RESOURCE RECOVERY & REUSE SERIES 13

ISSN 2478-0529

13

Assessing the Value of Resource Recovery and Reuse

SOCIAL, ENVIRONMENTAL AND ECONOMIC COSTS AND BENEFITS FOR VALUE CREATION AND HUMAN WELL-BEING

Anita Lazurko

About the Resource Recovery & Reuse Series

Resource Recovery and Reuse (RRR) is a subprogram of the **CGIAR Research Program on Water, Land and Ecosystems (WLE)** dedicated to applied research on the safe recovery of water, nutrients and energy from domestic and agro-industrial waste streams. This subprogram aims to create impact through different lines of action research, including (i) developing and testing scalable RRR business models, (ii) assessing and mitigating risks from RRR for public health and the environment, (iii) supporting public and private entities with innovative approaches for the safe reuse of wastewater and organic waste, and (iv) improving rural-urban linkages and resource allocations while minimizing the negative urban footprint on the peri-urban environment. This subprogram works closely with the World Health Organization (WHO), Food and Agriculture Organization of the United Nations (FAO), United Nations Environment Programme (UNEP), United Nations University (UNU), and many national and international partners across the globe. The RRR series of documents present summaries and reviews of the subprogram's research and resulting application guidelines, targeting development experts and others in the research for development continuum.

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Lazurko, A. 2018. *Assessing the value of resource recovery and reuse: social, environmental and economic costs and benefits for value creation and human well-being*. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE). 41p. (Resource Recovery and Reuse Series 13). doi: 10.5337/2018.229

ISSN 2478-0510 (Print)
ISSN 2478-0529 (Online)
ISBN 978-92-9090-880-7

/ resource recovery / resource management / water reuse / socioeconomic environment / environmental impact assessment / economic value / economic growth / cost benefit analysis / wastewater treatment / agroindustrial sector / agricultural wastes / industrial wastes / organic wastes / municipal wastes / solid wastes / food wastes / waste disposal / waste management / faecal sludge / decision making / decision analysis / farming systems / ecosystem services / equity / groundwater management / energy generation / biogas / composting / anaerobic digesters / rural communities / developing countries / fortification / social aspects / living standards / urban areas / nutrients / case studies / Spain / Italy / China / Israel / Thailand / Eastern Africa / Italy / Iraq / Malaysia / Ghana / USA /

Front cover photograph: Sharni Jayawardena/IWMI.
English Editor: Robin Leslie
Designer: W. D. A. S. Manike

Acknowledgements

The guidance of Miriam Otoo (IWMI) and Pay Drechsel (IWMI) and the constructive comments from the reviewers were much appreciated.

Project

This research study was initiated as part of the project, “Research and capacity building for inter-sectorial private sector engagement for soil rehabilitation”.

Donors

This research study was funded by the following:

Federal Ministry for Economic Cooperati and Development

German Federal Ministry for Economic Cooperation and Development (BMZ) as part of its project funding for International Agricultural Research Centers.

CGIAR RESEARCH PROGRAM ON Water, Land and Ecosystems

This research was carried out as part of the CGIAR Research Program on Water, Land and Ecosystems (WLE) and supported by Funders contributing to the CGIAR Trust Fund (https://www.cgiar.org/funders/).

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SUMMARY

Resource recovery and reuse (RRR) contributes to a range of social, economic and environmental benefits that affect human well-being in developing and emerging economies. Energy, nutrients and water can be recovered for safe reuse in agriculture or industry from urban wastewater, including fecal sludge from on-site sanitation systems, as well as other sources of organic waste, such as the agro-industry and municipal solid waste (MSW). To understand the full value of RRR to justify action, there is a need for a systematic assessment approach that balances complexity with practicality. Cost-benefit analysis (CBA) is a well-established tool for weighing social, economic and environmental costs and benefits based on a common economic metric.

This report highlights the methods available for quantifying and valuing social, environmental and economic costs and benefits of RRR, focusing on CBA as the primary framework. Rather than prescribing a standardized technique for conducting CBA for RRR, this report presents broad frameworks and several examples that can be catered to individual contexts. This results in a suggested 8-step process accompanied with suggested assessment techniques. The CBA must be framed based on the type of question the assessment is meant to answer and system boundaries must be chosen. Potential social, environmental and economic costs and benefits must be identified, with possibilities depicted as the RRR 'universe'. The identified costs and benefits must be prioritized based on the impact on stakeholder groups. The costs and benefits must be attributed to the project and quantified based on a range of techniques. All non-financial costs and benefits must be monetized using suitable techniques, though this stage presents significant challenges. Finally, future costs and benefits are discounted to present terms and uncertainty is quantified to give context to the result.

Examples of CBAs conducted in RRR sectors around the world communicate environmental value to decision-makers, quantify long-term and indirect cost savings, and incorporate complex social costs associated with human health and lifestyle. These examples led to various insights explored in the report; for example, the option value of resources can be significant in contexts with resource scarcity and should be included in the CBA. These examples also reveal common challenges in the quantification and monetization stage, and in attributing costs or benefits directly to the project within an acceptable margin of uncertainty. These findings provide a range of methods and examples for practitioners in RRR to draw from and reveal opportunities for further research.

While CBA is useful in decision-making, its limitations are well documented. The concept of human well-being encompasses a broader set of metrics, including security, basic needs for a decent life, health, good social relations, and freedom and choice of action, allowing for more robust reflection of the implications of RRR on society. This report explores the relationship between RRR and human well-being to help decision-makers reflect upon the limitations of CBA and to suggest that human well-being should be further explored as an assessment metric for justifying action in RRR. A conceptual framework relating human, social, built and natural capital to individual and community well-being was adapted for RRR. This relationship justified the exercise of relating the social, environmental and economic costs and benefits generated in a real-world CBA to a framework definition of human well-being. The results of this exercise highlight the elements of human well-being that were excluded from the CBA. This type of information can help practitioners make more contextualized decisions for investments in RRR.

1. INTRODUCTION

Resource recovery and reuse (RRR) in developing countries contributes to a range of socioeconomic and ecological benefits that affect human well-being including poverty reduction, sustainable natural resource management, food security, ecosystem service functions and improved nutrition and health (Hanjra et al. 2015). RRR addresses concerns about resource scarcity and the negative externalities of waste by harnessing the value of waste materials as productive inputs. A range of technologies, business models and institutional arrangements may be employed for RRR solutions in domestic wastewater treatment and reuse for agriculture or industry, agro-industrial waste management systems, organic municipal solid waste (MSW) management and on-site sanitation of fecal sludge. For example, treated or partially treated wastewater from municipal wastewater treatment plants may be sold or given to farmers, reducing demand for freshwater irrigation and chemical fertilizers by transferring nutrients directly back into the agricultural system (Hussain et al. 2001). Capturing nutrients from fecal sludge and organic solid wastes reduces demand and resource requirements for conventional disposal methods and may reduce the severity of pollution (Cofie 2003). Energy recovery from biogas provides an alternative energy source and contributes to climate change adaptation and mitigation (Hanjra et al. 2015).

Despite the range of benefits, RRR may introduce environmental and social costs. Risks to public health and the environment from pathogens (Kazmi et al. 2008), heavy metals and high salinity (Li et al. 2009), and high levels of nutrients (Kalavrouziotis et al. 2008) may increase. Furthermore, the financial feasibility of RRR solutions can be complex, requiring multiple stakeholders and innovative cost recovery mechanisms, particularly in developing countries where pro-poor policies are critical. Previous experience with harmful waste management practices, or a generally negative public perception, can result in social resistance to RRR (Hanjra et al. 2015). Weak institutions, inadequate regulatory frameworks and a general lack of enabling environments in many developing countries introduce barriers to RRR solutions and may increase public health and environmental risks (Di Mario et al. 2018). In addition, RRR is often introduced as an alternative to entrenched waste management systems that involve many different stakeholder interests.

Understanding the full value of RRR to justify action demands a systematic approach to assessing costs and benefits that balances complexity with practicality. There are various tools to help determine whether an intervention is beneficial and justified, each with characteristics appropriate for answering different questions in various contexts. Examples include cost-effectiveness analysis, multicriteria analysis, and most commonly, cost-benefit analysis (CBA). Existing research on techniques for decision-making in RRR focuses on applications of CBA and other tools to case studies in specialized sectors (e.g. Kiratikarnkul 2010), focusing on economic and financial feasibility (e.g. Pandyaswargo and Premakumara 2014). In addition, recent efforts to establish a common framework for measuring the environmental value proposition of circular economy business models highlighted the need to develop environmental assessment methods specifically for businesses reflecting a circular economy approach. (Manninen et al. 2018).

While CBAs may be required to justify action for RRR, these projects have broad implications for society and the environment that are difficult to fully address. CBAs relate social, environmental and economic costs and benefits of RRR to a common economic metric, and costs or benefits that are difficult to quantify or attribute to the project may be necessarily excluded. The concept of human well-being contains a broader set of non-financial metrics, including security, basic needs for a decent life, health, good social relations, and freedom and choice of action (MEA 2005). This concept may provide a more robust set of criteria for understanding of the implications of an RRR project on society.

This report aims to highlight the methods available for quantifying and valuing social, environmental and economic costs and benefits of RRR, focusing on CBA as the primary framework. Rather than prescribing a standardized technique for conducting CBA for RRR, this report provides broad frameworks and several examples that can be catered to individual contexts. In addition, this report also aims to explore the relationship between RRR and human well-being and to investigate the limitations of CBA in addressing the multiple dimensions of human well-being.

2. RRR SECTORS

The RRR sectors considered in this report focus on the recovery and reuse of nutrients, water and energy from wastewater, agro-industrial waste, organic MSW and fecal sludge.

2.1 Wastewater

Growing urban populations and water scarcity place pressure on water resources, resulting in diversion of water for irrigation and other applications towards the higher economic value potable urban water supply. There is increasing investigation into reclaimed wastewater as a solution to balance the need for freshwater for urban use and the need to serve the social and environmental benefits of agriculture (Winpenny et al. 2010). Urban wastewater may be partially or fully treated and used by farmers for agricultural irrigation, or by other sectors for landscaping or industrial processes. Partially-treated reclaimed water can replace valuable freshwater in agricultural and industrial sectors, freeing up freshwater for urban potable use and reducing pressure on groundwater aquifers. The additional nutrients in treated wastewater may provide crop productivity benefits and reduce fertilizer and soil amendment costs for farmers (Hussain et al. 2002). However, wastewater reuse presents risks that must be mitigated, as use of untreated or improperly-treated wastewater can introduce pathogenic microorganisms to the human environment (Hussain et al. 2001). In addition, wastewater reuse introduces financial costs associated with installing or upgrading wastewater treatment schemes to a level suitable for reuse, and to build the additional conveyance that may be required to distribute reclaimed water to end-users.

2.2 Agro-industrial Waste

Many developing countries struggle with the impacts of agro-industrial waste, including contamination of waterbodies, low energy supply and distribution, and climate change impacts (Njau et al. 2011). Yet, agricultural and industrial wastes contain valuable fractions of nutrients and energy that can be recovered and reused. For example, animal husbandry produces manure that can be used as compost for inputs into crop production or for biogas energy (Torquati et al. 2014). Agro-industrial waste can be pelletized and used as a fuel for household cooking or as a soil amendment (Frank 2015). Effectively, recovering and reusing the valuable fractions of agro-industrial waste can result in reduced pollution and eutrophication in waterbodies, public health gains, reduced greenhouse gas (GHG) emissions, increased renewable energy generation, improved crop productivity and reduced deforestation rates (Njau et al. 2011). It can also improve cost recovery and business models of agro-industry and waste management processes in general by producing a marketable commodity. Despite these benefits, the reuse of agro-industrial waste may introduce public health and cost-related risks similar to wastewater reuse.

2.3 Organic Municipal Solid Waste

MSW management in developing countries is put under pressure by rapid urbanization, population growth and the rise in waste generation that accompanies increased living standards. In the past, the least-cost option was to use landfills or open dumping sites, resulting in a missed opportunity to recover the valuable components of MSW. In addition, the MSW management sector is plagued with high costs and low service outputs: in 2010, 20% to 25% of the annual budgets of public authorities in developing countries were spent on solid waste management (Nzeadibe and Ajaero 2010), but these expenditures resulted in a mere 50% service coverage (Kadafa et al. 2013). Still, MSW in developing countries tends to be high in organic materials, presenting an opportunity to recover nutrients, biomass and energy. In addition to producing a valuable by-product that can increase crop productivity, composting and production of fuel pellets can reduce GHGs and other air pollutants (Favoino and Hogg 2008) and reduce the strain on existing landfills and dumpsites. Anaerobic degradation of organic waste also provides opportunities to produce electricity and heat from biomass (Zulkepli et al. 2017). RRR from organic MSW may also provide benefits by avoiding pesticide and fertilizer use, removing pathogens and displacing nutrients that would otherwise enter the environment.

2.4 Fecal Sludge

Fecal sludge also contains important amounts of nutrients and organic matter, which can be recovered and used in agriculture. Many developing countries have the simultaneous need to improve fecal sludge management for sanitation and to improve soil fertility in crop-producing regions at a low cost (Nikiema et al. 2014). The more common method for linking fecal sludge management to agriculture is by providing fertilizer through composting, co-composting with other organic waste, or slurry use after anaerobic digestion of the sludge. Some entities are compressing and/or pelletizing dewatered fecal sludge or compost as another marketable by-product, such as fuel briquettes (Nikiema et al. 2014). The co-composting solution has a technical advantage as it adds carbon-rich organic waste to the fecal sludge which improves its composting quality (Cofie 2003). Anaerobic digestion allows the generation of energy as well as the use of the remaining sludge cake as a safe organic fertilizer. Biogas production can support self-sufficiency of the sludge treatment process or provide electricity to nearby users or the electricity grid (Zulkepli et al. 2017).

3. METHODOLOGIES FOR COMPARING OPTIONS FOR DECISION-MAKING IN RRR

RRR projects are often associated with the public sector and require significant investment. Thus, the project must be economically justified,[1] cost-effective and financially viable,[2] operating within a financial model that enables project success over the long term (Winpenny et al. 2010). Four common assessment techniques that can support decision-making are highlighted below: CBA, positional analysis (PA), cost-effectiveness analysis (CEA) and multicriteria decision analysis (MCDA).

