designed (and financed) for absorbing municipal solid waste (MSW) in order to reduce municipal service costs as a whole. Energy production is in these cases often only a secondary revenue stream, while MSW sorting cost and its low calorific value constrain the business. Another example are enterprises engaged in the collection of human excreta from non-sewered sanitation systems, which might engage in composting, primarily to reduce the costs of waste disposal, and not because of expected compost revenues.

In addition, energy or phosphorus recovery within wastewater treatment processes is largely driven by cost reduction. The recovery of phosphorus, for example, prevents damage of pipes and valves through unwanted precipitation. The resulting savings in chemicals otherwise needed to remove the crystals can more or less finance enterprises specialized in P recovery while the generated P-fertilizer is a side product which is often struggling to find more than a niche market (Otoo et al., 2015; see also Business Model 16).

A second prominent RRR bottleneck is the understanding of the impact and related value of planned interventions compared with the counterfactual 'business as usual'. Internalizing any possible externalities especially on human and environmental health is important to attract public subsidy as a well-justified revenue stream. When the environmental and societal benefits of investments in sanitation and waste management are accounted for, most RRR projects will be viable (ADB, 2011; Andersson et al., 2016). However, while benefits can be easily and fully internalized by governments and citizens, they are very difficult for a private company to monetize (Muspratt, 2016a). On the other hand, the private sector is under increasing pressure to accept corporate social responsibility (CSR), account for its own externalities, and engage in mitigation measures.

Corporate social and environmental responsibility

The call for corporate responsibility is echoed in SDG 12.6 (Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle). While CSR has a high potential to support a circular economy, its success at national level will not only depend on the private sector but also how governments, which carry the responsibility for achieving the SDGs, will 'encourage' firms to take part (Fogelberg, 2015). For example, section 135 of India's Companies Act 2013 requires (on a "comply-or-explain" basis) that firms satisfying specific size or profit thresholds spend a minimum of 2% of their average (pre-tax) net profit on CSR; moving a voluntary CSR contribution into a law. The risk is that this transforms CSR more into an offset tax than social or environmental consciousness, as a company can choose

to contribute, e.g. to funds of the Central Government or the State Governments for socio-economic development (Grant Thornton India LLP, 2013), independently of the company's own practices and challenges, e.g. in view of responsible resources management.

A closer monitoring is provided by independent CSR assessment agencies, as for instance by the Newsweek Green Rankings. The ranking is based on eight key performance indicators, including waste generation/recovery/reuse, GHG emissions, energy and water demands and so forth. Companies failing to disclose data for the rigorous analysis by Newsweek and partners would receive a score of '0', thus negatively affecting their overall performance and public image. The rise of the social media is in this regard an important factor. When catering to global markets, big companies sell millions of products every day. However, any negative press can set off within the shortest period a series of consequences via social media that may be detrimental to a product or brand's image. These days this puts much higher pressure on companies to maintain their image compared to a decade ago and a number of rating agencies support these efforts (Novethic, 2013).

Corporate social and environmental responsibility can thus directly and indirectly trigger and support RRR. The key words are "responsible and sustainable sourcing of raw materials", including direct commitments to the circular economy (Box 3).

Sustainable sourcing is increasingly receiving attention as consumers and other stakeholders want to know where their food comes from and how it was produced. Supply chain audits can have a far reach and catalyze environmental consciousness at an unexpected pace and far from the company's home. In one of the reported cases in this catalogue (Chapter 18), local private textile suppliers offered their own government to co-finance wastewater treatment plants to be able to comply with the responsible sourcing criteria of their European buyers as otherwise they would no longer be accepted, resulting in financial crisis.

Box 3. Towards a circular economy in the food sector

Based on CSR principles global companies such as Cargill, Nestlé, Starbucks, Unilever etc. support in many low-income countries extension services, traders and farmers, e.g. in view of access to inputs and markets along the companies' value chains. Social and environmental commitments include responsible sourcing of raw materials and a high commitment to personal and product safety, resource recovery and zero waste schemes, or for example the provision of fortified but affordable food. In larger companies, these commitments are part of the corporate value proposition and monitored through audits and certifications by independent accredited bodies issuing sustainability rankings and indices. The same applies to agricultural input suppliers like BASF and its resource use efficiency optimizing 'Verbund' principle. Global food company, Danone, to give another example, has announced in 2016 a new partnership with the global waste-management company, Veolia, to embed circular economy principles inside the company and to promote them widely. Danone aims for systemic change to preserve natural resources and to move to a more circular value chain. Danone was recently awarded the Environment Top Performance prize by the Environmental and Social Governance (ESG) ratings agency Vigeo, among 1,300 companies assessed. The company has circular economy projects like recycling by-products from yoghurt production for animal feeds, fertilizer and energy.

See also: www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/toward-a-circular-economy-in-food?cid=eml-web (accessed November 7, 2017)

The next step of corporate responsibility is the monetary valuation of the ecosystem services that are positively or negatively affected, and to integrate these financial values into corporate accounting. Negative balances could be offset through carbon or ecosystem credits (NSW, 2007; The Rockefeller Foundation, 2015). Internal carbon pricing, which is of particular interest for RRR, is now becoming a widely used tool helping companies shift to lower-carbon business models. Over 1,200 companies reported to CDP, formerly the Carbon Disclosure Project, in 2016 that they are currently using an internal price on carbon or plan to do so within the next two years (CDP, 2016).

To avoid that offsetting becomes the main investment and a license for 'business as usual', green accounting requires shared definitions, indicators and methodologies for measuring and monitoring impacts to allow public sector investment ideally in the same area of concern, e.g. in wastewater treatment (DeLonge, 2012; Meyers and Waage, 2014).

