City, Culture and Society 2 (2011) 177–187

Contents lists available at SciVerse ScienceDirect

City, Culture and Society

journal homepage: www.elsevier.com/locate/ccs

Urban growth and waste management optimization towards 'zero waste city'

Atiq Uz Zaman *, Steffen Lehmann [1]

Zero Waste SA Research Centre for Sustainable Design and Behaviour (sd+b), School of Art, Architecture and Design, University of South Australia (UniSA), G.P.O. Box 2471, SA 5001, Australia

ARTICLE INFO

Article history:
Accepted 30 November 2011
Received in revised form date 10 November 2011
Accepted 30 November 2011
Available online 24 December 2011

Keywords:
Sustainable waste management
Zero waste concepts
Zero waste city
High consuming cities
Urban growth
Adelaide
Stockholm

ABSTRACT

Today, many developed cities such as Stockholm, and Adelaide are aiming to transform their current waste management practice into a more efficient and sustainable way, called zero waste practice. Increasingly people move from rural to urban environments due to the economic activities and quality of life provided to inhabitants, causing cities to expand. Over-crowded cities are compromising the quality of urban life due to their rapid growth and ever-increasing generation of waste. The concept of the "zero waste city" includes a 100% recycling rate and recovery of all resources from waste materials. However, transforming current over-consuming cities to zero waste cities is challenging. Therefore, this study aims to understand the key drivers of waste management and the challenges, threats, and opportunities in transforming traditional waste streams and optimizing practices toward zero waste practices. Part of this study is an in-depth case analysis of waste management systems in two cities, Adelaide and Stockholm. Cities from high consuming countries, such as Australia and Sweden, have been analyzed based on five waste management contexts: social, economic, political, technological, and environmental. In addition, key drivers are identified. Both Adelaide and Stockholm have the vision to become "zero waste cities". The study concludes that strategies based on tools, systems, and technologies can assist cities in their transformation into "zero waste cities"; however, they must also be affordable, practicable, and effective within their local regulatory framework.

Introduction

Currently, half the world's population lives in urban areas and almost all regions of the world will be predominantly urban by the middle of this century (UN-HABITAT, 2008, p. IX). Urbanization is higher in high-consuming counties compare to low-consuming countries, for instance in Australia, one of the highest consuming countries on earth, almost 89% of people live in urban areas (Lehmann, 2010a, p. 20). Cities that generate economic growth (Lehmann, 2010a, p. 20) create mega-regions, urban corridors, and city regions depending on various urban forms. However, people move from inner cities to "satellite" or dormitory cities and suburban neighborhoods because of more affordable housing and living conditions (UN-HABITAT, 2008, p. IX).

Designing sustainable cities is very challenging. Among all key challenges, waste management is one of the most important challenges for sustainable city design. In high consumption cities in the industrialized world, large amounts of paper waste, over-packaging, food waste, and e-waste are all causing particular problems. "Zero waste" means designing and managing products and processes systematically to avoid and eliminate the waste and materials, and to conserve and recover all resources from waste streams (ZWIA, 2004). Therefore, zero waste cities would recycle 100% of their waste or recover all possible resources from waste streams and produce no harmful waste for our environment. From the holistic point of view, designing zero waste cities is relatively hard to achieve.

Today's consumption-driven society produces an enormous amount of waste. This large amount of waste creates a huge pressure for the city authority to manage waste in a more sustainable manner. Waste management systems have not received as much attention in the city planning process as other sectors like water or energy. Therefore, gaps can be observed in waste management in current city planning.

* Corresponding author. Tel.: +61 08 83027372; fax: +61 8 8302 0211.
E-mail addresses: zamau001@mymail.unisa.edu.au (A.U. Zaman), Steffen.Lehmann@unisa.edu.au (S. Lehmann).
[1] Tel.:+61 8302 0654; fax: + 61 8 8302 0211.

1877-9166/$ - see front matter Crown Copyright © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ccs.2011.11.007

Waste management systems include socio-economic, political, environmental, and technological aspects and have many stakeholders. All these aspects are inter-related and dynamic in nature. Therefore, waste management systems create a complex cluster of different aspects, and functions of this complex cluster are also dynamic and interdependent. Global climate change and its various effects on human life drive current society toward a more sustainable society. Depletion of finite global resources forces us to consider resource and product stewardship. Therefore, "zero waste" management is a holistic view of preventing and managing waste and resources in a sustainable city.

The aim of this study is to analyze the challenges, threats, and opportunities to transform traditional waste management practice toward zero waste practice. Part of this study has been done by case studies of waste management systems in Adelaide and Stockholm and lessons learnt from case studies to identify the key challenges, threats, and opportunities in city design. Waste management systems in Adelaide and Stockholm have been analyzed in the contexts of socio-political, economic, environmental, and technological contexts. Based on the case studies and findings, key recommendations are formulated and presented as guiding principles for zero waste cities.

This study focuses on municipal solid waste (MSW). Therefore, heavy industrial, clinical, agricultural, radioactive, and mining waste are excluded from this study.

Materials and methods

The study is based on a literature review and two case studies in Adelaide and Stockholm. Qualitative and quantitative data analysis has also been done and case studies have been conducted to identify five core aspects of sustainable waste management. This study has been conducted with a practice-based research methodology. Practice-based built environment research includes case-based, evidence-based, and performance-based research modes (Lee, 2011). In this study only case and evidenced-based research methodology has been considered to identify the key challenges, threats, and opportunities for designing zero waste cities.

Fig. 1 shows the contexts that have been analyzed during the case studies. Five different contexts, namely, (i) social (ii) economic, (iii) political, (iv) technological and (v) environmental aspects are explored in the case studies of municipal solid waste management systems in Adelaide and Stockholm.

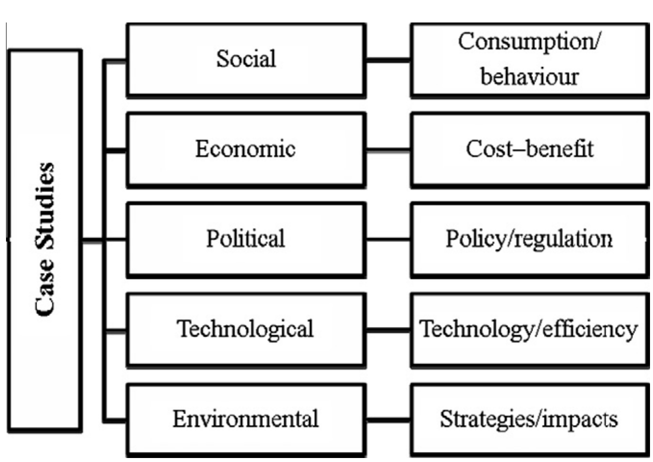

Fig. 1. Framework for case studies.

