Cloud-based Smart Waste Management for Smart Cities

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***Abstract*— With the ever increasing population, urbanization, migration issues, and change in lifestyle, municipal solid waste generation levels are increasing significantly. Hence, waste management becomes a challenge faced not only by the developing nations, but also the developed and advanced countries. The overall waste management involves three main types of entities: 1) users who generate waste, 2) waste collectors/city admin., 3) stakeholders. Waste management directly effects the lifestyle, healthcare, environment, recycling and disposal, and several other industries. Current waste management trends are not sophisticated enough to achieve a robust and efficient waste management mechanism. It is very important to have a smart way of managing waste, so that not only the waste status is notified in-time when to be collected, but also, all the stakeholders are made aware in timely fashion that what type of waste in what quantity is coming up at what particular time. This will not only help in attracting and identifying stakeholders, but also aids in creating more effective ways of recycling and minimizing waste also making the overall waste management more efficient and environment friendly. Keeping all this in mind, we propose a cloud-based smart waste management mechanism in which the waste bins are equipped with sensors, capable of notifying their waste level status and upload the status to the cloud. The stakeholders are able to access the desired data from the cloud. Moreover, for city administration and waste management, it will be possible to do route optimization and select path for waste collection according to the statuses of waste bins in a metropolis, helping in fuel and time efficiency.**

***Index Terms*—waste management; smart waste management; smart cities; IoT; Cloud of Things; cloud computing; pay-as-you-throw; Big Data; healthcare.**

I. INTRODUCTION

Waste is produced wherever there is life and humans are living. It will be a part of everyday lifecycle as long as the life exists. According to World Bank's review report [1], in 2012, the global Municipal Solid Waste (MSW) generation levels were around 1.3 billion tons per year. This figure is expected to reach 2.2 billion tons per year by 2025. Per capita waste generation rates are between 1.2 to 1.42 kg per person (varying by region, country, and city) per day in the next one decade or so. Further in the report, in region wise waste generation statistics, sub-Saharan Africa approximately generates 62 million tons per year. Statistics for per capita waste generation are low on an average with 0.65 kg/capita/day. However, the span is wide, ranging from 0.09 to 3.0 kg per person per day. Highest per capita in this region is in islands, mainly due to tourism industry. East Asia and Pacific region annually generates 270 million tons of waste. The main contributor in this regard is China, with 70% of the regional total. Per capita average is 0.95 and it ranges from 0.44-4.3 kg/person/day. Eastern and Central Asia, excluding eight countries where data was not available, generate 93 million tons of waste per year. Per capita daily average is 1.1 kg, ranging from 0.29-2.1 kg/capita/day. Latin America and Caribbean generate 160 million tons waste annually with an average of 1.1 kg/capita/day, ranging from 0.1-14 kg/capita/day. Middle East and North Africa generate 63 million tons/year, per capita daily range of 0.16-5.7 kg/capita/day, averaging 1.1 kg/capita/day. South Asia has a figure of 70 million tons annual waste generation, with per capita average of 0.45 kg/day, ranging from 0.12-5.1 kg per person daily.

With the increasing population, increasing urbanization, and change in the lifestyle, waste management has become a challenge not only for the developing countries, but also for the developed ones [2]. By 2050, more than 84% population in the developed countries and more than 64% in the developing ones will be in urban areas [3]. City administrations and waste management organizations in different metropolises face the challenge to provide efficient and effective system to collect, dispose-off properly, and recycle the waste, keeping in view the health standards and environment friendliness. In waste management, collection, transfer, and transport practices are negatively influenced by improper bin collection systems, lack of information about collection schedule, inefficient route planning, insufficient resources, and other factors [2]. Moreover, waste facilities also significantly affect the way waste disposal is done. Inadequate supply, insufficiently equipped waste containers, and longer distance to these containers increase the probability of dumping waste in open areas and roadsides [2] [4]. Relative to recycling, social influences, altruistic, and regulatory factors are some of the key reasons of developing a robust recycling system. Enabling factors, which include technical, cultural, and financial, also affect waste management. Better technology and better ways of handling waste enables a systematic approach in this regard. Improvement in waste management methodology is required to provide effective, efficient, and sustainable solid waste services; which have an influence on many actors as well as are affected by some of them. Better technology will also help in identifying stakeholders [4].

