Sustainability **2014**, *6*, 545-570; doi:10.3390/su6020545

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Review

How Assessment Methods Can Support Solid Waste Management in Developing Countries—A Critical Review

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Received: 10 November 2013; in revised form: 9 January 2014 / Accepted: 15 January 2014 / Published: 27 January 2014

Abstract: Selecting actions for improvement of solid waste management in low and middle income countries and understanding how a specific decision choice will fit and impact on a local context is key to identifying sustainable solutions. Assessment of the choice (be it technical or managerial) and assessment of the local enabling or disabling conditions are both important steps in the decision making process. Various assessment tools and methods are currently available to support decision-making in solid waste management. Assessment can be used to identify weaknesses or strengths of existing systems in a structured way and hereby highlight factors of success and failure. Assessment methods can also evaluate and compare different possible choices as in project scenarios. This overview describes established and innovative assessment methods serving both these purposes. A range of assessment tools are often designed to assess a specific sustainability domain (technical, environmental and health, economic and financial, social and institutional, organizational aspects), others attempt to provide a more holistic picture by integrating different sustainability domains into the same tool. This paper reviews a number of methods describing and discussing each of them, and referring to their use in low and middle-income countries if published in scientific literature. The overview concludes that in low- and middle-income countries the use of comprehensive assessment methods is yet very limited. We hypothesize that most formal methods of assessment are still too complex and generally overburden the weak local capacities intended for their usage. The few applications identified, were conducted by academia for scientific purposes. Lack of resources to collect the vast data required for some assessment methods is a further restriction to their practical application. Future development is suggested to improve user friendliness of existing tools or to simplify certain approaches and develop more appropriate methods. A user-oriented focus in the development of assessment tools would enhance their application, provide sound data for informed decision making and foster a dialogue between technicians and policy makers in low- and middle-income countries.

Keywords: assessment methods; evaluation methodologies; developing countries; sustainability; decision making support tools; solid waste management

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1. Introduction

Solid waste management in low and middle-income countries has a lot of potential for improvement. Understanding how a specific decision choice towards improvement will match to enabling local conditions and thereafter impact on the local context, is crucial when identifying the most sustainable solutions. As defined in this paper, assessment tools are structured procedures or methods which, when used, result in objective and replicable information; either on the technological appropriateness of the decision choice or the local enabling or disabling conditions influencing success or failure of the decision choice (be it technical or managerial). Formalized assessment tools help to ensure a structured way of thinking and provide a comprehensive method for data collection and analysis. Furthermore, by using a systematic and defined methodology they can ensure objectivity and replicability. Two main reasons can be identified for using or further developing assessment methods for decision support:

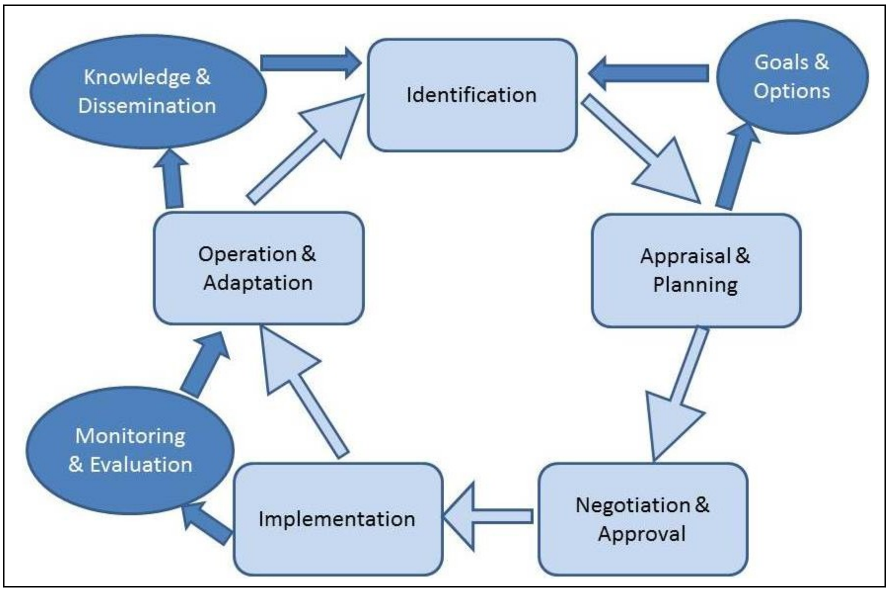
a. Well-defined assessment methods which are used on existing cases (situations) can help evaluate their performance/impact (in all sustainability dimensions) to better understand how and why the performance/impact is as it is.
    I. Each case assessed and analyzed in a structured and systematic way can help identify the specific weaknesses in that moment of time. Based on the identified weakness, mitigation measures can be evaluated and implemented to rectify the negative aspects and improve performance and impact.
    II. Using a standardized approach to assess a multitude of cases helps to compare cases between each other. With many cases assessed, some general valid factors of performance success or failure in projects may be identified. Such knowledge can then help decision makers avoid the same mistakes others have already experienced or highlight how specific risks during project development and planning can be avoided early on.
b. Using assessments for prospective analysis of project scenarios can help evaluate and compare between alternative options, be this different financing models, technology elements and/or organizational setups.

Currently a large number of methods, approaches and modeling tools have been developed to support decision-making in solid waste management. With the large number of methods available, however, it is becoming increasingly difficult for practitioners and decision makers to understand, select and apply the method which is the most appropriate for their specific needs [1–3]. Decision support models or decision support systems (DSS), also called "system analysis platforms" [1], are now available and predominately in use in the academic realm. These are approaches that utilize one or more methods of assessment in combination to develop a more holistic view of the situation or most often to depict the consequence of a suggested alternative. They are all designed to help decision makers apply improvements by providing better knowledge on the situation and the consequences of a particular choice.

