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Perspectives for Sustainable Resource Recovery from Municipal Solid Waste in Developing Countries: Applications and Alternatives

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1. Introduction

Municipal solid waste (MSW) is the most complex solid waste stream (Troschinetz & Milheic, 2009). The search for sustainable development and in particular factors such as fast population growth, land limitations and difficulties associated with finding suitable sites for establishing landfills, as well as the decrease of raw materials, make that practices for the management MSW traditionally used in developing countries such as collection and final disposal, be complemented with recycling as a preferable option for dealing with the solid waste generated. This position has been promoted in international events such as the Johannesburg Summit on Sustainable Development, in which the recycling and reuse of waste were identified as key strategies for the accomplishment of the main objectives and essential requisites for a sustainable development, since it contributes to reduce the negative effects on the environment and increases the efficiency of the use of resources (United Nations, 2002). From this perspective, there are notable efforts made in developing countries such as Tanzania (Mbuligwe et al., 2002), Colombia (Minambiente, 2002) and Botswana (Ketlogetswe & Mothudi, 2005), where policies that give priority to recycling immediately after source reduction have been enforced; however, the application level of these policies is variable and final disposal on the land still remains as the primary option with significant application (Fricke et al., 2001; OPS, 2005; UNEP, 2008).

The data in Table 1 show per capita production and composition of solid waste in different cities in developing countries. In all cases there are significant proportions of putrescible waste in the form of food and yard wastes. The dependency on agriculture for subsistence and economical development of these countries, as well as conservation requirements for soil quality, the productivity and gradual increase of the costs of mineral fertilizers, generate

the necessity of using alternative soil amendments. In this sense, the organic matter and nutrients contained in the putrescible fraction of solid waste constitute a viable alternative for this situation (Diaz et al., 2007). Another element that can stimulate the recycling of these wastes is the reduction in the production of greenhouse gases (GHG) compared with traditional techniques of final disposal. Barton et al., (2008) compared the generation of carbon dioxide in final disposal systems at open dump and sanitary landfills (considering three forms of managing emissions) with alternatives such as composting and anaerobic digestion with electricity production, finding that in the open dumpsites and sanitary landfills, emissions varied between 0.09 and 1.2 t CO₂e/t, whereas in composting the emissions were neutral and in the anaerobic digestion plant it was -0.21 tCO₂e/t; however, costs of the last option limit significantly its applicability.

City	PCP (Kg/cap- day)	Putrescible	Paper	Metal	Glass	Plastic, rubber and leather	Textiles	Ceramics, dust and stones
Bangalore, India ¹	0.4	75.2	1.5	0.1	0.2	0.9	3.1	19.0
Manila, Philippines ¹	0.4	45.5	14.5	4.9	2.7	8.6	1.3	27.5
Asunción, Paraguay ¹	0.46	60.8	12.2	2.3	4.6	4.4	2.5	13.2
Mexico City, Mexico ¹	0.68	59.8 ^a	11.9	1.1	3.3	3.5	0.4	20.0
Cali, Colombia ²	0.39	65.54	6.23 ^b	1.06	2.56	11.12	1.98	11.51 ^c

^a Includes small amounts of wood, hay, and straw; ^b Includes cardboard; ^c Includes all the others

Sources: ¹UNEP & CalRecovery (2005); ²DAPM & UNIVALLE (2006)

Table 1. Per capita production (PCP) and composition of solid waste in different cities in developing countries

In the same manner, other materials with reuse potential such as different types of paper, metal, glass and plastics generally represent more than 6% of the MSW generated. Taking into account that most of the developing countries do not have one or more of the raw materials (e.g. iron ore, bauxite or petroleum of importance for its economical development) or other substitute materials, reuse of these materials also is an option (Diaz et al., 2007).

