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Article

Challenges and Opportunities in Transforming a City into a "Zero Waste City"

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Abstract: The currently consumption-driven society produces an enormous volume of waste every day. Continuous depletion of natural finite resources by urban populations is leading the globe to an uncertain future. Therefore, to prevent further depletion of global resources, sustainable consumption and a strategic waste management system would be required. It is evident that a significant number of global non-renewable resources such as cadmium, mercury and tellurium will experience permanent shortfall in global supply within the next two to three decades. Astonishingly, the current recycling rate of these very scarce metals is significantly low in all cities around the globe. The concept of the *zero waste city* includes a 100% recycling of municipal solid waste and a 100% recovery of all resources from waste materials. However, transforming currently over-consuming cities into zero waste cities is challenging. Therefore, this study aims to understand the key factors waste management systems in cities such as consumption, resource depletion and possible decoupling opportunity through implementing the "zero waste city" concept. The study proposes five significant principles for transforming current cities into zero waste cities in the context of long-term sustainability. A simultaneous and harmonized application of sustainable behaviour and consumption, product stewardship, a 100% recycling and recovery of resources, legislated zero landfill and incineration are required to transform current city into a zero waste city.

Keywords: resource depletion; sustainable consumption; waste management; behaviour change; zero waste city; zero waste principles

1. Introduction

1.1. Background to Urban Waste Management

Today's consumption-driven society produces an enormous amount of waste. This large amount of waste puts huge pressures on 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 such as water or energy. Therefore, gaps can be observed in waste management in current city planning.

From the time of the first Eve, it took human history over 3 million years to reach 1 billion people in the early 1800s. Now, we gain 1billion people every 12–14 years and the world's population grows by more than 200,000 each day [1].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 [2]. Urbanization is higher in high-consuming counties compared to low-consuming countries. For instance in Australia, one of the highest consuming countries on earth, almost 89 per cent of people live in urban areas [3]. Cities that generate economic growth [3] create mega-regions, urban corridors, and city regions depending on various urban forms.

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 socio-economic and environmental 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 [4]. 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.

Global climate change and its various effects on human life drive current society toward a more sustainable society. Waste is a small contributor to global greenhouse gas (GHG) emissions (<5%) with total emissions of approximately 1,300 $MtCO_2$-eq in 2005, mainly from landfill methane (CH_4), followed by wastewater (CH_4 and N_2O); in addition, minor emissions of carbon dioxide (CO_2) result from incineration of waste containing fossil carbon (C) (plastics; synthetic textiles) [5]. The concept of "zero waste city" would tackle the issue like GHG emissions and the provision of potential specific solutions for emissions reduction and sustainable waste management.

Continuous depletion of finite global resources forces us to consider resource and product stewardship. Therefore, "zero waste" management is a holistic view of managing waste and resources in a sustainable city. 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.

The aim of this study is to analyze the challenges, threats, and opportunities to transform traditional waste management practice into a zero waste practice. The study identifies the key challenges, threats, and opportunities in city design. A holistic "zero waste city" model has been proposed and explained in this study. We are suggesting five principles that would be required for transforming a city to a zero waste city and the principles apply to both industrializing Asian/African cities and also Australian (and presumably other western) cities. The study explores the possibility, challenges and strategies that would facilitate the long journey towards Transforming a City into a Zero Waste City. This study focuses on municipal solid waste (MSW) and reference data are presented on municipal solid waste from different country contexts. Therefore, heavy industrial, clinical, agricultural, radioactive and mining waste are excluded from this study. This study primary focuses on the holistic key principles for the zero waste in a city, therefore, specific waste management provisions such as transport of goods and services; waste collection services *etc.* have not been considered and kept in the delimitation of the study.

1.2. Material and Methods

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 [6]. In this study only case-based and evidenced-based research methodology through peer reviewed literatures have been considered to identify the key challenges, threats, and opportunities for designing a zero waste city. Findings from literature review have been presented below in different sections.

