Improving Sustainability of Municipal Solid Waste Management in China by Source Separated Collection and Biological Treatment of the Organic Fraction

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Introduction

Rapid economic development in China has led to high urbanization rates and significant improvement in living standards. Besides many positive effects of this development, one of the negative results is the enormous increase in the generation of municipal solid waste (MSW), at the moment at an annual increase rate of approx. 10%. In the year 1998, over 50% of MSW in China still was dumped in the suburbs and on farm land, causing heavy environmental pollution to soil, groundwater and surface waters. The solid waste pollution asks for immediate actions to improve MSW management in China.

This paper introduces the MSW management approaches adopted in the European Union (EU) which focus on the triple-R strategy of reduction, re-use and recycling. More specific, the treatment of the biodegradable organic fraction of MSW will be discussed. EU experiences and practices could possibly be adapted to the urban context of China to improve China's MSW management performance in the short term. Although MSW may also comprise solid waste from municipal services and from institutions and commercial activities, this paper limits MSW to residential waste, i.e. solid waste generated by households.

Sustainability MSW management in EU

Cities concentrate increasing numbers of people, consuming increased amounts of natural resources and producing vast quantities of emissions and solid waste. It is therefore essential to find ways to minimize urban impacts on resource depletion and the environment. At present, the metabolism of most cities is essentially linear (Figure 1), with resources flowing through the urban system and without any concern about the destination of its wastes. This type of city is characterized by high consumption rates of resources and enormous pollution to the environment. Moreover, the flow of materials inclines towards global scale, consuming vast quantities of energy for transportation of goods. We should strive for a sustainable city concept, which adopts a circular metabolism (Figure 1). A sustainable city re-uses and recycles its materials resulting in reduced resource consumption and less environmental impacts. Additionally, material flows are more on a regional scale resulting in less transportation, being more energy efficient.

In order to develop more sustainable cities, the key challenges are how to de-couple the increase in quality of life from growth in solid waste generation and how to use less materials but use them more efficiently. With respect to solid waste, we should not only focus on the reduction of the volume of solid wastes and its environmentally safe disposal but adopt an integrated resource and waste management strategy which also tries to minimize the generation of wastes.