It is evident that a much more efficient and effective waste management mechanism is required, which helps in identifying the stakeholders, informing them in time about what is coming up in the waste and in what quantity. Additionally, the waste related data should be stored in a more accessible location, like a cloud, where stakeholders are able to analyze and adapt accordingly. In this paper, we present Cloud-based Smart WAste Management (CloudSWAM), where waste bins are connected to the cloud and data is stored there in real time. There are separate bins for each category of waste, namely: organic, plastic and bottles, and metal. Equipped with sensors, bins update their status to the cloud and other stakeholders, making it a more efficient and convenient way to handle waste. The waste collection is also done when it is required, helping the waste management to decide a cost-effective route while collecting the waste within a metropolis.

In rest of the paper, section II discusses already done works. Section III is on smart waste management. Section IV discusses the scenarios and advantages associated with smart waste management. We conclude in section V.

II. RELATED WORK

Since smart cities concept is still novel and research and development work is ongoing, not a lot of work is done on smart waste management, making use of the technologies like cloud computing and Internet of Things (IoT). In this section, we present the most relevant related work done in this regard.

Guerrero et al. [2] provide a review of several research papers on waste management also including their outcome of visiting 22 countries in 3 continents. The authors come to a conclusion that all the stakeholders and factors impacting waste management systems are affected by the way waste is collected, separated, and transported for recycling and other disposal. The authors emphasize on the importance of an efficient and smarter way of reporting the waste and creating means for the recycling agencies to analyze the quantity and timing of the generated relevant waste material. Caniato et al. [3] provide a method of surveying solid waste management through the integration of Social Network Analysis (SNA) and Stakeholder Analysis (SA). The outcome of the survey suggest that stakeholders are more concerned about the communication in the waste management and seek improvement in that regard. Moreover, stakeholders' involvement should be more in system development planning and waste management should be redesigned to identify stakeholders as well. Service beneficiaries should directly be made part in order to attain sustainability of the solid waste services. This is possible with more advanced technologies in this area.

Yang [5] state that with the complex situation of rapidly growing population, increase in migration, instable situations in various countries, unavoidable change in the climate, energy and resource limitations, etc. pose a challenge in addressing diverse interests, values, and objectives, inherent among stakeholders. Therefore, a more efficient and effective mechanism is required, such that the stakeholders are aware of what is relevant to them and in what measure. Stakeholders can thereafter prepare and effectively handle the waste. Greene and Tonjes [6] provide an analysis of waste management in New York State, USA. The authors state that in the USA, from 19th century till 1960s, public health was a key driver of waste practices. However, the drivers have shifted to environmental concerns now. This shows the importance of a more sophisticated waste management mechanism. Kollikkathara et al. [7] also emphasize on the same points while discussing USA's waste management trends. Zhang and Huang [8] reiterate the importance of in-time collection of solid waste, since waste management activities result in releasing Greenhouse Gases (GHGs) in to the atmosphere which results in global climate change. Mitigation of GHG emissions is very important and is only possible with timely notification and collection of waste.

Moh and Manaf [9] provide an overview of the solid waste recycling policy in Malaysia. The authors state that even being an Emerging Economy, Malaysia still heavily relies on landfilling as a disposal of waste. This has resulted in space limitation, health issues, and environmental problems. One of the best ways to tackle the recycling issue in Malaysia and other such nations is to have a proper notification and data availability, so that the type and quantity of recycling material is known and stakeholders are involved in the process in an effective way. Al-Jarallah and Aleisa [10] provide a study on characterizing municipal solid waste in Kuwait. The authors mention that the daily average of waste generation is 1.01 kg/person. Most of the waste is of organic matter, comprising 44.4%. Rest is composed of 11.2% film and 8.6% of corrugated fibers as the noteworthy types of waste. In order to have a complete waste management mechanism, it is very important to have a smart way of notifying the quantity of each type of waste and involve the stakeholders effectively. Same is the conclusion of Bing et al. [11], who investigate EU countries waste management mechanisms. Zhang et al. [12] mention in their work that one of the important IoT applicability in cities is food industry. It is very important to monitor, analyze, and manage the food industry and it is possible by keeping track of the organic waste. Provenance of waste also plays an important role in managing food industry and other related processes.

