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Greenhouse gas emission and its potential mitigation process from the waste sector in a large-scale exhibition

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ABSTRACT

As one of the largest human activities, World Expo is an important source of anthropogenic Greenhouse Gas emission (GHG), and the GHG emission and other environmental impacts of the Expo Shanghai 2010, where around 59,397 tons of waste was generated during 184 Expo running days, were assessed by life cycle assessment (LCA). Two scenarios, *i.e.*, the actual and expected figures of the waste sector, were assessed and compared, and 124.01 kg CO_2-equivalent (CO_2-eq.), 4.43 kg SO_2-eq., 4.88 kg NO_3^--eq., and 3509 m^3 water per ton tourist waste were found to be released in terms of global warming (GW), acidification (AC), nutrient enrichment (NE) and spoiled groundwater resources (SGWR), respectively. The total GHG emission was around 3499 ton CO_2-eq. from the waste sector in Expo Park, among which 86.47% was generated during the waste landfilling at the rate of 107.24 kg CO_2-eq., and CH_4, CO and other hydrocarbons (HC) were the main contributors. If the waste sorting process had been implemented according to the plan scenario, around 497 ton CO_2-eq. savings could have been attained. Unlike municipal solid waste, with more organic matter content, an incineration plant is more suitable for tourist waste disposal due to its high heating value, from the GHG reduction perspective.
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Introduction

Climate change presents unprecedented challenges to the global community (Kiem and Austin, 2013; Metz et al., 2007). The increase in greenhouse gas (GHG) levels in the atmosphere and the already observed global warming of the Earth's surface have raised concerns about GHG emission from human activities (Metz et al., 2007; AUMA, 2011), and therefore the reduction of anthropogenic GHG emission is an urgent matter (Metz et al., 2007; Kerr, 2007).

Large-scale exhibitions are important intensive human activities, which are constantly on the rise following rapid global economic growth and urbanization. For example, around 157 international trade fairs and exhibitions were held in Germany in 2010, with 10,074,724 visitors (AUMA, 2011). Similarly, in China, there are about 80 exhibition centers distributed in 39 cities,

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where numbers of exhibitions are presented every year. These anthropogenic activities result in the generation of waste, which may cause some problems for the local environment and global warming (GW) through GHG emission (Vergara and Tchobanoglous, 2012). Against this background, large-scale event organizers have the responsibility to neutralize the carbon generated, or minimize its impact on climate and the environment.

Shanghai Expo, 2010 was the latest large-scale exhibition event, and was also the first time an event of this kind was held in China, the most populous developing country. It provided a good opportunity to assess the influence of human activities on climate change (Ping, 2009; Liu and Li, 2010). Meanwhile, the ever-increasing amount of waste is one of the urgent challenges for modern cities, to an extent that most of them have been christened as “city besieged by garbage”. In fact, the waste industry is considered one of the most significant sources of anthropogenic GHG, a matter that is currently a great concern to environmentalists. Therefore, the waste sector is an important component in the achievement of a low carbon world Expo, and has become a big challenge to the organizers (Hong et al., 2006; Cao and Zhang, 2010). Measurement and estimation of the carbon footprint are the prerequisite requirements in addressing and understanding the environmental impact from such huge events.