Municipal solid waste

Waste can be defined in different manners based on various perceptions. For instance, one person might discard something they see as waste; however, the same thing could be treated as a resource by another person. One such example is "e-waste": the "e-waste" of high-consuming counties is used as resources in low-consuming countries. Municipal solid waste includes different sources of generation such as residential, commercial, institutional, industrial, and municipal (Pichtel, 2005, p. 6). The composition of waste also varies depending on its source. Table 1 shows the common municipal solid waste generation as a function of source.

The concept of "zero waste city" from the 'eco-city'

The nature of the city is dynamic and ever changing. In the current over-consuming society per capita waste generation is relatively higher in high-consuming cities compare to low-consuming cities. Currently, many cities are designed or planned based on "eco-city" concepts and those cities are designed to deliver a high quality of life to their residents. Completed "eco-city" projects such as Vauban Freiberg (Germany), Hammarby Sjöstad (Sweden) and uncompleted projects for example Masdar City (UAE), Tianjin Eco-City (China) are designed to offer a good quality of life. All those eco cities are designed by considering sustainable city design practices. Population density of those completed and uncompleted "eco-cities" were between 50 and 150 people/ha (Lehmann, 2010a, p. 111). However, there can be argument on the definition of a true "eco-city"; for example a modern city built with a high ecological footprint is not an "eco-city"; moreover, it is not possible to accommodate all the world's people in the limited global land area in the same design criteria.

The concept of eco-city is generally used in broader sense. Philosopher and author Richard Register first coined the term 'eco-city'(Ekblaw, Johnson, & Malyak, 2009). Eco-city enhances the well-being of its citizens and of society through integrated urban planning and management that fully harness the benefits of ecological systems and renewable energies- aiming for zero-emissions and zero-waste (Lehmann, 2011, p. 853). Therefore, the concept of zero waste is a subset of the concept of eco-city. The concept of the "zero waste city" includes a 100% recycling rate and recovery of all resources from waste materials generated in the city. Cities attract people because of the economic and social activities and quality of life offered to their inhabitants. However, inadequate urban management, often based on inaccurate perceptions and information, can turn opportunity into disaster (UNFPA, 2007, p. 15).

Cities are not only over-populated and over-consuming in nature but also deplete global finite natural resources at a high rate. There is a positive relationship between urbanization and poverty (UN-HABITAT, 2008, p. 24) and the relationship indicates that expanding cities in a

Table 1
Municipal solid waste generation as a function of source (edited and updated) (Pichtel, 2005, p. 6).

Generation sources	Composition types	Excluded waste fractions in this study
Residential	Food scraps, food packaging, cans, bottles, newspapers, clothing, yard waste, old appliances	Hazardous waste i.e. battery, paints etc.
Commercial	Office paper, corrugated boxes, food waste, disposable tableware, paper napkins, yard waste, wood pallets, construction and demolition waste	Hazardous waste
Institutional	Office paper, corrugated boxes, cafeteria waste, restroom waste, classroom waste, yard waste	Clinical and hazardous waste commonly managed by specialized management authority
Industrial	Office paper, corrugated boxes, wood pallets, cafeteria waste	Heavy industrial waste commonly managed by the industry itself
Municipal	Litter, street sweepings, abandoned automobiles, e-waste, some construction and demolition (C&D) debris	General C&D managed by construction company

sustainable manner is an important factor for global sustainability. How to redesign the existing systems, how to design new products for consumption systems and how to design new scenarios (Vezzoli & Manzini, 2008, p. XI) for quality of life are now major questions for planners or researchers.

Previous studies

Two background studies have been explored to understand the generation of waste and valuation of resource in current practices based on two different contexts: (a) philosophical context and (b) material flow context. It is important to understand the philosophy behind current overconsumption practices, the cause of the depletion of resources and the generation of the huge amount of waste in our everyday life. The following paragraphs discuss some background about consumption of resources and material flow in cities.

Consumption and waste generation

To develop strategies to transform cities into zero waste cities it is important to discover the reasons why our society produces so much waste. Environmental ethics, valuation of resources, human behavior, individual and social perceptions on waste and resources, social and environmental well-being, economic development, conservation of global resources, technical improvement, and the interrelations between these things are important to understand when developing holistic zero waste management systems. However, very few researchers have tried to establish the linkages between those aspects in a holistic point of view.

Generation of waste has a direct relationship with the consumption of resources. Today, our society is consumer driven in nature where high consumption is the way of getting recognition and being treated as an identity in the community. On the contrary, consumption was the reverse of noble for Aristotle (Sagoff, 2001, p. 474). According to Sagoff, there are two concepts of consumption: (i) getting and spending resources and (ii) depleting finite resources (Sagoff, 2001, p. 473). Therefore, consumption is the acquisition and use of resources which leads to the depletion of earth's limited resources. Therefore, it is important to understand human behavior in the context of consumption and generation of waste.

It is difficult to place a monetary value on natural and environmental resources because the "value" varies according to our desire and inclination and is also embodied in our culture (Foster, 1997, p. 3). We cannot do a consistent non-anthropocentric valuation (Hargrove, 2003) using "cost-benefit analysis", "contingent valuation", "existence value" or "hedonic pricing" because people's judgment not only includes preferences about well-being but also various ethical principles, values, commitments, and so on (Foster, 1997, pp. 21–43). Therefore, knowledge gaps exist in understanding different environmental philosophies as well as in valuation of environmental resources.

Approximately 40% of the carbon emissions in the UK have been attributed to household and transport behavior (UK Government data, 2010). Behavior change and consumer behavior at an individual level is influenced by views and attitudes people hold around household goods, energy habits, purchase, the use of domestic appliances and transport behavior; however, to influence and change these values, attitudes and beliefs of citizens in relation to their consumptive preferences and patterns is very difficult and policy initiatives will therefore need to increasingly focus on the facilitation of 'sustainable behaviors'.

Material flow in cities

We can measure material flow through cities by measuring the materials and energy entering the city as needed products and leaving as wastes (Ackerman, 2005). Different researchers have studied the material flow of cities and found that recycling (Sinha & Amin, 1995; Ackerman, 2005; Kofoworola, 2007; Lehmann, 2010b) is one of the key issues in sustainable waste management. However one study, "Towards the Sustainable City", conducted by the UK Engineering and Physical Sciences Research Council (EPSRC) to understand the city as a system (Leach, Bauen, & Lucas, 1997), found that "recycling wastepaper may not be the best use" rather than incineration or digestion as those technologies have lower environmental impacts in certain circumstances.