1.2.1. Municipal Waste Management

The term "waste" can be defined in different ways based on variations in understanding and concepts of resource value. Based on the physical composition waste can be liquid, solid and gaseous. However, in this research the term 'waste' refers to solid waste including any trash, garbage, refuse or abandoned materials [7] which have 'no economic value' or functions for anybody [8], consequently, their owner discards, intends, is required to discard [9]. Therefore, definition of "waste" varies depending on various perceptions. For instance, one person might discard something as waste; however, another person could treat the same thing as a resource. One such example is "e-waste". The e-waste of high-consuming countries is used as resources in low-consuming countries. Municipal solid waste includes different generation sources such as residential, commercial, institutional, and industrial [8]. The composition of waste also varies depending on its source.

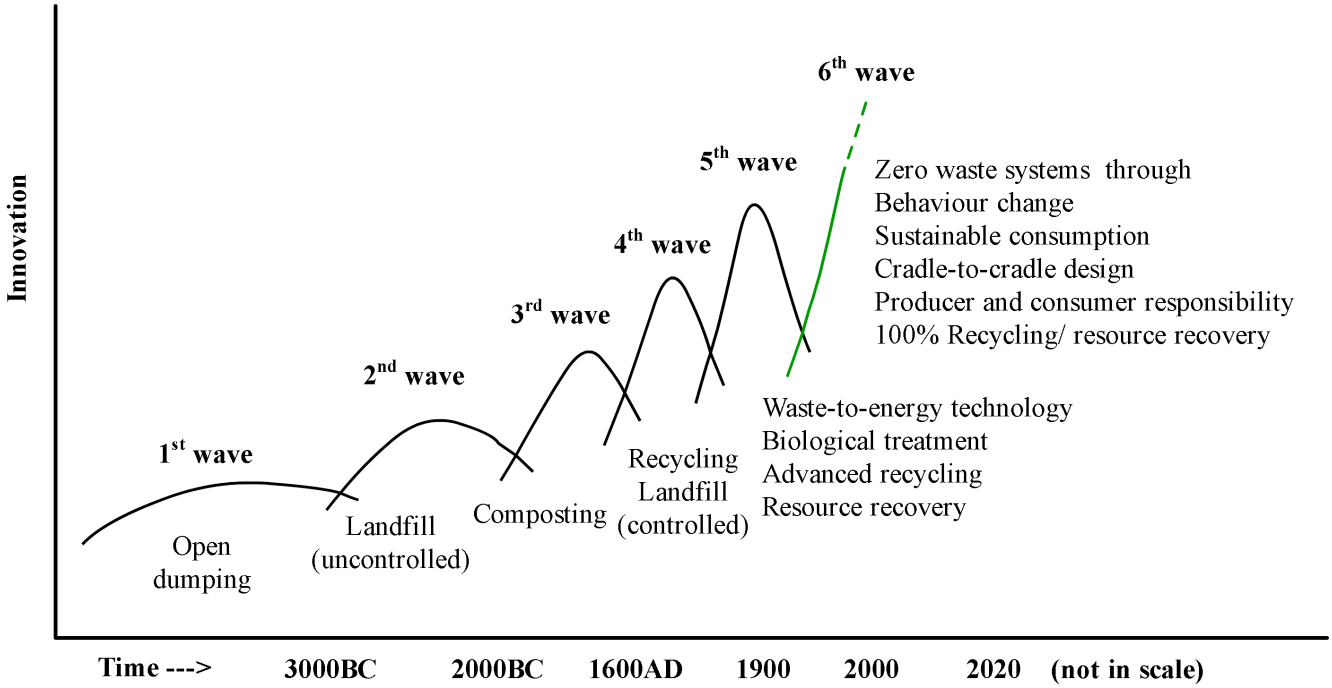
Municipal solid waste management (MSWM) is considered on its generation, on-site storage, collection, transfer, transportation, processing and recovery, and ultimate disposal of wastes [8] and is inclusively linked with economic, ecological and social issues [10]. Management of municipal solid waste refers to the systematic way of managing the waste by the local municipal authority.