3.1 Cost-benefit Analysis

CBA is an established technique for assessing the social costs and benefits of projects, policies or programs by translating monetary and non-monetary social, economic and environmental elements to a common unit of value (Moberg 1999). Costs and benefits without market prices are valued through various monetization techniques according to an overall assumption that a CBA reveals which option allocates resources according to the preferences of society (Moberg 1999). However, some argue that the presentation of a single cost is not transparent, the technique is too human-focused (Turner et al. 1994) and it may favor costs and benefits that are more easily valued in monetary terms. It may also be biased toward decision-makers conducting the CBA and ignore intangible social dynamics such as culture and equity (Ackerman 2008). Also, many methods of valuing social and environmental costs and benefits in economic terms are controversial and introduce monetary bias or at least uncertainty.

3.2 Positional Analysis

PA is an emerging alternative to CBA, focusing on institutional economics and general systems theory (Moberg 1999). At its core, PA looks at interdisciplinarity or 'many-sidedness', with the goal of providing strategic decision support (Söderbaum 1995). The process is unique, as it brings the ideologies and biases of decision-makers into the open, highlighting conflicting interests and providing the flexibility needed to thoroughly assess many different types of problems. Unlike CBA, PA is able to clearly describe irreversible effects with its less technocratic approach. However, PA places high demands on the analyst and introduces the risk of considering too many alternatives, thereby diluting the results of the analysis (Moberg 1999). In addition, most positional analyses have been conducted in Scandinavia in a select few sectors, making it difficult to translate the technique into the developing country context.

3.3 Cost-effectiveness Analysis

CEA is a useful tool for projects with benefits that are difficult to quantify or value. Like CBA, CEA is a decision-support tool to be used when several alternatives are available to achieve a specific objective. The output of a CEA is a single figure for each alternative: the total cost divided by a physical output (Winpenny et al. 2010). For example, several alternatives for solid waste management may be compared using the cost per ton of waste treated. CEA is essentially a simplified version of CBA: both analyses result in a single figure for comparison, but CEA avoids the need to estimate use or non-use values of intangible or public goods. However, by only measuring the cost-effectiveness according to the primary objective of minimizing costs, CEA may neglect to show that an alternative achieves poorly on one or more secondary objectives (Cameron et al. 2011).

3.4 Multicriteria Decision Analysis

MCDA is a decision-making support tool that structures a decision problem in terms of multiple alternatives and assesses each alternative under several criteria simultaneously (San Cristóbal Mateo 2012). There are many different MCDA methods that rank and compare options according to the chosen criteria, with criteria measured in several possible ways. MCDA can consider qualitative and quantitative criteria alongside one another, promoting stakeholder interaction and transparency. However, the process can be time consuming and technically complex, and is viewed by some as technocratic (San Cristóbal Mateo 2012). A summary of the strengths and weaknesses of all four decision-making tools is summarized in Table 1.

This report focuses on CBA as the primary framework for assessing the costs and benefits of RRR, because it is the only method that can be adjusted to meet three important factors. First, it can be conducted in developing country contexts due to methods that can be adjusted for low data and resource environments. Though PA and MCDA have many strengths over CBA, they inherently require the analysis to absorb greater complexity, demanding data and resources. Second, CBA allows both positive and negative costs and benefits with or without economic value to be absorbed into economic terms, which can be meaningful for a range of stakeholders. This is not the case for CEA, which excludes benefits. While MCDA and PA can be very useful for complex decisions, they may not allow for direct comparability as they leave costs and benefits without direct economic value in other units. Lastly, the final output of a CBA, such as a benefit-cost ratio (BCR), net present value (NPV) or internal rate of return (IRR), has two functions: it allows for an overall judgement on the justification for an intervention to take place and it allows for comparability between alternatives. In comparison, the result of an MCDA or a CEA is not meaningful unless compared alongside other alternatives.

[1] Economic justification is based on net costs benefits to society, while financial viability is based on net costs and benefits to an enterprise or government entity.

[2] Financial feasibility in the RRR context includes projects that require external financial support or government subsidy.

TABLE 1. SUMMARY OF THE STRENGTHS AND WEAKNESSES OF DECISION-MAKING SUPPORT TOOLS.

DECISION TOOL	STRENGTHS	WEAKNESSES
Cost-benefit analysis	• Presents a single, clear result (beneficial or not beneficial) • Allows for comparability between analyses • Can include external costs	• Presenting the single result may not be transparent • Human-focused • Environmental issues may not be adequately reflected • Different effects are considered interchangeable • Irreversible effects are not included • Significant uncertainty in valuation
Positional analysis	• Provides a platform for decision-makers to evaluate from their own perspectives • Flexible method • Conflicting interests revealed • Many-sidedness is incorporated • Provides a systemic view of the problem • Irreversible effects included • Effects are disaggregated	• Demands on the analyst are high • Flexibility of the method requires integrity of the analyst • The decision-maker must do a lot of work • Many-sidedness may lead to confusion • May be too broad and theoretical
Cost-effectiveness analysis	• Presents a single, clear result (most cost-effective option) • Allows for comparability between analyses • Simplified as it avoids the need to value non-economic goods or services	• Presenting the single result may not be transparent • Human-focused • Externalities (environment, social, etc.) not considered • Different aspects are interchangeable • Irreversible effects not included • Focus on cost-effectiveness may hide poor performance on secondary objective
Multicriteria decision analysis	• Presents a single, clear result • Considers multiple economic and non-economic criteria, each measured according to its own preference function • Flexible method • Promotes stakeholder transparency	• The process can be very time consuming • Additional complexity • Success very dependent on the priorities of the analyst

Sources: Moberg (1999); San Cristóbal Mateo (2012); Cameron et al. (2011).

4. COST-BENEFIT ANALYSIS FOR RESOURCE RECOVERY AND REUSE

The process of assessing the overall value of recovered resources and RRR projects is complex and requires clearly defined objectives and resource constraints. The process may uncover negative impacts to avoid/mitigate or benefits to leverage. The results of monetary valuation may be used to incentivize the actions of key stakeholders who may not otherwise prioritize a specific issue and to help choose the most cost-effective and beneficial alternative.

This section of the report demonstrates a process for CBA within the context of RRR. The processes described herein build from previous studies on impact assessment in RRR, including Gebrezgabher et al. (2016), to present a framework for assessing the overall social, economic and environmental costs and benefits of resource recovery. The result is a long list of options that can be applied to recovered resource streams of nutrients, water and energy, and several RRR project types including agroindustrial waste recovery, wastewater reuse in agriculture, organic MSW and fecal sludge management.

Table 2 outlines eight steps that may be followed when conducting a CBA of RRR business models and projects. Each of the steps (1 to 7) are described in more detail in sections 4.1 to 4.7. Section 8 simply requires that the findings of the economic valuation process are presented as an aggregate BCR, NPV, IRR or another form determined by the needs of the study.

TABLE 2. STEPS TO CONSIDER WITH MAJOR ACTIVITIES AND STAKEHOLDERS INVOLVED IN CONDUCTING A CBA FOR RRR.

STEP		ACTIVITIES	STAKEHOLDERS INVOLVED
1	Framing	• Identify questions that the CBA is answering • Choose initial system boundaries • Establish a business-as-usual scenario for comparison	• Decision-makers • CBA analysts
2	Identifying	• Identify costs and benefits, including social, environmental and economic externalities • Identify geographies and social groups affected by each externality over time	• Decision-makers • CBA analysts • Directly affected social groups • Society at large
3	Prioritizing	• Prioritize costs and benefits to be quantified and monetized based on: o Relative monetary value o Quantifiability and monetizability o Data availability o The perceived value of externalities from different social groups	• Decision-makers • CBA analysts • Affected social groups
4	Quantifying	• Quantify changes from the baseline status of each cost or benefit expected from the RRR project using the most appropriate method	• CBA analysts
5	Monetizing	• Economically value (monetize) each quantified change from the baseline status using the most appropriate method	• CBA analysts
6	Discounting	• Discount costs and benefits over time, based on the chosen discount rate	• Decision-makers, CBA analysts and other stakeholders to choose the discount rate • CBA analysts to perform discounting
7	Quantifying uncertainty	• Conduct sensitivity analysis	• CBA analysts
8	Presenting	• Present findings in a format appropriate for the CBA	• CBA analysts and decision-makers

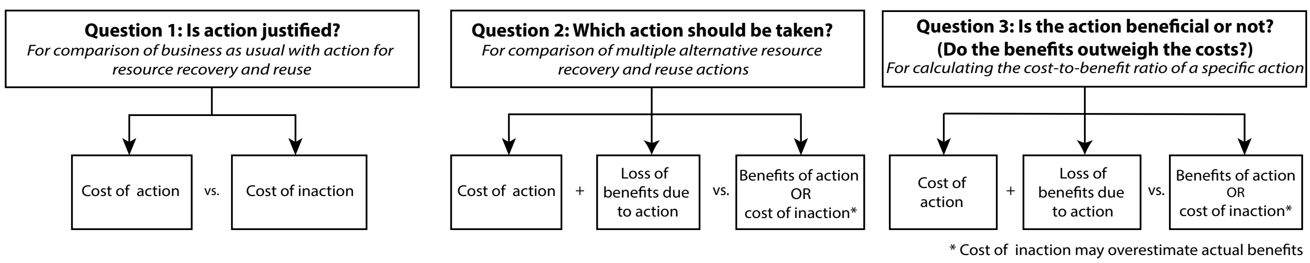
4.1 Step 1: Framing the Cost-benefit Analysis

The first step of framing ensures that it feeds directly into decision-making. The CBA is utilized to answer a specific question, the system boundaries are drawn in a way that includes the appropriate amount of information and the baseline scenario is defined.

4.1.1 Questions of Concern

CBA can be used to address various types of questions. Global assessments of the value of ecosystem services, such as the economic value of wastewater, use a CBA framework to understand the overall cost of action versus the cost of inaction to emphasize future risks to governments and society (Hernandez-Sancho et al. 2015). Other assessments simply compare alternatives, such as the difference in environmental impacts of organic waste management via composting or anaerobic digestion for a municipality (Zhang and Chauo 2012). A CBA can also be used to contextualize the impacts of a project and implement avoidance or mitigation strategies to minimize the social and environmental costs. A CBA may be commissioned to answer one or all of the three questions depicted in Figure 1.

FIGURE 1. FRAMING A CBA BY DEFINING THE TYPE OF QUESTION TO BE ANSWERED.



A simple comparison of the cost of action and the cost of inaction, answering the question "is the action justified?", can be used to determine the costs borne by society if an action is delayed or avoided, providing a clear depiction of the potential negative consequences of two possible future scenarios, with action and without, to policy-makers and the broader public. For example, the cost of inaction on climate change due to floods, droughts and severe storms has been quantified and communicated in the mainstream media as a critical concern for government risk management and the finance sector (The Economist 2015). A similar study on drought mitigation and preparedness revealed that drought costs the USA USD 80 billion per year and the European Union €7.5 billion per year (WMO and GWP 2017). New methods for quantifying financial, environmental and social risk are emerging, including a recent study on the economics of land degradation. The study presents a cohesive framework for a global assessment of the cost of inaction for land preservation and rehabilitation, including previously unconsidered costs and benefits (Nkonya et al. 2016).

A comparison of multiple alternatives for action for RRR, answering the question "which action should be taken?", considers benefits alongside costs, requiring a more clearly defined scope. The costs include the cost of action and the loss of benefits due to the action, or opportunity cost. The scope of the benefits of an alternative can be defined in two possible ways: as the benefits derived from the action taken or the cost of inaction. However, assessing benefits based on the cost of inaction may result in an overestimation of benefits, because it does not consider different levels of action that would likely be taken in the future by various stakeholders to deal with future impacts and costs borne from inaction (ELD Initiative 2015). Care must be taken to avoid double counting of benefits, particularly when considering both processes and end-use benefits, such as water purification (process) and the use of purified potable water (benefit) (Nkonya et al. 2016). For example, a CBA of wastewater reuse in Puglia, Southern Italy assessed the costs and benefits of irrigation use of treated water for newly irrigated land and as an alternative to current groundwater sources, focused on clearly delineated direct costs and benefits of action without considering opportunity costs (Arborea et al. 2017). The same framing of costs and benefits can be used when calculating the BCR of a specific action to determine whether it is beneficial or not, answering the question "do the benefits outweigh the costs?".

4.1.2 System Boundary

Defining clear system boundaries for the CBA begins with choosing the type of CBA from Figure 1, but also includes several other decisions based on data availability, sensitivity analyses and other factors. The unit under assessment can be defined as a product, project, process or program. Spatial, temporal and supply chain system boundaries define which social, environmental and economic costs and benefits are considered, and which on- and offsite impacts are included. For example, a CBA of an agro-industrial waste facility may include the emissions due to transport of waste to the site and distribution of recovered resources, but exclude the emissions of the initial on-farm production of agricultural waste because it is unaffected by the choice of alternatives considered in the study. Opportunity costs are very important to some analysis techniques as they highlight the avoided damage or cost due to an alternative (see Box 1). However, this must be done carefully to avoid double-counting or overestimating the benefits of a given alternative (Nkonya et al. 2016). System boundary definition is not a single decision, but is rather a process that continues as the analysis progresses. For example, life-cycle analysis (LCA) requires a very specific definition of system boundaries for each resource, based on a sensitivity analysis that determines at which point the resource flows in compounding supply chains that no longer have a significant contribution to the overall cost and benefit measured (Moberg 1999).

BOX 1. ASSESSING ENVIRONMENTAL AND HEALTH IMPACTS OF FOOD WASTE AS ANIMAL FEED USING A HYBRID LCA.