Whatever the decision problem at stake, it must be firstly defined through clear objectives that are specific, measurable, agreed, realistic and time-dependent. Once the objectives are set, the steps that follow are: (i) establish a thorough understanding of the current situation; (ii) identify options for achieving the objectives; (iii) identify and weight the criteria to be used to compare the options; (iv) analyze the options; and finally (v) make the choices [4].

Whatever methods are used for assessment, a first step requires defining the scope of the assessment and the respective boundaries of the case or system which will be assessed. The scope relates to the project cycle, *i.e.*, if the assessment has the goal to evaluate options for planning and project design purposes or, if it shall assist with the monitoring, evaluation and adaptation process during the operation of a project (Figure 1).

Figure 1. The project cycle where assessments (in the dark phases) can support decision making.



Often, however, the method is chosen first which then implicitly affects the scope. Regarding boundaries and the extent of the case to be assessed, most assessment methods are suited for a subsystem level, to evaluate specific technical alternatives for a subsystem in the overall solid waste management system. Other methods are more encompassing and may also tackle the full system by integrating the individual subsystems to a whole; however, this task is much more complex and is often used to assess impact of a given choice and not to evaluate alternative options.

This paper aims to critically review some assessment methods applied by both scientists and/or practitioners. The available and most common assessment methods are listed and described. Their strengths and weaknesses are identified, and their use in developing countries, especially in a waste management context, described. Finally gaps on current knowledge are discussed to then propose new directions for research and development and on how to improve tools in order to provide more effective and practical assessment tools for practitioners in low- and middle-income countries.

2. Methods Description

This review follows a phased approach where assessment methods and tools were first identified by a search in the SCOPUS literature database using the key words "assessment, method, solid waste, developing country". This resulted in 48 findings, whereas omitting the term "developing country" returned 1551 results. Substituting the word "method" for "tool" returned 13 respectively 416 results. A second step was to then characterize and categorize the identified methods and tools into clusters (Table 1).

Table 1. Tools and methods described in the paper, divided according to the sustainability domain.

Sustainability Aspect	Tool/Method
Technical Aspects	Environmental Technology Assessment (EnTA) and Sustainability Assessment of Technologies (SAT) Technology appropriateness
Environmental and Health Aspects	Health impact and risk assessment Life cycle assessment Material flow analysis Clean development mechanism
Economic and Financial Aspects	Cost-benefit analysis Life cycle cost approach
Social Aspects	Stakeholder analysis Social and organizational network analysis
Organizational and Management Aspects	Business canvas and business environment assessment
Multiple Sustainability Aspects	Computer based multiple sustainability assessments Sustainability assessment by success and efficiency factors

Main clustering criteria are the dimension of sustainability in which the method or tool puts a major focus. The dimensions of sustainability were defined as: technical, environmental/health, economic/financial, social/institutional, and organizational [5,6]. Some assessment tools, however, could not be clustered in this way as they evaluate sustainability from more than one angle, considering different dimensions. In such cases they were clustered in the category of "multiple sustainability dimensions". The first section of this paper briefly describes the methods listed, independent of their proven use in solid waste management in the developing country context. It hereby refers to academic and non-academic texts. The second section then reviews the accessible and documented use of each specific method in the field of solid waste management—either from an academic or practitioners perspective—and its application in a developing country context. Methods and tools considered promising by the authors, which, however, do not yet show any proven application in academia or practice in relation to solid waste management and developing countries are discussed in a separate chapter of this paper based on a more methodological perspective.

2.1. Technical Assessment Tools

Technology assessment, in its most general understanding, refers to "a scientific, interactive and communicative process which aims to contribute to the formation of public and political opinion on societal aspects of science and technology" [7]. The procedure of technical assessment evaluates possible environmental and societal consequences of new scientific or technological developments. In this sense it does not only cover technical aspects but also covers the environmental and social sustainability domains. Technology assessment usually does not have a site-specific perspective but rather starts from the generic technology specifications and then evaluates a regional or global impact using other impact assessment techniques like Risk Assessment (RA) or Life Cycle Assessment (LCA) [8].

The new way to look at technology developed in the 20th century, when technology started to be considered not only from an operational perspective, but also started to take into account the impact on society and environment. In development cooperation, the concept of appropriateness was developed, suggesting that an appropriate technology should empower people to manage their resources and provide a long-term develop to the community, especially in poor settings [9,10]. The importance of technology developed in the country of use [11] is considered the fundamental aspect of appropriate technology. A streamlined approach to the assessment of technical appropriateness was, however, not pursued in the field of solid waste management. Bhamidimarri and Shilton [12] discuss the concept of appropriate technology in waste management and cite Jequier and Blanc (1983) on the characteristics of appropriate technology as: (i) low investment cost per unit of output; (ii) organizational simplicity; (iii) high adaptability; and (iv) sparing use of natural resources. However, at the same they argue that the concept of appropriate technology suffers from the image of being low-tech. As such, the understanding of such technology is directed towards the poor and developing countries although the technology's application may be very well suited also for developed countries. Zelenika and Pearce [13] agree and see this as a significant barrier to widespread implementation since appropriate technologies can be seen as holding back modernization and infringing on competitiveness by denying developing regions the same technology as in developed regions. UNEP-IETC in Japan has been most active worldwide on developing guidance and training materials for technology assessments. This started with the development of Environmental Technology Assessment (EnTA) which then developed further into the Sustainability Assessment of Technologies (SAT), which included improvements from the initial method to put more focus on the process of informed and participatory decision making and the respective outcomes [14,15]. In its scope of application the SAT specifically mentions its potential use for "end-of-pipe or waste management technologies" where it evaluates and compares technology system options among each other through a three phased evaluation process with increasing level of detail. The first screening eliminates some options through logical yes/no operators. The second phase consists of scoping, which evaluates the options using qualitative or easily available quantitative information. The final phase then assesses the remaining options in detail with quantitative information [15]. While taking into account many dimensions of sustainability criteria (economics, social, environmental, technical) the SAT gives little attention to the human factor or the capacity of the organization its management to operate the technology in a correct way.