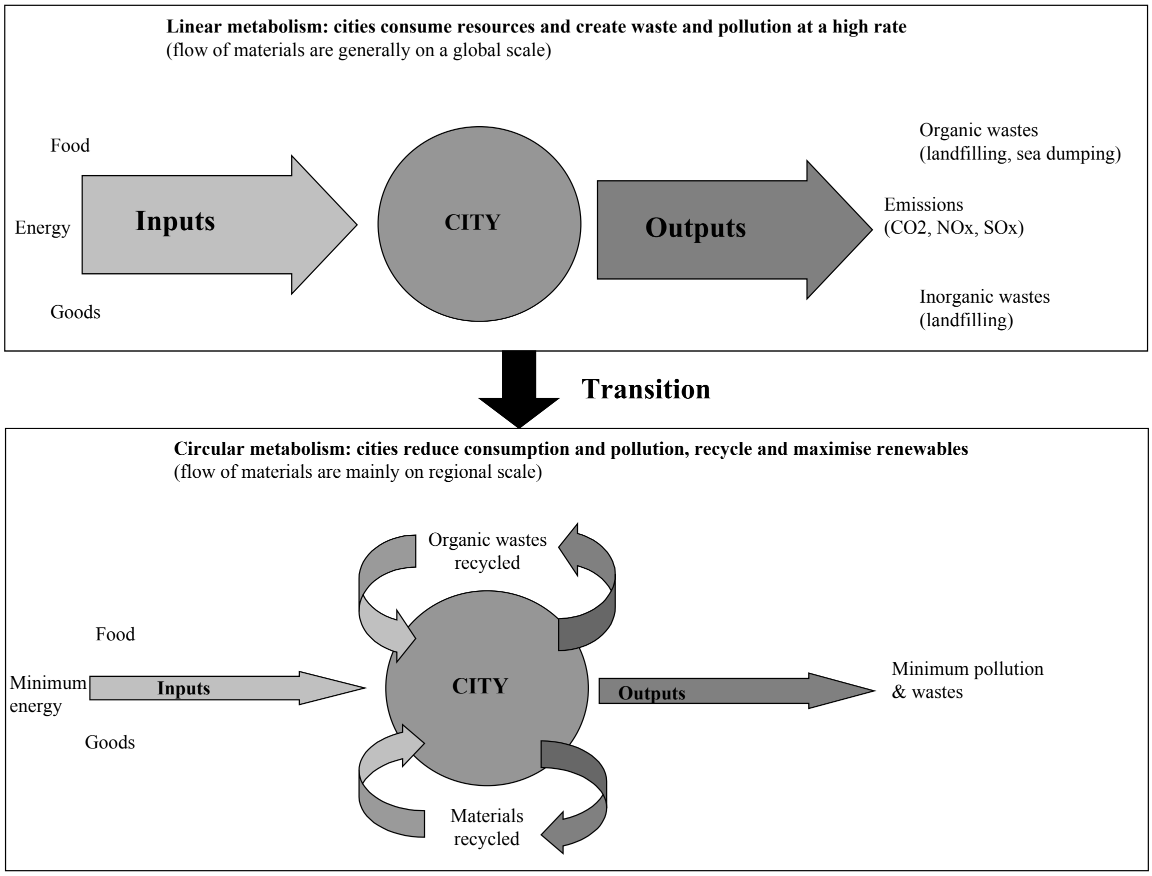

Figure 1. Transition towards a sustainable city: from a linear towards a circular metabolism

The EU policy has shifted from "end-of-pipe" waste management towards integrated "sustainable resource management" which is part of an integrated environmental assessment. One of the major priorities and objectives of the European Commission for environmental policy over the first decade of the 21th century is "sustainable use of natural resources and management of waste" (European Union, 2003) One of the key elements of MSW management in the EU is the waste hierarchy as illustrated in Figure 2.

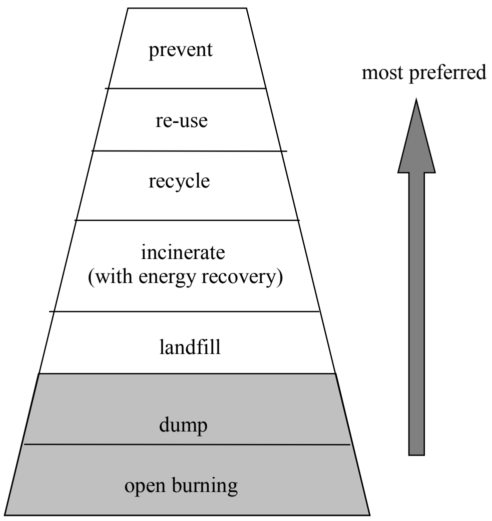

Figure 2. The solid waste hierarchy as adopted by the European Union

The most efficient way to deal with the problem of solid waste is prevention, i.e. to make less of it. By designing goods that have the least possible impact on the environment, from the time they are produced until the time they are disposed of, manufacturers help to cut down the amount of waste and pollution they generate. By choosing goods that have least possible impact on the environment, consumers help to reduce waste and give manufacturers an incentive to produce "greener" products.

Much of what we throw away could be recycled into new products, saving money, resources and energy. Schemes for recycling paper, plastic and glass in Europe are already showing encouraging results. Attention has now turned to recycling worn-out cars and electric and electronic equipment. Composting is nature's way of recycling its own organic waste. It is easy, economical, organic and useful.

Solid waste that cannot be reused or recycled has to be incinerated or landfilled. Incineration of solid waste can reduce its volume by up to 75% and its weight by 40-60%, as well as producing useful energy. However, what is left over must still be disposed of carefully. It must be emphasized that only incineration with energy recovery is regarded as a recovery method. Landfilling is still the most common way of disposal. But this can create serious pollution if dangerous substances leak out into the air, soil, or nearby rivers and lakes. It is therefore important to stop these materials escaping from the landfill.

