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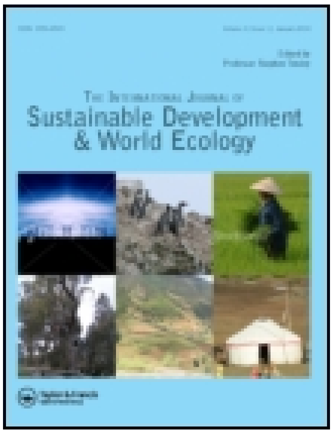

International Journal of Sustainable Development & World Ecology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tsdw20

Household waste management for a peri-urban area based on analysing greenhouse gas emissions for Jimei District, Xiamen, China

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Published online: 21 Jul 2010.

To cite this article: Lingyang Pan , Tao Lin , Lishan Xiao , Yu Zhao & Shenghui Cui (2010) Household waste management for a peri-urban area based on analysing greenhouse gas emissions for Jimei District, Xiamen, China, International Journal of Sustainable Development & World Ecology, 17:4, 342-349, DOI: 10.1080/13504509.2010.492654

To link to this article: http://dx.doi.org/10.1080/13504509.2010.492654

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International Journal of Sustainable Development & World Ecology
Vol. 17, No. 4, August 2010, 342–349

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This study aims to find the generation characteristics of household waste (HW) in a peri-urban area and establish an optimal HW management system to improve inhabitants living environment and for energy saving and pollution abatement. Jimei District, Xiamen, was chosen as a case study and 10 representative communities were selected as study areas. Questionnaires and a field survey were applied to investigate the characteristics of peri-urban area HW generation. After combining the results for communities of different urbanisation levels, representative communities were classified into three groups. Greenhouse gas (GHG) emissions from the current HW management system and a proposed integrated management system were compared. The results show that the integrated HW management system would achieve greater energy savings and GHG mitigation. Emissions from HW management in the lowest urbanised communities remained highest. However, the relationship between emissions and community urbanisation level was not completely linear. Finally, three kinds of integrated management strategy for HW generated from different community groups are proposed and suggestions given to establish an optimal integrated HW management system for peri-urban areas.

Keywords: peri-urban area; greenhouse gas emissions; household waste management system

Introduction

With the process of urbanisation and industrialisation, the boundary between city and rural area has become ambiguous, and a new type of area – the peri-urban area – has emerged, which challenges the traditional dichotomy between rural and urban (Iaquinta and Drescher 2000). Presently, developing countries and regions, particularly in Southeast Asia, East Asia and the coastal area of China, have been studied as the focus of peri-urban areas (Dick and Rimmer 1998; Webster 2002; Webster et al. 2003). It is important and common for urbanisation research to ascertain the boundary of the peri-urban area and ascertain its characteristics, including the transitional and dynamic nature.

In China, there are many environmental problems in peri-urban areas due to the complex and unstable characters. The challenge of domestic waste management has become a priority for municipalities; however, little attention has been paid to peri-urban waste management (Liu et al. 2004). In fact, the composition and properties of peri-urban waste are more complicated than that in rural areas, while the waste management system is not as efficient as that in urban areas. As a result, ever-increasing and poorly managed waste is having adverse environmental impacts and may result in health hazards, particularly for people who live near waste treatment facilities (Misra and Pandey 2005).

Greenhouse gases (GHGs) can trap heat in the atmosphere and subsequently lead to global climate changes, and have gained high priority on the public agenda. Waste disposal is one of the main anthropogenic sources of GHGs (Liu 2007). In China, the emission of methane (CH_4) from waste disposal sites represented approximately 23% of gross emissions of CH_4 in 1994 (NDRCC 2004). However, appropriate waste management strategies can minimise energy consumption and reduce environmental pollution (IPCC 2000; Liu 2007; Zhao et al. 2009). Thus various waste management strategies have built-in options for GHGs reduction and are included officially in China's National Climate Change Programme (NDRCC 2007).

In the past, very little analysis has been done to optimise technologies to deal with ever-increasing household waste (HW) in peri-urban areas (Li et al. 2003a; Liu and Chen 2003; Hu 2009). In this study, Jimei District of Xiamen was taken as a case study, and 10 representative communities with different levels of urbanisation were selected as study areas. The aim was to find an appropriate HW management strategy for peri-urban areas based upon evaluations and comparisons of GHG emissions in the current and proposed waste management options.