Many studies have been done in different cities to design effective waste management systems aiming at zero waste, including studies in Masdar city (Nader, 2009), Tshwane (Snyman & Vorster, 2010), Taiwan (Young, Ni, & Fan, 2010), India (Colon & Fawcett, 2006), Australia (Clay, Gibson, & Ward, 2006), Greece (Malamakis et al., 2008), and England (Phillips, Tudor, Bird, & Bates, 2011). However, there have been very few studies on a holistic approach to zero waste cities.

No single strategies can solve today's waste problems. Therefore, a holistic approach to material flow within cities and long-term sustainability concepts are required to design a truly sustainable zero waste city.

Municipalities will need to answer questions in regard to their plans to improve their resource recovery performance (assessed in terms of per capita waste generation, per capita landfill disposal, and resource recovery rates – compared to international best practice benchmarks), such as: What additional resource recovery facilities are needed in order to meet the various targets, what level of capital investment will be required, and where will these new Advanced Waste Treatment (AWT) facilities be constructed? What can be done to improve performance? Obviously, if waste generation levels continue to increase (as predicted), much more material will need to be pulled from the waste stream in order to meet higher recovery targets.

Study areas

Case studies have been done by analyzing the waste management systems in Adelaide and Stockholm in the context of waste generation, management, treatment, and environmental impacts. Background information about Adelaide and Stockholm is given below:

Adelaide, Australia

Adelaide is the capital city of South Australia and comprises 19 local council areas. A total of 1089,728 inhabitants live in a 841.5 km^2 urban area (UN-HABITAT, 2010). Population growth rate was 3.3% in 2001–2006. Therefore, the city of Adelaide is growing rapidly compared to other cities in high-consuming countries. Adelaide is among the high income and consumption group compared to cities around the globe. Australian per capita GDP was US $41,300 in 2010 (CIA, 2011). Almost 85% of population in South Australia live within the Adelaide metropolitan area.

Adelaide City Council (ACC) is responsible for waste management in Adelaide central business district (CBD). Zero Waste SA (ZWSA) is a South Australian state government organization established by legislation called *Zero Waste SA Act* (2004). ZWSA enables people to improve their recycling and waste avoidance practices at home, work, and industry (ZWSA, 2011).

In the context of waste management systems, Adelaide has a high percentage of waste collection systems compared to other capital cities in Australia. Container deposit legislation was adopted in 1977; therefore, recycling of different packing containers has been practiced for more than three decades. Zero Waste SA is working to achieve a zero waste area in South Australia.

Stockholm, Sweden

Stockholm is the capital city of Sweden with 847,073 inhabitants (2010) living in a 188 km^2 land area and the population density is 4503 person/km^2 (Statistics Sweden, 2010; USK, 2011). As one of the high income countries, Sweden's per capita GDP was US$39,000 in 2010 and Stockholm accounts for about 28% of the gross domestic product (Indexmundi, 2011).

Stockholm is one of the leading cities in Europe with high environmental standards and has ambitious goals for further environmental improvement. The Municipality of Stockholm is responsible for the waste management system in the capital. Avfall Sverige is an organization that supports all municipalities in Sweden. Stockholm municipality started a project called "Vision Stockholm 2030" for Stockholm's sustainable development in the future. Stockholm has established the goal to be fossil fuel free by 2050 (City of Stockholm, 2009). One of the key objectives of the 2030 vision is transforming Stockholm into a resource-efficient region (RUFS, 2010).

Results and discussion

MSW management in Adelaide

Waste management systems in Adelaide include recycling, composting, resource recovery, and landfills. Currently six landfill sites – Inkerman, Nuriootpa, NAWMA, Dublin, Southern Waste Depot, and Southern Region – serve the Adelaide metropolitan region. Approximately 60 million cubic meters of airspace is available which could serve Adelaide for the next three decades (ZWSA, 2005). As a part of South Australia's Waste Strategy 2005–2010, ZWSA has implemented and conducted different measures to reduce the total waste volume and divert waste from landfills.

Landfill tax has been increasing every couple of years to encourage people to do more recycling and less landfill and the per ton fee for landfill in 2007–2008 was AUS $23.40 (ZWSA, 2009b). Out of almost 3.6 million tonnes of waste generated in 2006–2007 in South Australia close to 2.5 million tonnes was recycled, which still leaves 1.1 million tonnes being disposed of in landfill (ZWSA, 2009b). Around 69.5% of waste was recycled and 30.5% was taken to landfill in 2007. Landfill quantity has dropped from 2006 to 2007 to its lowest level in the last five years in Adelaide (ZWSA, 2009a). According to ACC, Adelaide City Council alone earned about AUS $7 million net a year in revenue from Wingfield landfill, and produced 20.9 MW from the methane gas from the six landfills.

ACC is introducing different approaches to improve recycling and resource recovery from waste and to ensure less waste goes to landfill. ACC introduced "Bio-Basket" and currently approximately 1250 city of Adelaide residents received bio-baskets to collect green organic waste.

MSW management in Stockholm

Waste management in Stockholm uses similar technologies to Adelaide. However, in Stockholm a major part of MSW such as combustible waste like paper, plastic, and C&D are treated by incineration; organic wastes are treated by composting or anaerobic digestion. Stockholm is promising to implement extended producer responsibility (EPR) for most of the major products such as e-waste, cars, hazardous waste etc. in which industries take care of their own wastes. Now under EPR programme, only packaging and end -of -life vehicles are collected and managed in Stockholm (Table 2).

A total 3925 tonnes of food waste are collected from households and 1440 tonnes are treated by digestion, 1485 tonnes are treated by central composting and the remaining 1000 tonnes are treated by home composting. Total bulky waste collected from recycling centers is

Table 2
Waste collected and recycled under extended producer responsibility tools in Stockholm.

Types of waste	Tonnes
Newspaper	540,506
Cardboard and packaging	4251
Glass	13,794
Metal	625
Plastic	717
Lead batteries heavier than 3 kg	1350
End-of-life vehicles	14,400

73,200 tonnes and total bulky waste collected by recycling contractors is 59,518 tonnes.

In the context of corporate producer responsibility, the following amount of waste was collected and managed in 2006.

In 2006, 1.75 kg/person of battery waste was collected in Stockholm city and 29,957 end-of-life vehicles were collected in Stockholm County. The average weight of the vehicles was 1.2 tonnes; adding the 12,000 scrapped cars in the city gives 14,400 tonnes.

Municipal solid wastes as well as commercial and industrial wastes are managed by 13 waste recycling and treatment facilities in Stockholm. Among all treatment facilities in Stockholm, 5 of them are government-owned waste treatment facilities which treated 746,742 tonnes of solid waste in 2006. Nine private waste recycling and treatment facilities treated 985,877 tonnes of waste in 2006, which is more than the government treatment facilities.