1.2.2. The Waves of Innovation in Waste Management Systems

Historically, waste management systems were developed long before the development of our modern civilization as we see it now. Different key innovations have been taken place in waste management development history. If we consider major key innovations in waste management systems, four major innovations can be identified with different major technologies, methods and tools for waste management systems. Figure 1 shows the schematic waves of innovations in waste management systems (time and significance of the waves are not presented in scale) adopted from the UNEP and the Natural Edge Project 2004. The first wave of innovation of waste management systems is open dumping and which is still available in many low-income countries. The second wave of innovation is uncontrolled landfill. The first recorded landfill discovered to date, was used in 3000 BC in Greece. Waste composting is common practice in China and has been used from 2000 BC, which is the 3rd wave of innovation [11].

The 4th wave of innovation is the recycling and controlled landfill. Recycling other than organic waste composting was first recorded in Philadelphia where paper was produced from recycled fiber from waste [11]. After great global oil crisis in 1970s, resource recovery and recycling of waste has been spreading widely around the globe.

Figure 1. Waves of innovation in waste management systems adopted from [11].



Therefore, the 5th wave of innovation of waste management systems in the twentieth century is the waste-to-energy technologies such as incineration, pyrolysis-gasification, plasma arc *etc.*, advanced biological treatment, anaerobic digestion for example, advanced recycling and resource recovery facilities. The zero waste is the 6th wave in waste management and the most holistic innovation of twenty first century for waste management systems for achieving a true sense of sustainable waste

management systems. Zero waste systems include a holistic approach of cradle-to-cradle closed-loop design systems, sustainable resource consumption and resource recovery from waste.

1.2.3. The Concept of "Zero Waste" Systems

The term "zero waste" was first used by Dr. Paul Palmer in 1973 for recovering resources from chemicals [12]. There is no concrete definition that can singularly define "zero waste" concepts. However, a structured definition given by Zero Waste International Alliance [4] states: zero waste is the designing and managing products and processes to systematically avoid and eliminate the waste of materials and to conserve and recover all resources [4]. The concept of zero waste includes different concepts which have been developed for sustainable waste management systems and such concepts include reducing, reusing, redesigning, regenerating, recycling, repairing, remanufacturing, reselling [13-16], zero landfill and incineration of waste, full life cycle of cradle-to-cradle design systems [17-22]. Therefore, zero waste design principle goes beyond recycling to focus first on reducing wastes and reusing products and then recycling and composting the rest [23].

There is a growing interest from architects and urban planners in zero waste concepts and in implementing it by redesigning the urban system with "zero waste" and upgraded recycling infrastructure to achieve the "low-to-no carbon" city districts [24]. The concept zero waste includes recovery of all resources from waste materials and, aiming for a 100% recycling rate for municipal solid waste management systems. The main barriers to zero waste include the following: short term thinking of producers and consumers, lack of consistency in legislation across the states, procurement versus sustainability, the attitude that the cheapest offers get commissioned and lack of community willingness to pay [25].

1.2.4. The Notion of the "Zero Waste City"

Cities are over-consuming and per capita waste generation is relatively higher in high-consuming cities compare to low-consuming cities. 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 [26].

Currently, many cities are designed and 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 like 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 [3]. 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 the entire world's people in the limited global land area in the same design criteria.

Many studies have been done in different cities to design effective waste management systems aiming at zero waste, including studies in Masdar City [27], Tshwane [28], Taiwan [29], India [30], Australia [31], Greece [32], and England [33]. However, there have been very few studies on a holistic approach to zero waste cities.

Cities are not only over-populated and over-consuming in nature but they also deplete global finite natural resources at a high rate. There is a positive relationship between urbanization and poverty [2] and the relationship indicates that expanding cities in a 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 [34] for quality of life are now major questions for planners or researchers.