A hybrid LCA approach was used to quantify the environmental and health impacts of using municipal food wastes as pig feed in the UK. The study compared two technologies for recycling food waste (dry or wet pig feed) with two established alternatives for organic waste management (composting and anaerobic digestion). The study is 'hybrid' because it uses an expanded system boundary that considers the emissions of the given process, in addition to the emissions avoided by not using a conventional process. For example, using food waste for pig feed has avoided emissions from substituting conventional pig feed and the knock-on emissions from the anaerobic digestion or composting that did not occur (Salemdeeb et al. 2017).

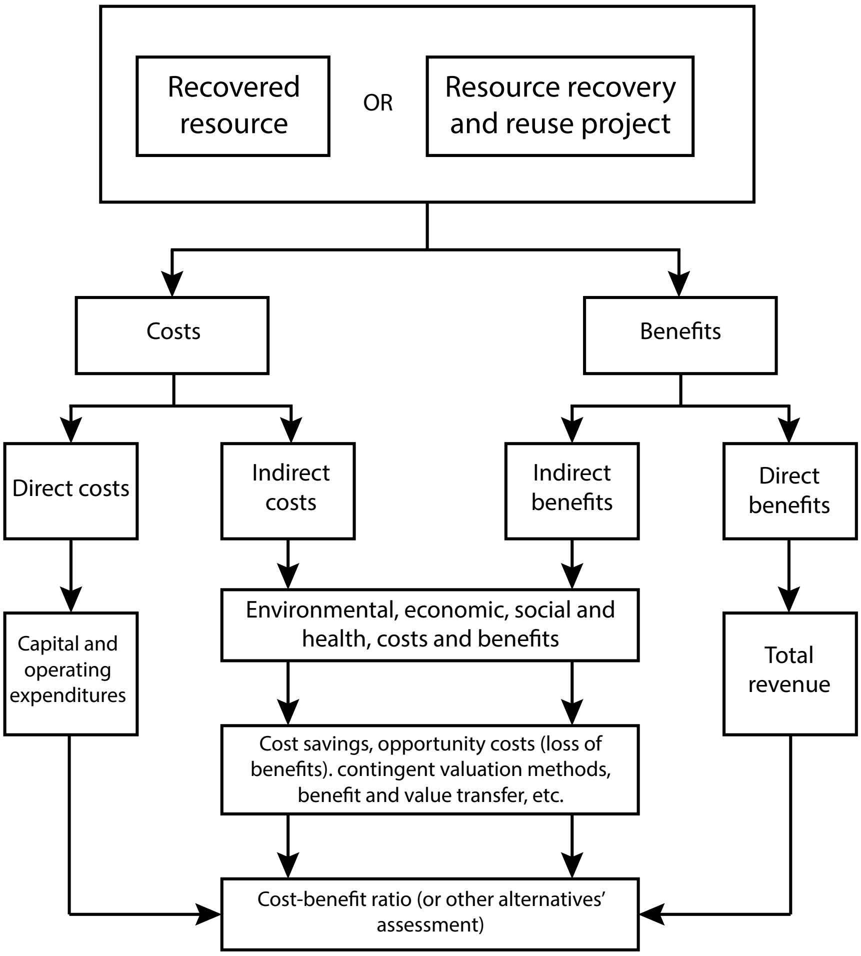
4.1.3 Defining a Baseline Scenario

RRR projects do not generally create new costs or benefits, but rather change the status of a cost or benefit from a baseline or status quo. As many of these costs and benefits are manifested over time, it is important to establish a clearly defined baseline scenario to which these costs and benefits can be compared. These changes should not be compared to a baseline of 'before project', but rather compare the costs and benefits with and without the intervention, looking forward into the future. This baseline scenario may employ a status quo perspective or use stakeholder engagement techniques to define alternative development scenarios into the future.

4.2 Step 2: Identifying Costs and Benefits

Identifying costs and benefits of RRR requires a balance of expert consultation, scientific analysis and stakeholder engagement. Figure 2 depicts a guiding framework for breaking down these potential costs and benefits into direct and indirect impacts, each treated differently during the CBA process.

FIGURE 2. BREAKDOWN OF COSTS AND BENEFITS FOR CONSIDERATION IN THE CBA OF A RECOVERED RESOURCE OR AN RRR PROJECT.



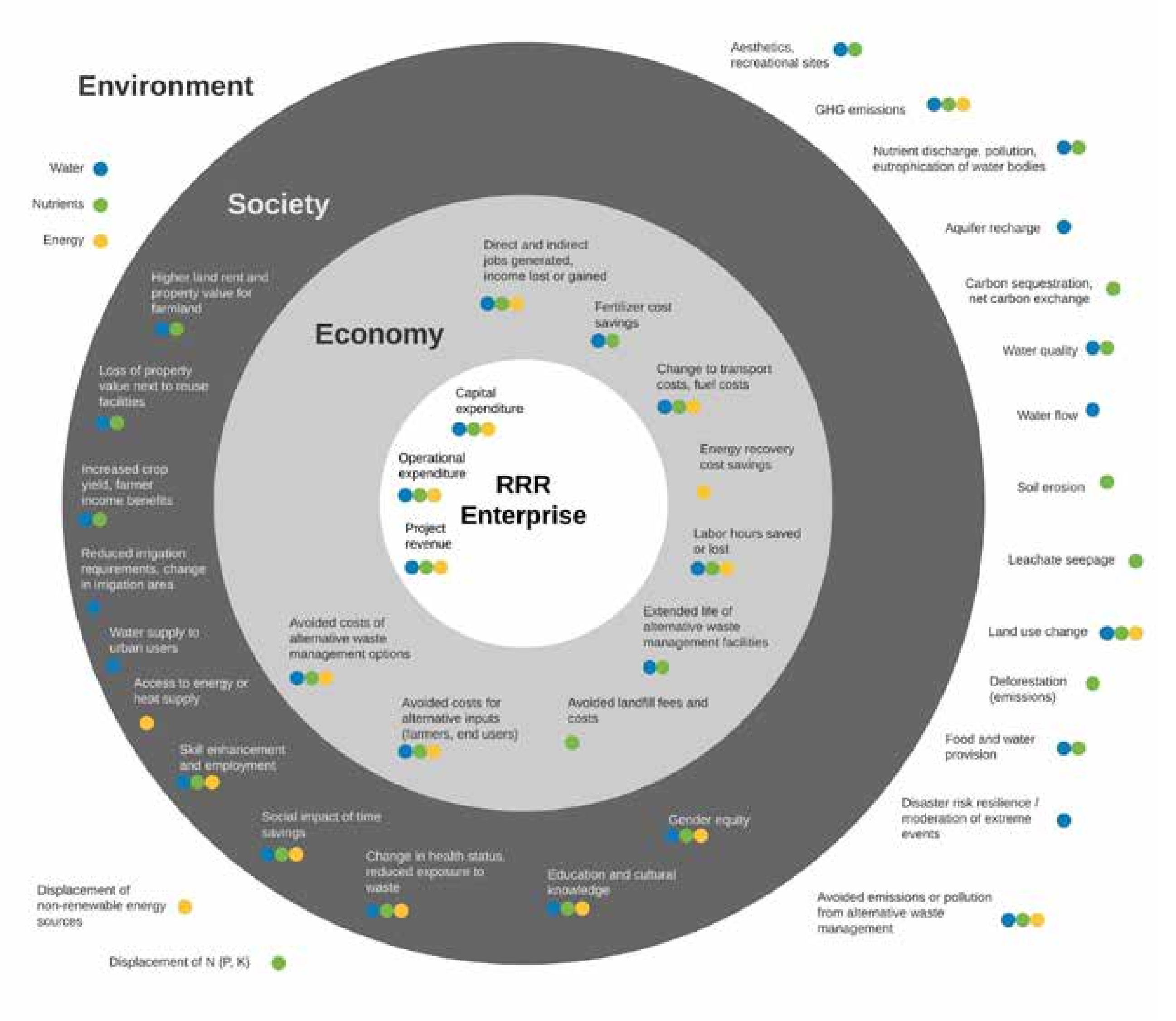
Source: Adapted from Gebrezgabher et al. 2016.

Identifying environmental and socioeconomic costs and benefits requires multiple perspectives. The more traditional project-level view is to conduct an Environmental Impact Assessment (EIA) or a policy or program-level Strategic Environmental Assessment (SEA). An ecosystem services lens expands on the limited scope of EIAs and SEAs, by highlighting the more complex environmental costs and benefits associated with the relationship between a recovered resource or RRR project and the surrounding ecosystem. The Millennium Ecosystem Assessment is a commonly used framework to identify ecosystem services delivered by an ecosystem and affected by an intervention (MEA 2005), though other useful frameworks exist. The World Resources Institute provides a framework to integrate ecosystem services assessment into a traditional environmental or social impact assessment framework (Landsberg et al. 2013). As changes to ecosystem services are manifested differently for different locations and different social groups over time, it is important to disaggregate these changes based on various characteristics.

An ecosystem services' lens considers the social perspective through the value derived from ecosystems that have benefits or costs to society. However, recovered resources and RRR interventions also have a purely social impact. Several methods exist for conducting quantitative and qualitative social impact assessments though not all are conducive to quantification and economic valuation. Such tools include social impact assessments, analytical tools like stakeholder and gender analysis, community-based methods like participatory rural appraisal, focus groups and interviews, and developing workshop-based methods.

The RRR projects considered in the scope of this report focus on circularity of water, nutrients and energy. Figure 3 shows the possible result of identifying costs and benefits to society of RRR of water, nutrients and energy. The result is depicted as the RRR universe, with the RRR project embedded within an economy, which is embedded within society and the environment. The RRR project in question may be from any of the sectors introduced in Section 2. This figure is not comprehensive, as an RRR project does not always generate all of the indicated costs or benefits in different contexts.

FIGURE 3. THE 'UNIVERSE' OF POSSIBLE SOCIAL, ENVIRONMENTAL AND ECONOMIC COSTS AND BENEFITS ASSOCIATED WITH RRR, SEPARATED IN TERMS OF WATER, NUTRIENTS AND ENERGY AND GENERATED FROM PROCESSES IN FIGURE 2.



4.3 Step 3: Prioritizing Costs and Benefits to Include in the Cost-benefit Analysis

Analysts, decision-makers and stakeholder groups affected by the project should go through an inclusive process that prioritizes the most relevant costs and benefits into a consolidated list. This process should pay particular attention to vulnerable groups where impacts may be concentrated and coping capacity may be low. This prioritization could consider the following criteria:

1. Costs and benefits that may have an absolute economic value that is high enough to influence the overall result.

2. Costs and benefits with a perceived high value from certain stakeholder groups, particularly vulnerable communities.

Part of this process may include further refinement of system boundaries. For example, forward and backward linkages into the economy may be considered depending on the goals of the project and of the CBA. National or subnational policies and strategies may influence which costs and benefits are included. Economic benefits for sectors that use the output of the RRR project or supply inputs to the project may be significant, but care must be taken to avoid overestimating the resulting social or environmental benefit. Box 2 shows one of many examples of the case-by-case decisions that stakeholders must make when choosing which impacts may be included in a CBA.

4.4 Step 4: Quantifying Costs and Benefits

Quantifying the change from the baseline is the most data- and analysis-intensive portion of the process. RRR is intersectoral and costs and benefits reach across several disciplines, requiring collaboration and consultation. Quantifying and valuing direct costs and benefits (Figure 2) require a simple mathematical process that translates financial and revenue generation models into appropriate costs and benefit metrics. These may require some mathematical adjustments, as economic and financial valuation may be treated differently. However, financial accounting methods do not always include all financial elements that are important for RRR projects. For example, contingent liabilities are costs that should be included, as they are costs of commitments that fall on the government or sponsor if an event occurs (Winpenny et al. 2010). Physical contingencies, such as extra equipment or materials obtained to 'be on the safe side' should not be included in a CBA, as they have a disproportionate impact on the big picture result, but a potential price cover cost increase should be included as it introduces genuine uncertainty (Winpenny et al. 2010).

Methods for quantifying the identified environmental and socioeconomic costs and benefits (Section 4.2) are designed for different purposes by different entities (Box 2), each with unique strengths and weaknesses. Some methods quantify the primary cost or benefit, while other methods quantify the secondary cost or benefit, so care must be taken to avoid double-counting. For example, measuring the change in water flow from an RRR project in a river can be done using data from an existing hydrological or ecosystem model, but if an LCA or water footprint study is also completed it would also consider an increase in water consumed or withdrawn for the process. Table 3 describes some common methods for quantifying costs and benefits, though it is not exhaustive. In addition, quantifying effects on ecosystem services can also be assisted with the use of tools, such as the Natural Capital Project Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST), which maps and values goods and services from nature that "sustain and fulfill human life" (Natural Capital Project 2017).

The most appropriate and exhaustive methods for quantifying environmental costs and benefits may be limited by data, capacity and resource constraints, introducing uncertainty to the final result of the CBA. For example, it may be desirable to quantify the costs and benefits of an input material, but quantifying resource flows through a complex supply chain and attributing the effects to the RRR project may be difficult. A robust understanding of the underlying assumptions and the quality of data available for performing the assessment are critical for choosing the right tools to inform valuation of costs and benefits.

BOX 2. ENVIRONMENTAL BENEFITS OF COMPOST ASSESSED WITH A COMBINED ECOSYSTEMS' SERVICES AND LCA APPROACH.

A study reviewed the progress in understanding the benefits of using compost through a LCA using short-, mid-, and long-term data. The study tried to quantify nine identified benefits: While for nutrient supply and carbon sequestration, quantifications and impact assessments could be performed, for other benefits like pest and disease suppression, soil workability, biodiversity or crop yield, quantitative figures are rare or highly location specific, or impact assessment methodologies missing (Martinez-Blanco et al. 2013).

Quantifying social impact is necessary for making decisions, but the process is difficult and controversial. Two areas of social impact that are most commonly quantified and valued using government data and established techniques, are livelihoods or economic opportunity and public health, disaggregated based on age, gender and other demographics. The simplest metrics of social impact related to livelihoods are jobs and additional income created, though others exist. These can consider upstream or downstream impacts of jobs and income created from input and output supply chains. The process of drawing system boundaries related to the social linkages in the economy must reflect the objective of the study and the priorities determined by the stakeholders involved in and affected by the CBA process.