Assessment of the technical functionality depends not only on the site specific physical conditions and the technical infrastructure (hardware), but also on the available know-how and skills to operate the technology and the organization and management related factors [16]. Recently, the main author of this paper developed the approach of SAT further to also include organizational aspects paper [17].

A review of academic literature regarding technical assessments in solid waste management related to developing countries reveals a large amount of published studies related to different geographic locations. A systematic search in SCOPUS using "technology assessment", "solid waste" and "developing countries" however only resulted in one reference, instead using the term "appropriate technology" helped identify 13 results, whereas using only term technology without any other word attached showed 141 papers. The scientific studies published all have the goal to identify appropriate upgrading or describe technology alternatives in the technical elements of the waste system. For technical considerations of collection and its appropriate vehicles [18] discuss the situation in Somaliland, El-Halwagi in Egypt [19], Stern [20] in Ecuador slums. Similarly Ali [21] evaluates collection vehicle sustainability in Pakistan while Coffey discuss overall robustness and appropriateness of waste collection vehicles in developing countries in more general terms [22]. Coffey [22] and Bleck [23] also elaborate on intermediate storage containers. Other authors focus on specific treatment options, for municipal solid waste recycling technologies [24], organic waste treatment technologies [25–29], hospital waste treatment [30–37], e-waste treatment [38,39], or landfill disposal [40–42]. Only a few publications, however, systematically check how the suggested technology improvements would conform to the criteria established for appropriate technologies. Cost, energy requirements, skills for operation and maintenance are aspects frequently considered beside other non- technical issues such as environmental emissions.

2.2. Environmental and Health Aspects

Besides the objective to protect public health, achievement of conservation of the (global) resource base and the protection of environment is measured through resource and environmental sustainability. Health impact assessment (HIA) and LCA for environmental impact were the most two frequently environmental assessment tools used for solid waste research in the last 15-year research period [43].

How to conduct HIA is well documented and supported by the publication of the International Finance Corporation (IFC) published in 2009 [44] "Introduction to health impact assessment" and by Lerer [45]. Two key characteristics define HIA: (i) predicting the consequences of project-related actions; and (ii) providing information that can help decision makers develop and prioritize mitigation strategies throughout the project cycle. The stages of a HIA are: Screening, Scoping, Risk Assessment, Health Action Plan, Implementation and Monitoring.

In the context of solid waste management projects, a literature search using the terms "health impact", "solid waste" and "developing country" found 16 results, whereas using only "health" found 203. Health risk studies documented in literature focus on studies regarding effects of waste on health of nearby residents as well as occupational risks of waste workers [46]. Gladding [47] in the edited book of Hester and Harrison (2002) analyzed health impact on workers in recycling facilities, recommending caution and need for more research. Giusti [48] provides a review of literature on waste management practices and their impact on human health and comes to the conclusions that the evidence of adverse health outcomes for the general population living near landfill sites, incinerators, composting facilities and nuclear installations is usually insufficient and inconclusive. Finally, in a developing country context, Ayomoh [49] uses a hybrid structural interaction matrix (HSIM) to prioritize major identifiable environmental health factors to thus prioritize waste management improvements for major improvement benefit. Boadi [50] studied the impact of deficient waste services and practices in residential areas showing connections between presence of houseflies in the kitchen and the incidence of childhood diarrhea as well as the link between waste burning and the incidence of respiratory health symptoms among adults. Further results are reported from e-waste recycling (especially relevant in low- and middle-income countries) [51,52], or health care waste management [53].

Of the wide range of methods for environmental assessment, Finnveden *et al.* [2] distinguish between procedural and analytical methods. Procedural methods relate to a societal and decision making context whereas analytical methods focus more on the technical aspects of the analysis (Wrisberg *et al.* 2002, cited in [2]). The most frequently used analytical assessment approach is LCA, also called life-cycle analysis, or cradle-to-grave analysis. LCA is a method to assess the environmental performance of products or services over their whole life cycle including resource consumption, production, utilization and finally the disposal aspects. The procedure of conducting a LCA is well defined and described by the Standard ISO 14040 [54]. The design of a LCA contains four main steps whereby the individual steps are in succession but should also allow an interactive process: (i) definition of goal and scope; (ii) inventory; (iii) impact analysis; (iv) interpretation [55]. Common impacts, or impact categories which are used in LCA are: global warming, stratospheric ozone depletion, photochemical ozone formation (smog), acidification, eutrophication, as well as human and ecotoxicity. Depending on the impact categories of interest respective methods for attributions and characterization can be used.

In waste management, LCA methods are frequently being integrated into computer based models. One example is EASEWASTE now called EASETECH (Environmental Assessment of Solid Waste Systems and Technologies), a computerized LCA-based model for integrated waste management [56]. EASEWASTE has also been applied in low- and middle-income countries, for example in China [57]. Gentil *et al.* [58] provide an overview of the available different models and provide a word of caution as large discrepancies have been observed among different waste LCA models regarding the results. The aspects mentioned which have significant impacts on the results are functional unit, system boundaries, waste composition and energy modeling.

Researchers produce a range of studies doing comparative analysis of different waste treatment options in developing countries. However, fewer studies are available which were conducted in a developing country context. Some of these use LCA for analysis of the whole waste management system [59–61]. Mwai [59] used a life cycle approach in combination with Millennium Development Goal (MDG) indicators for the solid waste system of Nairobi, Kenya. Here 10 options differing in their level of recycling, composting and landfill were compared and assessed not only in terms of environmental impact but also in terms of costs/revenues and social criteria. Other studies use LCA for specific waste system elements such as done for landfills and incineration in Brazil by Mendes [62].