In this article a description and analysis of the application of the options for recovering resources from MSW in different regions of developing countries, identifying common elements that favor or limit the application of these and suggesting alternatives that contribute to the sustainability, is made. The approach is carried out from the Integrated Sustainable Waste Management concept, which proposes to have a vision of the situation that involves the stakeholders, the components of the waste system and sustainability aspects that determine the functioning of the systems to reach technically appropriate,

economically viable and socially acceptable solutions that do not degrade the environment (Van de Klundert & Anschutz, 2001). Also, this article focuses in recycling and composting since both of these alternatives constitute the options with the highest degree of application providing an overview of the findings reported by several authors worldwide, with experiences in countries or regions in Africa, Asia and Latin America and the Caribbean (LAC).

2. Discussion

2.1. Recycling

In developing countries it is acknowledged that the recovery of materials such as iron, steel, copper, lead, paper plastic and glass will decrease the investment in importing these materials and save energy (Kocasoy, 2001); however, proper recovery is scarcely applied. Some of the reasons for this situation are: shortage of properly trained professional, absence of appropriate technology, poor public awareness and the relatively high initial capital investments costs required for their implementation. Although a few large-and medium-scale solid waste treatment facilities – imported from industrialized countries, have been built and operated, the intensive mechanical and energetic requirements of these technologies have finally driven most of these facilities to be shut down (Diaz et al., 2002). On the other hand, the prices obtained for some of the recovered materials typically are lower than the segregation / reprocessing costs, which can be even higher than the costs of virgin materials, so that recycling activities usually have to be subsidized, except for materials such as aluminum and paper (Bogner et al., 2007). Table 2 shows the waste recycling rates in some developing countries.

Country/region	Recycling rate of municipal waste (%)				
	Glass	Metal	Paper	Plastic	Total
LAC ¹	0.8	2.1	2.0	3.4	
Brazil ²	41		30		
China ²					7- 10
Colombia ³	10				
Nepal ²	5				
Thailand ²	18	39	28	14	15
Turkey ²	25	30	36	30	
Vietnam ²	13-20				

¹Sources: ¹OPS (2005), ² Troschinetz & Milheic (2009); ³ Contraloría General de la República (2005)

Table 2. Recycling of waste in developing countries/regions

Waste recovery practices generally are carried out in an informal manner mainly by scavengers on the streets and at final disposal sites, under inadequate working conditions. The formal sector has concentrated on the collection and final disposal; although recycling is viewed as an option, its application is very weak. In the same way, the attitude of the formal

waste management sector towards informal recycling often is very negative regarding it as backward, unhygienic and generally incompatible with modern waste management systems (Wilson et al., 2006). Nevertheless, recycling rates reached by the informal sector in several countries are quite high, fluctuating in a range of 20% - 50%, values that are comparable to those achieved by modern waste management systems in industrialized countries (Wilson et al., 2009).

In Africa there are few formal systems for material recovery instituted by public agencies or the private sector. Recovery of materials, including source separation and recycling is carried out mainly by the informal sector. This activity is centered on materials of economic and/or social value; plastic bags, bottles, paper, cardboard and cans are reused before entering the waste chain. A few materials are converted into new products for local use; some examples are the smelting of aluminum cans and scrap metals into household utensils, and paper and plastic residues into products for tourists (Otieno & Taiwo, 2007).

In Kenya, recycling has gained importance due to the increasing costs of raw materials. Initially it was carried out informally by impoverished people, but it is now emerging at an industrial level (Rotich et al., 2006). In Cameroon, governmental policies establish strategies for environmental protection and promotion of conservation of materials through an adequate disposal and recovery of MSW; however, in practice management is focused on, collection and disposal on the land (Manga et al., 2008).

In Nigeria, although SWM is identified as one of the environmental elements to include in the Poverty Reduction Strategy, characterization studies carried out in the central part of the country indicate that the recyclable materials contained in the solid waste do not warrant investment in recycling as a waste management approach (Sha' Ato et al., 2007). In Lagos, recycling and resource recovery exist, but have not received the attention of the government and the waste management authorities. It is estimated that approximately 5- 8% of MSW are recycled through refuse dealers, who separate the materials and sell them to consumers, as well supply them to mills and factories (Kofoworola, 2007).