Description of the study area

Jimei District, one of the six districts within Xiamen City, is a typical peri-urban area (Figure 1) and an important portal for the Xiamen downtown area. This district has approximately 410,000 people and covers an area of 276 km^2 containing 35 communities. At present, it is undergoing high-speed development and urbanisation (About Jimei 2009), and has representative characteristics of a peri-urban area, including dynamic, transitional and mixed nature, that are increasingly obvious under the interactive drivers of globalisation, urban expansion and economic,

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ISSN 1350-4509 print/ISSN 1745-2627 online

DOI: 10.1080/13504509.2010.492654
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Figure 1. Location of Jimei District and the representative communities. 1: Countryside village, Qigou (QG); 2: Suburban village, Xinglin (XL); 3: Town, Guankou 2nd community (GK); 4: Industrial fringe community, Maluan (ML); 5: Village in city, Dashe (DS); 6: Urban fringe community, Yecuo (YC); 7: Education area, Jimei University (JMU); 8: Villa area, Bihuali (BHL); 9: Industrial zone community, Ridong (RD); 10: Downtown community, Yinting (YT).

cultural and environmental factors. Accordingly, Jimei District was chosen as representative to analyse the characteristics of peri-urban areas in China (Huang 2009).

Jimei District has diversified communities in terms of morphology and function, and 10 representative communities were selected in this study (Figure 1). Their urbanisation levels were ranked as follows: countryside village (QG) < suburban village (XL) < town (GK) < industrial fringe community (ML) < village in city (DS) < urban fringe community (YC) < education area (JMU) < villa area (BHL) < industrial zone community (RD) < downtown community (YT).

Methodology

Questionnaire survey

The questionnaires were distributed to inhabitants in representative communities from 28 April and 7 May 2009 through five investigation groups, with each group consisting of two to three interviewers, to administer questionnaires orally if necessary. The questionnaires in Bihuali community were distributed with the help of property management staff, without a direct structured interview.

The amount and components of HW generated per day per family were surveyed in the questionnaires. According to the ‘Classification and Evaluation Standard of Municipal Solid Waste’ (MCPRC 2004), the HW was separated into the following general categories:

Recyclable materials: Metals, plastics, paper, cardboard, books, glass.
Bulk waste: Discarded furniture, electrical appliances.
Compostable waste: Kitchen waste, yard waste, leaves.
Combustible waste: Napkins, packaging materials, scrapped wood, scrapped textiles.
Harmful waste: Electronic waste, strip lamps, cosmetics, batteries, chemicals.
Inert materials: Stones, dust, construction waste and cinder.

In this survey, of the 220 questionnaires distributed, 180 valid questionnaires were used in analysis of the results.

Field investigation

A field investigation was initiated to compare and reinforce the questionnaire survey. In typical communities, stacks or containers of HW were designated for sampling and selected at random as representative of the waste stream. From the stack of HW, samples were collected using a three-dimensional diagonal sampling method to a gross weight of approximately 20 kg; from each container of waste, the same weight of sample was collected and mixed until the aggregate was also about 20 kg. Subsequently, samples were converged and sorted into the following items: compostable waste, plastics, paper, dust and cinder, wood, textiles, metals, glass and other materials (MCPRC 1995).

Hierarchical cluster analysis

In the statistical analysis system (SAS) program, hierarchical cluster analysis is a general approach to clustering, in which a number of different algorithms are encompassed to assign observations of similar kinds into respective clusters. The average linkage clustering is an algorithm to calculate average distance between observations from the first cluster and observations from the second cluster. Finally, the result was represented graphically as a horizontal dendrogram (Huang et al. 2006). In analysis for this study, HW generation and components from questionnaires were taken as parameters.