Although this ranking of waste management options provides policy makers with an effective base, the waste hierarchy should be used in a flexible way and is only intended as a general guideline to achieve the best environmental solution on the long term. The waste hierarchy only refers to environmental effects and ignores economic and social criteria, aspects that should not be ignored. In order to encourage resource recovery and minimize land disposal of MSW, additional regulations are set up in the EU. EU legislation forbids the landfilling of biodegradable organic waste and a landfill tax is introduced in most EU countries for combustible waste (total organic carbon exceeds 5%) to promote recycling and incineration with energy recovery.

Unfortunately, in developing countries it is still common practice that large quantities of waste is dumped in an uncontrolled manner, or worse, burned in the open air.

Re-use and recycling of MSW components

Figure 3 shows the average composition of generated MSW in the Netherlands. Most of these fractions can be recycled. Paper, glass and metals can directly be recycled as raw material for the production of paper, glass and metal, respectively. The organic part of MSW (plastics, biodegradable organics, textile, wood, etc.) can be incinerated with recovery of energy. At least 70% of MSW can theoretically be recycled in this way.

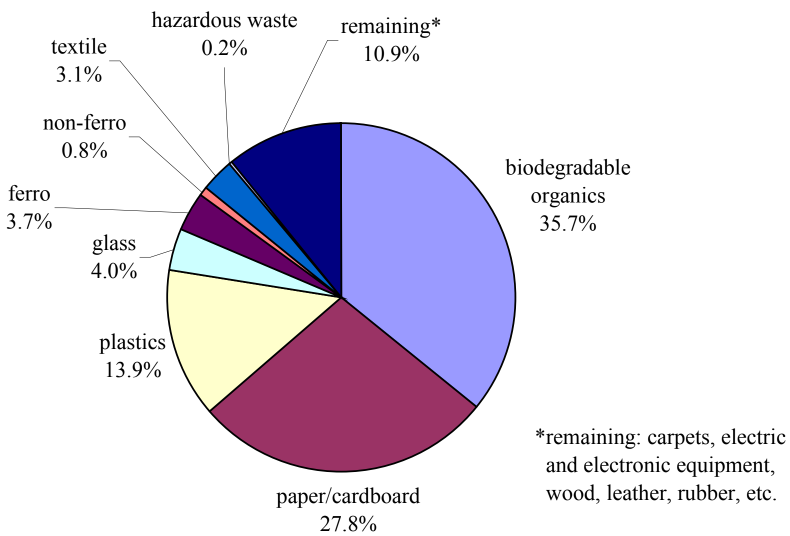

Figure 3. Average composition of MSW in the Netherlands

The biodegradable organic part of MSW consists of indoor-collected organic material, such as food remainders and flowers, and outdoor-collected organic matter, such as grass and branches from gardens. As the moisture content of biodegradable organics is relatively high, the calorific value of this solid waste is very low and does not give a positive contribution to energy recovery by incineration. Therefore, it is better to recycle the biodegradable organic part of MSW by aerobic composting or anaerobic digestion into an organic fertilizer where digestion also produces a renewable energy source (methane gas).

There are two strategies for recycling the various fractions of MSW: separation at the source by the citizens before collection and centralized separation after integral collection. Table 1 gives the characteristics of both strategies.

Table 1. Main differences between source separation and centralized separation of MSW components

Source separation	Centralized separation
Better product quality	More polluted products
Increased waste awareness	Shielding waste awareness
Complex logistics	Easier logistics
Public involvement needed	Less involvement needed

It is advised to collect the various fractions of MSW separately at the source, i.e. by the citizens before it is collected. It not only produces a better product quality but also makes the public more aware of the necessity of waste reduction and waste separation. Of course, separate collection should be logistically feasible and the costs should be realistic. Over the past decade, source separation in combination with the strategy of "pay as you throw", in which citizens reduce their individual waste production because of financial incentives, has successfully been implemented in several EU countries (Reichenbach, 2005).

Table 2 shows the average composition of MSW in several cities of China as obtained from a study of Wang and Nie (2001). The study did not make clear if MSW covers only residential waste but we assume that also solid waste from municipal services and from institutions and commercial activities are most probably included. Therefore, the MSW figures for China cannot directly be compared with MSW data from the Netherlands. Table 2 shows that the organic components make up 61-95% (average 76%) of Chinese MSW, where food accounts for 38-73% (53%), paper and cardboard for 2-12% (5.7%), plastics for 2-14% (7.9%), textiles for 1-6% (2.5%) and wood for 0.5-13% (6.7%). The low ash content in cities as Beijing and Shanghai (2-3%) compared to cities as Manshan and Chongqing is due to the use of gas as a fuel instead of coal which produces much inorganic ashes. MSW in most cities has a high moisture content (55-75%) and a low calorific value (3000-5000 kJ/kg) which makes the application of incineration technology very difficult.