Indicators for quantifying public health impacts have been used extensively, namely Disability Adjusted Life Year (DALY) and Quality Adjusted Life Year (QALY). DALY measures the "burden of disease and illness by reflecting total amount of healthy life lost from all causes", while QALY "multiplies each life year gained with an intervention by a quality-weighting factor that reflects the person's quality of life in the health state for that year" (Winpenny et al. 2010). Different RRR projects involving different levels of effluent treatment or use limitations would score different DALYs (see for example Box 3). Though these indicators are used widely in the public health sector, the comparative weighting of different health states remains controversial.

4.5 Step 5: Monetizing the Quantified Costs and Benefits

Economic valuation of social and environmental costs and benefits brings them under a common monetary unit. Some costs and benefits can be related directly to a market price, such as the treatment of carbon dioxide emissions or the scale of water consumption, while other environmental impacts may require a variety of techniques from contingent valuation to calculating the total change in productivity resulting from the change to an ecosystem (see for example Box 4).

4.5.1 Monetizing Environmental and Ecosystem Service Costs and Benefits

These values are best presented within the Total Economic Value (TEV) framework in Figure 4 (ELD Initiative 2015), which can help break down the major themes of costs and benefits and the type of economic valuation technique that may be appropriate.

The TEV framework views ecosystems as providing functions for humans that have economic value and first categorizes these functions in terms of use value and non-use value. Use value represents the monetary value of the profitable activities derived from an ecosystem, including direct use, indirect use and option values. Non-use value is the monetary value of the ecosystem that is unrelated to consumption, including existence, bequest and stewardship value, as defined in Table 4.

TABLE 3. METHODS FOR QUANTIFYING ENVIRONMENTAL IMPACTS.

QUANTIFICATION TECHNIQUES	DESCRIPTION AND KEY CHARACTERISTICS
LCA Resource footprint (water footprint, carbon footprint, etc.)	• A quantified assessment of the impacts of a product or service over its lifetime, from 'cradle to grave' • Avoids shifting problems from one life cycle to another • Widely acknowledged, with standardization efforts underway • Time consuming and data intensive • Does not consider future changes, synergistic effects • System boundary definition is critical and may be subjective
Mass balance, mass/volume budget Nutrient balance, water balance, water budget	• An analysis of the physical flows of materials and natural resources in, out and through a defined system (various levels, usually an economy) • Material flow analysis (MFA) quantifies all target flows, substance flow analysis (SFA) focuses on a particular substance
Material intensity per unit service analysis (MIPS)	• An analysis of the material used or affected in producing a service or function is aggregated • Waste and emissions are not considered directly • 'Ecological rucksack' or material intensity are often used as descriptive terms
Ecological footprint (EF)	• An assessment that considers the total area required to support an economy or a population, considering various categories of 'ecologically productive sectors' • Highlights unequal appropriation of the productive land area, raising questions about long-term sustainability
Tracking or forecasting electricity consumption, fuel use	• Tracking or future prediction of electricity consumption rates and quantities of fuel use for operations and transport • Similar to an LCA, but with system boundaries directly around the project or program under consideration, without life-cycle quantities
Indices (Water Sustainability Index, Water Poverty Index, etc.)	• Indices that consolidate a score or ranking according to several criteria related to a given resource
GIS mapping, remote sensing	• Tools that can be used to quantify land area or vegetation affected or changed • Use data gathered by satellites or aircraft scanning the earth
Ecosystem models	• An abstract representation of an ecological entity that combines field data, known ecological relationships and system dynamics to predict system responses

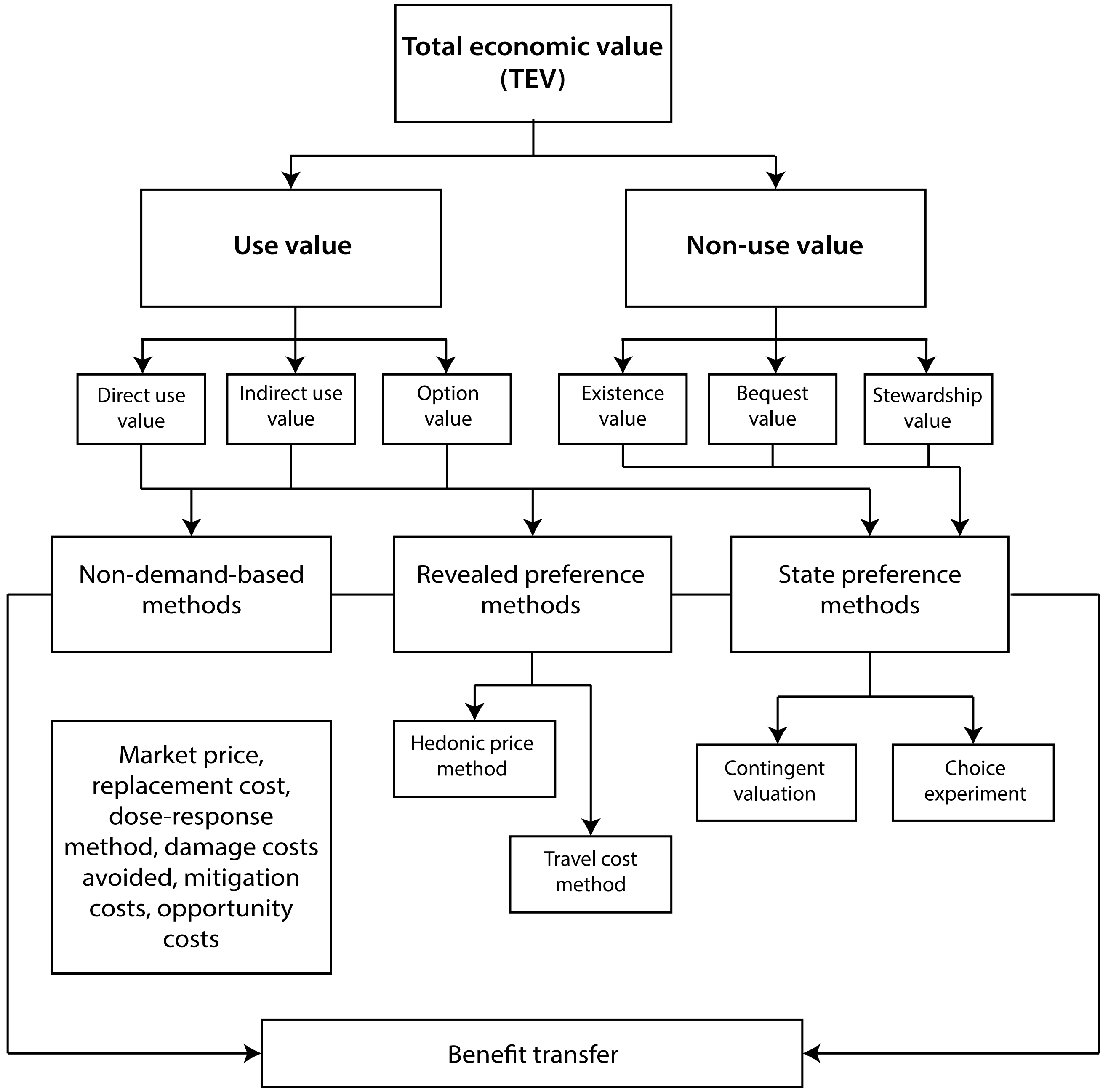
BOX 3. BCR AND COST PER DALY AVERAGED FOR SANITATION INTERVENTIONS IN SOUTHEAST ASIA.

A study attempted to measure the economic efficiency of sanitation interventions for the management of human excreta in Cambodia, China, Indonesia, Lao PDR, the Philippines and Vietnam. Benefits (health improvements, water pollution avoided, time reduction for accessing sanitation, resource recovery) were estimated based on field study evidence and published studies. The BCR and cost per DALY averted were estimated. Results showed that the BCR for pit latrines was greater than 5 for all locations except Cambodia, where it was 2. Septic tanks with wastewater management showed a BCR of at least 2, and all of the most pessimistic scenarios resulted in a BCR of greater than one (Hutton et al. 2014).

BOX 4. A SOCIOECONOMIC ASSESSMENT OF THE CHICAGO METROPOLITAN REGION'S WASTE MANAGEMENT SYSTEM.

The Delta Institute conducted a study on the impacts of current waste management systems in 20 municipalities in the Chicago Metropolitan Region using the Municipal Solid Waste Decision Support Tool developed by RTI International and the U.S. Environmental Protection Agency. The tool is a modeling program that measures the current and future environmental and economic impacts of waste management interventions using full cost accounting and life-cycle assessments. The data for inputs were informed by interviews with 28 regional system stakeholders and a review of reports from the waste agency (Delta 2014).

FIGURE 4. TEV FRAMEWORK TO BE USED TO MONETIZE THE NON-FINANCIAL ENVIRONMENTAL IMPACTS AND ECOSYSTEM SERVICES RELEVANT TO THE RRR PROJECT THAT ARE IDENTIFIED IN FIGURE 2 AND QUANTIFIED IN SECTION 4.4.



Source: Adapted from ELD Initiative 2015.

TABLE 4. DEFINITIONS OF THE TYPES OF VALUE INCLUDED IN THE TEV FRAMEWORK.

VALUE	DEFINITION
Direct use value	Value of the direct consumption of products delivered by the ecosystem (e.g. potable water)
Indirect use value	Value of the indirect consumption of products delivered by the ecosystem (e.g. pollination enabling food production)
Option value	Value of maintaining flexible options for future uses of an ecosystem
Existence value	Value allocated to the land simply because it exists
Bequest value	Value of potentially bequeathing the land to future generations
Stewardship value	Value of the land kept in good condition for direct economic production and maintenance of the adjacent ecosystems

Source: Derived from ELD Initiative 2015.

Some environmental costs and benefits associated with direct resource use from outside of spatial ecosystem boundaries may not be reflected in the TEV framework. For example, the cost of non-renewable resource use, or the use of renewables in excess of replenishment, should be included as depletion cost or user cost, as they are costs to future generations.

There are many techniques for valuing ecosystem services, each with its own positive attributes, assumptions and limitations. The TEV framework includes non-demand-based methods for economic valuation, which are pricing mechanisms that do not consider consumer demand. Revealed preference methods analyze the choices made by individuals, to infer the value they place on an ecosystem service. Lastly, stated preference methods use carefully worded surveys that gather answers with monetary amounts, choices, ratings or other preference indicators to infer a measure of value. Several techniques are described in Table 5.

Each of the described methods has limitations. Market prices may be distorted due to subsidies. The RCA may underestimate the value of an ecosystem service if a human-induced equivalent does not provide the same benefits as the ecosystem, or it may overestimate the value if a human-induced placement would not be adopted to offset foregone benefits in the real world. Many methods require relating specific levels of damage to the quality of the ecosystem, which requires several assumptions and may result in an over- or under-estimation of benefits and costs. For example, flood mitigation is a service provided by some ecosystems, but the value of protecting the ecosystem does not necessarily equate to the total cost of flood damages expected if the ecosystem is affected by an intervention.

4.5.2 Monetizing Social Costs and Benefits

In addition to social impacts of changes to ecosystem services (Section 4.5.1) there are several methods for economic valuation of public health impacts. The first is a revealed preference approach, where the value of a certain health status is inferred based on a policy-maker's choice to spend on health and safety measures. For example, a program to spend USD 2 million to produce 100 QALYs implies valuation of USD 20,000 per QALY. A second direct valuation of changes to health status requires surveys to determine the WTP to avoid a particular illness, accident or incapacity, though this is particularly controversial in the developing context when individual purchasing power is very disparate (Winpenny et al. 2010). A third technique relates health-related income and productivity effects to economic value, where improved health means that more time is available for productive activities that have economic value. This technique should include the opportunity costs of the time lost due to an illness, taking the human capital approach and using labor market prices to value changes in health status (Renwick and Monroe 2006). For example, in a study on the health benefits of clean energy, sanitation and drinking water interventions in Sub-Saharan Africa these were valued at between USD 80 to 126 year^{-1} for each household impacted by the intervention (Cameron et al. 2011). Other social costs and benefit indicators associated with changes to public health status include reduced morbidity and mortality, the calculated total time savings from a reduction from a certain illness, the total time savings for the alternative to the intervention and overall savings on health care (Cameron et al. 2011). Converting social impacts using narrow definitions of public health and productive time are very controversial in their limited scope and possible ignorance of what humans themselves actually value. This can be addressed through community based valuation approaches (Box 5).

4.5.3 Summary of Methods for Monetizing RRR of Water

The impacts of RRR can be quantified and valued with a variety of methods. Table 6 attempts to match quantification and monetization techniques in Table 5 to the costs and benefits pictured in Figure 3. The table does not provide every possible quantification and monetization method, but provides a basic set of options. Each of these methods introduces uncertainty; the suitability of each method depends on the local context.

4.6 Step 6: Discounting

Once costs and benefits have been quantified and valued, those that are manifested over time must be discounted to consider the time value of money (Hanjra et al. 2015). The discount rate may reflect the social time preference chosen by decision-makers, to reflect the present sacrifices necessary to make investments for future public benefits. Alternatively, it may be framed to reflect the opportunity cost of the capital used for a project or business, by assessing what it would earn if it was used for another purpose. It may also be a 'capital rationing device' to allocate the budget capital available to the most attractive group of projects. The discount rate can also be used to practically compare projects with costs and benefits occurring at different time periods into the future to

BOX 5. SOCIAL LIFE-CYCLE ASSESSMENT (LCA) OF URBAN AND RURAL WASTEWATER TREATMENT AND REUSE OPTIONS IN MEXICO.

The Instituto de Ingenieria Unam in Mexico conducted a social LCA to compare the social and economic characteristics of scenarios for wastewater treatment and reuse in a specific region in Mexico. There is no standard for social LCA, so the study established a set of indicators and community engagement processes, resulting in several spider diagrams that compare an urban and rural wastewater treatment and reuse scheme (Padilla et al. 2013).