Evaluation of GHG emissions

GHG emissions from the waste management system assessed in this study were carbon dioxide (CO_2), CH_4 and nitrogen oxides (N_2O). The Intergovernmental Panel on Climate Change (IPCC) proposed a global warming potential (GWP) and established CO_2 as the reference gas for measurement of trapped heat capacity. Compared to CO_2 over a time horizon of 100 years, the GWP of CH_4 for the same time period is 21 and for N_2O is 310, thus allowing emissions of CH_4 and N_2O to be converted to CO_2 equivalents (OAR 2001; NDRCC 2004).

In the waste management system, the primary source of CO_2 was decomposition of biogenic material, which was considered to be 'carbon neutral' and not a net contributor to global warming, so CO_2 emissions from landfill and composting were not counted. On the other hand, CO_2 emission from incineration was included since such emissions mainly originate from burning fossil carbon. CH_4 emissions from waste management were counted, even though the source of carbon was primarily biogenic, because of the significant GWP of CH_4.

GHG emissions from landfill. By volume, CH_4 comprises almost half of the landfill gas released from waste decomposition, and can be estimated from the following formula (Ngnikam et al. 2001; Yang & Ma 2006; USEPA 2009b):

$$\mathrm{EL_{CH_4}} = \mathrm{HW} \cdot \alpha \cdot \mathrm{DOC} \cdot r \cdot 50\% \cdot \frac{16}{12}, \tag{1}$$

where HW is the gross weight of waste generated from households, α is the ratio of HW land-filled, DOC is the percentage of degradable organic carbon and r is the fraction of DOC that can decompose; 50% is the percentage of CH_4 in generated landfill gas, and 16/12 is the molecular weight ratio CH_4/C.

GHG emissions from composting. During HW composting, emissions of CH_4 and N_2O were low, and the equation for estimating emissions is expressed as (Pipatti et al. 2006a):

$$\mathrm{EC}_i = \mathrm{HW} \cdot \beta \cdot \mathrm{EF}_i \cdot 10^{-3}, \tag{2}$$

where i stands for CH_4 or N_2O, β is the ratio of HW composted and EF_i is an emission factor for i. The default emission factor for CH_4 is 4 g/kg and for N_2O is 0.3 g/kg.

GHG emissions from incineration. The calculations of CO_2 and N_2O emission in HW incineration are given in Equations (3) and (4):

$$\mathrm{EI_{CO_2}} = \mathrm{HW} \cdot \gamma \cdot \mathrm{FC} \cdot \sigma \cdot \frac{44}{12}, \tag{3}$$

where γ is the ratio of HW incinerated, FC is a fraction of fossil C in wet waste, σ is an oxidation factor and 44/12 is the conversion factor from C to CO_2.

$$\mathrm{EI_{N_2O}} = \mathrm{HW} \cdot \gamma \cdot \mathrm{EF} \cdot 10^{-3}, \tag{4}$$

where EF is emission factor for N_2O and the default value is 0.05 g/kg.

GHG emissions from HW transport. Emissions of CO_2, CH_4 and N_2O are also produced during fuel combustion. The average emission factor of a unit distance for CO_2 and CH_4 used in the following equation was deduced by Li et al. (2003b) after rectification of the MOBILE 5 model proposed by the USEPA. The emission factor for N_2O is identical to the factor for CH_4, owing to limitation in available data and consistency between the two default values given in national GHG inventories (Pipatti et al. 2006b). The emission equation for GHGs from transport is:

$$E_{tj} = \left(\frac{T}{L} \cdot D \cdot 2\right) \cdot EF_j, \tag{5}$$

where T is the amount of HW transported to the facilities, L is average practical loadage of vehicles, D is haulage distance (average distance between Jimei District and landfill site is about 33 km); 2 means to and from without taking into account the difference between a full load and no load; j denotes CO_2, CH_4 or N_2O, and EF_j is the emission factor for j.

Results and discussion

Characteristics of HW generated from representative communities

Based on the results from questionnaires, data were normalisatised and the generation characteristics as weights of aggregation and fraction of components for HW from a family in various communities obtained (Figure 2). Both the HW aggregation and the compostable materials generated from a family per day in XL were highest of all the representative communities. The percentages of recyclables in GK and ML were slightly higher than in other communities. Community YT had the largest amounts of combustible and harmful waste, and JMU had the least bulk waste due to the fact that most of the respondents interviewed were students living in dormitories.