In rest of the document, the entity that collects waste is referred to as waste collectors.

III. SMART WASTE MANAGEMENT

Although the idea of sensors-based waste bins [13] [14] [15] [16], capable of notifying waste level status, is not new to its entirety, however, the goal here is to go beyond an automatic waste bin and make use of cloud computing paradigm to evolve a more robust and effective smart waste management mechanism. Smart waste management is not limited to notifying the trash level. There is a lot associated with it if it is to be called 'smart' in a true sense. Waste management is linked to different types of entities, one of which is stakeholders. Different stakeholders, including recyclers, importers and exporters, food industry, healthcare, research, environment protection and related organizations, and tourism industry are a few examples to mention. It is very important and the whole process starting from waste generation to disposal is tracked in real-time or close to it. Later in this section the importance and related scenarios in this regard are discussed.

The basic form of waste management currently prevailing in most parts of the world is presented in Figure 1.

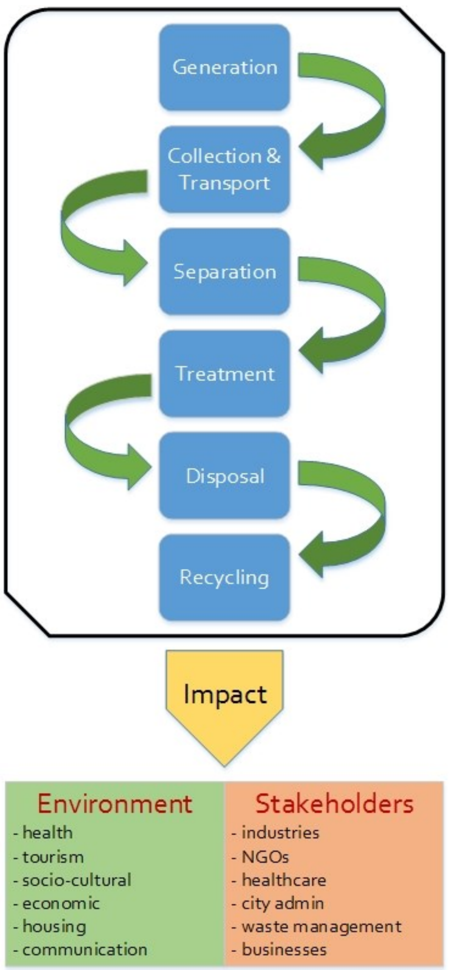

Figure 1. Waste management generic workflow.

It is shown that the whole process of waste management has an impact on the environment as well as stakeholders in different aspects. Environmentally, it effects public health and hygiene, tourism, housing – since it depends a lot on the waste management in a particular area while finding an accommodation, economy, and transport/communication.

In case of stakeholders, it effects various industries, including recycling, disposal, import/export, food, various related businesses, waste collectors, and healthcare, etc.

In the proposed CloudSWAM, each bin is equipped with sensors to notify its waste level. Figure 2 shows the smart bin with (a), (b), and (c) show different bins for each category of waste, namely: organic, plastic/paper/bottle, and metal. In this way, each type of waste is already separated and through the status, it is known that how much of waste is collected and of what type. This method of pre-separated waste is adopted in places like Korea, to name one, and it helps a great deal in efficiently dealing with the waste management process. Illustrative example in (d) shows an alert message once the waste level reaches a particular level where waste collectors have to plan collection of it. While (e) shows an exhausted bin, therefore, the user and the waste collectors are updated without the need of reaching it and/or opening it up to see the status.