TABLE 5. METHODS FOR ECONOMIC VALUATION OF NON-ECONOMIC ENVIRONMENTAL RESOURCES OR CHANGES TO ECOSYSTEM SERVICES.

METHOD	DESCRIPTION
Market price approach (MPA)	Value of the net loss or gain of a resource, good or service based on direct observation of the markets
Replacement cost approach (RCA)	Value of the additional input required to compensate for a loss of ecosystem services; value of the cost of replacing ecosystem services with a 'shadow asset' or human-induced service Value of the cost of mitigating the effects of a loss of ecosystem service function
Damage cost avoided (DCA)	Value of avoided damage due to the benefits of ecosystem services
Productivity change approach (PCA); Total factor productivity (TFP)	Values change in supply of a good or service caused by an action
Production function approach (PFA)	Estimates value by finding a link between environmental change and production conditions for a final marketed commodity
Net factor income (NFI)	Value of the revenue from selling an environment-related good (minus the cost of all other inputs)
Contingent value method (CVM); Willingness-to-Pay (WTP); Choice experiments	A survey-based technique where respondents are directly asked how much a particular 'state of nature' or change is worth to them (how much they are willing to pay for benefits or method and willingness to accept an adverse change) Respondents are directly asked to choose between options; WTP is inferred based on choices between trade-offs
Hedonic price method (HPM)	Estimated value of an environmental characteristic on a marketed good Valued by relating the relationship between the price paid for a surrogate good or service that is marketed with an 'implicit market'
Travel cost method (TCM); Random utility model (RUM)	Value of the travel and time costs consumers are willing to pay to access a resource (free habitat or local amenity)
Averting behavior method (ABM)	Estimates the economic value of defensive behavior consumers actually adopt to protect themselves from environmental risks
Opportunity cost (OC)	Benefits from an option that was given up when the alternative was chosen; alternative uses of the resources used in the project/process

Sources: Pagiola et al. (2004); Drechsel et al. (2004); Farber et al. (2006); Haines-Young and Potschin (2009); Grohs (1994); Bateman and Willis (2001); Bishop et al. (1990); Winpenny (1991); Palmquist (1991); Bockstael (1995); Freeman et al. (2014).

calculate the NPV (Winpenny et al. 2010). If the discount rate is too low, it may encourage a high pace of investment in less productive and capital-intensive projects. In contrast, if the discount rate is too high it may discourage investment that may be productive, missing out on long-term costs and benefits (Winpenny et al. 2010). The discount rate can be related to pricing used throughout the CBA for special cases, for example the price of a finite resource could increase proportionally to its discount rate (Schaeffer and Kouassi 2014). One of the major criticisms of CBA is its tendency to underprioritize future generations, thus discount rates must be chosen wisely.

The analysis period for the CBA is another important consideration. The technical life represents the amount of time that the expected output is achieved with reasonable maintenance. Maintenance can be considered as an annual cost resulting in a residual value at the end of the technical life, or by incorporating obsolescence with minimum recurrent costs and no residual at the end of the technical life. The economic life is often shorter than the technical life, as it is the length of time relevant to the use of the capital and is influenced by the discount rate (Winpenny et al. 2010). It is important to note that there is a risk that the choice of analysis period and the use of discounting may undervalue the long-term effects of a business or project.

4.7 Step 7: Quantifying Uncertainty

There is uncertainty in any estimation of the long-term value of non-monetary (i.e. social and environmental) costs and benefits. The results of a CBA must be viewed alongside an estimation of this uncertainty to help decision-makers put the results in perspective (Winpenny et al. 2010), The depth of analysis depends on data quality and the intended study application. Ad hoc methods, such as adjusting costs upwards and benefits downward, or shortening discounting periods for benefits may mitigate the risk of overestimating benefits and underestimating costs. Gross sensitivity analyses measure the sensitivity of the final NPV calculations to changes of input variables. Stress testing can reveal the best- and worst-case scenarios, while Monte Carlo simulations can produce the distribution of input variables in the CBA, thereby depicting distributions of NPV. These calculations can produce confidence intervals of the NPV, allowing for estimation of the probability of the project producing a positive NPV (Platon and Constantinescu 2006). Sensitivity analyses also go hand-in-hand with system boundary choice, to help determine which impacts may not have a significant contribution to overall value (Cameron et al. 2011).

TABLE 6. COSTS AND BENEFITS OF RRR, NUTRIENTS AND ENERGY.

	Costs and benefits	Quantification	Valuation/monetization
Environmental	Aesthetics, recreational sites	• N/A	• TCM • CVM
	GHG emissions	• LCA • Mass balance	• RCA • MPA (price of carbon)
	Nutrient discharge, pollution, eutrophication of waterbodies	• Net nutrient balance	• CVM • PCA • PFA • ABM • DCA
	Aquifer recharge	• Water budget • Surface water studies (e.g. seepage meters, modeling) • Unsaturated/saturated zone studies (e.g. water table fluctuation, Darcy's Law, modeling)	• RCA
	Carbon sequestration (net carbon exchange)	• Remote sensing and GIS • Biometric estimation • Ecophysiological methods • Micrometeorological methods • Ecosystem models (e.g. carbon stocks and fluxes)	• RCA
	Water quality	• Water quality metrics/index • Other indices (e.g. Water Sustainability Index)	• CVM • ABM • PCA • TCA
	Water flow	• Velocity area method • Overflow weir gauging • Hydrological models • Remote sensing	• CVM • MPA
	Soil erosion	• Erosion index (calculations and empirical methods) • Universal Soil Loss Equation (empirical models) • Vegetation cover change	• RCA • PCA • PFA • DCA (siltation)
	Leachate/seepage	• Water balance method • Mass transport model/pollution monitoring • Other models (e.g. Hydrologic Evaluation of Landfill Performance model)	• DCA
	Land-use change	• Vegetation cover change • Agricultural land area converted • Land-use intensity (input intensity, output intensity) • Secondary impacts (biodiversity and carbon storage)	• PCA • PFA • HPM • CVM
	Deforestation (emissions)	• Changes in forest area via remote sensing • Changes in carbon stocks per unit area forest (secondary datasets from IPCC, in situ plots) • Stock-difference method or gain-loss method	• RCA • HPM
	Food and water provision	• Converted agricultural land area or diverted water volume • Methods for primary impacts (water quality, water flow, land-use change, etc.)	• MPA • Valuing the primary impacts (water quality, water flow, land-use change, etc.)
	Disaster risk resilience/ moderation of extreme events	• Climate projections (extent, degree of impact, probabilities) • Secondary impacts (change to crop yields, flood damage, etc.)	• MPA • PCA • CVM

(Continued)

TABLE 6. COSTS AND BENEFITS OF RRR, NUTRIENTS AND ENERGY. (CONTINUED)

	Costs and benefits	Quantification	Valuation/monetization
	Reduced use of pesticides and other inputs	• Field trials and studies • Secondary data from studies quantifying change of input requirements with RRR	• MPA • PCA • OC
	Avoided emissions or pollution from alternative waste management	• *Quantify emissions and pollutants using relevant methods*	• DCA • OC • Monetize emissions and pollutants as for other costs and benefits
	Displacement of non-renewable energy sources	• *Quantify emissions of non-renewable sources using relevant methods*	• DCA • OC
	Displacement of N (P,K)	• *Quantify secondary impacts (e.g. reduced eutrophication, nutrient balance, etc.)* • *Directly value costs (see Fertilizer Cost Savings)*	• DCA • OC • *Value of secondary impacts* • See Fertilizer Cost Savings
Social	Higher land rent and property value for farmland	• Area of agricultural land (or properties) converted or impacted by the initiative	• MPA • HPM
Social	Loss of property value next to reuse facilities	• Area of land (or properties) impacted by the initiative	• MPA • HPM
Social	Increased crop yield, farmer income benefits	• Remote sensing and GIS (land area affected) • Ecological modeling (forecasting crop yield)	• PCA • NFI • MPA • Full cost accounting (direct value of income or yield)
Social	Reduced irrigation requirements, change in irrigation area	• Water budget • LCA	• NFI (if irrigation has a cost) • DCA
Social	Water supply to urban users	• Water budget • LCA • Number of users, households, etc. affected	• RCA • OC • MPA
Social	Access to energy or heat supply	• Number of individuals or households affected, time savings, etc. • Beneficiary assessment (social impact of access to energy/heat)	• CVM • MPA • NFI
Social	Skill enhancement and employment	• Jobs created • Surveys, self-assessments • Beneficiary assessment, stakeholder analysis	• MPA (labor, jobs created)
Social	Social impact of time savings	• Stakeholder analysis • Gender analysis • Social impact assessment • Beneficiary assessment • Secondary data review	• Market price (labor) • CVM
Social	Change in health status, reduced exposure to waste	• DALYs and QALYs • Beneficiary assessment • Productive time gained or lost • Stakeholder analysis • Gender analysis • Social impact assessment • Secondary data review • *Quantify primary changes (e.g. water quality)*	• CVM • DCA (change in health care expenditures) • Value of productive time for economy (labor)
Social	Education and cultural knowledge	• Surveys with baseline/control • Written tests, self-assessments • Practical exercises • Beneficiary assessment	• MCDA

(Continued)

TABLE 6. COSTS AND BENEFITS OF RRR, NUTRIENTS AND ENERGY. (CONTINUED)

	Costs and benefits	Quantification	Valuation/monetization
Economic	Gender equity	• Stakeholder analysis • Gender analysis • Secondary data review • Social impact assessment	• MCDA
	Direct and indirect jobs generated, income lost or gained	• Number of employees in the facility (or including forward/backward linkages into the supply chain) • Full cost accounting (income) • Employment elasticity, other economic indicators	• MPA (labor)
	Fertilizer cost savings	• Equivalent mass of alternative inputs for the same nutrient value and N availability • Farmer cash flows	• MPA • NFI
	Change to transport costs, fuel costs	• Distance traveled, trips per time period, fuel consumption rates, etc.	• MPA • NFI • Full cost accounting
	Energy recovery cost savings	• LCA • Tracking current or forecasting future energy consumption or recovery	• MPA • Full cost accounting
	Labor hours saved or lost	• Tracking or projecting labor requirements for chosen method and alternatives	• MPA • Full cost accounting
	Extended life of conventional waste management facilities	• Diverted waste volume or mass, correlated to extended life and change in residual value of facilities over the given time period • Life cycle assessment	• DCA • OC
	Avoided landfill fees and costs	• Diverted waste volume or mass and landfill fees in region in question	• MPA • DCA
	Avoided costs for alternative inputs (farmers, end users)	• Quantify input costs and benefits of alternatives using relevant methods	• DCA • OC • RCA
	Avoided costs of alternative waste management options	• Quantify all costs and benefits of alternatives using relevant methods	• DCA • OC

4.8 Other Considerations

4.8.1 Option Value and Irreversible Effects

The inability of CBA to consider irreversible effects is a controversial weakness of the method. Some argue that this deems CBA unsuitable to analyze many global policy issues, such as climate change mitigation or global land degradation. The uncertainty of future events and outcomes means that there is option value in maintaining the freedom to decide upon a proposed solution, particularly if the proposal has potential irreversible effects or important data may be obtained at a later date.

4.8.2 Dealing with Data Quality and Data Scarcity

The quality of data used to conduct a CBA is a significant challenge, particularly in developing countries where monitoring of natural resource flows and social metrics may be limited. Benefit transfer is used to generate values used in a CBA using data from empirical studies with characteristics relevant to the project under assessment, particularly when the alternative is to conduct original data collection that may be complicated and resource intensive (Winpenny et al. 2010). Benefit transfer, or the application of available information from a study already completed in another location or context to a current study (Dumas et al. 2005), is often used to overcome data scarcity and resource limitations, but must be used with caution, as unsuitable use can result in over- or underestimated costs and benefits (Dumas et al. 2005). Other methods, such as feasible benefit and plausible scenarios exist as a way to include more costs and benefits in the CBA (O'Brien 2010).

4.8.3 Equity and Standing

The issue of equity highlights the importance of the prioritization step of the CBA (Step 3 in Section 4.3). There is a risk of bias that perpetuates existing inequity in the process of deciding whose preferences are to be counted in the CBA. Trumbull (1990) states that CBA is useful "only to the extent that there exists a general consensus that the value assumptions are legitimate". In other terms, a thorough analysis of who is most affected by the costs and benefits of RRR in Step 3 of the CBA procedure may require further critical analysis of how bias and equity issues intersect with the weighting of costs and benefits and which actions are taken to mitigate costs or leverage benefits. The issue of which stakeholders have standing in CBA is often misunderstood and controversial.

5. CASE STUDIES OF CBA IN RRR

Real-world applications of CBA in different RRR sectors are numerous. The following section is based on a comprehensive review of case studies included in the academic literature and public documents from the public and private sectors, aiming to demonstrate case studies of CBA in four major RRR sectors (Section 2.0): wastewater, agro-industrial waste, organic MSW and fecal sludge. The basic background and context of each case is summarized and each example applies different system boundaries, quantification and monetization methods, discount rates and other elements of the CBA process introduced in Section 4. These examples demonstrate that some costs and benefits may be more easily included than others and catering the CBA for local data availability and context is key.

5.1 Wastewater Recovery and Reuse

The costs and benefits of wastewater recovery and reuse projects have been thoroughly studied relative to other RRR sectors. The following case studies provide some guidance based on previous experiences of other analyses that reveal which costs and benefits others found to be most relevant, quantifiable and significant to the overall value proposition of a wastewater reuse project. Table 7 is not an exhaustive list of all possible costs and benefits, but includes the costs and benefits that emerged from the following case studies split into financial, economic, social and environmental categories.

5.1.1 Agriculture-urban Water Exchange in the Llobregat Delta, Spain

The Llobregat River Delta in northeastern Spain faces significant environmental pressure from the growth of the adjacent city of Barcelona. The regional water authority considered water reuse as a method for offering farmers reclaimed water in exchange for their freshwater entitlement for urban use. The CBA in Table 8 was conducted prior to any action and did not consider that there may be years without need for water exchange in which the high-end treatment plants (designed for agricultural reuse) might not be required to operate. However, the benefits occur and outshine the costs (also of those in previous years) under severe drought when water exchange is activated. During the last drought Barcelona ran out of water and the regional economy suffered a loss of €1.6 billion (Drechsel et al. 2018).