In Botswana, most of the local companies dedicated to recycling are only in charge of collection, the recovered materials are exported to different countries such as South Africa and Zimbabwe. The amount of recyclable materials recovered in final disposal sites is taken as an indication of the potential for developing a recycling industry on a large scale at the local level (Ketlogetswe & Mothudi, 2005).

In the Southern and Western regions of Asia, industries that deal with repairing items and with used products are important sources of recovery and reuse of waste. In the cities of low or medium income of the East and Pacific regions, informal source separation and recycling have been a common practice for many years; gathering, trading, and reprocessing materials is the work of many people (UNEP, 2008). In the East this activity is generally carried out by medium- scale or household enterprises, and is predicted to grow where it offers economical benefits (Nguyen Ngoc & Schnitzer, 2009).

In Jordan, recycling is carried out by scavengers in final disposal sites and through formal systems managed by the municipalities or NGO's; scavengers usually search for cardboard,

tins and plastic bottles. Experiences managed by municipalities include recovery of recyclables from the solid waste stream prior to landfilling and a pilot material recycling facility (Abu Qdais, 2007). In the case of the Gulf Co-operation Council States (Kuwait, Saudi Arabia, Bahrain, Qatar, United Arab Emirates y Oman), Alhumoud (2005) affirms that most of the countries do not report recycling goals or programs and the only comprehensive form of recycling available is the recycling of paper and cardboard; a limited amount of recyclable materials such as cans, metals and cardboard are collected from the waste containers in front of the houses by scavengers. In a research project conducted in seven Palestinian districts there was no evidence of reuse and recycling programs, identifying only the informal recovery of metal scrap from waste collection containers and dump sites (Al-Khatib et al., 2007).

In Pakistan, although in the last four decades the generation of waste has increased significantly, there are not specific recycling programs on a country-wide scale or in the big cities. In Lahore, 1.97 million tons of waste are generated annually, of which 65% to 70% are collected; approximately 0.04 million tons are sold directly to industry; households reuse around 0.054 million and 0.09 million of recyclables are commercialized at junkshops by scavengers and households annually. It is estimated that 21.2% of the total recyclable waste is being used for recycling, generating around US\$ 4.5 million a year (Batool et al. 2008).

In Ankara (Turkey), recyclable materials constitute around 18% of the total solid waste generated; Government Statistics Institute estimates that scavengers are collecting up to 50% of these materials. It is considered that the average income from recyclables is between US\$ 25.000 - 50.000 per day; however, the income per scavenger is between US\$80 and US\$100 per month and about US\$20,000 is for the owners the recycling system each day (Ali, 2002).

In China, MSW seems to revolve around small scale operations as a result of the application of the principle that the polluter is responsible for treatment and disposal. As a general rule there are not treatment operations only small- scale and inefficient plants (Suocheng et al., 2001); however discarded material is imported from different countries on a large scale for reuse and recycling, generating around 5000 enterprises, about 1.4 million jobs, with recovery rates of 85%, 47%, 25%, 20% and 13% in materials such as iron and steel, rubber, plastics, paper and glass, respectively (Shekdar, 2009).

In the case of Latin America and the Caribbean (LAC), the Pan-American Health Organization PAHO (2005) indicates that the nature of the solid wastes, particularly those generated in residential, commercial and institutional sources, creates a technological problem for the application of recycling since its quality is affected by the mixture of materials. In all the countries of the region informal segregation is common practice and a frequent source of income for the impoverished and unemployed fraction of the population. In Colombia, Mexico, Brazil and Venezuela recycling programs of considerable magnitude have been extended to the communities in order to promote the organization in cooperatives and private associations (Minambiente, 2002). Esteban García et al. (2001) point out that the recycling activity is a well established reality in the region, which reflects in the acknowledgment through names such as "cirujas" in Argentina, "buzos" in Bolivia, "cachureros" in Chile and "pepenadores" in Mexico. They also indicate as an example in

Latin America, that in Mexico the informal sector is composed of people who work in dumpsites and in areas not covered by the collection service, as well as people from the middle class and part-time scavengers (students, retired persons and housewives, who obtain additional income).