1.3. Previous Studies

Background studies have been explored to understand the generation of waste by consumption and the valuation of resources in current waste management practices. Global non-renewable resources are also studied in the following part of the paper. It is important to understand the drivers 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 provide some background to the consumption of resources and material flow in cities.

1.3.1. Consumption of Resource and Generation of Waste

The 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 a 'noble' identity in the community. On the contrary, consumption was the reverse of noble for the great philosopher Aristotle [35]. According to Sagoff, there are two concepts of consumption: (i) getting and spending resources and (ii) depleting finite resources [35]. Therefore, consumption is the acquisition and use of resources that leads to the depletion of Earth's limited resources. Therefore, it is important to understand human behaviour in the context of consumption and generation of waste.

Today it is evident in different scientific research reports that rapid urbanization and climate change are inextricably linked especially in micro-climatic urban condition for example air emission, groundwater depletion in urban areas. Therefore, many research studies have been conducted primarily focusing on the climate neutral urban development. 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" [36]. 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.

Current patterns of consumption in the developed world are environmentally damaging [37] and due to the increasingly disproportionate utilization of ecological systems and externalization of negative environmental costs by core industrialized countries [38], the question of sustainable

consumption has a public and policy discourse. Sustainable consumption includes shifting human behaviour from unaccountable and irresponsible individual wellbeing manner to a broader accountable societal and intergenerational wellbeing through more responsible industrial design, valuing our social and individual norms and the fair share of our common goods [39-44].

In our modern society, we put monetary value on environmental resources to understand the problem that we cause on Earth by depleting the natural environment. However, 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 [45]. We cannot do a consistent non-anthropocentric valuation [46] using cost-benefit analysis, contingent valuation, existence value or hedonic pricing because people's judgment not only includes preferences about not only well-being but also various ethical principles, values, commitments, and so on [45]. Therefore, knowledge gaps exist in understanding different environmental philosophies as well as in valuation of environmental resources in the context of consumption and material flow within the city.

1.3.2. Global Non-Renewable Material Extraction

Mankind has long possessed a sense of scarcity, and recognized the limited nature of its resources compared with the extent of its needs [47]. However, the world grew beyond its limit and global resources are depleting increasing over time. The reality of the global limits to growth was first observed in the 1970s when great oil crisis affected the raw material market. In addition, many people believe that, the global economic crisis of 2008 was due to over-consumption and miss-management of the valuation of global natural resources.

A number of studies have been conducted to understand the global resources extraction trends, needs and future stocks [48-50]. One such study has been conducted by Chris Clugston to analyze non-renewable resources (NNRs) scarcity in the near future [51]. The study shows that 88% of NNRs were experienced global scarcity during the period 2000–2008. Approximately 23 NNRs will likely be experiencing permanent global supply shortfall by 2030. Five NNRs such as cadmium, gold, mercury, tellurium and tungsten are identified by the study as having a high probability of global supply shortfall by 2030. A study conducted by the UNEP on metals recycling around the globe and the study showed that the global recycling rate of cadmium was 10–25%, gold (>50%), mercury (1–10%), tellurium (<1%), tungsten (10–25%) in 2010 [52,53]. This trends strongly indicates that at the end of the day, we are not about to "run out" of any nonrenewable natural resources; we are about to run critically short of many. This reality will have a devastating impact on our industrial lifestyle paradigm" [51].

It is important to understand the material flows and material recycling in our society. We can measure material flow through cities by measuring the materials and energy entering the city as needed products and leaving as wastes [54]. Different researchers have studied the material flow of cities and found that recycling [24, 54-56] 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 [57], 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.