5.1.2 Wastewater as an Alternative to Groundwater Sources in Puglia, Southern Italy

An economic analysis of the costs and benefits from wastewater reuse in Puglia, Italy was conducted under two possible scenarios. The first scenario used reclaimed water for newly irrigated land, while the second scenario used reclaimed water as an alternative to groundwater. The CBA in Table 9 revealed that improving urban wastewater treatment for reclamation and irrigation would increase the availability of irrigation water by 10% of the overall demand (Arborea et al. 2017). The CBA also revealed that cost

TABLE 7. COSTS AND BENEFITS FOR WASTEWATER RECOVERY AND REUSE.

Common costs and benefits from case studies (not exhaustive)
Financial
Capital cost of new treatment
O&M of new treatment (including ongoing monitoring and control of wastewater reuse)
Costs of conveyance alternatives (net difference between previous conveyance and reused water conveyance)
Sales of effluent to various end users
Economic
Avoided cost to alternative water source (e.g. groundwater pumping)
Avoided costs of fertilizer
Social
Value of water exchanged for city use
Jobs created
Net change to agricultural sales revenue (includes potential market restrictions for products produced with reused water)
Change to health status or health risk
Residential resettlement, other social impacts
Environment
Benefits to freshwater source (preserving or restoring groundwater aquifer, surface water)
GHG emissions

TABLE 8. COSTS AND BENEFITS CONSIDERED IN THE CBA FOR WASTEWATER REUSE IN THE LLOBREGAT DELTA, SPAIN.

Costs and benefits considered	El Prat WWTP (€ million)	Sant Feliu WWTP (€ million)	Methods
Capital cost of new treatment	14.00	1.12	Full cost accounting
O&M of new treatment	2.6	0.51	Full cost accounting
Cost of conveying effluent	0.12	0.2	Full cost accounting
Net new benefits to agriculture	0.35	0.46	
Agricultural sales revenue		0.388	MPA (NFI)
Savings in groundwater pumping	0.32	0.06	MPA
Savings in fertilizer	0.03	0.01	MPA/NFI
Value of water exchanged for city use	14.43	8.12	MPA (current tariffs)

Note: The euro to USD exchange rate in 2010 was 1.33.

Source: Winpenny et al. (2010).

TABLE 9. COSTS AND BENEFITS CONSIDERED IN THE CBA FOR WASTEWATER TREATMENT, RECLAMATION AND IRRIGATION IN PUGLIA, ITALY.

Costs and benefits considered	Newly irrigated land (€ million)	Groundwater replacement (€ million)	Methods
Cost of treatment (3 alternatives considered)	Variable based on plant capacity	Variable based on plant capacity	DCA
Cost of on-farm monitoring and control (constraints on irrigated land)	Not applicable	0.02	DCA
Economic value of irrigation	0.21	0.02 (preserving aquifer) 0.02 (restoring aquifer)	HPM
Economic value of good groundwater quality (salinity)	Not applicable	0.22 (preserving aquifer) 0.19 (restoring aquifer)	Option value (difference between benefits derived by current and future use of the resource, as per farmers' future discounted revenues from reducing current abstraction to maintain the salinity level)

Note: The euro to USD exchange rate in 2010 was 1.33.

Source: Arborea et al. (2017).

factors like plant size and effluent quality were variable and affected the CBA results, while the benefits derived were relatively stable (Arborea et al. 2017). This example uses a combination of methods, including direct costs, hedonic pricing and option value, allowing for comparability between very different costs and benefits.

5.1.3 Wastewater Treatment and Reclamation in Beijing, China

Financial and economic analyses were conducted for wastewater treatment and reclamation for several end-uses at two wastewater treatment plants (WWTPs) in Beijing, China. Though several economic, social and environmental costs and benefits were identified, only the ones that were quantified and valued are included in Table 10. This example shows that context-specific social benefits can be included. Health risk was quantified using a DALY (Section 4.4) and monetized using the CVM (Table 5). In this case, residential resettlement would be necessary for the project to go ahead, increasing transportation costs for the commuting of resettled people. Lastly, social benefits due to an increase of jobs were quantified using employment elasticity.

TABLE 10. COSTS AND BENEFITS CONSIDERED IN THE CBA FOR WASTEWATER TREATMENT AND RECLAMATION AT GAO AND JIU WWTPS IN BEIJING, CHINA.

Costs and benefits considered	Gao (million yuan)	Jiu (million yuan)	Methods
Economic cost	425.53	112.89	
Initial investment			MPA
O&M cost			MPA
Environmental cost	19.24	0.38	
Carbon dioxide emissions			Coal energy inputs into plant, marginal 'damage cost' of USD 50 ton^{-1}
Social cost	15.28	6.4	
Health risk			DALY, CVM
Residential resettlement			Increased transportation cost due to resettlement
Economic benefits Cost saving on fertilizers	2.4	0.24	Unit cost-saving on fertilizers based on standard quality of reused water
Environmental benefits	3,225.26	645.05	Monetary value of water (from another study) using shadow price
Increased water availability			
Increased water level			
Social benefits	5.9	5	
Increase of jobs			Employment elasticity (ratio of employment growth to economic growth)

Note: CNY to USD exchange rate in 2012 was 0.146377.

Source: Liang and van Dijk (2012).

5.1.4 National-level Costs and Benefits of Agricultural Reuse of Wastewater in Israel

A national-level CBA for agricultural reuse of wastewater was conducted for Israel, comparing alternatives of river disposal, local agricultural reuse of wastewater and conveyance from central to south Israel. The costs and benefits considered in the study are depicted in Table 11. The result was that irrigation in the center of Israel saved USD 0.50 to 0.60 m^{-3}, compared to river disposal and USD 0.10 to 0.20 m^{-3} compared to conveyance to southern Israel (Haruvy 1997). This shows the potential for CBA in RRR as a national planning tool.

TABLE 11. COSTS AND BENEFITS CONSIDERED IN THE CBA FOR WASTEWATER TREATMENT AND REUSE IN ISRAEL.

Costs and benefits considered	Methods
Costs of treatment	DCA
Costs of conveyance	DCA
Hazard costs	
Seepage of nitrogen	Linear optimization model targeted at maximizing profits
Health risks	Probability of mortality increase by 0.001
Value of agricultural output	MPA
Decrease in fertilization costs	NFI
Aquifer recharge	Marginal value of water

Source: Liang and van Dijk (2012).

5.2 Agro-industrial Waste Management

Agro-industrial waste management provides several opportunities to recycle nutrients, water and energy back into the system as productive inputs. Though often strictly regulated, agro-industrial waste management is often driven by the private sector, contrasting with other public sector RRR projects such as wastewater reuse or organic MSW management. Though fewer case studies exist for analysis of economic, environmental and social costs and benefits, this section provides a snapshot of possible methods for valuing the broader costs and benefits of RRR in the agro-industrial sector. Table 12 is not an exhaustive list of all possible costs and benefits, but includes those that emerged from the following case studies according to financial, economic, social and environmental categories.

5.2.1 Alternative Pig Waste Disposal in Thailand

A CBA of five alternative pig waste disposal methods was conducted in three of the main livestock regions of Thailand (Kiratikarnkul 2010). The alternatives included biogas waste to energy for the farm, using pig waste as fish feed, producing and selling organic fertilizer, dumping waste into a deep pond and a mixed method that uses biogas alongside another method. The study was split into two analyses, an economic CBA (i.e. costs and benefits to society) and a financial CBA (i.e. costs and benefits of the project to the enterprise). The quantified costs and benefits are shown in Table 13, revealing that the best option according to the economic CBA was fish feed, though the financial analysis showed that the concrete dome biogas produced a higher NPV (Kiratikarnkul 2010).

TABLE 12. COSTS AND BENEFITS FOR AGRO-INDUSTRIAL WASTE RECOVERY AND REUSE.

Common costs and benefits from case studies (not exhaustive)
Financial
Capital costs
O&M costs
Transport costs along input and output supply chain
Economic
Change in property value due to external damage
Biogas and electricity (feed-in tariffs)
Market price of inputs and outputs (e.g. compost, recyclables)
Social
Cost savings on improved health conditions
Environment
GHG emissions

TABLE 13. COSTS AND BENEFITS CONSIDERED IN THE CBA FOR PIG WASTE DISPOSAL METHODS IN THAILAND (IN THAI BAHT).

Impacts	Fertilizer	Fish feed	Concrete dome biogas	Covered lagoon biogas	Deep pond	Mixed	Method for quantification
Costs (undiscounted)							
Capital	17,640,900	72,870,000	83,751,000	110,104,500	1,676,055	41,051,570	Investment costs farmers incurred in the first year to set up the necessary structure for waste disposal
Additional equipment	0	0	147,759,152	69,887,878	0	23,009,000	Additional costs, such as generator and gas cleaning equipment
O&M	6,254,964	37,872,216	10,090,607	3,400,942	942,736	10,503,091	Cost of land used (or rent)
External damage costs	104,970,359	0	0	0	9,233,400	0	Property value differential (HPM)
Benefits (undiscounted)							
Energy (biogas + electricity)	0	0	122,774,895	134,541,000	0	23,565,560	Volume of biogas produced from the sampled farms (MPA)
Organic fertilizer	134,880,142	0	57,659,613	8,115,751	69,050	3,676,070	MPA
Fish	0	214,614,600	0	0	0	88,900,000	MPA
Subsidies to farmers	0	0	0	0	0		MPA
Total costs (discounted PV)	**157,090,204**	**351,457,043**	**256,427,189**	**144,733,901**	**16,070,111**	**143,708 376**	
Total benefits (discounted PV)	**1,087,226,800**	**1,729,941,423**	**1,454,426,351**	**1,149,911,622**	**556,591**	**936,915,016**	
NPV	**929,324,596**	**1,378,484,380**	**1,198,008,162**	**100,517,721**	**(16,575,709)**	**793,206,640**	
NPV per tonne of pig waste	**197**	**358**	**125**	**144**	**(19)**	**146**	

Note: The Thai Baht to USD exchange rate in June 2018 was 33.168.
Source: Kiratikarnkul (2010).

5.2.2 Integrated Sustainable Agroprocessing Waste Treatment in Eastern Africa

In 2011, the International Livestock Research Institute brought together a consortium to look into the potential for integrated, sustainable agroprocessing of waste treatment in Eastern Africa. This process included "evaluat[ing] and disseminat[ing] the economic, environmental, and social benefits of integrated wastewater treatment bioprocesses" (Njau et al. 2011). Though left unquantified, the costs and benefits identified are included in Table 14 to show those deemed most relevant by the consortium.

TABLE 14. COSTS AND BENEFITS TO CONSIDER IN AGROPROCESSING WASTE TREATMENT PROJECTS.

Costs and benefits
Capital cost
Fixed and variable operating cost
Mode and delivery costs of moving treated biofertilizers and biogas to end-users
Cost of technology adoption and transfer
Woodfuel conservation benefit
GHG emission reduction
Biogas as a carbon neutral energy source
Cost savings on improved health conditions

Source: Njau et al. (2011).

5.2.3 Dairy Farm Biogas Energy Production in Umbria, Italy

An assessment of the environmental sustainability and economic benefits of biogas energy production on dairy farms was conducted, using Umbria as a case study. The environmental analysis used a life-cycle assessment and the economic analysis used the economic balance of agro-energetic supply chains, which measures the energy derived from activities that generate and reuse agricultural waste according to the budget cost of each performed activity (Torquati et al. 2014). The LCA used a functional unit of energy, quantified as electricity and heat in kWh, and the system boundary of the assessment included a 'cradle to grave' perspective of the agricultural process, energy conversion and end-of-life digestate. The economic analysis included cost items and income losses, in addition to sales revenue and government incentives. The results of the analyses are included in Table 15, revealing that biogas produces approximately half of GHG emissions compared to fossil fuels and energy crops used for biogas production have economic influence. It also reveals that energy production provides an opportunity to increase farmers' income, but the overall economic sustainability of the plant relies on the rate per kWh that government incentives can guarantee to renewable energy producers (Torquati et al. 2014). This example is important, as it provides a framework for including GHG emission accounting in the agro-industrial sector. It also provides an example of breaking down an agro-energy chain to allow for the revenue from a feed-in-tariff system to be quantified.

5.3 Organic MSW

Organic MSW management provides significant opportunities to improve public health and environmental factors associated with inadequate solid waste management. The generation of electricity, GHG offsets and fertilizer savings are the most common indirect aspects to consider. Quantifying these impacts and valuing them is very relevant for RRR from organic MSW, but this section also points to some of the challenges. Table 16 is not an exhaustive list of all possible costs and benefits, but includes those that emerged from the following case studies according to financial, economic, social and environmental categories.

TABLE 15. GHG EMISSIONS OF A DAIRY FARM BIOGAS FACILITY.

				Emissions		
Processes	**Stage of agroenergy chain**	**(€2012)**	**CO_2 kg**	**N_2O, CO_2eq, kg**	**CH_4, CO_2eq, kg**	**CO_2eq total, kg**
Cost analysis						
Biomass supply	Maize silage from farm	Production cost: 153,990	193,000	521,250		714,250
		Income loss: 66,460				
	Maize silage from others	Production cost: 94,800	141,000	380,800		521,800
	Triticale silage	Production cost: 41,770	3,640	9,830		13,470
		Income loss: 18,000				
	Manure	Income loss: 16,800	5,940			5,490
	Olive residues	Production cost: 2,000	1,630			1,630
Biogas production	Loading materials into plants	Operating cost: 12,400	8,940			8,940
	Anaerobic digestion	Fixed cost: 152,500	-		578,250	578,250
		Operating cost: 350,000				
Use of digestate	Composting	Fixed cost: 47,500	34,200			34,200
		Operating cost: 4,000				
	Spreading digestate		-		64,250	64,250
	Total		304,810	911,880	642,500	1,859,380
Total costs		€963,120				
Revenue analysis						
Energy production	Production of electricity fed into the grid	1,058,680				
Digestate production	Digestate production	42,000				
Total revenues		€1,100,680				

Note: The euro to USD exchange rate in 2017 was 0.23262 (average).