Fig. 2 shows the waste management systems in Adelaide and Stockholm. The pie diagram of waste management systems in Adelaide shows that recycling of waste is the major waste management method, with 54% of waste being recycled in 2010. Landfill is still significant: around 38% of waste went to landfill in 2010 and the rest of the waste was composted (8%). On the other hand, the waste management pie diagram for Stockholm shows that 59% of waste was incinerated in 2010, 31% was recycled and around 10% went to landfill in 2010. However, waste data for Stockholm was taken from national data due to data unavailability and the figure was created assuming national data also represents main capital city data.

Table 3 presents the summarized findings of the five contexts including social, economic, political, technological and environmental context with majors key indicators for Adelaide and Stockholm.

Challenges in transforming cities into "zero waste cities"

From the case studies, it is evident that waste management systems have social (consumption and generation of waste), economic (waste cost and benefit), political (waste

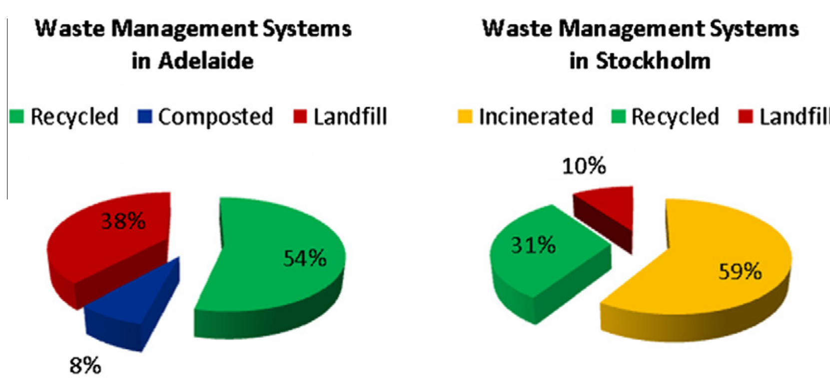

Fig. 2. Waste management systems in Adelaide (a) and Stockholm (b).

Table 3
Key features of waste management systems in Adelaide and Stockholm.

Key sectors	Indicators	Adelaide	Stockholm
Social	Consumption	High consumption	High consumption
	Generation of waste (kg/person/year) in 2010	566 kg	480 kg
Economic	Purchasing power parity*	US $889.6 billion	US $354 billion
	GDP per capita in 2010*	US $41,300	US $39,000
	Landfill tax/ton	US $25 (2007)	US $67.5 (2007)
	Landfill disposal cost	US $70	US $40.5
Political/ regulatory	Key waste regulations	Container deposit legislation 1977	Landfill tax in 2000
		Environment Protection Act 1993	Ban combustible waste to landfill in 2002
		Zero Waste SA Act 2004	Ban organic waste to landfill in 2005
Technical	Waste technologies	Composting, anaerobic digestion, incineration and landfill	Composting, thermal treatment and landfill
	Priority methods	Recycling, EPR	Recycling, EPR
Environmental	GHG emissions* (2008)	3% (16MT/yr)	2.92% (1.85MT/yr)
	Environmental targets	60% Diversion by 2012	Zero waste by 2020
		75% Diversion by 2015	Vision Stockholm 2030

* National average. EPR = extended producer responsibility. Adopted from (Bartelings, Beukering, Kuik, & Oosterhuis, 2005; ZWSA, 2006; Stypka, 2007; ZWSA, 2007; APH, 2008; Swedish EPA, 2008; DCC, 2009; UN-HABITAT, 2010; Avfall Sverige, 2011; CIA, 2011; EPA-SA, 2011).

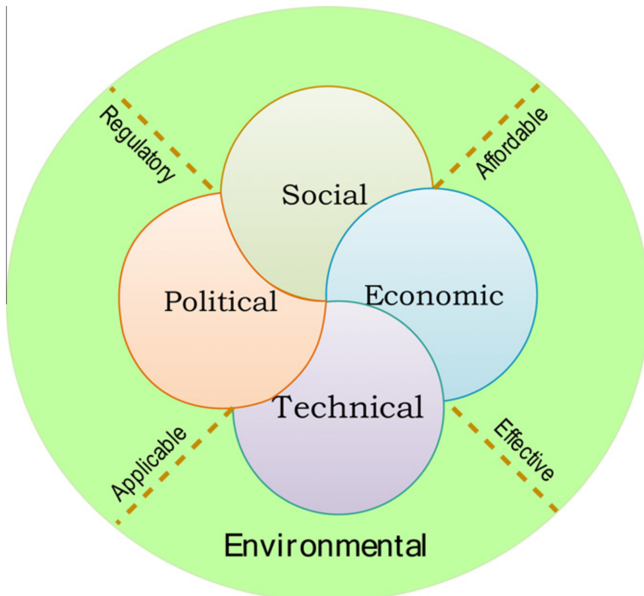

Fig. 3. Spheres in a sustainable zero waste city (Zaman & Lehmann, 2011).

regulation and laws), technological (various waste treatment technologies), and environmental aspects. All these aspects create a complex cluster in our society.

Therefore, cities are very dynamic in nature and combine with different complex spheres. Moreover, cities in one region are different from others due to geographical and environmental differences. Consequently, it is not easy to understand the dynamic nature of the factors involved in city development without holistic research approaches. Fig. 3 shows the complexity in designing zero waste cities, where the environmental sphere works as a rim for all other spheres such as social, economic, political, and technological, and all those spheres are dynamic in nature.

This study identified five core aspects that are most important in transforming cities into zero waste cities. The tools, methods, or strategies developed for recycling or managing waste in zero waste cities should be affordable in the socio-economic context, regulatory or manageable in the socio-political context, applicable in the policy and technological context, effective or efficient in the context of economy and technology, and finally all these aspects should be directly related to environmental sustainability.

Depletion of material and resources caused by inappropriate and outdated design and production methods

To make the "zero waste city" concept a reality, we will need to rethink the way we design, produce, maintain/operate, and recycle all products, buildings, neighborhoods, and cities. Much of the future energy and resource consumption of cities is inscribed and defined in the physical design of cities and their infrastructure. How can we design and construct our cities to overcome the challenges of urbanization while enabling all residents to have access to the full benefits of city life?

Some of our cities have existed for a very long time and one can learn a great deal from their history, for instance, from how cities have become resilient in the face of extreme situations and challenges, and how cities have been built and extended with the ecosystem in mind (Lehmann, 2011). Today we stand at a crossroads in history concerning the future of our cities. Many cities have been characterized by rapid urbanization over the last two decades. Just think how fast Asian cities have transformed during this short period, such as Shanghai, Bangkok, Hong Kong, Jakarta, Singapore and so on. But are these changes always heading in the right direction? Are they part of the necessary transition toward a low-carbon world that we need to make?