From business cases and opportunities to business models

With three SDG supporting directly RRR, and an increasing attention to the synergies between CSR and the circular economy, the objectives of this book are:

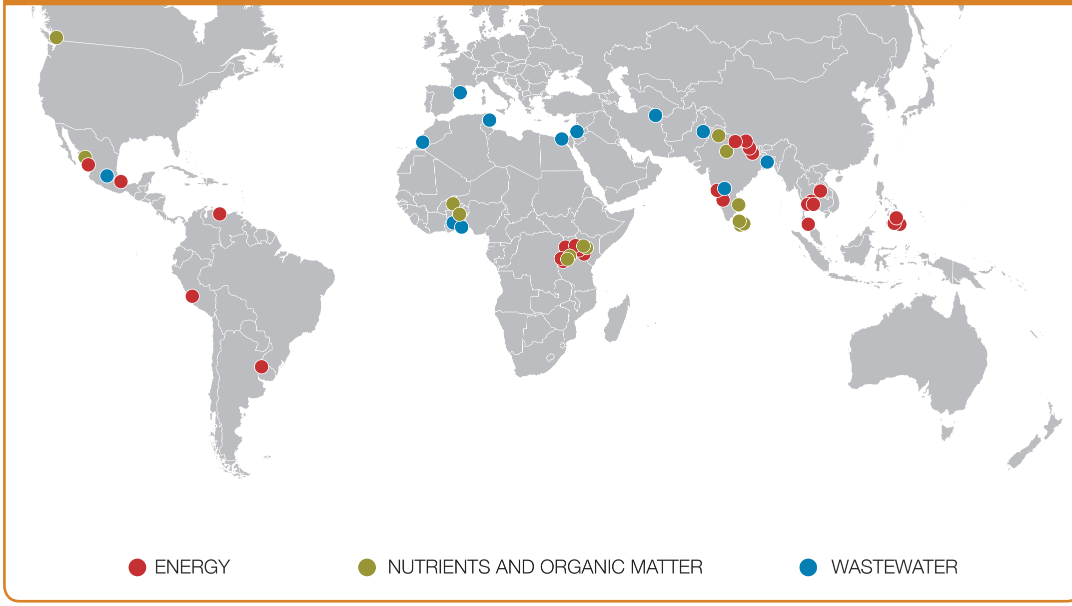
> To show scalable options for RRR as a value proposition to stimulate business thinking in the interface of sanitation, waste and agriculture.
>
> To build capacity for a more integrated and inclusive approach to the recovery of water, carbon, nutrients and energy from domestic and agro-industrial waste for reuse.
>
> To provide opportunities for local business model adaptation across low-income countries, where the public sector struggles to finance closed loop processes through household taxes and fees, and start-ups struggle with an only slowly emerging enabling environment.

Chosen from about 150 public and private RRR projects and enterprises, of which over 60 were analysed in detail, this catalogue presents a selection of 47 empirical business cases (Figure 2), from which 24 business models were extracted. Chapter 2 provides some background into the methodology and definitions used for the selection and analysis of the cases and models. A separate catalogue looking at 18 institutional business models for managing the 'ultimate' food waste, i.e. fecal sludge, including resource recovery and reuse as fertilizer and energy source, has been published separately (Rao et al., 2016).

Our understanding of the term 'business model' follows Osterwalder and Pigneur (2010), i.e. a business model describes the rationale of how a firm or organization creates, delivers and captures value in economic, social, cultural or other contexts. In our case, the common value proposition is the creation of a useful resource from material which otherwise would be wasted. Given the multitude of domestic and industrial RRR options, **in this publication we are looking mostly at those options where either the waste derives from the food chain and/or the recovered resources support the food chain**. In other words, most presented cases and models are limited to the recovery of (i) water, (ii) crop nutrients and carbon (organic matter) and (iii) energy, derived from domestic and agro-industrial waste, including food waste, wastewater and excreta. By limiting the scope to the food chain, other recyclable resources like glass, plastic or metal are not addressed.

In order to increase the probability of replication in low- and middle-income countries we tried to focus mostly on cases and experiences in Asia, Africa and Latin America, operating at community or city scale, i.e. we exclude individual household- or farm-based efforts for resource recovery and reuse. A few cases from high income countries, with potential for replication in other parts of the world,

FIGURE 2. LOCATIONS OF BUSINESS CASES DESCRIBED IN THE BOOK



are also included. The description of cases and models followed defined templates (see Chapter 2) bridging between the needs of students in business schools looking for detailed case studies and those of investors in need of a compact information, which was not easy to combine.

In the literature, the term ‘business model’ is commonly used for a broad range of informal and formal business processes, structures and purposes resulting in very diverse interpretations and definitions. Similarly, many options exist to name or cluster business cases and models in categories, especially in the young domain of sustainable development and green economy where existing examples are fragmented (George and Bock 2011; Beltramello et al., 2013). It is important in this context to stress that the term ‘**business**’ should not imply that ‘business models’ have to be profit-oriented or able to achieve through their value proposition full cost recovery. **In sectors, like waste and sanitation, which usually rely on public financing, any scalable efforts towards cost recovery or cost savings are already a paradigm shift and should be seen as a step in the right direction, next to the creation of social and environmental value**. Reduced expectations are in particular required in view of water reuse in agriculture. In many situations, the direct revenues from selling treated wastewater to farmers are small, given that fresh water prices are often subsidized or groundwater freely accessible. However, the situation can change if further value propositions are added, such as the use of the water for fish feed and fish production, energy recovery or treatment for industrial or potable reuse (Rao et al., 2015). In those cases, the full recovery of operational and maintenance costs, or even the recovery of capital costs, can be possible as the examples in the book show. But more common and equally important are those cases where operational cost recovery varies between 10 and 90% and it is critical to analyse what prevents a waste-based venture from moving up the scale.

In cooperation with different business schools, the catalogue adopted the **extended Business Model Canvas** (Osterwalder and Pigneur, 2010) to visualize the different business models, including their externalities. Externalities are very important as the waste and sanitation sectors not only benefit society but also are prone to environmental and human health risks. Hence, an important requirement

for any type of waste management scheme, including resource recovery, is the need to safeguard public health. Risk management and mitigation for safe waste handling and reuse are thus essential components of the sustainability and acceptance of any RRR business model, especially where the waste might contain fecal matter or other chemical contaminants. This was emphasized through collaboration with the World Health Organization (WHO) and development of the *Sanitation Safety Planning* (SSP) concept, which supports the operationalization of the safe use of wastewater, excreta and greywater in agriculture and aquaculture (WHO, 2015; Andersson et al., 2016).