1.3.3. Municipal Solid Waste Generation and Management in the Global Context

Parallel to the urbanization across the global cities, the generation of municipal solid waste has also been increasing significantly over the last couple of decades. A number of studies show that the global municipal solid waste generation rate has been increased over time. China is one of the leading developing nations in the world with a per capita GDP of 856$ and 35.8% of urbanized population [58]. China's waste generation rate increased from 0.50 kg/capita/day in 1980 to 1.06 kg/capita/day in 2002 [59,60]. The annual population increase rate from 1981 to 2002 in was 4.35% and municipal waste generation rate increased 3.69% during the same period in China [60].

High revenue countries produce 500 kg and more municipal waste per inhabitant per year and the highest number 730 kg is for the USA, Other emerging countries such as China have rates between 200 and 300 kg. As for the developing countries where data are available, and in particular for the urban areas, the figure is around 150 kg [47]. Current global municipal waste generation rate is 310 kg/capita/year and average generation rate in OECD countries is 580kg/capita/year and at the current rate of San Francisco in USA is 880kg/capita/year. The world currently generates an estimated 2 billion tonnes of municipal solid waste per year. If in 2025 everyone in the world generated municipal solid waste at the current per capita rate in San Francisco that would be 7 billion tonnes [61].

Due to the global population growth, economic development and high consumption of resources, continuously increasing amounts of municipal solid waste is one of the key problems in current urban cities. Therefore, seeking a sustainable solution for waste management is essential.

1.3.4. Decoupling and Improvement of Environmental Burdens

We live in an extremely unequal world where the global resources are unevenly distributed; resources are depleted by a significantly low proportion of global inhabitants and causing irresponsible continuous environmental impacts and affecting the global ecosystems. Since the recognition of sustainable development in 1987 [62], awareness of environmental distribution issues has increased. Decoupling of the environmental burden by efficient resource use can be an efficient tool for the future development; according to a recent study conducted by UNEP and IRP [49] for developing a decoupling strategy for global sustainable development. The study elaborates the concept of decoupling which means using less resources per unit of economic output and reducing the environmental impact of any resources that are used or economic activities that are undertaken. However, considering the rate of the global resource extraction and consumption and the development of efficiency in global technology, it is hard to achieve and meet the required target of decoupling. Decoupling will require significant changes in government policies, corporate behaviour and consumption patterns by the public [49].

The decoupling of economic growth and negative environmental impacts is an effective tool to forecast household waste prevention with recommendations relevant to policy makers and local authorities [63]. Hey and Steen identified three broad strategies for decoupling impacts and economic growth [64] such as dematerialization of the economy as a whole, reducing the spatial range of material flows and optimization of organization. A number of studies discussed about dual decoupling:

fundamental decoupling to restrain the growth of the total consumption of raw materials, the relative decoupling, to reduce through recycling, reuse and the share of the primary resources in the total production of raw material [65].

2. Results and Discussion

2.1. Challenges in Transforming Cities into Zero Waste Cities

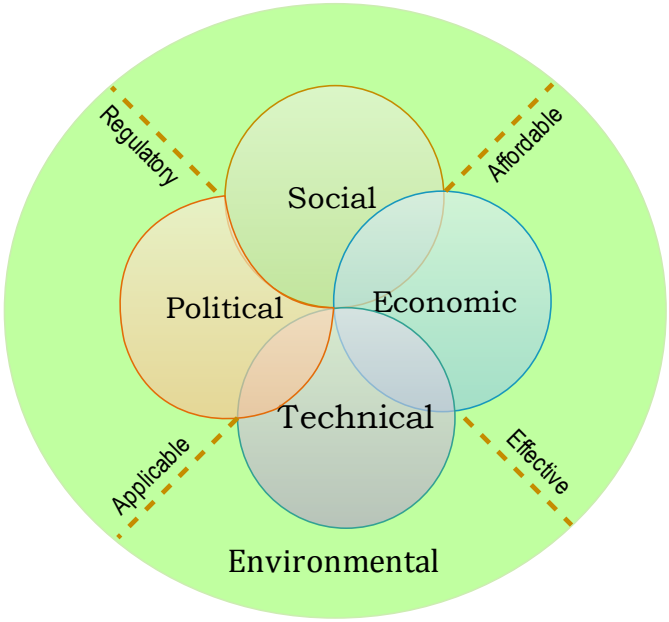
Both global economic growth and consumption rate have increased significantly all around the globe. Waste generation trends indicate that waste volume reduction is one of the key challenges for all cities. High consuming cities such as San Francisco, Copenhagen and Stockholm have been implemented different methods and policies to collect 100% of waste from the source of generation and to manage it properly. These cities are quite successful in the diversion of waste from landfill. However, all these cities are facing problems in the context of long-term sustainable resource recovery. Sweden and Denmark were incinerated around 50% of their municipal solid waste in 2009 to recovery energy and heat. However, incineration depletes the valuable resources such as plastic, paper and different materials that can be reused and recycled.