McBean et al. (2005) report that through the training and organization of the informal sector, in Tucuman (Argentina) has been possible to recover significant percentages of materials such as paper and newsprint, and plastic (4.3 and 27.2% respectively), making it possible for the people involved in this activity to earn an income 1.75 times the minimum wage in that region. In LAC, more than an impediment, recycling cooperatives represent an opportunity for the private sector and industries to increase the market and level of recycling (Lopes et al., 2007). In an assessment carried out by Do Prado Filho and Sobreira (2007) at 29 recycling-composting plants located in the state of Minas Gerais (Brazil), it identified infrastructure, operation and location conditions that allow to rank 95% of these sites as adequate or acceptable; however, the working conditions of the workers were ranked as regular in 13 and as bad in the rest of them. In the same way, it was also determined that in all of the cases it is feasible to sell the recycled materials.

The topics discussed in the previous paragraphs allow to affirm that recycling of some components of the waste stream constitutes a source of income generation and materials recovery, with market for the products that require the development of programs that integrate the actors involved in recycling and technological advances that take into account the local labor potential to improve the quality of the processes and products.

2.2. Composting

Composting is described as an economically viable method compared with other processes and also effective in contributing to the reduction in the amount of material that should be taken to the landfill (Barreira et al., 2006). However, although successful experiences have been reported in its application (Mbuligwe et al., 2002; Zurbrügg et al., 2005, Bezama et al., 2007) it is acknowledged that there are important limitations (Zurbrügg et al., 2005, Barreira et al., 2006, Körner et al., 2008). Dulac (2001) pointed out that the high organic content of the waste streams of developing countries is ideal for composting, but municipal services operators do not have enough and adequate information and even though they may be familiar with the application of composting in agriculture, it is not considered as a way to solve their urban wastes problems. Bogner et al. (2007) indicate that labor-intensive processes are more appropriate and sustainable for those countries than highly mechanized technological alternatives at large-scale operations.

In Africa, composting has failed in cities such as Dakar (Senegal) y Abidjan (Cote d'Voire), due to the lack of demand for the final product. International NGO's have subsidized small scale composting in countries such as Benin, Cameroon, Kenya, Nigeria and Zambia, without making a significant impact in the reduction of MSW going to the landfill. The problem with composting in African cities is the low quality of the product due to the inadequate segregation of the wastes, which results in a low demand (Otieno & Taiwo,

2007). In Kenya, some groups compost food wastes that are sold to urban farmers and landscapers (Rotich et al., 2006).

In Southeast Asian Nations, composting is not a common practice due to high operation and maintenance costs, the high cost of the final product with respect to commercial fertilizers, and the available market, so that the activity is supported by governments (Nguyen Ngoc & Schnitzer, 2009). Alhumoud (2005) points out that in the Gulf Co-operation Council States in the last 20 years municipalities have concentrated on composting as an alternative for the treatment of MSW in spite of the failure of a large number of plants in the region. This author also affirms that the main problems with these plants have been the poor performance, high operating and maintenance costs, lack of technical support and inefficient management. In Jordan, even with a high fraction of biodegradable organic solid waste generated in the country and the fact that 91% of the country land is arid to semiarid, composting has not been considered as an option for solid waste management (Abu Qdais, 2007).

Hui et al. (2006) indicate that although composting is a widely utilized practice in Western countries, in Chongqing, one of the four largest municipalities in China, it is rarely used due to reasons such as the low application of source separation, low acceptance of compost by farmers, limited usefulness of compost in comparison with chemical fertilizers and strict regulations, monitoring and quality standards of the product. In India, composting is a tradition mainly in rural areas; utilization of large-scale and centralized composting plants during the 1970's had not been economically feasible. Studies have determined that compost is difficult to use because the waste arrives mixed and with high quantities or inorganic materials (Narayana, 2009).