This catalogue with its cases and models targets a community more interested in business opportunities than technical solutions. The description of technologies as far as they relate to the value proposition or particular safety measures remains throughout brief except where business models are technology driven. With its focus on low- and middle-income countries, the catalogue does not include those high-tech solutions for RRR, which first have to show their replicability and sustainability in the context of these regions as stressed, e.g. by Wang et al. (2015), Nhapi and Gijzen (2004), Murray and Drechsel (2011) or Libhaber and Orozco-Jaramillo (2013).

Although neither the presented cases nor models cover the whole spectrum of agriculture related RRR value propositions, this catalogue is the most profound analysis and comprehensive compilation made so far to show the business side of RRR in the interface of sanitation, waste management and agriculture in low-income countries. While in some cases it was not possible to obtain from the private or public sector the requested financial information, or only under a non-disclosure agreement, the models should provide enough information to be an excellent starting point for business schools and investors to approach this so far uncharted sector.

An analysis, which is cutting across several of the presented cases and models was presented by Rao et al. (2015) for water reuse, Gebrezgabher et al. (2015) for energy recovery and Otoo et al. (2015) for nutrient and organic matter recovery and reuse.

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2. DEFINING AND ANALYZING RRR BUSINESS CASES AND MODELS

Miriam Otoo, Solomie Gebrezgabher, Pay Drechsel and Krishna C. Rao with support from Sudarshana Fernando, Surendra K. Pradhan, Munir A. Hanjra, Manzoor Qadir and Mirko Winkler

Defining and analyzing RRR business cases and models

The objective of this second chapter is to explain how the cases were selected and analyzed and how the authors derived the business models. The starting point was the identification of 'promising' empirical resource recovery and re-use (RRR) enterprises and governmental projects. In other words, the presented models are essentially not theoretical but have been tried – in most cases – in the context of low- or middle-income countries. 'Promising' in this context means that the cases, which informed the models, moved beyond a fully-subsidized pilot stage or were never designed as such, and aim at cost recovery or profit with potential for replication and scaling up. It does not mean that the selected cases are flawless, and there are many lessons to learn from their challenges. With some exceptions, every model presented in the catalogue derived its information from several empirical cases, which allowed extracting and flagging their strengths and opportunities as well as possible weaknesses and threats.

For the purposes of this catalogue, we define RRR **business cases** as:

> Business cases are entities, like enterprises, governmental projects or public-private partnerships (PPPs), that are engaged in the productive and safe recovery of water, nutrients, organic matter and energy from domestic and agro-industrial waste streams (including wastewater) by utilizing the recovery and/or re-use value of waste to generate revenue or recover costs in support of waste management and/or a healthy or more productive environment.

With the objective of showing scalable options, the presented cases are usually operating at community or city scale, i.e. household- or farm-based efforts in RRR have not been included.

Guided by Osterwalder and Pigneur (2010), a **business model** is defined in this catalogue as follows:

> A business model describes how a business creates, delivers and captures value; essentially the entire solution comprising the core aspects of the business – business process (e.g. technology), target customers, produce, infrastructure, organizational structures, trading practices, operational processes and policies, and the strategies it implements to achieve its objectives (be they for cost recovery, profit maximization, social impact, etc.).

Serving different target groups of this book, the presentation of empirical RRR business cases and models was challenging. While business schools might prefer detailed case studies, practitioners or decision makers will prefer a compact overview. The analysis of the cases and development of related business models does not come with the well-established base of literature and guidance that we are accustomed to from more conventional business sectors (George and Bock, 2011). Moreover, the assessment of both formal and informal RRR business cases requires significant groundwork to understand the factors that drive their success and likely sustainability, replicability and scalability barriers, particularities and opportunities. The analysis thus required the development of a suitable methodology, taking into consideration different types of readers, as well as both the micro- and macro-environment that cases operate in, while being flexible to cope with possible data gaps.

Assessment of RRR business cases

The business model concept

It is imperative that the concept of business modelling is clearly defined and more so in the context of resource recovery and re-use of waste. In the past two decades, the business model concept

has become an increasingly pertinent concept in management theory and practice and has received substantial attention from academics and business practitioners (Magretta, 2002; Hedman and Kalling, 2003; Osterwalder et al., 2005; Shafer et al., 2005; Zott et al., 2011). Numerous definitions of the concept have been proposed although no particular terminology has so far been accepted in the domain of RRR (Bocken et al., 2014). In general, a business model describes how a business creates, delivers and captures value. In the RRR or eco-innovation context, the generic value proposition is the recovery of a useful resource from material which would otherwise be wasted. The related direct or indirect benefits can be savings, cost recovery, profits, welfare benefits, or an improved reputation (Beltramello et al., 2013; Hanjra et al., 2015).

In order to understand and operationalize the business model concept, Osterwalder and Pigneur (2010) described a business model as consisting of four core elements which can be disaggregated into nine building blocks that, taken together, create and deliver value. These four core elements describe a firm's:

1) *Value proposition* which distinguishes it from other competitors through the products and services it offers to meet its customers' needs;
2) *Customer segment(s)* the firm is targeting, the channels a firm uses to deliver its value proposition and the customer relationship strategy;
3) *Infrastructure* which contains the key activities, resources and the partnership network that are necessary to create value for the customer; and
4) *Financial aspects* (costs and revenues) which ultimately determine a firm's ability to capture value from its activities and break even or earn profit.

Based on these core elements, Osterwalder and Pigneur (2010) describe a business model through a canvas of nine components. There are different possibilities to extend or modify the canvas.[1] In this catalogue, we use an extended canvas by the same authors, which considers, with two additional components, possible positive and negative externalities (Figure 3). This extension is particularly important for the waste and sanitation sectors given related risks for human and environmental health, but also significant social benefits.