GHG emission from the waste sector has been studied from different aspects in the past decades (Laurent et al., 2014; Chen and Christensen, 2010; Hong et al., 2010; Habib et al., 2013; Zhao et al., 2009, 2011), while the studies published were primarily concentrated in Europe with little application in developing countries (Laurent et al., 2014). Habib et al. (2013) assessed the implications regarding global warming potential (GWP) from waste management systems using life cycle assessment (LCA) based on the historical development in the municipality of Aalborg, Denmark, and found a continuous improvement in environmental performance from 1970 to 2010, which resulted in a shift from net emission of 618 kg CO_2-equivalent (CO_2-eq.)/ton to net saving of 670 kg CO_2-eq./ton of municipal solid waste (MSW) due to the increase in recycling. Laurent et al. (2014) concluded that the LCA results were strongly dependent on the local conditions of each waste management system, such as waste composition or energy system. Zhao et al. (2009) compared six scenarios for waste management in Tianjin city, China, and 467.34 mg CO_2-eq. per year was released from the MSW. The weak point is that most of the inventory data, such as the transfer co-efficient in landfill and incineration, are borrowed from other published reports, which does not reflect the real situation of Tianjin. To investigate trade-offs between economic factors and GHG emission mitigation in the waste sector, Zhao et al. (2011) also assessed and compared the GHG emission and the cost of Tianjin’s MSW management system by combined LCA and life cycle costing (LCC), and it was found to have the highest GHG emission and lowest cost in the current situation. Hong et al. (2010) estimated the environmental impact of the four most common municipal solid waste treatment systems of landfill, incineration, composting + landfill and composting + incineration in Suzhou city, China, and the technologies were found to significantly contribute to GW and increase the adverse impact of non-carcinogens on the environment. Direct CH_4 emission contributes the most to the potential impact from landfills. In addition, some of the reported works focus on single waste treatment processes, such as landfilling, incineration, or composting (Chen and Christensen, 2010), which provides some database for the study of scenarios in waste management. To the best of our knowledge, there are still no reports concerning tourist waste, for which the composition is somewhat different from MSW, and the establishment of inventory data from the working treatment processes will also contribute to obtaining a more accurate result and reflecting the local situation.

This study focused on the performance of the waste management system during an Expo event, and the corresponding environmental impacts, risks, and sustainability were examined and assessed. Two scenarios for the waste sector in practice and in the plan of Expo Shanghai 2010 were addressed and compared. The specific objectives were to answer the following questions: (I) what are the environmental burdens associated with the current waste management system in Expo Shanghai 2010? (II) What are the potential GHG contributors and savers in the waste sector in Expo Shanghai 2010? (III) How do we improve the waste management system to reduce these corresponding environmental impacts?

1. LCA processes

1.1. Basic information on waste management system in Expo Park

Shanghai Expo, 2010 ran for 184 days, and 73,084,400 participants joined in this program (Shanghai Expo Official Website, 2010). It is important to note that a record of 1.03 million visitors was reported for the single day exhibition on October 16, 2010. Usually, visitors spent more time in the Pudong area, and thus the distribution of tourist waste in Puxi and Pudong areas was around 1:3. Three types of wastes, *i.e.*, food waste, construction and demolition (C&D) waste, and tourist waste, were generated in Expo Park, and the total amounts of tourist waste, food waste and C&D waste were 28,219 tons, 7441 tons and 23,737 tons, respectively. To comply with legislation and management of waste reduction and recovery in Expo 2010, some emerging waste treatment processes were also applied in the park, *i.e.*, the extraction of fat and oil from food waste, and the recycling of construction and demolition waste on-site, and thus the environmental impact of the food waste and C&D waste disposal were not considered here due to the lack of accurate data. Particularly, the waste collection systems in Expo Park were new, and the waste was collected by an advanced enclosed aero-dynamic system and electric-powered trucks.

The tourist waste was the most important part of the waste sector in the Expo Park, with around 0.386 kg tourist waste per visitor, which was mainly composed of 25% paper, 20% plastic, 0.3% metal inorganic matter, 1.45% glass inorganic matter, 50% organic matter, 1.85% textile and 1.4% wood. Clearly, the waste composition here is special, with higher plastic and paper content and lower food waste compared to MSW. Thus the corresponding environmental impact will also be different. The tourist waste was planned to be disposed in Phase IV of Laogang Landfill, with the treatment capacity of 6300 ton MSW/day. Another waste-to-energy incineration facility, located in Jiangqiao of Jiading District, was also involved in the waste management Plan, with a treatment capacity of 1500 ton MSW/day (Shanghai Environmental Online, 2010).