From the results of the field survey (Figure 3) in the communities of YC and YT, compostable waste accounted for the greatest proportion; and in GK inert materials like dust and cinders were higher than other components. Except for

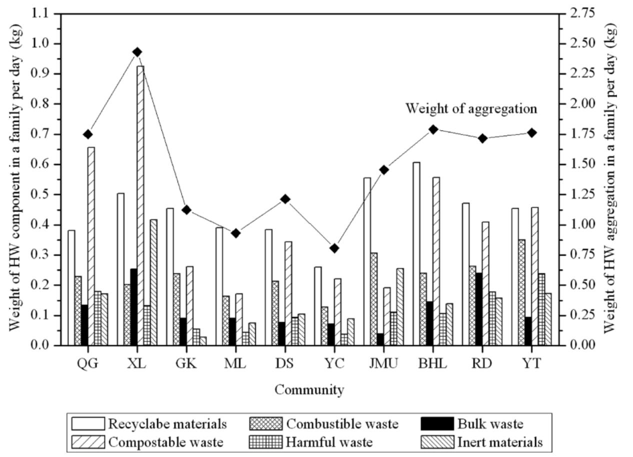

Figure 2. Average weight of aggregation and components for HW generated per family per day in the representative communities (results from questionnaires).

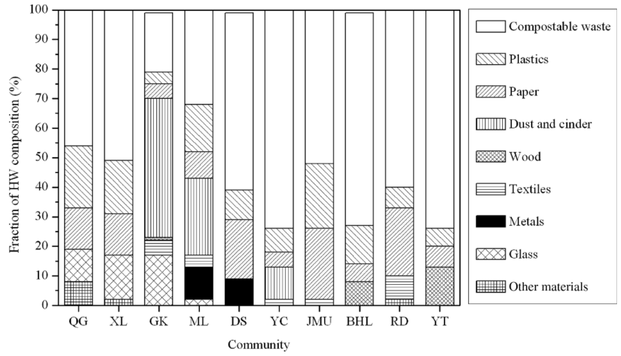

Figure 3. Fraction of HW composition in the representative communities (results from field investigation).

ML and DS, metals were hardly found during the field investigation. For QG, batteries, scrapped light bulbs, oil paint and some other harmful items were collected in the stacks of HW; however, one common characteristic among these various sampling points in the field investigation was that sweepings from streets and yard waste accounted for a large proportion.

In parallel with the field investigation, the questionnaire method is much closer to the source of HW, and therefore more comprehensive and authentic for government intervention. In particular, a questionnaire is better able to find the actual amounts of recyclable resources and bulk waste generation and treatment. In the field survey, many recyclable resources, which were too trivial to collect for sale, flowed into the terminal waste stream. However, a large proportion of these recyclables was separated in the recycling system by waste pickers and itinerant waste buyers. Furthermore, bulk waste was rare in the field investigation, because almost all of it was collected by professional recovery enterprises located outside of the district.

Hierarchical cluster analysis of different communities

Based on results of the questionnaires (Figure 4), combined with the community urbanisation levels, the representative communities can be divided into three categories:

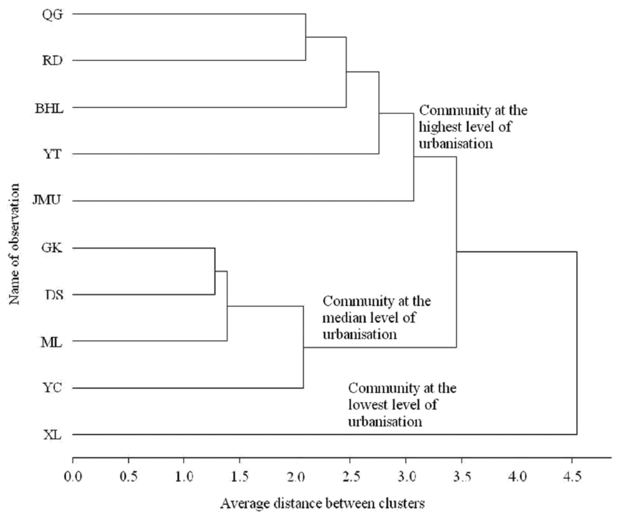

Figure 4. Horizontal dendrogram of hierarchical cluster analysis.