The cooperation with NGO's, the supply of free bins for organic materials and the governmental support for the investment have had a high correlation with the better performance of composting in Thailand (Suttibak & Nitivattananon, 2008).

In LAC, the percentage of recovered waste reaches figures of only 2.2% out of the total and even with the predominance of organic matter; the application of composting is carried out at small scale, reaching only 0.6% of these wastes. The problem does not end with the scarce application of reuse, recovery and recycling technologies, it transcends to the lack of trust and the unsuccessful application of these technologies. From the beginnings of the 70's several initiatives oriented to the establishment of composting plants with diverse imported technologies have failed due to factors related mainly with the inefficient maintenance of equipment, indetermination of markets, inadequate technologies and lack of linking with strategic environmental projects (OPS, 2005), which shows the necessity of conceptual and technological developments contextualized in the reality of the region.

In the case of Cuba, Körner et al., (2008) pointed out than only one facility for composting of MSW is known, and that composting this kind of waste has not been reported officially as a treatment alternative; however its implementation is anticipated by the government.

Fricke et al. (2001) affirm that from 23 composting plants implemented in Brazil only 6 were in operation and that many of those plants were decommissioned after a short period of operation

due to reasons such as unsatisfactory operation, high operational costs and low quality of the compost, low materials recovery and nauseous odors. In the monitoring reports of the quality of the compost produced in 20 recycling-composting plants assessed by Do Prado Filho and Sobreira (2007) is brought into focus the presence of heavy metals in variable amounts, which restricts the use compost in the soil. They also indicate that in these reports is rarely included the technical concept conclusive on the figures obtained for each parameter, the analytical methods used and the reference values as to the quality of the material and also that in spite of the presence of trained personnel for the operation of the plants there is considerable difficulty in understanding the results of the analysis of the quality of the products.

In Colombia, the Superintendencia de Servicios Públicos Domiciliarios (SSPD, 2008), determined that there were 28 MSW facilities that dealt with processing the putrescible fraction of MSW, from which 54% carried out composting, 15% vermicomposting and the remaining 31% used both methods. The processing time of the plants varied between 30 and 180 days, obtaining an average production efficiency of 33% (with respect to the material subjected to processing) and although quality control was not carried out, the obtained products were being utilized by farmers of different vegetable species and food without knowing the sanitary risk this could represent.

The scenarios previously presented contrast with the economical, social and environmental potential that the recovery, reuse and recycling of waste has had in regions such as Dhaka - Bangladesh (Zürbrugg et al., 2005), Dar es Salaam –Tanzania (Mbuligwe et al., 2002), Yala - Thailand (Mongkolnchaiarunya, 2005) and Turkey (Metin et al., 2003), where practices such as composting and recycling, besides the sanitary and environmental benefits of the reduction of the amount of materials to be disposed in the land, generate job opportunities and income generally for the sectors with the lowest economical capacity. Reported experiences by Zürbrugg et al. (2005) and Körner et al. (2008), for Bangladesh and Cuba respectively, indicate that the application of composting has had better success at small-scale and in decentralized facilities, but frequent failures are present in the marketing of the product. Drescher & Zürbrugg (2006) suggest that for the large cities, the combination of decentralized small- scale composting systems with medium- scale centralized composting schemes constitute an ideal strategy for the management of organic wastes; at the same time, decentralized composting systems are enough for small municipalities.

The use in agriculture, as soil conditioner or fertilizer, is one of the most usual ways to take advantage of the compost obtained with the processing of MSW; however the quality of the product is subordinated to variables such as the design of the composting facility, type and proportions of feedstock used, composting procedure and maturation period (Hargreaves et al., 2008) the evaluation of alternative techniques for improving and/or facilitating the monitoring of the process and quality of the product (Said-Pullicino et al., 2007, Barrena et al., 2008) that deserve to be assessed in more depth.