1.2. LCA model and system boundary

To identify the GHG emission and environmental impacts, LCA was applied to model the scenarios, since it can avoid a narrow outlook on environmental concerns by compiling an inventory of relevant energy and material inputs and environmental releases, and is also recognized as a valuable method for assessing direct and indirect impacts of waste systems. To

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make good use of LCA in waste management, some computer models have been developed, and the EASEWASTE model (Version 2008, kindly provided by Technical University of Denmark) is one of the active models still under development. As a process-based model, it contains a database including all options in the waste management process, as well as external processes that can occur either upstream or downstream of a solid waste management system (Kirkeby et al., 2006), which enables convenient use of the default databases to supply multiplication factors for model parameters. To enable comparability among the different life cycle inventory (LCI) categories, all relative environmental impacts and resource consumptions were normalized into the same units according to different standard references. The normalization was based on global data on global warming impact for the global-scale effect factor (Metz et al., 2007), Chinese normalization references for the standard impact categories (Li et al., 2007b), and European normalization references for the toxic categories (Stranddorf et al., 2005).

The overall inventory of resource and energy consumption in the waste sector is included in the model, and the system boundary starts from the point when waste is generated and ends when it is disposed of in the final waste facilities, as shown in Fig. 1. Both the directly or indirectly emitted pollutants and the avoided impacts are considered. The consumption of diesel fuel, electricity, activated carbon and chemical compounds is specified per ton of waste during the operation process. Emissions associated with the manufacture of equipment for the collection vehicle and vessels and disposal facilities are excluded from this analysis.

2. Results

2.1. Basic operating data for collection and transportation process

Seventy five refuse collection trucks were available in Expo Park, with the average trip distance of 60 km per day. Usually, it takes about 23 km to collect 1 ton of waste in Expo Park (Shi et al., 2006; Wan and Zhang, 2008), with the estimated electricity consumption of 0.32 kWh. An advanced enclosed aero-dynamic waste collection system was also applied, although only 2–3 ton waste was collected per day in practice, much less than 60% of the total waste generated in the Plan, since most of the visitors did not know how to use it (Wan and Zhang, 2008; Wu, 2008).

Two waste facilities were applied for the final waste disposal according to the Plan (Wan and Zhang, 2008). Waste generated in Pudong Park was collected and transported to the Xupu transfer station, and then sent to Laogang Landfill by containerized waterway transportation on a 300/500 ton ship 55 km far away. Waste in the Puxi area was taken around 25 km to the Jiangqiao incineration plant after being transferred in the Huangpu transfer station. The corresponding diesel consumption was 4.81 kg/ton waste for the landfill and 1.47 kg/ton waste for the incineration. In fact, all tourist waste