Practical applications of LCA are usually more directed to one certain process or subsystem, to analyze emissions and devise mitigation options. An example is from tanning industries, which in developing countries traditionally uses chromium in the tanning process [63] and thus contribute highly toxic emissions into the environment if not treated properly.

One method used in LCA but also used independently is Material flow analysis (MFA). It is a system analysis method which quantifies mass and substance flows among processes. Given the law of the conservation of matter, the results of an MFA can be controlled by a simple material balance comparing all inputs, stock growth or sinks, and outputs of a process management [64]. MFA can be applied to analyze flows of resources in a city or region and changes in consumption patterns, solid waste and/or wastewater treatment infrastructure, waste and wastewater reuse practices, peri-urban agricultural production, and environmental pollution. Similar to a MFA approach is the Input-Output analysis which also considers flows and mass balance but tends to put more focus on a spatial area (city, region) and a focus on flows and their economic value [65]. However, no evidence in the literature of its application in low income countries was found.

In the developing country context focused on solid waste, MFA was applied in the city of Kumasi (Ghana) to assess how much of the nitrogen and phosphorus demand in urban and peri-urban agriculture could be covered by compost produced from urban solid waste and excreta [66]. In the Caribbean, MFA was used to assess amounts of tire waste to judge if a treatment facility could be justified [67]. In China, dynamic MFA was used for strategic planning of the construction and demolition waste system [68] and in Taiwan heavy metal emissions from incineration plants in fly ash and slag were assessed using MFA [69]. In South Africa, the City of Cape Town drafted an energy strategy and an integrated waste management plan with the help of MFA, focusing on wood and paper waste [70]. Finally, MFA was also applied to household solid waste and marine litter collected from Kayangel Island in the Republic of Palau to provide a comprehensive characterization and spatial accounting of the inflow of non-putrescible materials that become solid waste [71]. MFA can also be combined with other methods, for instance, process cost accounting. A study to evaluate options of decentralized *versus* centralized composting applied MFA and cost accounting for the city of Asmara, Eritrea [72].

In 1997, the Kyoto Protocol was established with the goal to reduce greenhouse gas emissions worldwide. To assist countries in achieving lower greenhouse gas emissions, the Kyoto Protocol introduced three market-based mechanisms: (i) International Emission Trading (IET); (ii) Joint Implementation (JI) and (iii) Clean Development Mechanism (CDM). With CDM the Kyoto Protocol allows developing countries to implement emission reduction projects and obtain support for this by registering these carbon reduction emissions, which can then be traded on the international market as Certified Emission Reductions (CERs). Each CER is the equivalent to one ton of CO_2 whereby the emissions savings by the project are calculated using standardized and approved methodologies [73]. These methodologies are simplified procedures to estimate local or regional emissions and emission reduction potential by alternative waste treatment options [74]. Fewer studies look into more detail of the waste treatment process and verify through evidence if the parameters used in the CDM methods are justified [75]. Next to the climate relevant emissions large new infrastructure projects also typically require an environmental impact assessment (EIA). EIAs are, however, rarely published as scientific papers and seldom accessible in the public domain given their project specific legislative purpose. One example for a low-income country context is the EIA conducted in the Jinga Municipality, Uganda, for a new landfill and composting site [76]. Herein the impact on physical and biological environment, as well as socio-economic and cultural environment, are evaluated. The authors highlight the importance not only of the mitigating measures proposed but also of the crucial necessity of vigilance in implementation of the social and environmental monitoring and management plan.

2.3. Economic and Financial Aspects

Economic impacts are the effects of any project on the level of economic activity in a given area. A positive economic impact can be: (i) business sales; (ii) value added for customers; (iii) wealth increase in the area (e.g., property values); (iv) staff income or employment opportunities. Any of these can be an indicator of improvement in the economic wellbeing of the area.

The assessment method of cost-benefit analysis (CBA), sometimes also called benefit–cost analysis (BCA), is a systematic process for calculating and comparing benefits and costs of a project. The approach has the goal to justify the decision to invest, and to compare projects. Its importance has also been highlighted to question the strategic importance of the waste hierarchy [77]. Benefits and costs are calculated in monetary terms. To account for the time value of money, all money flows are expressed on a common basis in "net present value" (NPV) [78]. Such an analysis can be performed when a project is being considered (prospective analysis), during operation of the project (a snapshot in time) or after the project end as a way of evaluating performance (retrospective analysis).

CBA is related to, but distinct from, cost-effectiveness analysis—cost-effectiveness being a bit more straightforward and simpler. Cost-effectiveness analysis relates the costs to specific measures of effectiveness. In solid waste management this "unit of effectiveness" is typically a defined mass of waste managed/treated. Thus, cost-effectiveness is the ratio of costs and the unit of effectiveness, for instance $/ton of waste treated. In comparison CBA goes further by evaluating the value, in monetary terms, of the benefits. The "net-benefit" is the difference between benefit and cost. All impacts (financial, economic, social, environmental) should be assessed and put into monetary terms. When comparing between options, only the difference between the baseline and the various scenarios are assessed. This is called the marginal or incremental approach. Next to CBA there are other approaches for economic and financial assessment which are becoming more prominent in research and practice but still not frequently used in solid waste management. These are Full Cost Accounting, and Life Cycle Cost Approach (LCCA). Life-cycle costs refer to the costs of ensuring the delivery of services not just for a few years, but indefinitely (through the life cycle). For water and sanitation services, the LCCA was developed to provide a framework of analysis for cost data in developing countries. A breakdown of cost components is similar to the traditional cost accounting methods; however, this approach also takes the "source of expenditure" into account [79]. Similarly to life LCCA is full cost accounting, a systematic approach for identifying, summing and reporting the actual costs of solid waste management [80]. It accounts for past and future investments, the management and overhead costs (e.g., support services) and operating costs. For the Philippines, a specific guidebook on full cost accounting was developed to guide municipalities through the various steps of calculating and reporting full costs [81]. Also, for Latin America, this approach was strongly promoted and the Pan-American Health Organization (PAHO) developed a specific software tool for solid waste management—COSEPRE [82]. This shall assist municipalities pursue an approach to better know their costs and to identify those parts of the system that are consuming excessive resources and then take corrective action.