The biodegradable organic part of Chinese MSW (food, grass and leaves) makes up about 55% of the total. Separate collection of the biodegradable fraction followed by biological treatment could be an attractive management option. Moreover, by separate collection of the biodegradable part (with a high moisture content), the remaining MSW containing dry and combustible components such as plastics, textile, wood could be more suitable for incineration.

Table 2. Composition of MSW for several Chinese cities (% by weight)

	Organic					Inorganics			
City	Food	Paper[1]	Plastics	Textiles	Wood[2]	Ash[3]	Glass	Metal	Others
Beijing	56.0	11.8	12.6	2.8	8.6	2.8	3.8	1.7	-
Shanghai	58.6	6.7	11.8	2.3	13.7	2.2	4.1	0.7	-
Hangzou	55.3	1.8	5.0	1.5	0.4	33.2	1.4	1.1	0.3
Shenzhen	57.0	4.7	14.1	6.6	11.1	3.5	1.3	1.4	1.6
Manshan	38.2	3.9	5.0	1.7	12.4	35.6	2.6	0.3	0.3
Chongqing	24.3	5.4	11.8	2.8	1.5	20.2	2.2	1.1	26.5
Average	**52.9**	**5.7**	**7.9**	**2.5**	**6.7**	**18.9**	**2.4**	**0.7**	**4.8**

[1]paper and cardboard; [2]wood, grass and leaves; [3]ash, coal residue, dirt, etc.

Recycling of the biodegradable organic fraction of MSW by source separation and biological treatment

Recycling of the biodegradable organic fraction of MSW can be achieved by thermal or biological treatment. In all cases the organic matter is converted, for incineration by thermal conversion and for composting and digestion by microbial conversion. The characteristics of the treatment options and technological aspects are listed in Table 3.

Table 3. Technological aspects of incineration, composting and digestion (Eunomia, 2002)

Aspect	Composting	Digestion	Incineration
Process	Aerobic thermal conversion: $OM^1 + O_2 \rightarrow H_2O + CO_2$ + heat[2]	Aerobic microbial degradation: $OM + O_2 \rightarrow H_2O + CO_2$ + heat[3]	Anaerobic microbial degradation: $OM \rightarrow CH_4 + CO_2$ [4]
Energy production	None	Medium	Medium
Disposed residues	Oversize, rejects	Oversize, rejects	Fly ash, bottom ash
Complexity	Low	Medium	High
Scale	Small-medium	Medium	Large
Public acceptability	Medium	High	Low
Costs	35-75 €/ton[5]	80-125 €/ton[5]	75-145 €/ton

[1]OM=organic matter; [2]energy is produced out of heat; [3]heat is used to dry the compost; [4]methane is a renewable energy sources, an alternative for natural gas; [5]these figures also includes the separate collection of the biodegradable organic fraction which amounts to 0-15 €/ton

Due to the fact that the biodegradable fraction of MSW has a low calorific value, the incineration technology is complex and expensive, and the public acceptance of incineration is low, biological treatment of the biodegradable organic fraction of MSW is an attractive alternative. Moreover, digestion also produces energy in the form of methane gas (CH_4). The product of biological treatment, compost, can be recycled. Benefits of the use of compost are amongst others:

- its fertilizing properties: mainly N, P and K
- capacity to maintain and restore the soil quality: both physical, chemical and biological
- its positive effect on global warming (carbon sink): organic matter in compost is slowly degraded in the soil and slows down CO_2 emissions
- it possesses suppressive effects against soil born plant pathogens, reducing the use of pesticides
- it can be used as an alternative substrate for peat in horticulture

On the other hand, the application of compost to soil systems is of great concern because the frequent supply of compost may lead to the following risks:

- excessive supply of nutrients
- introduction of pollutants to the soil: especially accumulation of heavy metals is a serious risk
- spreading of human, animal or plant pathogens

To guarantee safe application of compost to the soil, the EU defined statutory standards to ensure protection of environment and health, among others standards for heavy metals. Table 4 lists the heavy metal content of composts derived from MSW which were prepared in three different ways together with the EU standards. The heavy metal content of the compost is significantly reduced when the biodegradable organic fraction of MSW is separated before composting. An even greater reduction is achieved when the biodegradable organic fraction of MSW is source separated. Table 4 shows that separate collection of the biodegradable organic fraction of MSW is absolutely necessary to produce compost that complies with EU legal standards for heavy metals. Moreover, the compost contains less physical impurities like glass, stones and plastics when the organic fraction is separately collected.

Table 4. Heavy metal content of different types of MSW-derived composts and EU legal demands (in mg/kg of dry matter)

Heavy metal	MSW compost[1]	OFMSW compost[2]	Biowaste Compost[3]	EU standards
Cd	9	2	0.8	1.5
Cu	530	150	35	150
Ni	80	40	9	75
Pb	830	400	85	150
Zn	1600	800	140	400

[1]MSW compost obtained from MSW which is integrally collected; the compost (organic fraction) is mechanically separated after composting; [2]OFMSW compost obtained from MSW which is integrally collected; the organic fraction (OFMSW) is mechanically separated before composting; [3]Biowaste compost obtained from the organic fraction of MSW which is separately collected at the source before composting

Separate collection and biological treatment of the biodegradable fraction of MSW is a sustainable way to recycle about 50% of total MSW in China. Composting is widely introduced in EU countries and is a proven technology. Proper management of composting facilities is absolutely necessary as many plants were closed down in the past due to complaints of odor nuisance of the neighborhood. Although still in its initial stage of implementation, anaerobic digestion could be an even more attractive treatment option than composting because digestion besides compost also produces a renewable energy source.

Both composting and digestion are relatively simple technologies that are also economically viable on smaller scale. Composting is especially attractive in areas and countries where labor costs are low and capital is limited. The costs of biological treatment are significantly lower than incineration (including the costs of separate collection). However, composting and digestion can only be economically viable when landfilling of organic wastes is prohibited as landfilling is still the cheapest waste disposal method (costs ranging from 20-40 €/ton). Therefore, EU countries have introduced environmental regulations and taxes in accordance with the waste hierarchy to promote recycling and recovery over disposal. At present, landfilling of biodegradable organic waste is banned or subject to extremely high landfill taxes in many EU countries.

Concluding remarks

An effective resource and waste management scheme needs the flexibility to design, operate and adapt systems in ways which best meet prevailing social (including legislative), economic and environmental needs. These needs are likely to change over time and vary by geography. The need for consistency in quality and quantity of recycled materials, compost or energy supply, the need to support a range of disposal options and the benefit of economies of scale, all suggest that resource and waste management systems should be organized on a large-scale, regional basis. Any scheme incorporating recycling, composting or energy from waste technologies must also be market-orientated.

Source separation and composting/digestion of the biodegradable fraction of MSW has been implemented successfully in several countries within the EU. More countries are beginning to implement this approach as it can significantly increase the recovery rate of MSW. It is a sustainable MSW management option as it returns organic matter and nutrients to the soil as compost, at acceptable costs and low environmental impacts. Digestion has the additional advantage that it produces a renewable energy source. It can be an attractive MSW management strategy for China as a large fraction of MSW in Chinese cities consists of biodegradable organic matter.

In order to improve MSW management in China, remedial strategies in three areas have to be initiated: institutional reform, technology development and legislative and administrative improvement. Wageningen University and Research Center (WUR) has expertise in both the managerial and technological aspects of MSW management. In cooperation with SenterNovem, WUR and five Chinese organizations have submitted a proposal within the framework of the EU Asia Pro Eco program (phase II) with the title “Adoption of EU experiences in MSW management in China”. The goals of the project are (1) improvement of the performance of municipal waste services of Chinese cities through the exchange of best practices, expertise and information between EU and China and (2) improvement of the relationship, communication and understanding of MSW management between EU and China.

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