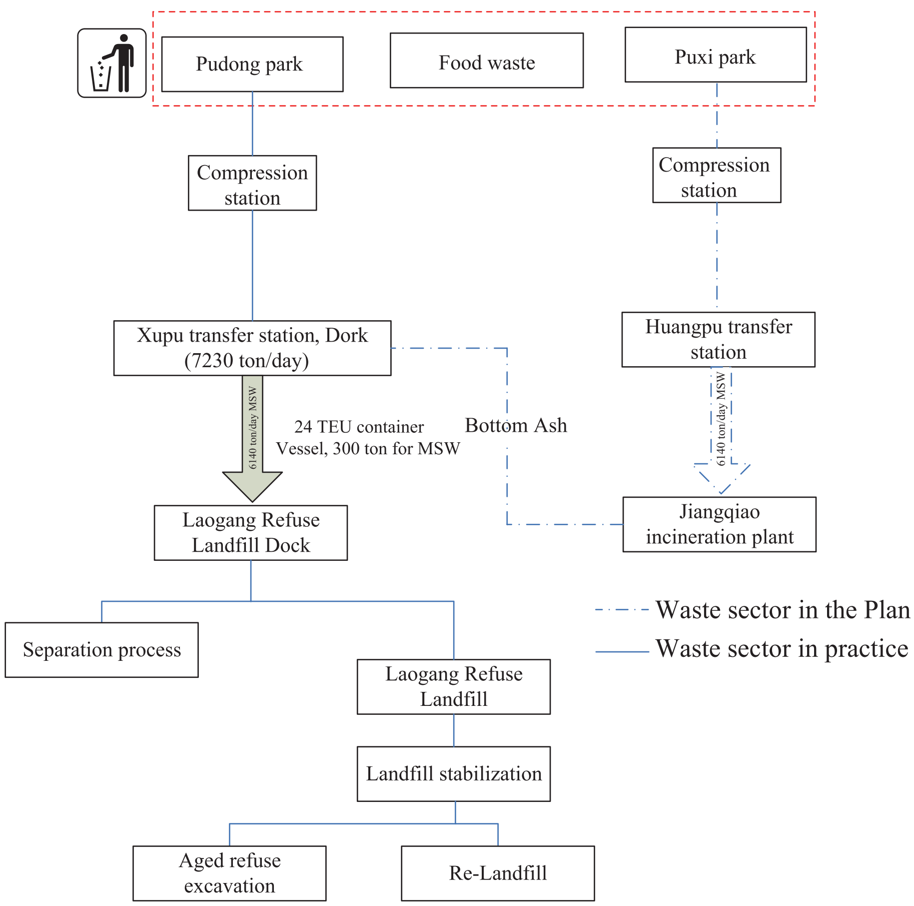

Fig. 1 – The schematic diagram of the waste management process in Expo Shanghai 2010. MSW: municipal solid waste.

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Table 1 – Inventory results of waste sector from Expo Shanghai.

	Collection process	Transportation process	Disposal process
GW (kg CO_2-eq.) [a]	0.36	16.41	107.24
AC (kg SO_2-eq.) [a]	0.00	0.60	3.83
NE (kg NO_3^--eq.) [a]	0.00	0.61	4.27
HTa (m^3 air) [a]	159,845	146,477,354	1,060,664,712
HTw (m^3 water) [a]	3.14	7.44	181.82
HTs (m^3 soil) [a]	0.01	0.04	0.43
ETw (m^3 water) [a]	1.42	4822.80	6946.57
ETs (m^3 soil) [a]	0.00	0.04	−1.65
POF (kg C_2H_4-eq.) [a]	0.00	0.02	0.10
SGWR (m^3 water) [a]	0.00	0.00	3509.52

GW: global warming; AC: acidification; NE: nutrient enrichment; HTa: human toxicity, air; HTw: human toxicity, water; HTs: human toxicity, soil; ETw: eco-toxicity, water chronic; ETs: eco-toxicity, soil chronic; POF: photo-chemical ozone formation; SGWR: spoiled groundwater resources.
[a] The actual waste sector unit is calculated by per ton waste.

collected was sent to the landfill due to the heavy pressure of waste generation. On average, 153.4 ton waste was collected in Expo Park per day, more than the estimate of 124 ton waste in the Plan (Wan and Zhang, 2008). In order to solve this problem, landfill was the only choice, because the waterway transportation capacity and landfill disposal capacity were more resilient, and the corresponding organization process was easier.

2.2. Inventory potential and normalization process of the waste sector

The inventory impact and normalization results of the waste sector in practice and in the Plan from Expo Park are shown in Tables 1 and 2. Positive values usually represent detrimental impacts, while negative values show beneficial impacts originating from material and energy substitutions in LCA results.

2.2.1. Impact of the practical waste sector

For the GHG emission, landfill contributed a total of 107 kg CO_2-eq. per ton waste, and the emissions of CH_4, CO and hydrocarbons were the predominant sources of 166.6, 2.492 and 0.186 kg CO_2-eq., respectively. With regard to nutrient enrichment (NE), NH_3 and P to the marine water in leachate and NO_x to air in landfill gas (LFG) were the main contributors, with the values of 3.822, 0.648 and 0.404 kg NO_3^--eq. For acidification (AC), NH_3 to the marine water in leachate and H_2S to air emission from LFG were the main sources at the rates of 1.917 and 1.59 kg SO_2-eq. per ton waste.