In low consuming countries like India and China, the volume of waste is increasing significantly over time parallel to the population growth. Consumption of resources has been increasing in China significantly in the last few decades, which indicates potential increasing rates of the waste generation in low consuming cities. Therefore, taking consideration of low consuming city contexts, where consumption level have been increasing and landfill is the main waste treatment technology, waste management in developing cities is also very difficult to manage in a sustainable way. The global waste management and finite resource scenario will be more difficult to manage when low consuming countries reach the same consumption rates as the high consuming countries.

The study also acknowledged that cities are very dynamic in nature and combine different complex spheres. Moreover, cities in one region are different from others due to geographical and environmental factors. Consequently, it is not easy to understand the dynamic nature of the factors involved in city development without holistic research approaches. Figure 2 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.

Figure 2. Spheres in a sustainable zero waste city.



2.2. The Holistic Model of Zero Waste City

In this 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 behaviour and attitudes. Indeed, 25% of the reduction in emissions will have to come from behavioural 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. 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.
- In future, we will generate energy from potential renewable energy sources like wind, geothermal, solar and biomass resources. 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 future, we will develop the zero waste city by producing less waste, by collecting all waste from the city, by 100% recycling and resource recovery and by ensuring sustainable resource use and consumption.

To achieve zero waste city objectives, we propose five inter-connected key principles that need to be applied simultaneously for transforming a city into a zero waste city. The principles are:

1. Behaviour change and sustainable consumption
2. Extended producer and consumer responsibility
3. 100% recycling of municipal solid waste

4. Legislated zero landfill and incineration
5. 100% resource recovery from waste

All these five principles are the key converters for transforming cities into zero waste cities. Moreover, all five principles should be applied simultaneously to get effective results in the transformation process. However, depending on ensemble application of each principle, a long term zero waste city vision would be required because the concept of a zero waste city vision is not only very hard to achieve but also requires long-term initiatives to achieve that. Figure 3 shows the holistic principles for transforming city into a zero waste city.

The zero waste city principles are developed based on waste hierarchy, *i.e.* avoid, minimization and recovery. Behaviour change and sustainable consumption practice will avoid the unnecessary waste generation from product production and use phases. Extended producer and consumer responsibility will ensure the sustainable choice of resource use and ownership of personal waste generation and management. An increased sense of responsibility will also lead to avoidance of waste generation. Resource and product stewardship would minimize the environmental impacts in the long term and ensure the wellbeing of the future generations by protecting resource through a behaviour shift from over-consumption to viable and sustainable consumption. By achieving total recycling of waste and legislation for zero landfill and incineration, a 100% recovery of resources would be possible in the zero waste city and thus ensuring the minimum depletion of finite natural resources.

Figure 3. A holistic zero waste city model, with five inter-connected key principles that need to be applied simultaneously.

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, recycle buildings, neighborhoods, and cities [66]. 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. Our proposed five key principles for transforming a city into a zero waste city are described below.