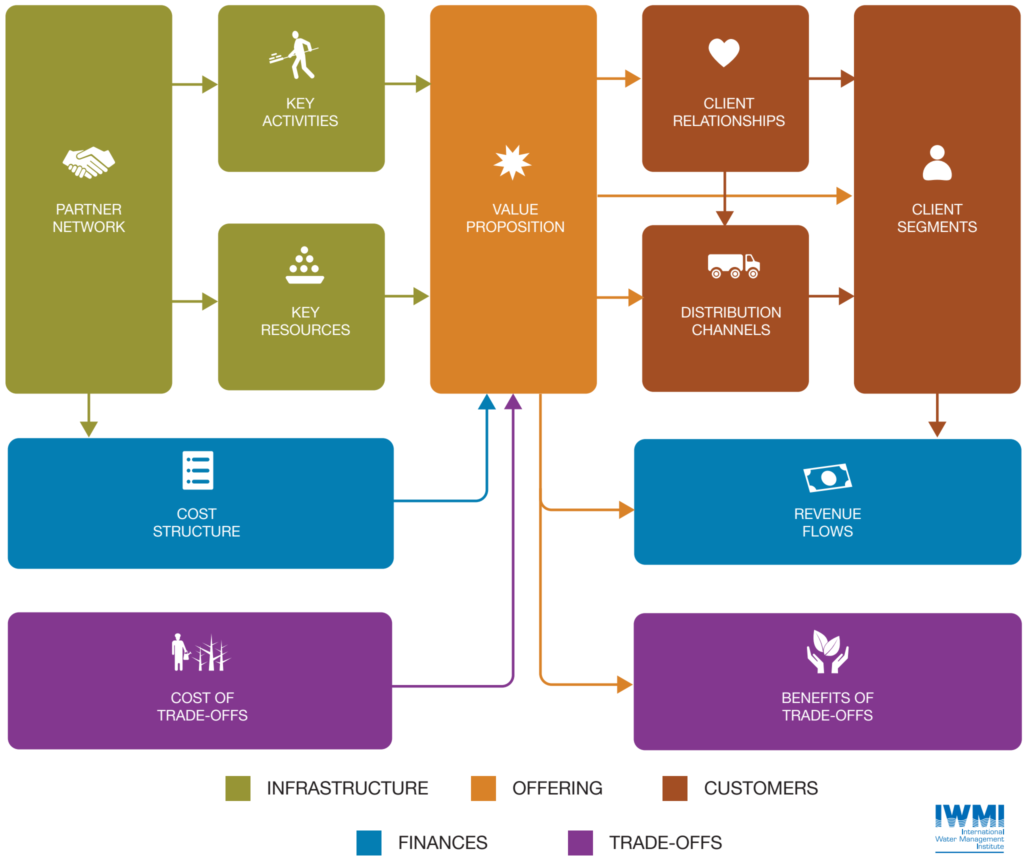
The business model canvas also provides many of the details needed to understand if a particular model could be viable in a different context than where it was used so far. However, the canvas does not provide information of the external business environment, like competition, regulations and the enabling business environment in general (see Chapter 19) which can be captured through RRR feasibility studies (Otoo et al., 2016).

Nomenclature and classification of RRR business models

Bocken et al. (2014) provide a structural approach towards business model categories in the domain of sustainability. The models described in this book fall in general under the archetype 'create value from waste' where we also find the concepts of 'closed loop' and 'circular economy'. However, while we could argue that water, energy and nutrients are indeed materials which are continually recycled through the production system, an alternative term could be 're-materialization', i.e. the innovative sourcing of materials from waste, creating entirely new products such as high-quality fertilizer or energy (Clinton and Whisnant, 2014). Business models within any of these structures could be categorized based on the type of waste, type of recovered resource, type of value proposition, partnership or ownership, or modes or scale of revenue generation (Evans et al., 2013).

These models can be very dynamic as with increasing environmental awareness and technical options, waste management approaches are continuously redesigned to optimize their value proposition. This includes their ability to capture so far missed RRR opportunities and values such as through carbon trading or biodiversity offset programs (Bocken at el al., 2013).

FIGURE 3. COMPONENTS AND INTERLINKAGES OF THE EXTENDED BUSINESS MODEL CANVAS



Source: Based on Osterwalder and Pigneur, 2010.

Given the paucity of a common terminology, the business model names and structure used in the following chapters were in large based on pragmatic reasoning and consent, not any particular academic discourse, and can be further developed and adapted as needed. Wastewater models might for example be distinguished by the agricultural end-product, energy projects by the business approach they use, nutrient cases by the way of waste valorization, while factors like the type of financing or PPP might allow other categories. The ideal categorization will thus vary between different readers of this catalogue and their objectives.

One possible classification of the models presented in this catalogue is to start with the main value-added product for reuse, means a) energy recovery, b) nutrient and organic matter recovery and c) water reuse. As any business model is driven by its objective, the next step considered in the decision tree could be the overall *business objective*, followed by the *business model* itself (Table 1).

TABLE 1. A POSSIBLE CATEGORIZATION OF THE PRESENTED RRR BUSINESS MODELS

VALUE-ADDED PRODUCT	SECTOR	OBJECTIVE	BUSINESS MODEL
Water Reuse	Public; Public/private	Cost recovery	Wastewater for greening the desert
			Enabling private sector investments in large-scale wastewater treatment
	Public/private	Welfare/profit maximization	Leapfrogging the value chain through aquaculture
	Public/ Informal Public/ private	Welfare maximization	Cities as their own downstream users
			Inter-sectoral water exchange
			Corporate social responsibility as driver of change
			Wastewater as a commodity driving change
			Farmers' innovation capacity as driver of change
Nutrient and organic matter Recovery	Public / private sector	Cost recovery	Subsidy-free community based composting
			Partially subsidized composting at district level
	Public and/ or Private Sector	Welfare/profit maximization	Large-scale composting for revenue generation
			Compost production for sustainable sanitation service delivery
		Cost savings	Nutrient recovery from own agro-industrial waste
			Phosphorus recovery from wastewater at scale
	Private and/or Informal sector	Cost savings	Outsourcing fecal sludge treatment to the farm
Energy Recovery	Public Sector	Cost recovery	Power from municipal solid waste
	Private Sector	Profit maximization	Briquettes from agro-waste or municipal solid waste
			Bio-ethanol and chemical products from agro- and agro-industrial waste
		Profit maximization/ Cost Savings	Combined heat and power from agro-industrial waste for on- and off-site use
		Profit and Welfare maximization	Power from agro waste
			Combined heat and power from agro-industrial waste for on- and off-site use
		Cost savings/Welfare maximization	Biogas from fecal sludge and kitchen waste
			Power from manure

Criteria and process for the selection of analyzed RRR business cases

The cases presented in this catalogue were selected in different steps each using different criteria. The main objective of the exercise was to understand drivers of success and sustainability strategies; and based on the analysis of different related cases, to extract/construct generic business models, which summarize innovative and promising components of these businesses with potential for scaling up

and out in (other) low- and middle-income settings including emerging economies. Following an initial screening of about 150 cases suggested by the literature, media and experts, over 60 empirical re-use cases were analyzed in detail of which 47 are presented here. As some operate in different locations, the actual number of cases is larger. These selected cases allowed for the development of 24 generic business models, which are also presented.