Cities are already systems under stress. The current development paradigm in most of the world's cities, based on ever-increasing consumption of resources and ignorance about resource recovery, is absolutely unsustainable, and urban planners and architects have to find a new one.

Today we know that rapid urbanization and climate change are inextricably linked. Global population growth means growing cities and increasing urban development. Unfortunately, most cities in China and India are using the developed, industrialized world's model of high consumption to drive their GDP growth, but this destroys the ecosystem. What we need instead is a new model of economic activity which benefits quality of life and allows the ecosystem to recover. Peter Head points toward the amount of land available per person, which has shrunk dramatically over the past 100 years. He notes: "In 1900 it was still 8 hectares, in 2011 it is 2 hectares, and by 2050 it will be just 1.4 hectares, as recent research shows. It is clear from this reduction that we must reduce our human ecological footprint and, at the same time, increase our resource efficiency by a factor of five" (Head, 2008). This means using five times less materials and resources to have the same quality of life. This demonstrates the size of the challenge for all researchers to come up with practical and realistic solutions and new shared values.

At the same time, there is still quite a lot of reluctance to confront climate change and to take measures to reduce our per capita CO_2 emissions. While there has been some impressive legislation – for instance in China, which is aiming for energy consumption per person to be half that of the current level in the European Union at the same level of GDP by 2050, and other countries have adopted similar targets – it is still unclear how to get there in the remaining time. Meanwhile, the United Nations Environmental Program and the International Energy Agency have stated that global action is well short of what is needed to limit global temperature rises to the desired 2 degrees Celsius.

Much of the work in the Sustainable Design and Behaviour (sd+b) Research Centre is about developing better models, making recommendations and establishing guidelines for cities and municipalities to improve their urban governance and help them in this difficult transition phase. We are strongly convinced that Asian cities can use their rapid urban development to their advantage and become leaders for the rest of the world. Resource shortages and climate change must be seen as a global economic opportunity to create new, highly skilled jobs and to build up more expertise in the area of sustainable urban development.

Hyper-consumption levels are a major concern. More important than the sheer number of people on the planet is the way people consume resources. For a long time, wealthy nations have used most resources, but emerging economies are catching up fast, leading to a rapid increase in consumption levels. It is becoming increasingly clear that the consumption of resources now enjoyed in the wealthiest nations will be impossible to sustain worldwide. Developing countries still have the advantage of low consumption and a smaller ecological footprint per person. It is important to understand that developing cities cannot simply develop in the same way as some of the car-dependent unsustainable cities in the US or Australia have developed in the past. They need another model: the "zero waste city".

What does the "zero waste city" look like?

In the new holistic model, we will have to abandon the aspiration to consume more and more, for instance to buy more and more products, and start the transition toward a low-carbon world. This means both making better, more efficient technologies available, and also mobilizing changes in behavior and attitudes. Indeed, 25% of the reduction in emissions will have to come from behavioral change. The new ecological model of doing business and urban development will be about systems integration and activating innovation on all levels. What does the "zero waste city" look like?

- In future, we will be retrofitting existing communities, infrastructure and building fabric at the same time as we develop new ones. Architecture and design will be less about new buildings, but more about retrofitting, urban renewal, and adaptive re-use of existing buildings and neighborhoods to be more resource efficient. We already see examples of old shopping malls being converted into high-density, mixed-use developments.
- In future, food production will be brought back into the city with urban farming, building efficiency will be improved, and public transport will be given priority over private vehicles. Private cars will increasingly be seen as a waste of space in the city, and public space will be upgraded to make walking and cycling more pleasant and safe. In most cities, public space needs significant upgrading, to improve urban waterfronts and the space between the buildings, with better opportunities for social interaction of all generations.
- In future, we will develop sustainable designs inspired by nature, where waste is seen as a resource and organic waste is used as a fertilizer; where new building materials are created from recycled waste; and the potential for renewable energy is fully unleased, harnessing wind, geothermal, solar and biomass resources to feed renewable energy into a smart grid. We will change the way we generate energy and see more and more decentralized systems on roofs and facades, where cities become power stations in themselves, and where all citizens can become energy producers (instead of just being consumers).

In the "zero waste city" strategy, existing cities need to be re-engineered to become more sustainable and resilient. From high-carbon fossil fuel use to low-carbon emission technologies, we will fundamentally change and reshape the way we design, construct, operate, and recycle buildings, neighborhoods, and cities (Lehmann & Crocker, in press). This requires us to think about many things differently than we have in the past, for instance about our emissions-intensive industries, our wasteful supply chains, and our outdated material-inefficient construction methods. In this transition, some cities and industry sectors are going to be leaping ahead while others will be at risk of being left behind. The waste management sector has some of the greatest opportunities to reinvent itself.

Reducing CO_2 emissions while increasing economic growth requires much higher efficiencies in all stages of industrial production and the construction process. The amount of waste from construction is still enormous. For instance, in Australia in 2007, only 52% of all waste was recycled; however, 42% of the recycled waste came from the construction and demolition waste stream; the rest went to landfill.

In the zero waste city, the waste management and recycling sector has the opportunity to reinvent itself

Resource recovery from dumped consumer products is growing in significance, as waste is increasingly seen as a valuable resource. For instance, e-waste and former landfill sites are now investigated for their hidden value. With hyper-consumption becoming the standard, new models of mobile phones and laptops are constantly introduced within shorter and shorter cycles, and the volume of scrap from electronic equipment is growing rapidly from year to year as a consequence of our throwaway society. As an outcome of these high consumption rates, the demand for rare earths and precious metals used in the manufacturing of electronic goods is equally growing, but a few countries control much of the world's supply of the rare earths and metals. These sought-after special metals, with names like palladium, dysprosium and neodymium, are essential for the manufacturing of high-tech products, but they are scarce and have become more and more valuable over the years.

The electronics industry has been warning of dangerous supply bottlenecks and is now searching for new sources. One solution could come from more effective e-waste recycling. To reduce the reliance on imports of rare metals the idea of "urban mining" has recently gained support, where the hidden value in e-waste dumped in landfill is recovered (Jung, 2011). E-waste usually contains all kind of precious metals, such as printed circuit boards in computers, copy machines, and monitors that contain copper, rhodium, lithium, and other precious metals. There are around 20 types of metals that e-waste recyclers extract and which are at least as sought after as gold. Most of them include gallium, a key ingredient in solar cells, and rhodium, which is used in catalytic converters. All are valuable resources that are much too precious to go to landfill or to be burnt in waste incinerators. Some recycling experts already predicted that "in future urban mining of landfill sites could become big business".