The pollution released from the waste sector resulted in human- and eco-toxicity impacts simultaneously. It was found that H_2S, VOC and unspecified particles emitted to the air were the three main contributors for human toxicity, air (HTa) impact, with the values of 9.39×10^8, 2.52×10^8 and 5.7×10^6 m^3 air per ton waste according to the LCI. The discharge of heavy metals contributed to human toxicity, water (HTw) impact significantly, *i.e.*, Hg, Pd and Zn in landfill gas and Hg in leachate at 80.01, 43.46, 28.15 and 47.74 m^3 water per ton waste. As and Hg to air were the main sources for human toxicity, soil (HTs) impact, with the values of 0.319 and 0.0598 m^3 soil per ton waste. The release of PAH to fresh surface water and the discharge of Zn and Cu to marine water were the main sources for eco-toxicity, water chronic (ETw), with the values of 5214, 1360 and 1213 m^3 water reported.

According to the normalization results, landfill contributed to the AC, NE and GW impacts greatly (as shown in Fig. 2), with the values of 0.1063, 0.0699 and 0.0123 Personal equivalent (PE), respectively. For the toxicity categories, the most critical impact was from photo-chemical ozone formation (POF), followed by ETw, HTa, HTw, HTs and eco-toxicity, soil chronic (ETs), with values of 0.1572, 0.0197, 0.0174, 0.0036, 0.0012 and 0 PE, respectively. In addition, landfill was found to be the only source for spoiled groundwater resources (SGWR) impact, with the value of 25.06 PE.

The highest influence observed in the waste sector was landfill, which constituted around 86.5%, 86.4% and 87.5% of the total impacts, in terms of GW, AC and NE. The organic content of landfilling waste and the potentially high direct release of methane made landfill the main GHG contributor. Moreover, landfill was found to contribute 87.9%, 94.5%, 88.7%, 59.2%, and 81.75% of HTa, HTw, HTs, ETw and POF, respectively, and landfill needs to be improved greatly by the increase of landfill gas

Table 2 – Inventory impacts of waste sector in the Plan.

	Collection process to incineration	Collection process to landfill	Transportation process to incineration	Transportation process to landfill	Incineration	Landfill
GW (kg CO_2-eq.) [a]	0.12	0.24	1.8	10.94	−102.68	71.53
AC (kg SO_2-eq.) [a]	0.0015	0.0031	0.01	0.4	−1.84	2.55
NE (kg NO_3^--eq.) [a]	0.0009	0.00	0.02	0.4	−0.82	2.84
HTa (m^3 air) [a]	5.32×10^4	1.07×10^5	7.07×10^7	9.77×10^7	1.94×10^8	7.07×10^8
HTw (m^3 water) [a]	1.05	2.10	0.53	4.96	35,210.09	121.27
HTs (m^3 soil) [a]	0.0033	0.0066	0.0024	0.03	22.43	0.28
ETw (m^3 water) [a]	0.473	0.947	5.21×10^2	3.22×10^3	1.32×10^4	4.63×10^3
ETs (m^3 soil) [a]	0.0011	0.0022	0.0025	0.024	0.2	−1.09
POF (kg C_2H_4-eq.) [a]	0	0.0001	0.0048	0.015	−0.035	0.068
SGWR (m^3 water) [a]	0	0	0	0	0	2.34×10^3

For GW, AC, NE, HTa, HTw, HTs, ETw, ETs, POF and SGWR refer to Table 1.
[a] The actual waste sector unit is calculated by per ton waste.

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removal efficiency, the reduction of potential GHG emission and other pollutants released thereafter.