In Myanmar, Tin *et al.* [83] used economic costing to find least-cost alternative systems for improvements to the collection system. In Indonesia economic assessments compared the options available for traditional market waste disposal, composting in labor-intensive plants, composting in a centralized plant, a centralized biogas production facility and a landfill for electricity production [84]. In Thailand, cost-benefit was also applied to options for market waste use, showing how converting organic waste into biogas is advantageous both environmentally as well as financially with a cost-benefit ratio three times higher after conversion, as compared to before [85]. In Eritrea an economic valuation compared three different scenarios of composting (decentralized, semi-centralized and centralized at the landfill) using process cost accounting and MFA [86] showing not only total cost but attributions to cost types.

2.4. Assessment of Social Aspects

The social enabling (or disabling) environment can be assessed by social assessment, whereas measuring impact of a project is captured by a social impact assessment [87]. Social endorsement of any proposed project by the residents and community will necessitate their interest, motivation and willingness to participate and contribute to the process and the objectives of the project [88]. This may include changing behavior and mind-sets or also financial contributions. On the other hand, every solid waste management project will have an effect and impact on the socio-cultural environment. Social impact criteria may include: equity (distribution of impact on different social groups), participation/collaboration, gender equity, employment, relationships, acceptance, motivation, interest, and influence (power). A first and critical step in any social assessment is stakeholder identification and analysis. Then social and organizational network analysis (SNA or ONA) looks at the interaction between stakeholders and social capital among other assets completes the picture.

Stakeholder analysis method can be applied to identify stakeholders and evaluate their characteristics. This is a systematic method that uses data (mostly qualitative) to determine the interests and influence of different stakeholders and stakeholder groups in relation to a project or activity [89]. This method is typically used together and as part of social assessments or social impact assessments. There are three steps in doing a stakeholder analysis: (i) identify stakeholders and develop a stakeholder table; (ii) assess each stakeholder using interviews and questionnaires; (iii) identify risks and assumptions and devise appropriate mitigation strategies. Stakeholder analysis, also called stakeholder mapping is a common approach used in development projects and thus frequently observed in a wide range of sector activities. In Indonesia stakeholder analysis was carried out to investigate the performance of the vegetable market and the impact of solid waste from the market on the waste disposal site [90]. In Pakistan and India the method was used to create a better understanding of participation in waste management activities [91]. Similarly in Cairo, Egypt the method was used to identify the key issues and conflicts between privatization efforts and the recycling Zabaleen communities [92]. In Zhu *et al.* [93] a case is quoted from Bangalore, India describing how, through stakeholder analysis, the stakeholders themselves were able to obtain a better picture of the overall stakeholder situation and by this, improve their communication to target specific stakeholders with their expressed needs. Social and Organization Network Analysis (SNA) complements stakeholder analysis by investigating the relationships among stakeholders [94]. This approach considers how the system is driven by knowledge contained in social actors, social roles and interaction among social actors in communicating and sharing information. Solid waste management involves many stakeholders. They can be formal or informal organizations, institutions, or individuals from different societal sectors. It is the interaction and collaboration between these stakeholders which is crucial to success, whatever the type project. A correlation exists between stakeholder involvement and the three dimensions of sustainability: Environment, society, and economy [95]. Also, Sohail shows that collaboration among community members shows higher degree of sustainability [96].

Studies have looked into social capital as a cornerstone for community action. Pargal *et al.* [97] show that trust, reciprocity and sharing can capture different aspects of social capital and how the level of social capital is an important determinant of whether voluntary solid waste management systems in neighborhoods exist or not. Thus, social capital determinants can be used as predictors of success when targeting neighborhoods for self-organized waste management activities. Beall [98] on the other hand argues, based on studies in India and Pakistan, that a focus on social capital alone masks the importance of local power structures and the effects of the "Transforming Structures and Processes".

2.5. Organizational and Management Assessment

A well-functioning solid waste system requires adequate organizational strength of the involved governmental authority or of a respective private sector stakeholder.

Using a concept of business model visualized by a business canvas, Osterwalder and Pigneur [99] describe nine important systematic elements that can describe any organization's complete business:

> Value Proposition, Customer Segments, Channels, Customer Relationships, Cost Structure, Key Activities, Key Resources, Key Partners and Revenue Streams.

With regard to business model development and assessment, one decisive element is the understanding the enabling environment and assessing how this "environment" has evolved and how it could further evolve in future. This then allows to assess under which conditions and assumptions the "environment" might positively or negatively influence the proposed venture. Another helpful method is to put the proposed business model into an overall perspective using SWOT analysis—Strengths, Weaknesses, Opportunities and Threats (also abbreviated by SFOT—Successes, Failures, Opportunities, Threats). Rouse *et al.* [100] suggest taking each element from the market environment and then considering how they might change in short and long-term: such assessment of the market environment is applied on the example of waste composting.

2.6. Multiple Sustainability Assessment

Sustainability assessment is described as a process in which the impact on sustainability of a policy, legislation, plan, program, project, practice or activity is evaluated [101] and extended to include social and economic considerations.

Many computer based decision support models integrate a variety of tools and methods, using predefined criteria in the various sustainability domains. Some also integrate spatial information through geographic information systems (GIS) and multi-criteria decision analysis (MCDA).

A review by Shmelev and Powell [102] on waste management models concluded that most models do not have a holistic view over the solid waste management system, but rather tend to focus on a single problem. However, there is a clear trend in research to establish more comprehensive models which take into account a large amount of data from different sustainability domains. A large number of waste management models are reviewed in Chang *et al.* [1], Shekdar and Mistry [103] and Kijak and Moy [104]. The most frequent technique embedded in the computer based models is LCA.