The unused potential for recycling e-waste is estimated to be enormous. Until now, the potential for the extraction of rare earths from recycled materials is still largely unexploited. While Sweden achieves recycling rates over 80% for glass and paper, the majority of e-waste is lost as a source of raw materials. Unfortunately, most Swedish e-waste still ends up in incinerators, where veritable treasures literally go up in smoke. For example, for every ton of mobile phones, or about 10,000 units, that are disposed of in an incinerator, around 150 kg of copper, 5 kg of silver and about 100 g of palladium are lost.

The Belgian company Umicore, one of the world's largest recycling providers, recently estimated that there are about 100 g of gold in each ton of e-waste. If electronic waste were systematically and efficiently recycled, companies could at least partially cover their demand for important metals on their own and manufacturing countries would be less dependent on the few mining and exporting countries. But this requires smarter product designs with products that can more easily be recycled, e.g. structured in modules that can easily be disassembled and re-used.

Decommissioned landfill sites are another untapped supply of resources, and are likely to contain tons of precious metals from the days when the concept of recycling was still largely unknown. German experts have estimated that household garbage dumps alone contain enough rare metals to cover the entire German demand for a year. In the same way abandoned landfills contain a huge amount of resources; however, until now the costs of extracting valuable e-waste from these sites have been higher than the expected revenues. A study by the United Nations Environment Programme (UNEP, 2011) arrives at staggering results: recycling rates for 32 of 37 special metals are currently close to zero; less than one-third of 60 metals studied have an end-of-life recycling rate above 50%; 34 metals are under 1%. The study concludes that recycling rates of metals are in many cases far lower than their potential for re-use and that the industrialized countries should radically change their wasteful use of resources.

Extended producer responsibility (EPR) systems need to be introduced and optimized

Product stewardship is an approach for managing the impacts of a product (such as a mobile phone) during its life and at end-of-life. It usually involves a take-back mechanism, where producers of the products need to take these back once the consumer does not use the product any longer. The first take-back system for electronic products was introduced in Germany in 2005 and has been in place since then. However, experiences with this legislation show that it is not enough simply to introduce an EPR system, but in order to be effective its implementation needs constant optimization. The recycling economy of the 21st century requires appropriate adjustments on the way toward the "zero waste city" to ensure collection and recycling systems are as effective as possible. There are some important lessons that can be learnt from the initial introduction of the system.

The German government compelled manufacturers to develop and fund an extended producer responsibility system, which is basically a take-back system where all manufacturers that sell electronic equipment in Germany are required to register. Registration is with the EAR foundation and currently approximately 8000 businesses are registered. Since then, consumers have been able to drop off electronic equipment at one of the country's 1500 community waste collection centers. There, e-waste is prepared for pick up and further processing, which is done by private-sector environmental service providers. Many experts complain that the program is costly and complex and the results are hardly satisfactory: according to recent figures, only 27% of new electronic devices sold end up at these collection sites. To improve the recycling rate, the German government is now running trials to find out whether a special waste container for recyclable materials (the "yellow bin", which is also used for packaging material and metals) could help solve the problem (Fig. 4). This additional bin is expected to be introduced to all households at the latest by 2015, as a new component in the existing system for recycling household waste, which has different color-coded bins for different classes of material such as paper, glass, and plastic. The bin will take small electronic devices, in addition to plastic and metal. However, the system is not without critics: the Federal Environment Agency (UBA) is opposed to the idea, as there could be a great risk of hazardous materials escaping from items like batteries and printer cartridges during processing.

Fig. 4. The yellow bin in Germany takes packaging material, metal, and small e-waste. Agencies are working toward a nationwide introduction of this collection bin by 2015 (Lehmann, 2010b).

Other recycling experts have suggested a voucher system, which could offer incentives to return disused e-waste equipment, especially for mobile phones. This would be beneficial, as currently no more than one in four mobile phones in Germany is being recycled, even though the network operators pay the postage for customers to return the devices.

What can researchers contribute in this process?

Climate change has created a sense of urgency for all in the design, planning, and engineering disciplines. Increasingly it is essential for academics to connect the dots – recognizing the connections and dependencies between seemingly unrelated subjects and systems – and to work across disciplines when conducting research in these fields. Researchers will increasingly team up with government, industry, and communities to find unique and practical solutions for the different needs of cities. In order to meet the global challenges governments will invest more in research and innovation in key areas, such as education and training. The Australian government, for instance, has started an innovation-centered approach to tackling climate change, where researchers are asked to innovate in material efficiency and construction technology, as well as in behavior change, to scale-up clean energy technologies. Education, training, and research are some of the major elements of an overall policy required to bring about the changes associated with adapting to, and mitigating, the impact of climate change. The contribution from universities and researchers to this transition process is of highest significance.

Each city will now need to develop its own targets and implement its own "low carbon zero waste development plan" as a uniquely suitable pathway to become a low-to-no carbon and zero-waste city. Governments are placed in a unique position in history to define and shape new forward-thinking ideas about urbanization that do not simply repeat the mistakes of the twentieth-century industrialized world. But decision makers need to act quickly with bold and visionary policies to draw on the research available for an energy-efficient, low-carbon-economy, zero-waste city that is not dependent on fossil fuels.

Lessons learnt and recommendations for optimization of material flow and resource recovery

The following lessons were learnt from the two case studies, allowing the authors to formulate five key recommendations to optimize waste management:

- *Lesson learnt:* Today's society is very dynamic and is characterized by a high level of consumption. Consequently transforming high-consuming cities into "zero waste cities" is very difficult; however, by first transforming high-consuming lifestyles into comparatively sustainable levels of consumption, it can be done. Personal behavior change has the potential to transform our society from a high-consuming to a low-consuming society. For instance, the introduction of an extended producer responsibility system in Germany turned out to be a costly and complex exercise and did not achieve the desired collection rates, because they failed to mobilize a change in attitudes and behavior. Frequently, a lack of information and services presents barriers to higher recycling rates.

  Recommendation 1: It is essential to understand human behavior in the consumption of resources and generation of waste. "Zero waste city" design strategies are significantly influenced by lifestyle, values, and personal behavior. Raising awareness and educational programs to trigger behavior change are becoming increasingly important.
- *Lesson learnt:* The sheer volume of waste is one of the prime concerns in zero waste cities. Therefore, introducing mechanisms to avoid, minimize or prevent the creation of waste is one of the key challenges for all urban precincts. Sustainable product design and product stewardship could significantly reduce the waste volume during the up-cycling stage of waste generation. Radical waste reduction poses a potential threat for certain waste treatment technologies; for instance, the existing incineration plants constantly require huge amounts of waste to operate and to burn to generate energy, so a significant reduction of waste volume poses a potential threat to incineration technology.