2.2.2. Inventory result of the waste sector in the Plan

The inventory impact for waste management in the Plan is shown in Table 2. It was found that landfill was a significant source of CH_4 at a rate of 102 kg CO_2-eq. per ton waste, while −121.8 kg CO_2-eq. saving was observed in the incineration process due to the electricity recovery from the heat energy produced. From the GHG emission reduction perspective, it should be pointed out that the incineration plant is more suitable for tourist waste disposal, since it contains more papers/plastics and low organic matter, which results in a higher heating value and low CH_4 potential, compared to MSW with higher food waste involved (Li et al., 2007a; Shi et al., 2006). However, during the collection and transportation process, the consumption of diesel and electricity led to an increase in GW impact, with the emission of 0.36 and 12.74 kg CO_2-eq. per ton waste, respectively. Release of NH_3 and P to the marine water was the main contributor of NE, with the values of 2.55 and 0.27 kg NO_3^--eq., followed by Total N to the surface water at the rate of 0.0276 kg NO_3^--eq. per ton waste. Meanwhile, discharge of NH_3 to the marine water and emission of H_2S were the main contributors of AC, at a total of 1.32 and 1.06 kg SO_2-eq. per ton waste. The emission savings of SO_2 to air from electricity recovery in incineration plant significantly reduced the same impact by −1.19 kg SO_2-eq.

Release of H_2S, Pb and VOC to air contributed to HTa greatly, with the values of 6.26×10^8, 2.41×10^8 and 3.37×10^8 m^3 air per ton waste, respectively. Unspecified particles represented the main savings of -2.98×10^7 m^3 air for HTa due to the substituted electricity from the coal energy production process in China. For HTw, the main contributors were Hg to the air, Cd to surface fresh water, Pd to air and dioxins, with the values of 3.5×10^4, 250.4, 127.6 and 75.9 m^3 water per ton waste, respectively, while Hg to air and Pd contributed to the HT impact at the rate of 26.01 and 0.20 m^3 soil per ton waste. For ETw chronic, Cd and PAH to the fresh surface water were the main contributors, with the values of 1.05×10^4 and 3890 m^3 water per ton waste. For ETs, Hg, Pb, chloroform and dioxin were the four most important sources, with the values of 1.71, 0.026, 0.006 and 0.002 m^3 soil per ton waste.

Generally, landfill has a great influence on the contamination of groundwater due to the leakage of leachate. Results show that the HTw, HTs, ETw and ETs impacts from the incineration plant were higher than that from landfill, while HTa from the incineration plant was lower than that from landfill. The heavy metal content of waste was found to have a high influence on toxicity impact, especially Hg, and thus the main source of Hg, such as batteries, should be collected and separated at the source. The performance of the flue gas cleaning system, *e.g.*, the removal efficiency for Hg, dioxins and nitrogen oxides, has an important role in the environmental impact results, especially for the toxic impact categories, and should be improved greatly.

3. Discussion

To promote environmental awareness and adopt the green Expo concept, activities like reuse of C&D waste and energy recovery from food waste have been implemented in Expo Park. However, the emergency plan for the waste disposal process, including non-classified collection, non-source sorting, and landfilling only, was implemented during the Expo, although waste was planned to be sent not only to the landfill but also to the incineration plant for electricity production, and the reduction and minimization of waste is one of the promising ways to reduce GHG emission from the Expo.

Source reduction is the only sustainable solution for the endless treatment requirement of the ever-growing waste in cities (Merrild et al., 2008). For the waste concept in Expo Park 2010, material recovery through source sorting and energy recovery from waste-to-energy facilities could offset the GHG emissions from the waste sector. The environmental performance of these two issues was identified, and the total GHG emissions in practice and in the Plan are presented in Table 3.

3.1. Difference in performance before and after source sorting

The environmental performance of the waste sector is influenced by the waste composition, especially by the organic matter and the fossil carbon content. In order to identify the potential implementation of source sorting in China, a survey on the visitors' willingness to sort waste at the source was investigated in our previous work. The result showed that 93.4% of visitors know about the idea of source