Source: Torquati et al. (2014).

TABLE 16. COSTS AND BENEFITS FOR ORGANIC MSW RECOVERY AND REUSE.

Common costs and benefits from case studies (not exhaustive)
Financial
Capital costs
O&M costs
Transport costs
Collection fees, revenues from sales
Economic
Fertilizer savings, pesticide savings
Displaced energy operational costs
Biogas electricity, combined heat and power
Social
Time savings
Land requirements
Environment
Nutrient displacement, pesticide reduction
Avoided disposal of processed water, other outputs
Avoided burden of alternative disposal methods (e.g. incineration)
GHG emissions

5.3.1 Food Waste Composting at the University of Minnesota, Morris

The University of Minnesota, Morris (UMM) started a program to compost its food waste and food-soiled paper as an alternative to off-site incineration. A CBA was conducted to determine whether the composting program should continue, and that further investments in the program might be warranted. A previous feasibility study determined that windrow composting was the most appropriate for the application (Beattie 2014). The study included several impact categories with measurable indicators that were quantified and monetized. Table 17 presents a summary of the costs and benefits and the methods required for quantification and monetization. It is clear that several of the identified costs and benefits were not considered due to challenges in the monetization stage.

5.3.2 Solid Waste Management Options in Basrah, Iraq

A comparative CBA of different solid waste management options was conducted for the city of Basrah, Iraq, in

TABLE 17. COSTS AND BENEFITS OF INCINERATION AND WINDROW COMPOSTING AT UMM.

Costs and benefits	**Incineration (USD)**	**Windrow composting (USD)**	**Method**
Collection fee	6,114.08 $year^{-1}$		Hauling fees and transport
Incineration externalities: *Incineration inefficiencies* *Reduced BTUs during incineration* *Longer hauling distance*			Not quantified
Time savings for UMM staff			Not quantified
Less equipment and infrastructure required			Not quantified
Organics collection containers		975	
Compost facility operator certification training		1,185 (3 people)	
Tipping and mixing area		10,500	
Temperature probe and probe guard		231.10	
Gas used to operate the bobcat		600 $year^{-1}$	MPA
Labor		562.50 $year^{-1}$	MPA
Reduced need for chemical fertilizers			
Reduced waste hauling fees		6,114.08	DCA
Research and educational opportunity			Not quantified
Non-use value: reputation of UMM as renewable, sustainable education			Not quantified
GHG emission reduction		21-161 ton^{-1} $year^{-1}$	Social cost of carbon (not cumulative because GHG not quantified)

Source: Beattie (2014).

2011, as the waste management system had recently deteriorated. The CBA considered technical, economic and environmental aspects of three solid waste management scenarios (Elagroudy et al. 2011). The current open dumping practice served as the baseline scenario. The first scenario was disposal of all waste in a sanitary landfill, the second scenario included transportation to a transfer station before disposal in a sanitary landfill and the third scenario considered sorting, recycling, and composting, before disposing into a sanitary landfill (Elagroudy et al. 2011).

The economic analysis included capital and operations costs of each of the three scenarios. The environmental assessment used a life-cycle perspective model to quantify the environmental burdens of waste management, including elements of collection, transfer, sorting, recycling, composting, energy recovery and landfilling (Elagroudy et al. 2011). For example, the model calculates the energy consumed and produced, and the emissions to air, land and water. The results of the CBA favored the third scenario, which included sorting, recycling and composting, due to the environmental benefits gained. However, the revenues from sales of recycled products and compost were not enough to justify this scenario from a purely financial perspective (Elagroudy et al. 2011).

5.3.3 Composting and Anaerobic Digestion in a Rural Community in Malaysia

A preliminary CBA was conducted in Malaysia to assess alternatives to landfilling MSW. A baseline scenario in which all MSW would be sent to a landfill without a methane gas recovery system was compared to two alternatives. A composting scenario included a small community-managed composting site with small-scale sites for food waste processing in which the waste is transformed into a more uniform, drier product for multiple uses. The process inputs included water, feedstock and energy, and the process outputs included carbon dioxide or air, compost and residuals. The anaerobic digestion scenario included a central plant to treat waste generated by the community, with process inputs of energy, feedstock and water and process outputs of biogas, digestate and energy that feed back into the anaerobic digestion operation. Both the composting scenario and anaerobic digestion scenario assumed that source segregation was 100% and required no additional inputs (Zulkepli et al. 2017). This CBA in Table 18 was limited in scope but demonstrates the value of using a baseline scenario to provide context for an alternatives assessment.

TABLE 18. CBA OF ORGANIC MSW OPTIONS IN MALAYSIA.

Costs and benefits	Baseline	Composting	Anaerobic digestion	Method
Waste generation (ton day^{-1})	0.2	0.2	0.2	
Average distance from transfer station to hub	N/A	7	7	
Tipping fee/waste collection fee (MYR year^{-1})	80	N/A	N/A	
Capital cost (MYR)	N/A	1,802	19,323	Normalized for 20 years
O&M cost (MYR)	N/A	1,000	1,000	
Fertilizer price (MYR ton^{-1})		1,000		
Electricity price (MYR kwh^{-1})		1.09		
Biogas price (MYR m^{-3})		18.5		
Electricity production from biogas (kWh m^{-3})		N/A	2.1	
Heat production from biogas (kWh m^{-3})		N/A	2.5	
Biogas production (m^3 ton^{-1} MSW)		N/A	203.6	
Fertilizer production (tons year^{-1})		18	1.07	

Note: MYR = Malaysian Ringgit. The MYR to USD exchange rate in 2017 was 0.23262 (average).

Source: Zulkepli et al. (2017).

5.4 Fecal Sludge Management

Fecal sludge management presents emerging opportunities for RRR in developing countries as fecal sludge is converted into energy and other useful by-products. The costs or benefits associated with GHG emissions, impacts on public health, impacts on agriculture and the avoided costs of other methods of disposing of the waste appeared most relevant according to the examples below. Table 19 is not an exhaustive list of all possible costs and benefits, but includes those that emerged from the following and other case studies according to financial, economic, social and environmental categories.

TABLE 19. COSTS AND BENEFITS FOR FECAL SLUDGE RECOVERY AND REUSE.

Common costs and benefits from case studies (not exhaustive)
Financial
Capital costs
O&M costs
Direct revenue (e.g. compost sales, waste disposal/tipping fees)
Avoided costs of fecal sludge removal or penalties for not doing so
Economic
Reduced transportation cost to final depot
Landfill (depot) space saved
Increase in property value
Social
Public health savings, diarrhea treatment cases avoided
Increased crop yield or productivity
Time savings
Environment
GHG emissions
Reduced environmental health risks

5.4.1 Co-composting of Fecal Sludge and MSW in Kumasi, Ghana

An economic analysis of co-composting of fecal sludge and MSW was conducted on the Buobai Co-composting pilot plant in Kumasi, Ghana, based on the assumption that it can be a viable option for waste management and a source of nutrients and soil conditioning in the long term (Cofie 2003). The cost streams in the economic assessment only included direct costs, such as investment capital, operations and maintenance costs. Hidden social costs, or indirect costs, were not included due the challenges associated with quantification and monetization. However, benefit streams included both direct revenues and indirect economic gain made from project operations (Cofie 2003). Table 20 summarizes the main findings of the economic analysis, which shows that market price and damage costs avoided were used to monetize indirect costs to the environment and society.

TABLE 20. COST-BENEFIT ANALYSIS OF CO-COMPOSTING OF FECAL SLUDGE WITH MUNICIPAL WASTE AT BUOBAI CO-COMPOSTING PILOT PLANT, KUMASI, GHANA.

Costs and benefits	**USD (2002)**	**Method**
Investment capital	21,753	Direct cost
O&M (costs per year)	1,800	
Direct revenues (2002 shadow prices)		
Sale of compost	4,477	MPA
Waste removal charges	13,000	MPA
Indirect benefits		
Transportation cost saved	600	DCA
Landfill space cost saved	3,100	DCA
Public health bill reduction	3,750	DCA

Source: Cofie (2003).

5.4.2 Fecal Sludge-to-fortifier Composting in Northern Ghana

A study of the feasibility of composting fecal sludge or market waste composting into fortified excreta pellets was conducted from an economic perspective in Tamale, Ghana. The study investigated two business models in which the community and entrepreneur operate the system together or operation falls to the entrepreneur alone. The study revealed that the model operated jointly by the community and entrepreneur generated the highest cost-to-benefit ratio and the lowest capital cost. The study identified several costs and benefits from the social, environmental and health perspectives alongside the financial analysis, though not all were quantified and monetized. The main results of the study are summarized in Table 21. This example shows that CBA can be used to compare alternative operational arrangements of the same facility.

TABLE 21. CBA OF FECAL SLUDGE-TO-FORTIFIER COMPOSTING IN TAMALE, GHANA.

Costs and benefits	Method	
Social		
Increase in yield/productivity	Difference between Net Value Output with and without fortifier	
Increase in property value	Not quantified	
Health		
Health care costs savings	Less expenditure on treatment of diarrheal disease and less related cost, less expenditure on transport in seeking treatment	
Productivity gains due to improved health	Value of avoided days lost at work or school	
Time savings	Less time lost due to treatment seeking	
Increased health risks due to possible pathogen survival	Human capital approach and market price	
Environmental		
Estimated GHG emission reduction	Not quantified	
Area of landfill saved and cost saving of land used for dumping sites	Not quantified	
Monetized costs and benefits[1]	**Model 1**	**Model 2**
Financial (monetized costs and benefits)		
Capital costs (per year)	345,714 (19,678)	422,714 (19,687)
O&M cost	417,653	417,653
Benefits	1,187,585	1,187,585
Compost sales	645,120	645,120
Landfill disposal avoided	25,000	25,000
Diarrhea treatment cases avoided	517,465	517,465
NPV @ 9%	5,248,046.69	5,171,046.69
B/C ratio	1.94	1.91
EIRR	100.25%	21%

Notes: GHS = Ghana Cedi.

[1] Costs with 20-year amortization, 9% social discount rate, in GHS.

Source: Frank (2015).

5.4.3 Qualitative Costs and Benefits of Technology Options for Fecal Sludge Management in Developing Countries

An analysis of the qualitative costs and benefits for fecal sludge management in developing countries (Singh et al. 2017) focused on the benefits of resource recovery and reuse. Table 22 demonstrates that a qualitative assessment of costs and benefits can still be a valuable tool when used to make preliminary decisions in a low resource environment.

TABLE 22. DECISION-MAKING MATRIX FOR SLUDGE TREATMENT TECHNOLOGY WITH RESPECT TO CONSTRAINTS.

Constraints	Co-composting	Deep row entrenchment	Vermicomposting	Anaerobic digester	Solar drying	Shallow trenches	Solar sludge oven	BSFL
Land requirements	+++	+++	+++	+	+++	+++	+	+++
Energy required for daily operation	+	+	+	+	+	+	+	+
Shallow groundwater table	++	+++	++	++	++	++	++	++
CAPEX	+++	+	+++	+++	++	+	++	+++
OPEX	+++	+	+++	+++	++	+	+	+++
Skill requirement	+	+	++	+++	++	+	++	++
Reuse opportunity	+++	+	+++	++	+++	+	+++	+++

Source: Singh et al. (2017).

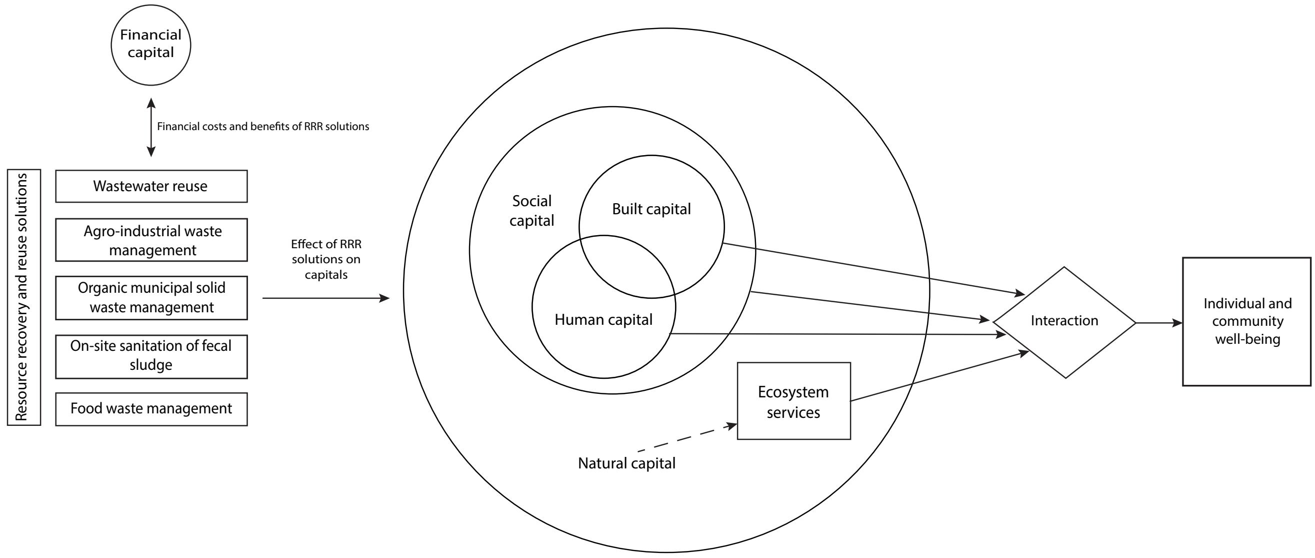
6. RELATING COSTS AND BENEFITS OF RRR TO HUMAN WELL-BEING

CBA can help make more informed decisions for RRR, but the method is limited in its ability to absorb complexity and the multiple dimensions of human well-being over time. By relating the costs and benefits considered in a CBA for RRR directly to human well-being, the value and limitations of CBA results are put in context. This should encourage decision-makers to consider elements that may be excluded from the CBA in their decisions. The concept of three-dimensional human well-being argues that well-being arises from a combination of what a person has, what a person can do with what she/he has and how a person thinks about what she/he has and can do with it. This involves the interplay of the resources that an individual is able to command, what she/he is able to achieve with those resources, including the needs and goals that can be met, and the meaning attributed to the goals achieved and the process engaged to meet them (McGregor and Sumner 2009). Over time, a positive correlation between ecosystem services and human, physical, physiological and psychological well-being has been defined (King et al. 2014). While a range of definitions exists, this report defines human well-being according to the constituents of well-being in the Millennium Ecosystem Assessment (MEA 2005). This definition connects constituents of well-being, ecosystem services, and the direct and indirect drivers of change, highlighting security, basic material for a good life, health, good social relations, and freedom and choice of action.