Group 1: The least urbanised community, only XL, constituted this group. The average gross weight of waste generated per household per day was higher than in other communities because of a high population density per family. Furthermore, compostable waste and inert materials generated in daily life were considerably higher among the communities surveyed.

Group 2: Communities in this group had a median level of urbanisation, and included DS, YC, GK and ML. These inhabitants generated a great proportion of recyclable material and combustible waste in their daily lives.

Group 3: Highly urbanised communities constituted this group, i.e. YT, BHL, QG, RD and JMU, where inhabitants discarded excessive amounts of compostable material and harmful waste every day. Although QG was selected as a representative of the least urbanised countryside village, the characteristics of HW were very similar to those of YT, BHL, RD and JMU.

Hence, the average amount of the aggregate HW in a family per day first decreases and subsequently rises with increasing urbanisation. In contrast, after an initial increase, recyclable and combustible materials decreased because of a substantial reduction in the use of disposable and over-packaged products with an improvement in educational level and environmental awareness. With respect to compostable materials and harmful waste, there was a continuous rise with urbanisation, especially of discarded vegetables and food leftovers. On the other hand, due to a transition in domestic fuel use, generation of cinders declined gradually. In addition, the amount of bulk waste discarded in representative communities increased with urbanisation, and an increasing number of items were thrown out within their product lifetimes.

GHG emissions from HW management

In accordance with references from the environmental sanitation department and waste composition data recommended by Pipatti et al. (2006b), the proportion of degradable organic C in HW from Jimei was approximately 12%, and the ratio of the fossil C in combustible waste was about 5%. Based on analysis of questionnaires, the average amount of HW generated per household was 1.4 kg per day, and each household had four members on average. As a result, the gross weight of HW was about 52,000 t, generated by 410,000 habitants per year in the whole of Jimei District.

Most environmental sanitation vehicles in the district are medium-sized diesel vehicles. Supposing that the average rated load capacity is 8 t per vehicle and the average actual load is about 5 t per vehicle, then the average emission factors per unit distance for CO_2, CH_4 and N_2O are 533.04, 0.01 and 0.01 g/km, respectively (Li et al. 2003b). In the current HW management system of Jimei District, almost all HW was collected to a landfill site in the Eastern Solid Waste Processing Centre (ESWPC) located in Xiang'an District. From the assumption that the mixed HW is not separated 'from cradle to grave', we can estimate that annual emissions from the landfill site were considerable. The landfill gases were mostly 4000 t CH_4 and 11,000 t CO_2. In addition, emissions from transportation were 365.9 t CO_2, 6.9 kg CH_4 and 6.9 kg N_2O. Total emissions of GHGs from the current HW management system were about 95,000 t CO_2 equivalents, and were equivalent to annual emissions from 38,000 t standard coal combustion or 12,000 households' electricity consumption in a developed country (Lu 2004; USEPA 2009a).

In order to explore the contribution of waste classification to GHG mitigation, and the differences among community groups, another management option – an integrated system mainly consisted of recycling, incineration and composting – was proposed. The GHG emissions from terminal treatments of current and proposed management systems were calculated and the results are presented in Figure 5. However, emissions from diesel consumption in waste transportation were not included because they were far less than the emissions of waste decomposition. In addition, both plants for waste composting and incineration will be constructed in ESWPC, close to the landfill site, so the differences in transportation between the two kinds of management system would not be notable.

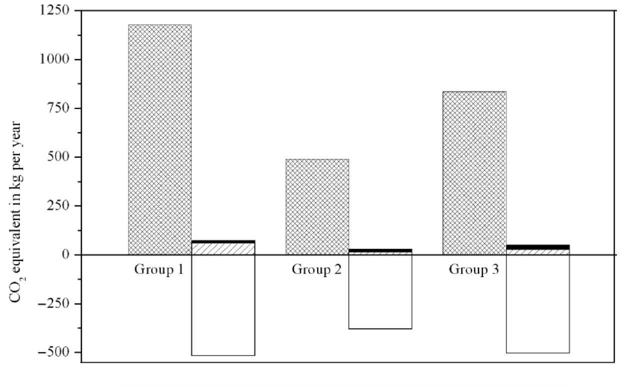

Figure 5. Comparison of current and integrated management systems for GHG emissions in different community groups.