  Recommendation 2: In zero waste city design, material flow of the city should be designed or controlled in a balanced way, considering sustainable design and product stewardship concepts. Technology applied in waste management systems needs to be adaptable to the context of future volume reduction and resource recovery from waste.
- *Lesson learnt:* Regulations, levies and policies influence and drive waste management systems. For instance, the implementation of landfill tax in Stockholm in 2000 diverted waste streams from landfill to incineration. Equally, the ban of organic waste to landfill in 2005 was the catalyst for effective anaerobic digestion and composting systems in Stockholm. Similarly in Adelaide, container deposit legislation was enacted in 1977 which lead to residents collecting and recycling bottles and containers. After putting monetary value and tax incentives on depositing containers, the percentage of recycling of packaging containers has significantly increased, to currently over 75% (in South Australia in 2010 84% of glass bottles and cans are recovered).

  Recommendation 3: Policies and regulations have significantly influenced the development of waste management systems and cities should continue to use them.
- *Lesson learnt:* Innovative technologies for recovering resources from waste are vital for reducing depletion of finite global resources and virgin materials. Most of the time, efficiency and applicability of waste treatment technologies depend on local circumstances; for instance, incineration is extensively used in Sweden to generate electricity and produce district heating. However, the process of incineration terminates resources for a single output of energy gain without seeking any alternative reuse or resource recovery options.

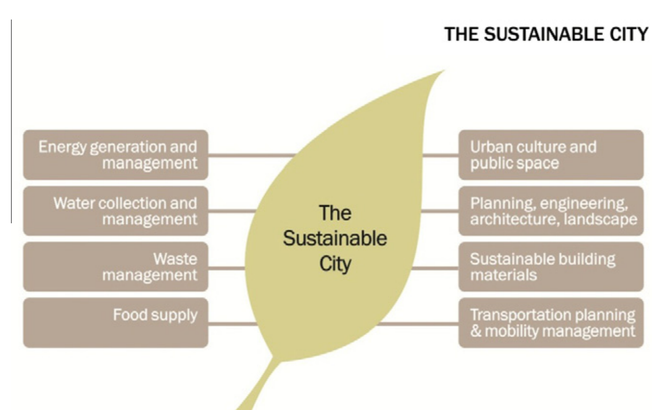

Fig. 5. The zero waste city based on holistic system thinking and integration (Lehmann, 2010b).

Recommendation 4: Selection or application of waste treatment technologies for zero waste cities should consider holistic inter-generation resource recovery and product stewardship, rather than trying to solve a current singular waste management problem disconnected from the wider context.

- *Lesson learnt:* Waste management is an integral part of the sustainable city model (Fig. 5). Therefore, a holistic, integrated cradle-to-cradle approach aimed at avoiding or eliminating waste from the whole life cycle is needed, i.e. from generation to final disposal of waste. Both Adelaide and Stockholm have the vision to become "zero waste cities". However, it would be difficult to transform cities into zero waste cities without a properly defined action plan and a well-coordinated implementation schedule.

Recommendation 5: Holistic zero waste management strategies based on integrated tools, systems and technologies are required for the transition phase of a city; however, these tools, systems and technologies must also be affordable, practicable, and efficient within each local regulatory framework.

Conclusions

Concluding remarks

There have already been major changes to the way society manages waste and both waste generation and recycling rates have been constantly going up. However, to make the recycling economy of the 21st century a reality, behavior change and educational programs to raise awareness are needed. Consumers need to be made aware of the fact that waste is a precious resource – for instance the value of food waste, e-waste, glass and packaging cardboard – that waste is valuable, in the same way as legislation is need to make product manufacturers and construction companies operate in a more material-efficient and less wasteful manner.

This study is an initial step for achieving a better understanding of the complexities in city dynamics within the context of urban waste management. Extensive research is still required for better understanding of the inter-relations of different aspects including human behavior change, waste avoidance, and recycling. Compromising present lifestyles and limiting economic growth might be the most critical challenges for all cities all over the globe.

As global citizens we must realize that we are living on a planet with finite resources. Therefore, efficient use of resources and resources recovery from wastes are vital for global sustainability. A city that can grow its own food, use water from its own areas, produce energy from its own systems, create jobs and economic activities, regulate the whole system efficiently, and finally recover all resources from waste streams can be a true sustainable "zero waste city".

Further study

Additional research will need to be done to gain further knowledge and a better understanding of the influencing drivers in socio-political, economic, and environmental areas of urban waste management systems in regards to urbanization processes. This will include an analysis of different aspects, for example, how human behavior change can influence urban waste management systems or how policy or technology can transform cities into zero waste cities.

Acknowledgments

This article was supported by the Zero Waste SA Research Centre for Sustainable Design and Behaviour (sd+b) at the University of South Australia. The Zero Waste SA Research Centre is an interdisciplinary research center with interest and expertise in a wide range of environmental and sustainability issues. The authors thank two anonymous referees for their insightful comments.