For the first selection round, the cases had to provide evidence, as much as possible, of the following:

i. Operation in Africa, Asia or Latin America, with special consideration for wastewater re-use cases in the Middle East and Northern Africa (MENA) regions;
ii. Conversion of waste into one or more of the following outputs: nutrients, biomass, energy or water for agriculture (i.e. waste becomes an asset and compensates for resources in short supply);
iii. Generation of revenues from RRR or supporting, at least, cost savings;
iv. Transactions (will) support cost recovery and ideally also parts of the sanitation chain financially;
v. Replicability in low- and/or middle-income countries at scale, i.e. not only at the level of one household or farm;
vi. Distinct creation of social and/or environmental benefits; and
vii. Likelihood of data accessibility.

The empirical investigation of the preselected 60+ RRR businesses was based on a template (Box 4) with questions tailored to the different waste streams and recovered resources. Information was obtained, wherever possible, through local data collection by project staff or consultants, i.e. in direct interaction with the businesses, or remotely via email, explaining the purpose and background of the study and incentives[2] for collaboration. Depending on the sensitivity of the case/business entity, and/or its responsiveness, in-depth literature surveys combined with expert consultations were also employed.

Box 4. Business case assessment template

1) **Context and background:** Describes the wider perspective on the history and development of the business. It also describes the geographical location and the government policy on re-use activities within which the business is operating. Most of the information contained in this section is gathered from business entities or secondary literature.
2) **Market environment:** Describes the needs in the market that drive the existence and development of the business, i.e. it describes what the business does and how it serves market needs. The assessment of the market environment was also supported by a literature review.
3) **Macro-economic environment:** Discusses briefly the global or national market conditions or economic infrastructures that enable or represent a supportive factor or a constraint to the business. Relevant information on the macro-economic environment was gathered from country policy reviews and other relevant literature.
4) **Business model description:** Describes the RRR business case by applying the business model canvas as illustrated in Figure 3. This section discusses the linkages between the elements of the business model and focuses on answering: why the business model works, the core element for its functioning and the essence of the business model. Most of the information was gathered from business entities.

Where identified value propositions are analysed separately, associated descriptions use the same background colour within the canvas. In the case where characteristics relate to several or all value propositions, a color coding, different from those of the value propositions is used.

5) **Value chain and position in the chain:** Describes the value chain in which the enterprise positions itself. This section applies Porter's five forces methodology (Porter, 1985) to describe the critical relationships with suppliers, partners, customers and other value chain actors.
6) **Institutional environment:** Describes institutional responsibilities and any legal or regulatory factors in the respective country that support or represent a constraint to the business.
7) **Technology and processes:** Describe the technology or process used by the business. The status of the technology as to whether it has been commercially proven, its local appropriateness and risks associated with the technology are also examined.
8) **Funding and financial outlook:** Describes the source of financing for the enterprise. Where data are available, the key capital and operational cost, revenue streams and cash flow statements are presented.
9) **Socio-economic, health and environmental impact:** Discusses not only the socio-economic impact of the business in terms of, for example, number of jobs created, health and environmental benefits, but also experienced or possible negative externalities.
10) **Scalability and replicability potential:** Discusses the potential for scaling up/out the business in other geographical locations or settings.
11) **SWOT analysis:** This section summarizes the model looking at its strengths, weaknesses, opportunities and threats.
12) **Contributors, links and references:** Acknowledge local and international experts and business staff who assisted in data gathering, web links and literature used to compile the case.

The collected data were analyzed using a combination of the multicriteria approach, business model canvas and strengths, weaknesses, opportunities and threats (SWOT) analysis. Depending on data availability and time, the amount of gathered data/information varied. In several cases, financial data were, for example, only available under the condition of non-disclosure, or insufficient for any financial analysis or representative presentation.

Development of RRR business models

The key objective for the assessment of existing RRR business cases was to understand their success, drivers, challenges and sustainability strategies and, based on these cases, construct generic business models with the potential for scaling up and out in other settings. Thus, instead of building theoretical RRR business models, the presented models are based on existing cases, or in other words, each model comes with several application examples. Only a few models were derived from just one case and only one was formulated on promising developments without a particular empirical case. This concerns the potential of corporate social responsibility for addressing unsafe wastewater use in the informal irrigation sector where the priority value proposition would be risk reduction.

The Business Model Canvas (BMC) was the main tool used for the development of RRR business models, based on the 11 fundamental building blocks (see Fig 3). The strength of the BMC lies in its simplicity and ability to provide a holistic overview of the essential components of the business model that the firm leverages. The BMC is best used as a pre-business planning activity to map out the various options a business has for adopting a particular business strategy. In addition, the

BMC allows for stepping away from the details of technological innovations and focusing on the best-fit business organizational form that will support successful implementation and adoption of the technological innovation. The BMC can be used to map existing models (such as the presented cases in this catalogue) and develop new models as adaptations to existing ones or entirely different ones. However, as mentioned above, the canvas only addresses parts of a business case, and requires additional information.

The presented business models draw strongly on the analyzed business cases, supported by additional information from related cases in the literature and interviews. Each model represents an optimized generic business model building on the success factors of its supporting cases, with different degrees of innovation, while incorporating strategies that address identified or likely shortcomings. These relate in particular to the analysis of possible health risks (IFC, 2009) to identify likely hot spots for risk monitoring (WHO, 2015).

The business model description follows, like the case description, a standard template (Box 5) with exception of some wastewater models, which are based on only one case, and follow a hybrid of both templates. Compared with the business cases, some additional components of the model presentation require further explanation. This concerns, in particular, the assessment of potential risks and risk mitigation measures and the summary assessment based on selected criteria.