As shown in Figure 5, emissions from different community groups varied but were not entirely consistent with the different community's urbanisation level. GHG emissions are closely related to the amount of HW generated; therefore, emissions of communities of Group 1 were more than in other community groups. In the integrated management system, HW treated in the composting plant produced about 0.18 kg CO_2 equivalents per kg of compostable waste, which is 0.02 kg CO_2 equivalents per kg less than from incineration. In addition, the recycling system had a significant mitigation benefit for reduced use of primary resources and a corresponding emission reduction of GHG, even though there are insufficient available data in Jimei District to determine the specific reduction. In Taiwan, emissions from a municipal solid waste recycling system are around -2.8 t CO_2 equivalent per tons of waste by applying the life cycle inventory model (Chen and Lin 2008). If the same recycling system can be established for Jimei District, in contrast to emissions from the current unitary system, the mitigation of the integrated system will reach 155%, 171% and 138% for communities in Group 1, Group 2 and Group 3, respectively. Thus, we believe that source reduction via waste classification and recycling is almost inevitable for development of waste management in peri-urban areas.

Suggestions for integrated HW management system in peri-urban areas

The characteristics of HW from different community groups varied in amounts, components and GHG emissions. To implement energy saving and pollution abatement strategies in waste management, various options can be adopted in light of the community characteristics of HW generation. From the study on Jimei District, we know that the predominant HW management strategy in peri-urban areas is unitary: a part of the recyclable resources is collected by waste pickers and itinerant waste buyers, without government intervention; the rest is a mixture that is transported to an open dump site or sanitary landfill site without CH_4 utilisation, not only causing resource waste but also the potential risk for dump security (Wang et al. 2006).

Based on the above issues, three options for a HW management strategy are suggested (Figure 6(a)–(c)), for the different communities with various urbanisation levels in Jimei District. These considerations can also be applied to other peri-urban areas. Since inhabitants living in peri-urban areas have great life pressures but weak environmental awareness, waste source separation cannot be achieved overnight. It would be much more acceptable to first ask inhabitants to separate HW into two or three categories rather than into six categories. In our investigation, the higher urbanised communities of Group 3 had a high recovery rate for recyclable resources. In contrast, due to remoteness and decentralisation, less urbanised communities of Group 1 had a low recovery rate, and the recycling depots had serious problems, including extremely poor organisation and secondary pollution. Moreover, there were high amounts of compostable material generated by these

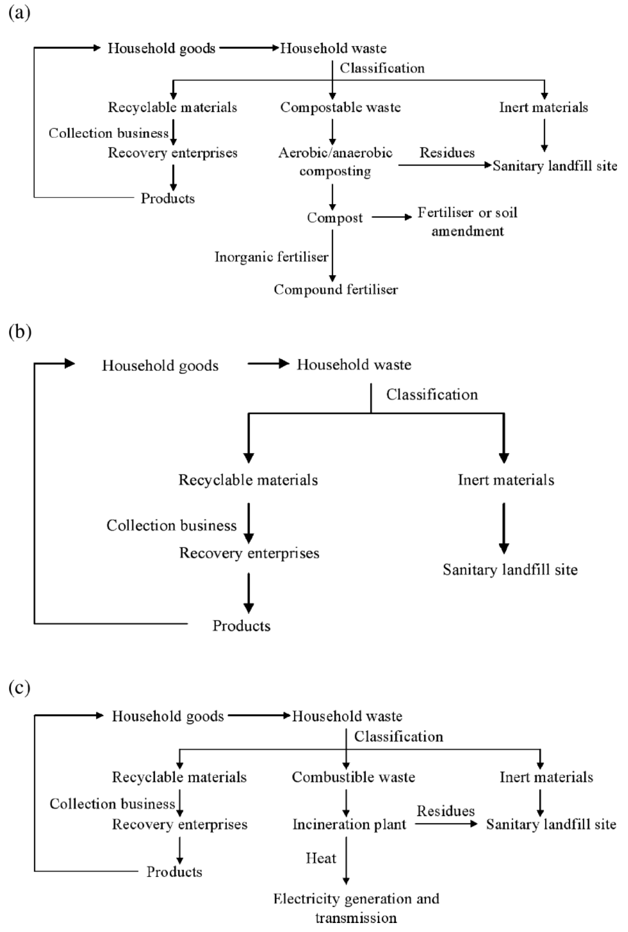

Figure 6. Sketch map of integrated HW management system for communities in (a) Group 1, (b) Group 2 and (c) Group 3.