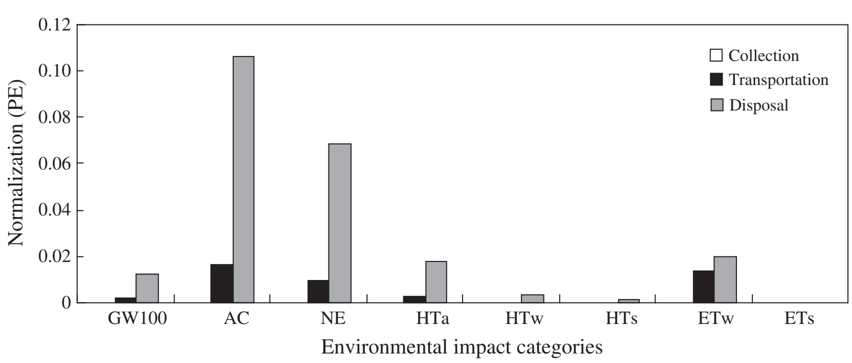

Fig. 2 – The normalization process of the waste sectors in Expo Shanghai. GW: global warming; AC: acidification; NE: nutrient enrichment; HTa: human toxicity, air; HTw: human toxicity, water; HTs: human toxicity, soil; ETw: eco-toxicity, water chronic; ETs: eco-toxicity, soil chronic.

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waste sorting, and 57.4% of them are willing to separate the waste at the source, while only 29.3% of visitors will carry out this action strictly (Shi et al., 2006).

Papers (25%) and plastics (20%) made up around 45% of total waste in Expo Park, while the corresponding amounts in MSW in Shanghai were only 7.3% and 12.8%. Both could be separated from the waste flow at selected points with good organization (Shi et al., 2006; Li et al., 2007a). Fifty percent of papers and plastics were assumed to be separated from the waste management system here, with the aid of manual and mechanical separation, and 11% of water content was removed simultaneously according to our previous research (Li et al., 2007a). Therefore, around 73.37% of the original raw materials were included in waste sector after source sorting, and the corresponding percentages were 17.19%, 13.35%, 2.55%, 62.51%, 2.43% and 1.93% of paper, plastic, inorganic matter, organic matter, textile and wood.

LCA results showed that GW and POF impacts per ton waste from the scenario after waste source sorting were higher than that without source sorting, and the corresponding values of 144.98 kg CO_2-eq. and 0.124 kg C_2H_4-eq. per ton waste were obtained. In addition, other impacts, such as HTa, HTs, HTw, ETs, ETw, NE and AC, were lower, with the values of 1.204×10^9, 0.45, 168, −2.065, 11,614.1 m^3, 4.84 kg NO_3-eq., and 4.39 kg SO_2-eq. per ton waste disposal. For GW, CH_4 from landfill was still the main contributor, with the value of 145 kg CO_2-eq. per ton waste after source sorting, while only 124 kg CO_2-eq. per ton waste was generated before source sorting. It is possible that the higher percentage of organic waste content present in the waste after source sorting was responsible for the higher amount of CH_4 generated from the landfill disposal process. Therefore, waste composition has a relatively high influence on environmental impact, and the fossil-carbon content of residual waste can be lowered dramatically by the efficient sorting of papers and plastics, which will significantly decrease the total detrimental effects on GW impact.

3.2. *Total amounts of environmental impact*

The total waste was around 28,219 tons and 20,704 tons (73.37%) for the final disposal before and after sorting, and the corresponding GHG was about 3499 and 3002 ton CO_2-eq., respectively. Around 497 ton CO_2-eq. saving could be attained due to the source sorting. If the substitute of plastic and paper for virginal materials is considered, the total CO_2 savings would be higher according to reports in the literature (Chen et al., 2007; Merrild et al., 2008; Lazarevic et al., 2010). The total GHG emission in the collection and transportation process was around 10.2 ton and 463.1 ton CO_2-eq. in the entire Expo period, and around 2.71 ton and 123.32 ton CO_2-eq. would be saved through the recycling of paper and plastic at the source.