The software tool ASPIRE [105] provides an integrated planning, monitoring and evaluation tool for appraising the sustainability and poverty reduction performance of infrastructure projects. It was developed through a partnership between Arup and Engineers Against Poverty (EAP). Attention is given to infrastructure and its contribution to poverty reduction. The ASPIRE conceptual framework considers four dimensions: society, environment, economic and institutions. The criteria and indicators relate to qualitative information and cover issues particularly relevant to developing country contexts. The tool can be used as planning tool to identify priorities and support informed decision making or also as an evaluation tool to assess project performance and to promote mutual learning. However, ASPIRE has not been used yet for evaluating solid waste systems or projects.

Other approaches towards sustainability assessment use experience and learning from development projects. This approach is based on establishing what works and why (success factors) and then translating this into an overall framework of analysis [106–108]. Derived from this work, the main author of this paper developed a set of guiding questions to assess "critical aspects" influencing success or failure [17]. The guiding questions are listed in Table 2.

Table 2. Fundamental questions about sustainability domains [17].

Sustainability domain	Questions
Institutional and legislative aspects	Are adequate policies and legislation in place and implemented to support the operation and existence of the case?
	Does the case comply with environmental standards and regulations concerning emissions to the aquatic environments, soil and groundwater?
	Does the case comply with quality standards of service and/or product as defined by legislation, standards and regulations?
	Is the case endorsed by, and does it obtain support by local and national authorities?
Organizational aspects	Does the organization have a clear organizational status (formal or informal enterprise, NGO, CBO, cooperative)?
	Does the organization have a clear and viable business model and plan, independent of its organizational form or affiliation and manage the project with responsibility, accountability and transparency?
	Does the organization have dedicated talented leadership and dedicated skilled staff?
	Are employee contracts attractive and conform or exceed to national and labor union recommendations (e.g., minimum salaries, work contracts, benefits, social security, insurance, *etc.*)?
	Does the organization interact successfully with other stakeholders in the system to structure and maintain a successful cooperation?
	Does the organization maintain a data monitoring system or benchmarking to evaluate performance?

Table 2. *Cont.*

Sustainability domain	Questions
Financial and economic aspects	Is accounting and regular financial analysis an important part of the organizations operations? This includes if breakdown of cost components is available and if there is regular monitoring and evaluation of cost effectiveness. Is cost recovery of the project (revenues) viable and sustainable? Do revenues outweigh the cost? Are depreciation reserves to renew equipment available and capital costs/repayment of loans ensured? Does and can the project obtain access to capital (financial loans from different sources, e.g., banks, government, development agencies)?
Technical aspects	Is the technology appropriate and appropriately designed to operate under the local physical (e.g., climate, topography) and/or infrastructure conditions (e.g., roads, power supply)? Is there sufficient local availability of know-how and experience (skills) to design and build the technology? Ideally construction would be possible with local available material resources. Is there sufficient local availability of know-how and experience (skills) to operate the technology? This includes it the employees & operators working with the technology been sufficiently trained? Can the technology be maintained and repaired easily by the staff? If not, is there an existing supply and service chain established that can do this timely and at an affordable cost? Can the technology easily cope with and adapt to changing conditions (e.g., amounts or characteristics of waste)? If the technology be easily replicated and/or modularly up-scaled, this a sign of flexibility and adaptability. Has the most cost effective technology been selected for the project?
Health and environmental aspects	Does the case prevent nuisances like bad smell, dust, noise and insects/animals? Does the case safeguard workers' wellbeing and health? Does the case safeguard community wellbeing and health? Does the case contribute to recovery and recycling of waste materials? Does the use make an effort to minimize use scarce natural resources or polluting energy sources? Ideally the case recovers energy from waste to reduce its own consumption.
Social aspects	Do beneficiaries (residents or local authorities) regard the case as socially beneficial and are they supportive to the project? Does the project empower local structures (development committees, user groups, consumer associations and elected representatives, *etc.*) and provide direct or indirect local employment opportunities? Does the project provide equitable service or products, which also addresses the needs and potentials of the most vulnerable and marginalized groups of society? Is community participation/involvement considered and implemented in the project?
Development of critical aspects over time	How have the aspects evolved over time (favorable or unfavorable)? How are the future perspectives in this regard? Is there anything the project team is doing to foster a future favorable development?

3. Discussion

Most assessment methods focus on the subsystem level, to evaluate a certain technical element in a system (e.g., a composting facility) with its respective requirements, performance levels and impacts. The same methods may also tackle the full system by integrating all individual subsystems to a whole, whereby the task is thus much more complex and is often used to assess impact of a given choice.

Another aspect to consider is which criteria and impacts are assessed. The criteria domains are often linked to disciplinary expertise and the overall sustainability framework with its three pillars of social, economic and environmental sustainability.

Currently, several tools are available to analyze specific aspects of a certain system. These have been described in the previous chapter. Such tools have different characteristics, with pros and cons, and have been applied to different case studies. The definition of the methodologies and the accuracy of results have been greatly improved, thus now the range of application is quite wide. In particular it is now possible to focus on very specific aspects, achieving quantitative data though standardized methodologies. Nevertheless the overall bulk of current publications describing case studies in solid waste management of developing countries are rather descriptive in nature and most often do not seem to follow a strict framework of procedures and questions. Exceptions are when a specific well established method such as LCA is used.

3.1. Technical Aspects

Only few studies systematically use a checklist or defined method how appropriateness of a technology is evaluated. Although aspects of appropriateness are defined in a qualitative way, it is not obvious how data is collected to answer the issues raised. The most quantitative aspects defining the technology are cost, energy requirements, waste characteristics and amounts that can be processed. Other aspects such as required skills for construction, operation and maintenance are also frequently describe but given their qualitative nature are difficult to estimate in a scientific and replicable way. More research and development is need at this level to describe the aspects and provide answer typologies which can serve a reference for the person assessing a case or technology.