Box 5. Business model description template

Business value chain: Describes the basic concept behind the business, explaining the different partners and their roles, the organizational structure (public, private etc.), the overall business process flow and value chain, the technology and financial arrangements.

Business model description: Describes the linkages between the elements of the business model canvas (Figure 3) and focuses on answering: why the business model works, the core element for its functioning and the essence of the business model, including information on partners and financial aspects to the extent available. Where identified value propositions are analysed separately, associated descriptions use the same background colour within the canvas. In the case where characteristics relate to several or all value propositions, a color coding, different from those of the value propositions is used.

Alternative model scenarios: Describe the option for alternate models derived from the parent model.

Potential risks and mitigation measures: Describe the potential risks associated with the business model and related mitigation measures. The risks considered include market, competition, technology performance, political and regulatory risks, social equity, and environmental and health risks.

Business performance: Summarizes the potential for scaling up/out or for replicating the business in other geographical locations or settings. It also describes in general how the business model has been appraised based on five performance criteria (cost recovery/profitability, scalability, replicability, social impact and environmental impact). It provides an overview of the conditions under which the business model should be undertaken and which factors, such as those related to land, investment and finance, should be given particular consideration.

Business risks and risk mitigation

An optimized business model will seek to minimize business risks. These can include but are not limited to: a) market risks, b) competition risk in both input and output markets, c) technology performance risk, d) political and regulatory risks and e) the risk of undermining social equity. Thus, the business models presented here tried to capture possible risks based on the analysis of their supporting cases. As business-related risks are context-specific, the risk section can only touch on the possible complexity. For market risks, the key factors considered were, e.g. changes in supply and demand, as well as likely sources of competition and ease of entry into the market, which depends again on location-specific market structures. Technological performance risks are related to whether the technology is commercially proven and if there are anticipated challenges with repair and maintenance from a developing country perspective. As fledgling businesses and their sustainability are largely influenced by their enabling environment, political, regulatory and financial instruments to rectify, for example, market failures (e.g. price subsidies), are briefly addressed. However, given its crucial role, Chapter 19 provides more details and examples on how regulatory mechanisms and finance instruments can shape an enabling environment for RRR. Finally, social equity related risks were assessed in view of poverty alleviation (employment) and gender inclusiveness.

To illustrate the qualitative assessment steps and criteria used, further details for the (i) health and environmental risks and (ii) social equity risks are provided in the following:

(i) Health and environmental risk assessment

Given that RRR businesses deal with potentially harmful source materials, special attention was given to environmental and health risks. Although the 'models' imply, per definition, full compliance with safety measures, it is important to flag critical control points and common mitigation measures. Given the generic nature of the models for possible application in different countries, the risk assessment had to remain generic. In the instance of a model being implemented, a concrete and site-specific risk assessment will be needed, taking into consideration the actual technology, scale of the enterprise and possible risk factors in the environment, such as groundwater proximity (Otoo et al., 2016; Winkler et al., 2017).

The risk assessment drew from the studied cases although it was not applied to the same extent to the cases themselves, which generally followed local safety standards and regulations. Reported or observed deviations were analyzed if they represented generic shortcomings to be captured for the related models. Some of the presented business models have submodels in which, for example, an alternative institutional set up was suggested. In such cases the assessment was conducted for the generic model. However, if submodels implied, for instance, a change in technology or inputs and outputs possible implications were marked. Following the structure of the catalogue each of the main categories – (1) energy, (2) nutrient/organic matter and (3) wastewater – were analyzed for key exposure groups and risk pathways. Models on water and nutrient recovery, for example, usually have farmers as users of the generated product, while the possible risk groups continue along the food chain. The situation is obviously different for energy models with biogas, electricity or briquettes as the final product. Based on this analysis, a generic risk assessment template was developed following the source-pathway-receptor model.

The four key exposure groups are shown in Table 2.

TABLE 2. THE FOUR EXPOSURE GROUPS

RISK TYPE	EXPOSURE GROUPS
1. Occupational risk on site	Workers, employees
2. Occupational risk off site	Farmers/users of RRR products
3. Consumption risk	End users
4. Social environment	Communities near treatment facilities

Table 3 shows typical pathways linking exposure groups with potential risks. In some countries, natural resources themselves are considered as receptors (e.g. water resources in the United Kingdom). In this analysis, air, water and soil were mainly considered as pathways rather than receptors. Table 2 also presents common mitigation measures that can be put in place to prevent likely risks.

TABLE 3. EXPOSURE PATHWAYS AND MITIGATION MEASURES

EXPOSURE PATHWAY	DESCRIPTION	TYPICAL MITIGATION MEASURES
Direct contact	Handling, sorting, mixing, collecting, transportation	Protective wear – boots, gloves, coats and overalls, and good hygiene
Insects	Breeding sites for carriers and vectors	Insect spraying, cleaning, netting
Air	Aerosols, particulates and gases	Protective wear – goggles and masks, ear plugs, wind barriers (e.g. tree belts), coverage of waste piles
Water and soil	Effluent, leachate and leakages	Avoid untreated discharge, support e.g. phytoremediation
Food	Insufficiently treated waste products used in farming	On-farm risk (contact) reduction, crop restrictions, produce washing and/or boiling

The level of risk was categorized as low, medium or high considering: nature of exposure (direct, indirect, external, internal, etc.), intensity of exposure (severity and probability), and required effort of mitigation (**simple** like via safety gear; **advanced**, e.g. via emission reduction; **substantial,** e.g. via addition treatment). Emphasis is placed on likely hazards, not all theoretically possible hazards:

(a) Direct contact

Low risk	Contact with hand and foot during operations possible (or use of less hazardous waste). Contact can be easily avoided by employing simple risk mitigation measures.
Medium risk	Contact with skin during operations likely. This can be easily avoided by employing more advanced mitigation measures.
High risk	Contact with skin during operations is difficult to avoid, unless by applying substantial mitigation measures.

(b) Insects (flies, mosquitoes, etc.)

Low	Process creates unfavourable conditions for breeding and waste materials have low pathogen levels. Risks can be avoided by employing simple mitigation measures.
Medium	Process creates favourable conditions for breeding or involves materials (feces) with high pathogen loads, but risks can be avoided by employing advanced mitigation measures.
High	Process creates favourable conditions for breeding and/or deals with high pathogen loads which are difficult to avoid unless by employing substantial mitigation measures.