For the other non-toxicity impacts, *i.e.*, AC, NE and SGWR, the total amounts were 124.98 ton SO_2-eq., 137.58 ton NO_3^--eq. and 9.90×10^7 m^3 water. Moreover, HTa, HTw, HTs, and ETw, ETs and POFh (POF, high NO_x) were 3.41×10^{13} m^3 air, 5.43×10^6 m^3 water, 1.36×10^4 m^3 soil and 3.32×10^8 m^3 water, -4.53×10^4 m^3 soil and 3.24 ton C_2H_4-eq. from the waste sector, respectively. After source sorting, the corresponding AC and NE impacts were around 4.39 kg SO_2-eq. and 4.84 kg NO_3^-eq. per ton waste, with the total amounts of 90.9 ton SO_2-eq. and 100.26 ton NO_3^-eq., respectively. Around 34 ton SO_2-eq. and 37 ton NO_3^--eq. savings were observed. The total amounts of HTa, HTw, HTs, and ETw, ETs and POFh were 2.49×10^{13} m^3 air, 3.48×10^6 m^3 water, 9.38×10^3 m^3 soil and 2.40×10^8 m^3 water, -4.28×10^4 m^3 soil and 2.78 ton C_2H_4-eq. after source sorting. Around 9.14×10^{12} m^3 air, 1.95×10^6 m^3 water, 4.24×10^3 m^3 soil and 9.17×10^7 m^3 water, -2.40×10^3 m^3 soil and 0.67 ton C_2H_4-eq. savings were obtained, respectively. For SGWR, around 2.63×10^7 m^3 water could be saved after source sorting.

At the technology level, we can draw the conclusion that landfill was the main source for the non-toxicity categories impact, and the incineration plant would lead to more toxicity categories impact. It is therefore important to improve the removal efficiency of flue gas from the incineration plant and of landfill gas as well as leachate from the landfill. The energy recovery from waste incineration gives high credits in terms of GW impact, and is thus central for determining the environmental impact of waste management systems. Meanwhile, the waste composition generated in the exhibition was special, with the food waste content reduced while papers and plastics increased greatly, which resulted in high heating value and low CH_4 potential. Incineration with electricity recovery

Table 3 – Environmental impacts of waste disposal processes before and after source sorting.

	Actual waste disposal—before sorting	Actual waste disposal—after sorting	Waste disposal in plan—before sorting	Waste disposal in plan—after sorting
GW (kg CO_2-eq.) [a]	124	145	−18	50
AC (kg SO_2-eq.) [a]	4.43	4.39	1.13	1.79
NE (kg NO_3^--eq.) [a]	4.88	4.84	2.45	2.84
HTa (m^3 air) [a]	1.207×10^9	1.204×10^9	1.07×10^9	1.091×10^9
HTw (m^3 water) [a]	192	168	35,340	35,787
HTs (m^3 soil) [a]	0.48	0.45	23	24
ETw (m^3 water) [a]	11,771	11,614	21,565	21,670
ETs (m^3 soil) [a]	−1.60	−2.06	−0.87	−0.68
POF (kg C_2H_4-eq.) [a]	0.13	0.13	0.05	0.07
SGWR (m^3 water) [a]	3510	3510	2341	2341

For GW, AC, NE, HTa, HTw, HTs, ETw, ETs, POF and SGWR refer to Table 1.
[a] The actual waste sector unit is calculated by per ton waste.

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will be the better choice for such tourist waste, compared to landfilling. To attain a comparable impact savings, energy and material recovery should be the most preferred method in the waste sector for large-scale human activity events, since more valuable materials are present in waste generated in such a concentrated zone. On the other hand, the crowd of visitors leads to a concentrated environmental impact in the exhibition venue, and a higher GHG emission is released through the intensive consumption of resources and energy. A combination of online and offline exhibitions might be a potential way to reduce this environmental impact.

4. Conclusions

The GW impact from the waste management system was around 124 kg CO_2-eq. per ton waste, with the total amount of 3499 ton CO_2-eq. in the actual scenario of the 2010 Expo. Around 497 ton CO_2-eq. might have been saved if source sorting had been implemented. H_2S in landfill gas contributed to human toxicity, air (HTa) impact greatly, and the main contributor of GW was CH_4 released from landfill gas. For NE, NH_3 and P to marine water from landfill leachate were the main contributors. NH_3 to the marine water and H_2S in air emission were the main contributors from the landfill for AC.

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