3.2. Environmental and Health Aspects

HIA is a very valuable tool which is well defined and documented. It is increasingly becoming a routine feature of the project permitting and approval process. Nevertheless, methodologies for HIA have been developed, validated and applied in Western Europe and there is a need to adapt methodologies for developing country settings where the baseline health data is lacking [109].

Assessing impact on human health (workers or nearby residents) is clearly a high priority of those affected as well as the local authorities in charge of solid waste management. This priority is somewhat in contrast to the interest of the global actors more concerned with global impact (e.g., climate) of solid waste management. Therefore, increasingly it is the global community and its international representatives who are pushing local governments to prioritize the "green agenda" of waste management. This green agenda directs priority towards issues of environmental and ecosystem protection and the mitigation of detrimental effects from human activity on the environment at the regional and global scale. It is supported by a range of well-developed methods and tools such as LCA and simpler ones such as the CDM methods. This green agenda, however, may not necessarily be on the top list of priorities for local community faced with the immediate problems at local level that focus and affect direct upon human health and wellbeing and are those typically suffered most by poor communities. In solid waste management a typical example of this dichotomy is the global pressure to reduce methane emissions and mitigate climate change typically by landfill gas capturing and flaring.

At a local level it is, however, often not landfill management which is ranked first in the list of priorities but rather providing collection services to the poor in urban slums which reflects an immediate and direct health threat for the population.

The analytical approaches designed to assess environmental aspects have been and are usually further developed by academia in Europe or North America. These methods are complicated and not easy to use for practitioners with limited training, education and capacity. The main barriers can be considered as:

- The lack of appropriate data (for inventory data specific to developing country conditions);
- The lack of methodology (e.g., LCA) expertise/know how;
- The lack of funding resources for specific and detailed application of the methodology;
- The absence of perceived needs.

For LCA, in order to compile the inventory, good knowledge of the system to be analyzed is necessary. This is a challenge when a range of potential future options shall be evaluated [38]. Information is often complemented by default values: most of this information, however, is not developing country specific but is derived from studies in Europe and North America.

A critical view of LCA and its practical use and application for developing countries is summarized in the UNEP publication "Life Cycle Approaches: The road from analysis to practice" [110]. Here a need was identified to include also environmental issues that are relevant for developing countries, and to broaden to the social and economic dimensions of sustainability. These limitations of focusing only on environmental aspects have in recent years been taken into consideration and (environmental) LCA is now one tool among a portfolio of other tools, such as risk assessment, LCCA, value chain, and social analysis. MFA is considered a helpful tool for visual representation of a defined system with its processes and flows. MFA, however, in developing countries, suffers from limited data availability, reliability or means for data collection (e.g., laboratory equipment, trained staff, or financial resources). These factors challenge the use of MFA as a policy-making tool. Nonetheless, new developments in using literature values combined with expert judgment to establish probability distributions for model parameters looks promising and would help to overcome this barrier [111].

3.3. Economic and Financial Aspects

The major difficulty with CBA and economic and financial tools is that is often difficult to place monetary terms on many costs and benefits. This issue of monetizing benefits, not double counting benefits, *etc.*, is by itself a field of complex and intricate research, most waste management specialists can only tackle with assistance by experts of that specific disciplinary field. CBA is most useful when analyzing a single project and its total costs and benefits to society or when comparing alternative programs to see which one achieves the greatest benefit to society. Cost-effectiveness analysis, however, is useful when the project outcome is already determined and the goal is to find the least cost option for that outcome. It is also useful in cases where major outcomes are difficult to monetize [78].

3.4. Social Aspects

Social and institutional systems are usually very dynamic, thus it is difficult to include all the stakeholders, and to determine their importance for the future development of the system. Thus also typical livelihood activities can change frequently and fast, completely change the situation.

In developing countries, duties and responsibilities of a certain institution are often not clearly defined, thus assessment results can strongly differ from each other. In particular relations between stakeholders are often not clear nor only based on organizational basis: hidden motivations can strongly affect networks and should be deeply investigated.

Thus social and institutional assessments are particular strategic, as they can highlight some hidden aspects or drivers which strongly affect a certain system or its development. However, they are very site-specific, as they depend on stakeholders, local conditions, *etc.* Thus they are not normally included in the usual outcome of an analysis, and are difficult to be compared with other cases.

3.5. Organizational Aspects

Similarly to social aspects, an organization is strongly affected by the context where it operates. "The human factors" (e.g., organizational culture, staff commitment and involvement) are often very relevant and are crucial to ensure sustainable and reliable service, thus an assessment has to consider them carefully. If seriously considered this highlights the importance of training and education at all stakeholder levels. Private and public organizations typically differ significantly in their structure and culture. Drivers, time of reactions and goal differ depending on organizational setup, thus it is important to look at them differently. Also, the environment which they are embedded in is different, even if formally it is the same: different organizations can be affected differently, by different aspects. Thus it is difficult to compare two organizations from different contexts in a holistic way, though analyzed with the same method.

3.6. Multiple Sustainability Assessment Tools

Such tools can be applied to all kinds of development projects. A stronger focus was given to those tools which are embedded and used in development practice rather than those that are solely of academic significance. These tools are usually quite complicated, so they could either get quite superficial results per each aspect, or be very time- and resource-consuming. Then the choose or identification of coefficients can be disputable, and strongly affect the results.

Conducting an assessment with Sustainability Assessment by Success and Efficiency factors does not allow the user to identify the critical factors of strength or weakness but rather assists in establishing a comprehensive situation analysis.