(c) Air (aerosols, dust, particulates, gases, machinery sound, etc.)

Low	Low emission and noise which can be avoided by employing simple mitigation measures.
Medium	Significant emission and/or noise which can be avoided by employing advanced mitigation measures.
High	Significant emissions and/or noise which are difficult to avoid unless by employing substantial mitigation measures.

(d) Water and soil (leachate, leakages, etc.)

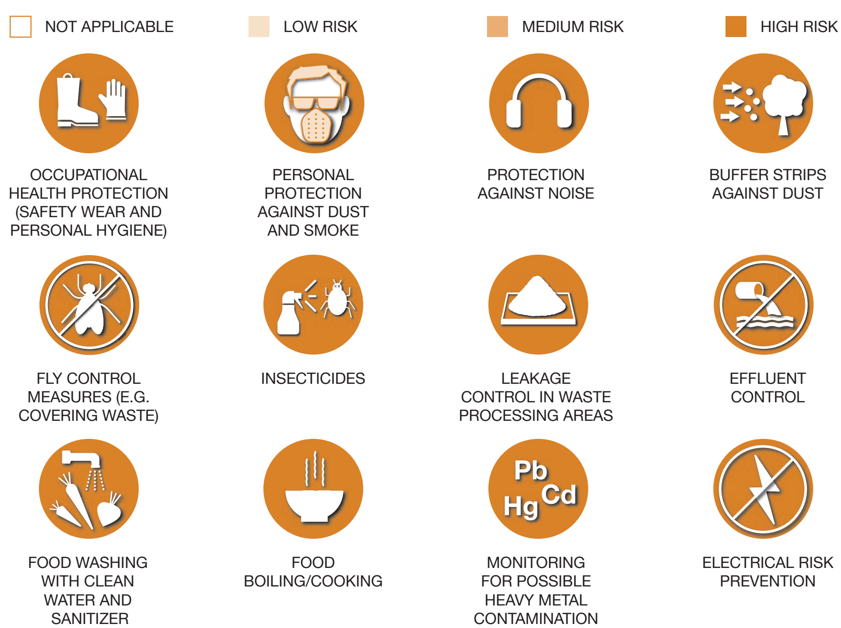
Low	Low leachate production or only partially treated effluent potentially released to the environment which can be avoided by employing simple mitigation measures.
Medium	High leachate production or partially treated effluent potentially released to the environment. This can only be avoided by employing advanced mitigation measures.
High	High leachate production or untreated effluent potentially released to the environment and it can only be avoided by employing substantial mitigation measures.

(e) Food chain

Low	Low risk of microbiological contamination which can be avoided by employing simple mitigation measures such as produce washing, smoking or boiling.
Medium	Microbiological contamination which can be avoided by employing mitigation measures that require more efforts such as investments in drip kits for irrigation and compliance monitoring.
High	Chemical contamination (e.g. heavy metals) which is possible but difficult to mitigate, unless via substantial mitigation measures, such as further waste sorting or additional treatment steps.

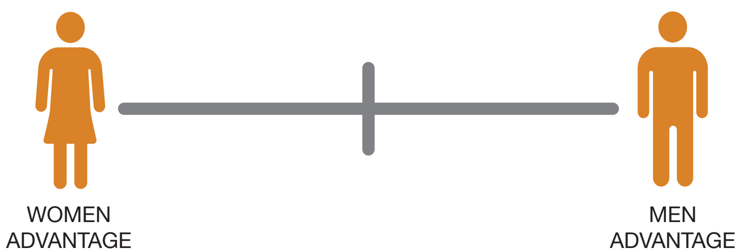
For more details on exposure pathways, risk evidence and mitigation, please see Stenström et al. (2011) and WHO (2015), and the application example to RRR business models by Winkler et al. (2017).

The overall risk assessment for each model used the following scale and risk mitigation symbols:



(ii) Social equity related risks

Equal employment opportunities and other gender-specific benefits or burdens were analyzed as far as possible for each business model. The assessment of equality considered in particular how far either men or women might be (dis)advantaged in engaging in the waste valorization process, as an entrepreneur or worker, or as a direct beneficiary of the resulting products. The assessment was qualitative and considered positive implications for (a) common gender roles, like time spent for water or fuel collection; and (b) comfort at home/workspace through the provision of improved services or clean energy (clean air, studying after sunset/girl literacy). The assessment also considered gender-specific disadvantages related to (i) the recommended technology, (ii) business-related job opportunities as well as (iii) gender-specific occupational health risks. Each analyzed model displayed between 0–3 factors which were given equal weightage. The most common factors providing advantages for women relate to energy production for the benefit of households, allowing women to save time for collecting external fuel, as well as a healthier (fire- and smoke-free) working environment. The most common factor to advantage men was related to gender-specific labor roles, like construction work or truck driving. Particular advantages for one group do, however, not imply a direct risk or disadvantage for the other. The judgement, which remains without local context tentative and preliminary, has been summarized in a pictorial balance beam reflecting possible gender specific dis/advantages.



Performance potential

For the last part of the business model template, the suggested models were evaluated for their performance potential, expecting a triple bottom line based on the following indicators/criteria: a) profitability/cost recovery, b) social impact, c) environmental impact, d) scalability and replicability and e) innovation. Each criterion was evaluated on a three-level scale based on the average score of a three-level ranking of the constituent parameters (Table 4). The ranking of the parameters and the resulting ranking of the indicators was based on a combination of quantitative and qualitative data sourced from empirical cases and application of the Delphi method[3], respectively.