undeveloped communities. Consequently, composting can be implemented as a primary strategy for integrated HW management.

Alhough slightly more GHGs are produced from incineration than composting, the heat can be used to generate electricity, and in addition the plant occupies a small land area and the technique has high efficiency in waste volume reduction (Gong et al. 2008); so for higher urbanised communities in Group 3, incineration is a preferable option for HW management. Inert waste that mainly consists of cinders, dust and other stable inorganic substances can be landfilled without a large amount of GHG emissions. Since bulk waste is usually collected and transported to factories or recovery enterprises out of the closed recycling loop in Jimei District, the emissions cannot be calculated due to limitations of the available data.

Based on the above results and considerations, more suggestions for optimising the integrated HW management system in peri-urban areas are given.

Improved investigation method. To make viable policy instruments suited to local conditions is a challenge for decision-makers, because it is difficult to obtain abundant and credible data. The questionnaire method is closer to local inhabitants and efficient to survey the generation and components of HW at source, especially recyclable resources and bulk waste. However, field investigation provides quantitative data of HW for comparison with questionnaires; thus, a combination of these two methods would be better to evaluate current waste management in China.

The need for source reduction. The growing amount of HW has created tremendous pressures on treatment facilities, so source reduction of HW is a fundamental approach for sustainable development. In particular, source separation can improve product quality of recyclables and compost, and also optimise incineration (McDougall et al. 2001; Zhuang et al. 2007). Furthermore, disorganised, unsupervised waste pickers are unstable factors in society, and government could provide them with authorisation and regulate them as official employees, which would enhance efficiency of waste collection and recovery. Environmental pollution would be abated and employment opportunities eventually be increased (Ma S and Ma J 2007).

Combination of centralisation and classification. A managed depot for recyclable resources could be set up for one or several communities. It could be operated by the environmental sanitation department of the district or transferred to individual enterprises. In communities where compostable waste accounts for a great proportion of HW, an anaerobic digestion plant could be built specifically to treat it. The biogas generated from the digestion process could be used for kitchen use and the digested matter used as fertiliser. Thus, a further decrease in possible emissions from waste collection and transport, and reduction in HW in downstream processes would be achieved.

Technical improvement and financing. It is best to improve the integrated management system by exploiting and optimising treatment techniques. Technology of waste incineration for power generation is popular in developed countries, while its application in China has not progressed due to high investment costs, technology import limitations, complex waste composition and potential dioxin pollution (Chen et al. 2007). Speeding up the independent development of techniques and facilities is an ultimate approach for China. Landfill gas utilisation for generating electricity is also a primary method to implement energy saving and pollution abatement; however, techniques for landfill gas purification need to be further studied (Batool and Chuadhry 2009). So far, HW management in peri-urban areas has been funded by the government, which distracts financial resources from economic development. Therefore, an independent financial structure is also important for optimal HW management systems in peri-urban areas. A lottery might be useful to encourage public support and broaden financial resources.

This study provides some suggestions for HW management systems in peri-urban areas; however, because these areas are complex and dynamic and the composition of HW varies with different levels of urbanisation, further studies are still necessary for China.

Acknowledgements

This study was supported by the Chinese Academy of Sciences (CAS) (KZCX2-YW-450; KZCX2-YW-BR-03), Ministry of Science and Technology of China (2009DFB90120), Bureau of Science and Technology of Xiamen (3502Z20081070) and the Academy-Locality Cooperation Program of CAS. We are grateful to Dr Shaopeng Huang of the Department of Geological Sciences, University of Michigan, for guidance and advice.

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