References

Ackerman, F. (2005). 'Materials flows for a sustainable city'. *International Review for Environmental Strategies, 5*(2), 499–510.
APH (2008). *Domestic jurisdictional comparison of waste levies*. Parliament of Australia.
Avfall Sverige. (2011). *Vision för 2020 "Det finns inget avfall"*. <http://www.avfallsverige.se/topmenu/om-avfall-sverige/aarsmoete-2011/> (viewed June 1, 2011).
Bartelings, H., Beukering, Pv., Kuik, O., & Oosterhuis, V. (2005). *Effectiveness of Landfill Taxation*. Vrije Universiteit, Amsterdam: Institute for Environmental Studies.
CIA. (2011). *The World Fact Book*. <https://www.cia.gov/library/publications/the-world-factbook/geos/us.html> (viewed 4th May).
City of Stockholm. (2009). *Stockholm city plan: Summery*. <http://international.stockholm.se/Future-Stockholm/Stockholm-City-Plan/> (viewed 21 May 2011).
Clay, S., Gibson, D., & Ward, J. (2006). Sustainability Victoria: Influencing resource use, towards zero waste and sustainable production and consumption. *Journal of Cleaner Production, 2007*, 782–786.
Colon, M., & Fawcett, B. (2006). Community based household waste management: Lessons learnt from EXNORA's waste management scheme in tow South Indian Cities. *Habitat International, 30*, 916–931.
DCC (2009). *Australia's National Greenhouse Accounts, National Greenhouse Gas Inventory (Accounting for the Kyoto target)*. Department of Climate Change.
Ekblaw, J., Johnson, E., & Malyak, K. (2009). *Idealistic or realistic? A compossion of eco-city typologies*. New York: Cornell University.
EPA-SA. (2011). *Container deposit refunds*, EPA-SA. <http://www.epa.sa.gov.au/environmental_info/waste/container_deposit_legislation> (viewed May 29, 2011).
Foster, J. (1997). *Valuing nature? Ethics, economics and the environment*. London: Routledge.
Hargrove, E. (2003). Weak anthropocentric intrinsic value. In A. La Holmes (Ed.). *Environmental Ethics* (Vol. III, pp. 175–190). Malden, MA: RolstonBlackwell.
Head, P. (2008). *Entering the ecological age: The engineer's role*. The Brunel Lecture Series, London, UK. <http://www.arup.com/Publications/Entering_the_Ecological_Age.aspx> (viewed 20th June 2011).
Indexmundi. (2011). *Sweden GDP – per capita (PPP)*. <http://www.indexmundi.com/sweden/gdp_per_capita_(ppp).html> (viewed 26 May 2011).
Jung, A. (2011). *"Urban mining" could reduce reliance on metal imports*, spiegel, Hamburg, Germany. <http://www.spiegel.de/international/business/0,1518,767178,00.html> (viewed 15 June 2011).
Kofoworola, O. F. (2007). Recovery and recycling practices in municipal solid waste management in Lagos, Nigeria. *Waste Management, 27*(2007), 1139–1143.
Leach, M. A., Bauen, A., & Lucas, N. J. D. (1997). A systems approach to materials flow in sustainable cities: A case study of paper. *Journal of Environmental Planning and Management, 40*(6), 705–723.
Lee, L. (2011). *An integrated design strategy for South Australia: Building the future*. Adelaide.
Lehmann, S. (2010a). *The principles of green urbanism: Transforming the city for sustainability* (1st ed.). London: Earthscan Ltd.
Lehmann, S. (2010b). Resource recovery and materials flow in the city: Zero waste sustainable consumption as paradigms in urban development. *Sustainable Development Law and Policy, XI*(1), 28–38.
Lehmann, S. (2011). Optimizing urban material flows and waste streams through principles of zero waste and sustainable consumption. *MDPI Special Issue: Sustainable Buildings, 3*(1), 155–183.
Lehmann, S. & Crocker, R. (in press). *Designing for zero waste. Consumption, technologies and the built environment*. London: Earthscan.
Malamakis, A., Zotos, G., Karagiannidis, A., Zampetoglou, S., Antonopoulos, I.-S., Kontogianni, S., & Tchobanoglous, G. (2008). 'Developing a holistic strategy for integrated waste management within municipal planning: Challenges, policies,

solutions and perspectives for Hellenic municipalities in the zero-waste, low-cost direction. *Waste Management, 29*, 1686–1692.

Nader, S. (2009). Paths to a low carbon economy – The Masdar example. *Energy Procedia, 1*, 3951–3958.

Phillips, P. S., Tudor, T., Bird, H., & Bates, M. (2011). A critical review of a key Waste Strategy Initiative in England: Zero Waste Places Projects 2008–2009. *Resources, Conservation and Recycling, 55*(3), 335–343.

Pichtel, J. (Ed.). (2005). *Waste management practices: Municipal, hazardous, and industrial*. LLC, Boca Raton: Taylor & Francis Group.

RUFS. (2010). *Office of regional planning, Stockholm County Council*, Office of Regional Planning, Stockholm County Council, Stockholm. <http://www.tmr.sll.se/english/RUFS-2010/> (viewed 25May 2011).

Sagoff, M. (2001). Consumption. In D. Jamieson (Ed.), *A companion to environmental philosophy*. London: Blackwell Publishers Ltd.

Sinha, A., & Amin, A. (1995). Dhaka's waste recycling economy: Focus on informal sector labour groups and industrial districts. *Regional Development Dialogue, 16*(2), 173–195.

Snyman, J., & Vorster, K. (2010). Towards zero waste: A case study in the city of Tshwane. *Waste Management & Research, 29*(5), 512–520.

Statistics Sweden. (2010). *Statistic centralbyrån: Regionala tjänster och indelningar*. <http://www.scb.se/Statistik/MI/MI0802/2010A01/mi0802tab3_2010.xls> (viewed 24 May 2011).

Stypka, T. (2007). *Integrated solid waste management model as a tool of sustainable development*. Stockholm: The Royal Institute of Technology (KTH).

Swedish EPA. (2008). *Swedish greenhouse gas emissions at record low in 2008*, Swedish EPA, Stockholm. <http://swedishepa.com/en/In-English/Menu/GlobalMenu/News/Swedish-greenhouse-gas-emissions-at-record-low-in-2008/> (viewed June 1, 2011).

UN-HABITAT. (2008). *State of the world's cities 2010/2011: Bridging The urban divide* (1st ed.). Earthscan.

UN-HABITAT (2010). *Solid waste management in the world's cities: Water and sanitation in the world's cities*. London: Earthscan.

UNEP. (2011). *Raising metal recycling rates key part of path to Green Economy*, The United Nations Environment Programme. <http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=2641&ArticleID=8750&l=en> (viewed 20 June 2011).

UNFPA. (2007). *State of world population 2007: Unleashing the Potential of Urban Growth*, New York.

USK. (2011). *Folkmängd den 31 Dec 1995–2019*, Stockholm. <http://www.usk.stockholm.se/tabellverktyg/tv.aspx?t=a1&sprak=eng> (viewed 24 May 2011).

Vezzoli, C., & Manzini, E. (2008). *Design for environmental sustainability*. London: Springer-Verlag Ltd..

Young, C.-Y., Ni, S.-P., & Fan, K.-S. (2010). Working towards a zero waste environment in Taiwan. *Waste Management & Research, 28*, 236–244.

Zaman, A. U., & Lehmann, S. (2011). Challenges and opportunities in transforming a city into a "zero waste city". *Challenges, 2*(4), 73–93.

ZWIA. (2004). *Zero waste definition adopted by zero waste planning group*. <http://www.zwia.org/main/index.php?option=com_content&view=article&id=49&Itemid=37> (viewed 16th July 2010).

ZWSA. (2005). *Background paper to South Australia's waste strategy 2005–2010*, Zero Waste SA, SA. <http://www.zerowaste.sa.gov.au/upload/resources/publications/waste-strategy/zw_strategy_background_paper_4.pdf> (viewed May 30, 2011).

ZWSA. (2006). *Position paper: Alternative waste technologies.*

ZWSA. (2007). *Review of solid waste levy.*

ZWSA. (2009a). *Zero waste South Australia: Recycling activity in South Australia.*

ZWSA. (2009b). *Zero waste SA business plan 2008–09 and directions for 2009–11.*

ZWSA. (2011). *Zweo aaste SA: About us*, Zero Waste SA. <http://www.zerowaste.sa.gov.au/about-us> (viewed May 31 2011).