Figure 5 presents a conceptual framework for relating RRR solutions to individual and community well-being using the capitals framework. Costanza et al. (2014) argued that a complex interaction of all capitals results in their overall effect on well-being. Built and human capital are connected and embedded in social capital, which is embedded within natural capital. Natural capital affects well-being primarily through ecosystem services. Because of the importance of the financial component to RRR, financial capital is shown as directly enabling and relating to the RRR solutions. Broader dimensions of the financial and economic component will emerge through analysis of other capitals. For example, human and social capital relates to effects on livelihood and employment. This framework is not static and should be considered with knowledge of the fact that several long- and short-range cycles of change are occurring due to environmental and socioeconomic development factors that constantly shift the state of the capitals. While this framework can help relate RRR to human well-being, the state of the underlying capitals is constantly changing due to broader socioeconomic and environmental factors.

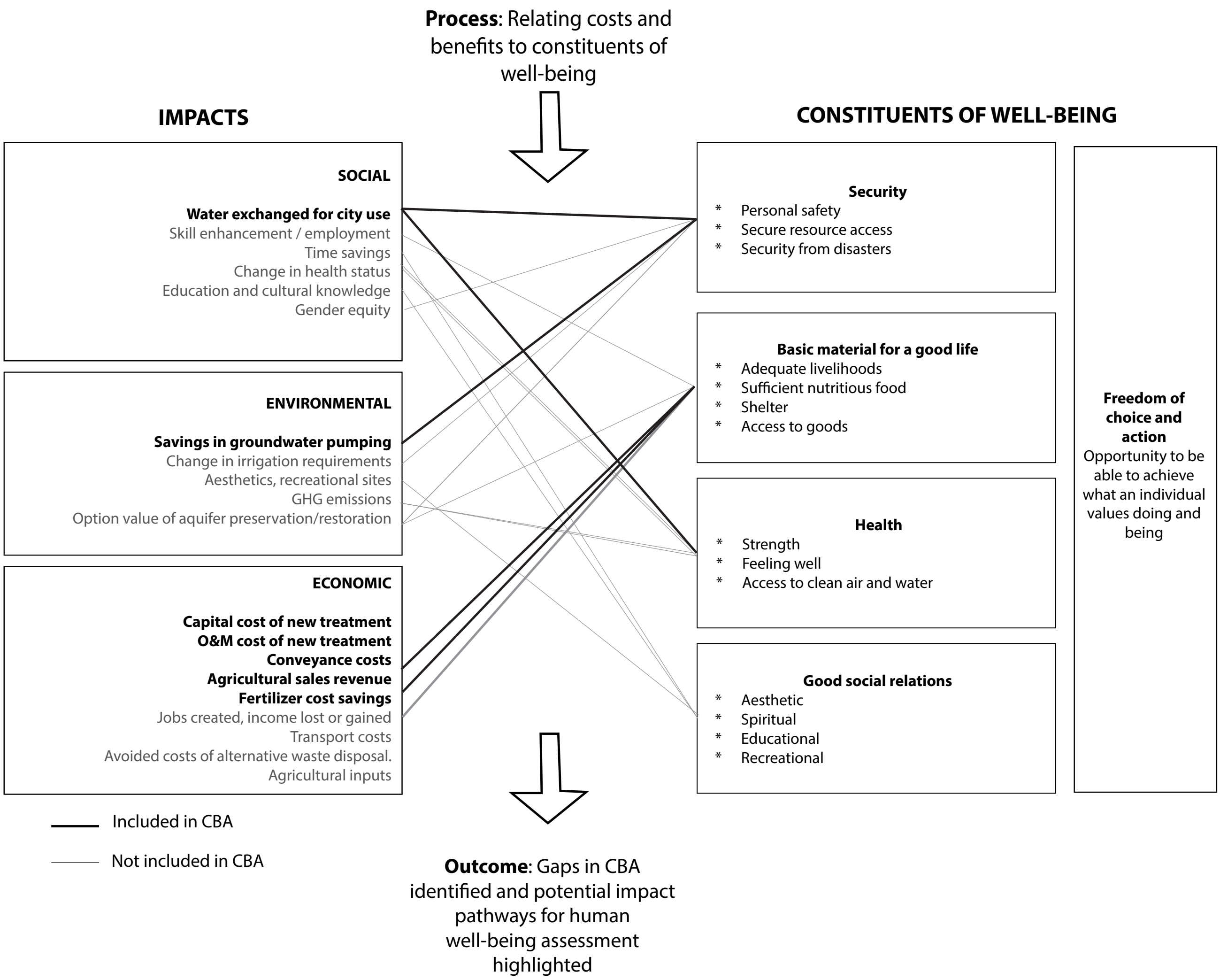
The outputs of the cost and benefit quantification and valuation process are a long list of quantified and unquantified outputs. Figure 6 presents a method for relating these outputs to constituents of human well-being from the Millennium Ecosystem Assessment (MEA 2005). For example, GHG emissions can relate to health, and quality of employment affects basic materials for a good life. The impacts in bold are quantified in the CBA in the example of wastewater reuse in Llobregat Delta, Spain, while the impacts in grey are other potential impacts that may be affected by the project. This process points to the limitations of the CBA. Costs and benefits that were excluded from the CBA due to challenges with the method may affect the impact of the project on human well-being.

FIGURE 5. CONCEPTUAL FRAMEWORK FOR RRR PROJECTS TO INDIVIDUAL AND COMMUNITY WELL-BEING.



Source: Adapted from Costanza et al. 2014

FIGURE 6. FRAMEWORK FOR RELATING OUTPUTS FROM A CBA OF RRR TO CONSTITUENTS OF HUMAN WELL-BEING USING THE EXAMPLE OF WASTEWATER REUSE IN LLOBREGAT DELTA, SPAIN.



Source: Adapted from MEA 2005.

7. CONCLUSION

The first objective of this report was to highlight CBA as one of several available methods for quantifying and valuing social, environmental and economic costs and benefits by providing suggested methods and examples applied to RRR projects. Methods for CBA in the literature began with framing the CBA based on the questions of concern, the system boundaries, and the baseline scenario, and identifying and prioritizing the costs and benefits for consideration. This was followed by analytical methods for quantifying and monetizing the chosen costs and benefits. These results were accompanied with discounting into the future and quantifying uncertainty. The wide range of methods available for supporting the various stages of a CBA highlight several opportunities to reveal a broader array of costs and benefits of RRR to society, helping to better justify implementation of RRR projects. This is best depicted in Figure 3 as the 'universe' of costs and benefits of RRR separated by RRR of water, nutrients and energy. Examples of CBAs in wastewater reuse, agro-industrial waste reuse, organic MSW reuse and fecal sludge reuse, show that the method has been used to incorporate different forms of environmental and ecosystem service values to different stakeholders, to quantify indirect, long-term cost savings and to incorporate the value of social costs and benefits to human health or residential resettlement. These examples led to various insights; for example, the option value of resources left unused because of an RRR project can be significant in contexts with resource scarcity. These examples also reveal that the challenge is not necessarily to identify potential costs or benefits, but to quantify and monetize the costs or benefits, to attribute them to the project under investigation and to do so within a margin of uncertainty that is acceptable to decision-makers. This report provides a range of methods and examples for practitioners conducting CBAs to justify action for RRR and reveals opportunities for further research in the method and its relative influence in decisions.

The second objective was to investigate the nexus of RRR and human well-being to contextualize the CBA method. The purpose of this exercise was not to discourage the use of CBA. Rather, it was meant to help decision-makers reflect on its limitations and to suggest that economic value may be complemented with a human well-being metric to justify project action. A conceptual framework for relating human, social, built and natural capital to individual and community well-being was adapted to relate RRR to well-being. This relationship informed an exercise to relate the social, environmental and economic costs and benefits generated in a real-world CBA to a framework definition of human well-being that considers security, basic material for a good life, health, good social relations, and freedom and choice of action. This exercise clearly highlighted the elements of human well-being that were excluded from the CBA. This type of information can help practitioners make more informed and nuanced decisions.

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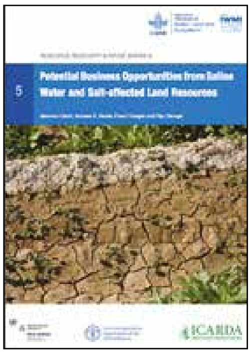

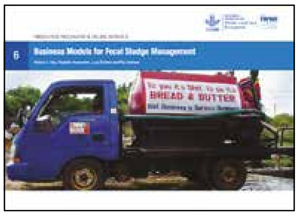

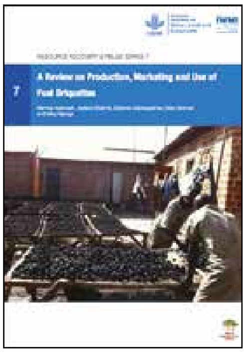

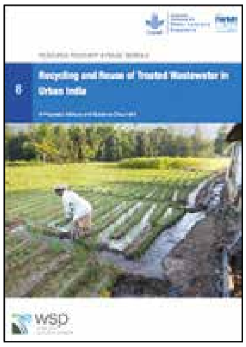

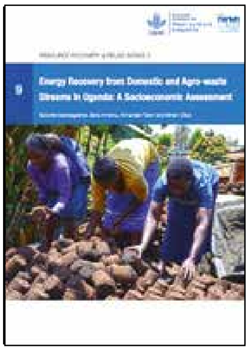

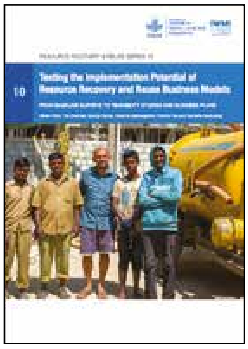

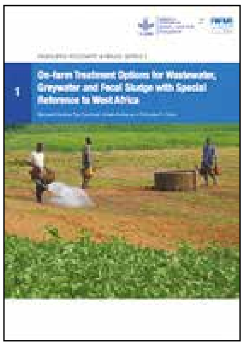

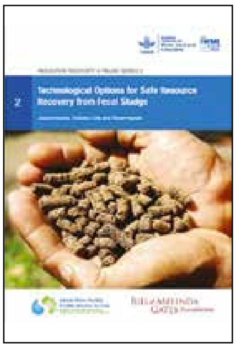

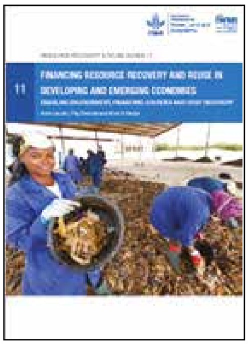

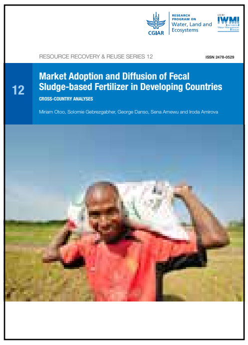

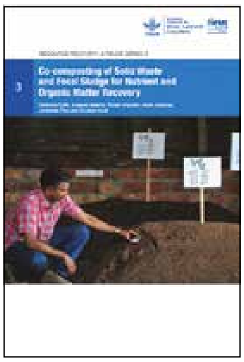

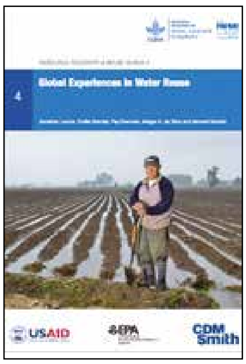

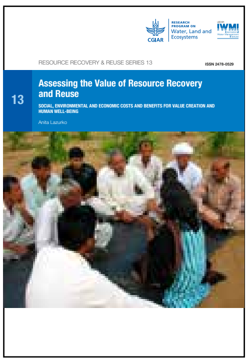

RESEARCH PROGRAM ON Water, Land and Ecosystems

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The **CGIAR Research Program on Water, Land and Ecosystems (WLE)** is a global research-for-development program connecting partners to deliver sustainable agriculture solutions that enhance our natural resources – and the lives of people that rely on them. WLE brings together 11 CGIAR centers, the Food and Agriculture Organization of the United Nations (FAO), the RUAF Foundation, and national, regional and international partners to deliver solutions that change agriculture from a driver of environmental degradation to part of the solution. WLE is led by the International Water Management Institute (IWMI) and partners as part of CGIAR, a global research partnership for a food-secure future.

Resource Recovery and Reuse (RRR) is a subprogram of WLE dedicated to applied research on the safe recovery of water, nutrients and energy from domestic and agro-industrial waste streams. This subprogram aims to create impact through different lines of action research, including (i) developing and testing scalable RRR business models, (ii) assessing and mitigating risks from RRR for public health and the environment, (iii) supporting public and private entities with innovative approaches for the safe reuse of wastewater and organic waste, and (iv) improving rural-urban linkages and resource allocations while minimizing the negative urban footprint on the peri-urban environment. This subprogram works closely with the World Health Organization (WHO), Food and Agriculture Organization of the United Nations (FAO), United Nations Environment Programme (UNEP), United Nations University (UNU), and many national and international partners across the globe. The RRR series of documents present summaries and reviews of the subprogram's research and resulting application guidelines, targeting development experts and others in the research for development continuum.

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ISSN 2478-0510 (Print)
ISSN 2478-0529 (Online)
ISBN 978-92-9090-880-7

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