2.3. Perspectives for the sustainability of resource recovery from Wastes

Recent studies conclude that amongst the main factors for the sustainability of the reuse and recycling systems are waste collection and segregation, MSW management plan, and a local

market for the recycled materials (Troschinetz & Milheic, 2009). To accomplish the sustainability, it is necessary to develop production and marketing strategies with a marketing vision that acknowledge and integrate the formal and informal sectors, requiring important agreements between stakeholders, the adaptation of educational schemes and technological options, the identification and positioning in the market and the setting of normative references.

At the same time, although the knowledge of the quantity and quality of the materials to be processed is one of the key elements for guiding the industrial vision, it is recognized that the lack of reliable studies on the composition and generation of waste constitute one of the main limitations for the management (Diaz et al., 2002). This situation could be related with the cost and complexity of the methodological procedures used for the execution of such studies (Hristovski et al., 2007). It is necessary to structure alternative methodological schemes that take into account limitations of the trained personnel and the low availability of financial resources, which can be successfully applied. In this aspect, there are some positive experiences in Santiago de Cali in Colombia, where a sampling and characterization program that involved the participation of local stakeholders was structured, adapting a method that utilizes one block as the sampling unit, obtaining results with high confidence levels and low errors, with affordable costs for the local conditions (Klinger et al., 2009).

It is also important to conduct efforts that allow all the stakeholders in the management chain to identify the waste as an element with possibilities of reuse and not as garbage, term associated with problem. At the same time, aspects such as the deterioration of the quality and loss of value of the materials to reuse, which starts at the point of generation and in the collection vehicles, must be avoided. The encouragement of practices such as source separation and separate collection are options with the potential to solve this situation; however, in this way additional costs for the user or for industry can be generated, encouraging the informal recovery which creates conflicts with personnel from the collection system. Analysis and local agreements that take into account these situations and identify a solution must be developed.

In the same way, it is necessary the research and development of technological options that facilitate the transformation in situ, allowing amongst others, the use of locally available resources for the operation and maintenance, as well as the reduction of volumes of materials and the consequent decrease in transportation costs, increasing the added value of the reuse of these products. In this sense, an alternative is the realization of adaptations of the technologies utilized for the recovery of industrial wastes, taking into account the quality and quantity of the MSW. It is also important to put into practice monitoring schemes and quality control of the products since the complexity and costs associated with those traditionally used limit its application.

The previously mentioned situations demonstrate that the sustainability of the reuse of the MSW transcends technical and economical aspects and that it is necessary to think of it as a

system. Then, a reuse system is a set-up of parts or interrelated elements that have as a function the efficient reincorporation of recovered materials from solid waste to the economical and productive cycle. Reuse system is maintained in time through technically appropriate and economically and socially feasible strategies, without threatening natural resources for future generations.

The reuse of waste can support dignified work for many people, the conservation of non-renewable natural resources and the reincorporation of products into the productive cycle in developing countries, for such reason its sustainability must be a goal for its human and sustainable development.

3. Conclusions

In developing countries, recovery is an alternative identified and/or applied as a solution to the problems associated with solid waste management. However, it requires that recovery be developed as an option with sustainability potential. For that, it is indispensable the participation of stakeholders and their integration with technologies and markets.

A key element for the sustainability of the reuse systems is the articulation of efforts and the mutual acknowledgement between the formal and informal sectors. The informal sector is one of the main elements of the recovery of paper, plastic, metals and glass, carrying it out generally under precarious working conditions and with inefficient technologies, making necessary the adaptation or development of technologies that favor the employment of local labor, dignifying their working conditions and under economical and sustainable conditions.

The valorization of waste as being an opportunity and not as something to be discarded by the generators is fundamental, so that not only the environmental but also the social and economical benefits associated with the reuse must be recognized, from these benefits also the generator must feel itself as a key part of the solution.

For the implementation of reuse systems from MSW it is important to obtain reliable estimates of the quantity and composition of the materials to take advantage of, as well as the characteristics and markets of the products. In the event of the necessity of a central installation for the reuse operations, siting, design and operation must be adapted to the local conditions.

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