3.7. Gaps on Knowledge

Assessment methods regarding solid waste management have greatly been improved in the past decade, but several gaps remain and should be filled, in particular with regard to the use in developing countries. In fact in such countries appropriate data is still lacking, in particular baseline information and coefficients which can be used for models. Furthermore tools are typically not very appropriate for a developing country context and target users. Standardized and easy to apply low-cost methodologies should be developed, in order to collect reliable data in low- and middle-income countries. This implies a major paradigm shift with researchers and academia where the current understanding is that complexity and specificity equals to strong perception of highly scientific. Rather acceptance must develop that “simpler and more practical is better”. In terms of encompassing multiple sustainability dimensions, particularly a dedicated tool to draw a holistic picture of a system is still lacking.

Globally a limited number of studies in low and middle-income countries have been published through scientific literature or reports, and only few people are aware of them. Few scientific journals have interest to publish such information as simplification often does not provide exciting material for scientific publication. Several studies, although conducted, have not been published or are very hard to find. Therefore, literature comprises only few case studies, and it is difficult to confirm if expected results could be achieved as expected when applying the tools described above (e.g., MFA, LCA, CBA).

At country and local level, expertise/knowhow at the user level on methodology is still lacking, thus it is difficult to provide good assessments. Here, the need of more education and training is apparent. Also very few studies are designed and managed completely by researchers from low-income countries: the role of external researchers could provide accuracy and independency from local interests, but also modify the goal and generally decrease the study ownership. The role of foreign actors could be required also due to the absence of perceived needs at country level of assessments, motivated by several factors. However, without accurate data, and the appropriate methodologies to collect them, solid waste management systems will hardly improve in a sustainable way.

3.8. Research Needs for the Future

Planning, designing, operating and maintaining a solid waste management project or activity is not a simple task. A wide and comprehensive understanding of the situation and local context is required. It is not sufficient to be a versatile expert “technician”. Only a multidisciplinary approach, which considers natural science, engineering and social science can properly be used to help understand and address such multifaceted urban environmental situations [112].

As the applicability of methodologies and tools in developing countries is challenging cases in developing countries should be assessed by expert users to provide a direct confrontation and identify challenges and potentialities. Moreover, a case study should be assessed not only in a specific moment, but the evaluation should be repeated to check the system development: in such a way it would be possible to clearly understand which drivers and means of development a tool can identify, and what cannot be identified.

Some methodologies (e.g., LCA, LCCA) are difficult to apply due to the lack of baseline data and site-specific coefficients: in order to overcome such challenges, researchers should dedicate attention to both collect and disseminate information. A hub (e.g., a website) could be developed to gather data and facilitate data and document sharing between practitioners and academics.

We consider the guiding list of questions of critical aspects of success an interesting start to evaluate a large number of cases/situations to thereby gain experience and practice with such a rather qualitative assessment [17]. The next step would then be to refine the list before handing it over to practitioners to test the ease of use. Further tools can also assist the decision-maker in terms of feasibility and expected impact.

The importance of the enabling environment has already been highlighted [88], but more methods should be developed to help assess it before a specific intervention. Finally, a framework and structure should be developed to document lessons learned not only with regard to the result and outcome, but also to better understand the process and development of the successful project. In such a way the knowledge of solid waste management systems could be drastically improved, facilitating the activity of practitioners and policy-makers.

4. Conclusions and Way Forward

Decision-makers at the local government level in urban areas of low- and middle-income countries are struggling to solve the problems of solid waste management. Existing solid waste services and infrastructures are often dysfunctional or lacking; severe environmental pollution is the consequence and the low-income fraction of the population suffers most.

Technology is only a small part of the larger picture towards sustainable solid waste management. Rather, an integrated approach is necessary, which considers social, economic, institutional, legal, technical and environmental issues, and tries to balance these to obtain best practicable means to manage waste. This holistic approach is embedded in the concept of "Integrated Sustainable (solid) Waste Management (ISWM)" which is now more or less accepted and acknowledged by governmental authorities. Nevertheless technical choices and an infrastructure and engineering dominated entry point are still the current practice within planning and implementation [113]. One reason for this is that it is easy to understand the concept of an integrated approach but when it comes to implementation it becomes quite complex and difficult to put into action.

The assessment phase is fundamental not specifically for technology selection, but rather for a complete a clear knowledge of a system. Technology selection will be obviously facilitated, as the technological aspect is one the determinants of sustainability [6]. Assessments methods are not only required for the development of a new solid waste management system or plant, but also to evaluate existing situations. Several tools are available, with several applications to waste management (Table 1). However, some limitations and gaps of knowledge are identified, requiring a serious work of researchers and practitioners to overcome challenges and to facilitate a positive application in low- and middle-income countries.

For providing effective and reliable assessments in developing countries, existing tools should be modified, in order to make them simpler and cheaper to apply. In fact such tools can provide very detailed and specific data, but required resources and information are not easily available. Moreover few methods or DSS, joining different tools, can provide holistic pictures of a certain system, and they are generally not designed for solid waste management. The guiding questions suggested (Table 2) could provide a good preliminary picture of an existing system, identifying which aspects require a deeper assessment. Such deepening could be provided applying the other tools described in this paper. In such a way the use of resources and time could be limited to what is strictly required, meeting conditions of a larger set of developing countries.

Acknowledgments

The authors wish to express their gratitude to C. Collivignarelli at the research centre CeTAmb at the University of Brescia, Italy for his support. We thank the Swiss Agency for Development and Cooperation (SDC), the Swiss National Centre of Competence in Research (NCCR) North-South and the Swiss Federal Institute of Aquatic Science and Technology.

Author Contributions

Christian Zurbrügg conducted the main research and review work which provided the basis for this paper. Marco Caniato drafted the manuscript of this paper and contributed significantly to the revisions. Mentore Vaccari was involved in preparation and contributed to the manuscript draft and its revisions.

Conflicts of Interest

The authors declare no conflict of interest.

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