2.2.1. Education on Behaviour Changes and Sustainable Consumption

Education on behaviour change and a sustainable consumption is the key principle for sustainable waste management solution. Most of the communities on Earth are aware of global climate change and its adverse effects on human life. People have already observed the bad consequences of climate change such as sea level rising, losing land area in Asia, long term droughts in Africa, cyclones and disastrous floods. However, yet there have been little evidence of behaviour change and reduction of consumption. Most of the time people are not willing to change their behaviour and lifestyle even though they are putting enormous pressure on the earth through their high level of consumptions. Therefore, education on importance of behaviour change and sustainable consumption is very important for the waste management sector in the future. Education for sustainable consumption is important for providing knowledge, values and skills to enable individuals and social groups to become driver of change towards a more sustainable consumptive society.

In order to meet the global challenges, governments will need to 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 behaviour 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.

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 of the 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.

There are three complementary ways to achieve sustainable consumption objectives and those are eco-efficiency, de-commoditization and sufficiency [67]. Without achieving the goal of sustainable

consumption, avoidance and minimization of the generation of municipal solid waste would be hard to achieve. The World Bank study shows that 1 billion people from high revenue developed counties generated the same volume of waste (1.4 million tonnes per day) which was produced by about 2.4 billion people in low revenue developing countries [1]. It also showed that the rest of the world population (3.0 billion from average revenue developing countries) produced approximately 2.4 million tonnes of waste per day in 2007 in urban areas.

2.2.2. Extended Producer and Consumer Responsibilities

Extended producer and consumer responsibility is the second principle for a zero waste city. Extended producer responsibility (EPR) is also known as 'product stewardship' principle or the "take back" principle. The concept of EPR was developed in Western Europe in the early 1990s [68] based on the similar concepts of polluter payer and pay as you throw which emphasize environmental sustainability, economic efficiency and the global equity. Extended producer responsibility or product stewardship is a very important tool for the innovative design of product and packaging to avoid and reduce a significant volume of waste generation during the product production process. Extended producer and consumer responsibility is to perform taking accountability of each action and work that one can do. For instance, a Company producing products and goods will be accountable for the environmental burden, pollution and depletion causes by unsustainable producing process. Similarly, when consumers purchase products and goods will also be responsible for their irresponsible consumptions, therefore, extended responsibility should be applied for both producers and consumers.

In addition, 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 twenty-first 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.

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.

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. 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 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.

2.2.3. 100% Recycling of Waste

A 100% recycling of municipal solid waste should be mandatory to achieve zero waste city objectives. Currently, many high consuming cities such as San Francisco, Adelaide and Stockholm are working on a 100% diversion of landfill by achieving 100% recycling of municipal solid waste. A 100% recycling of municipal solid waste would be difficult to achieve for low consuming cities such as Dhaka, Delhi and Lagos. A holistic waste management plan and initiatives can make the 100% recycling objective possible in reality if cities are able to implement the plan effectively.

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. E-waste usually contains many kinds of precious metals such as copper, rhodium, lithium and other precious metals in the printed circuit boards, computers, copy machines, and monitors. There are around 20 types of metals that e-waste recyclers extract and which are at least as sought after as gold including 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 have already predicted that: "in future urban mining of landfill sites could become big business" [69].

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.

100% recycling is promoted as one means of achieving a zero waste city, however, the question remains whether 100% recycling really possible or not. If we can design products with 100% recyclable materials then 100% recycling can also be achievable. Therefore, 100% recycling is significantly dependent on not only the collection of all waste but also on the cradle-to-cradle product design. One can argue on the point whether recycling always a more sustainable approach as compared to energy recovery or not, but considering the long-term sustainable development practice recycling is

desirable than incineration because recycling protects natural resources from depletion for future generation though recycling and reusing rather than depleting resource by incinerating them. Therefore, by achieving a 100% recycling of all municipal waste, further depletion of natural resource would be significantly reduced in future.