TABLE 4. GUIDELINES FOR RANKING OF BUSINESS MODELS

INDICATORS	GUIDING QUESTIONS	PARAMETERS	SCORE
Profitability/ cost recovery	What is the level of operational profits/ cost recovery achieved by the business model on an annual basis?	Loss making	1
		Break-even	2
		Profit	3
	How many revenue streams does the business model depend on and how strong are these revenue line items?	One strong revenue source	1
		Two or more revenue sources with one strong revenue line	2
		Two or more revenue sources with two strong revenue lines	3

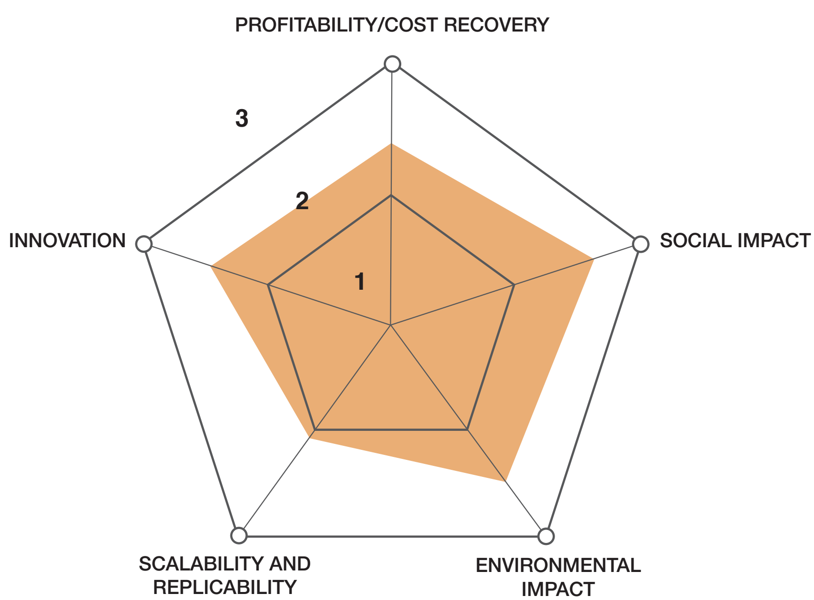
TABLE 4. *CONTINUED*

	How many of these factors represent a risk of increased costs to the business model? Factors are: 1) high worker and managerial skill requirements, 2) diverse customer base, 3) diverse products, 4) need for R&D and 5) self-distribution of product to end customer	More than 3 factors applicable	1
		2–3 factors applicable	2
		0–1 factor applicable	3
Social impact	How many jobs are created/provided by the business model compared with the range of all the business cases within the same section (energy or nutrients or water)?	Low	1
		Medium	2
		High	3
	Number of people with increased positive health impact from the business model compared with the range of all the business cases within the same section (energy or nutrients or water).	Low	1
		Medium	2
		High	3
	How many of these factors does the business model have an improved/ increased positive impact on? Factors are: 1) water security, 2) food security, 3) energy security, 4) improved living standards, 5) reduced governmental costs for waste management services (sanitation), health services and 6) gender	Meets 0–2 factors	1
		Meets 2–4 factors	2
		Meets more than 4 factors	3
Environmental impact	What quantity of waste is being processed/ re-used compared with the range of all the business cases within the same section (energy or nutrients or water)?	Low	1
		Medium	2
		High	3
	How many of these factors does the business model have an improved/ increased positive impact on? Factors are: 1) health of waterbodies, 2) reduced GHG emissions, 3) soil fertility, 4) renewable source/raw material and 5) reduced deforestation	Meets 0–1 factor	1
		Meets 2–3 factors	2
		Meets more than 3 factors	3
Scalability and replicability	How many of these factors limit the replication potential of the business model elsewhere? Factors are: 1) new technology, 2) policies and regulations, 3) strong institutional capacity, 4) specific waste availability 5) market demand and 6) ambiguity of product acceptance	Meets more than 4 factors	1
		Meets 3–4 factors	2
		Meets 0–2 factors	3
	What is the ease of scaling the business model vertically and horizontally?	Low potential for vertical AND horizontal scaling	1
		High potential for either vertical OR horizontal scaling	2
		High potential for BOTH vertical and horizontal scaling	3
	How easy is it to finance the business model elsewhere?	Investment is HIGH and financing is UNIQUE	1
		Investment is HIGH and financing is COMMON	2
		Investment is LOW and financing is UNIQUE	2
		Investment is LOW and financing is COMMON	3

Innovation	How innovative is the technology or process?	Known technology or process	1
		Relatively new to developing countries (technology transfer)	2
		New to the world	3
	How innovative are the partnership arrangements?	No partnerships required	1
		Partnerships within the same sector	2
		Partnerships cross-cutting different sectors (PPP, R&D, finance)	3
	How innovative is the product or value proposition?	Standard product and value proposition	1
		Relatively new product or value proposition	2
		New to the world	3

The overall appraisal of the indicators for each business model is represented in a radar diagram (Figure 4). It is important to note that this is an overview assessment and any actual implementation of any RRR business model will require a context-specific and more detailed ex ante feasibility assessment (Otoo et al., 2016).

FIGURE 4. PERFORMANCE APPRAISAL DIAGRAM EXAMPLE



Limitations

The information provided in the case studies refers to the **time of their individual assessment** between 2012 and 2017. The authors regret any possible error or missed update. Case descriptions are detailed to serve students as case studies, probably too detailed for practitioners and investors, while there are still many other criteria to assess business cases and describe business models, which we were not able to capture. This concerns for example the history and timeline of the cases, the personal engagement, contacts and investments of the entrepreneurs, their experiences with seeking an appropriate business partner and lessons learned *vis-à-vis* their local regulatory, financial and administrative challenges, or the difference between the official and *de facto* enabling environment. Other limitations faced, concern the availability or accessibility of (in particular financial) data and common lack of quantitative impact assessments. Data access from private enterprises was challenging. In several cases, they were unwilling to provide financials or information on the technology. In such cases, the authors had to rely on secondary sources with their limitations. While the private sector had its reasons to withhold data, accessing data from the public sector came with its own challenges related to their availability, like in many parts of Africa. Often only older data were available, if any. As business operations are dynamic, data of the presented cases will change over time. Finally, the investment ranges stated for the business models are largely based on the analysed case studies, and could be larger.

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Notes

1 See for example: www.ppplab.org/wordpress/wp-content/uploads/2016/04/PPPCanvas_Example.pdf (accessed November 5, 2017).

2 Exposure of success to the donor community, inclusion in this catalogue, participation in follow-up conferences, feasibility studies for their models in different continents.

3 https://en.wikipedia.org/wiki/Delphi_method (accessed November 5, 2017).