2.3.4. Legislate Zero Landfill and Incineration

Zero landfill has gained in significant importance due to increased awareness of resource recovery and greenhouse gas emissions from landfill. Zero landfill is regarded as an important progression in the transformation of cities into zero waste cities. Many cities such as San Francisco, Adelaide and Stockholm among many other high consuming and low consuming cities have been working on a 100% diversion of disposal of waste from landfill. A recent study of CEWEP [70] shows that, Germany reached zero landfill in 2009, which means a 100% municipal solid waste recovery from landfill and it is the first of the EU countries to archive such a zero landfill goal. The Netherlands, Austria and Sweden are about to achieve a zero landfill, in 2009, the recovery rate was 99% of those three countries. In 2009, Denmark and Belgium diversion rates were also among top of the least landfill deposit countries and around 4% and 5% respectively [70]. In many developing countries landfill is still the principle method of managing municipal solid waste, for instance, Bangladesh, India [71,72] any European countries like Bulgaria, Malta, and Rumania [73].

Despite of declining, waste incineration is still on the rise throughout the world, increase the capacity almost doubled from 180 to 350 million annual tons [74]. Waste incineration accounted for a fifth of total municipal waste treated in 2009 in 27 EU countries [73]. Around half of the total municipal solid waste was incinerated in Sweden and Denmark in 2009 around 49% and 48% respectively. Around 2400 incineration plants (commission/under-construction) are available around the globe and in Europe currently 429 incinerations plats excluding hazardous waste incineration plant were operating in 2009 to treat approximately 68.86 million tonnes of municipal solid waste [70]. Considering the true diversion rate of municipal solid waste in Europe would be less than which showed in 2009, because waste are diverted from the landfill but a significant volume of waste are incinerated in the Europe. Therefore, legislative zero landfill and incineration of waste is important strategy for achieving zero waste city objective.

2.3.5. 100% Recovery of Resources from Waste

Success of the sustainable waste management concept depends on a 100% recovery of resources from municipal solid waste. Sustainable consumption, less waste generation, innovative product design, a 100% diversion of waste disposal to landfill and incineration were the primary steps for achieving a 100% recovery of resource from solid waste. Moreover, resource recovery would be desire for the long-term sustainability context by providing the needs of now and in the future. On the contrary, resource recovery from incineration of waste would deplete the potential natural resources that could be further used if not incinerated; therefore, resource recovery from incineration of waste to energy would not be the solution for the long-term sustainability.

Resources 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 being

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 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 Program [48] 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. Therefore, in the zero waste city recovery of all resources would be ensured.

3. Conclusions

3.1. Concluding Remarks

To make the zero waste city concept a reality, we need to rethink the way we design, produce, maintain/operate, and recycle all products, buildings, neighborhoods, and cities. By understanding the complexities of city dynamics within the context of urban waste management, the study proposed five key principles for transforming a city into a zero waste city. It is also important to understand that the development of waste management systems depend on various socio-economic and environmental influential factors. An integrated design strategy including the harmonized application of all these five principles is essential to achieve the zero waste city objectives.

The current development paradigm in most of the world's cities, based on ever-increasing consumption of resources and ignorance about resource recovery, is unsustainable. Consumers need to be made aware of the fact that waste is a precious resource—for instance food waste, e-waste, glass and packaging cardboard have a value. Legislation is needed to make product manufacturers and

construction companies operate in a more material-efficient and less wasteful manner. A new solution such as the zero waste cities concept would need to implement.

3.2. Further Study

Additional research will need to be done to gain further knowledge and a better understanding of the barrier and opportunities of behaviour change and sustainable consumption in the context of waste avoidance. Decoupling of economic growth, technological improvement and potential environmental burden would need to be understood within the product stewardship and resource recovery contexts. Additional study would be done to explore further possibilities though case-study base research method. Further study on the complexity and opportunities in implementation of the five zero waste city principles will also be required. This study primarily focuses on the holistic key principles of the zero waste city, therefore more specific provisions like transport of goods and services or waste collection services have not been taken into consideration.

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