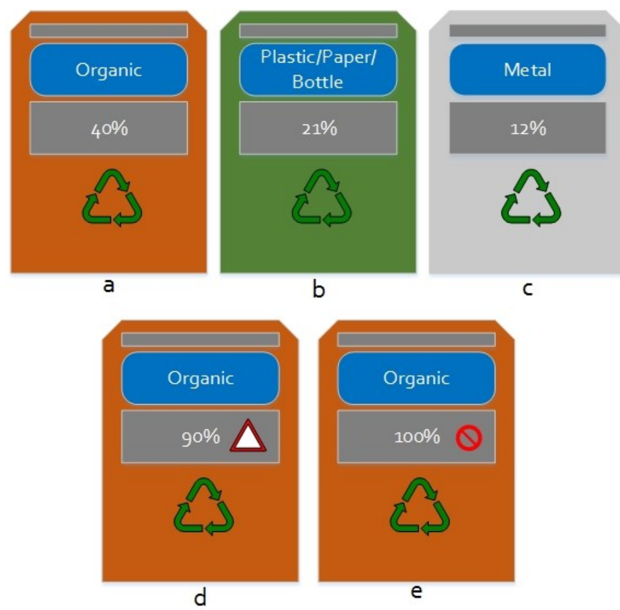

Figure 2. Smart bins for different waste categories, equipped with waste status notification.

In this way, not only the users are aware of which bin can still accommodate waste, but also the waste collectors are updated. Thus, the waste collectors can schedule their visit according to the waste statuses in different areas of a metropolis. As a result, not only route optimization is done and best possible path is selected, but also, the visit is made exactly when it is needed. This also helps in better resource management. The next section discusses the advantages in this regard in detail.

Figure 3 shows the overall architecture of CloudSWAM. It is shown that ubiquitous availability of data stored in the cloud can be useful for different entities and stakeholders in different ways. Analysis and planning can start from as soon as waste starts gathering and up to when recycling and import/export related matters are conducted.

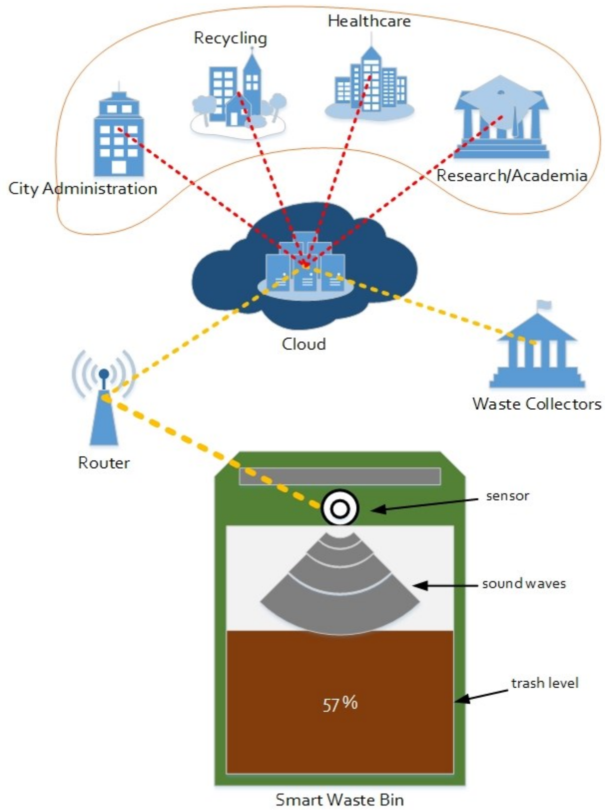

Figure 3. Cloud-based smart waste management architecture.

IV. CLOUD-SWAM SCENARIOS AND ADVANTAGES

This section presents some of the noteworthy scenarios where proposed architecture can be applied and the advantages it bears with it.

A. *Timely waste collection*

Collection of waste is an important part of waste management process. Timely and efficient way of collecting waste leads to better health, hygiene, and disposal. In different countries, different schedules and ways are adopted to collect waste. For example, in Canada, USA, Europe, and many other parts of the world, waste collectors visit a certain area of the city on a fixed scheduled day to collect waste. In Korea, since hygiene is of utmost priority, the visit is random and mostly every other day of the week, except weekend. If there is not enough waste to be collected, the visit is unserviceable. Hence, either hygiene is compromised or fuel efficiency and resources are compromised. The best way is to notify the waste status to the concerned department. In this way, a better planning can be made and in-time service is provided. Since our proposed smart waste management is associated with cloud, the statuses of all waste bins throughout the city or even country are accessible from the cloud. All the stakeholders, including recycling agencies, can take a note of that and plan accordingly.

B. *Route optimization*

In addition to the above mentioned advantage, when preparation to collect waste is being done, the collectors can plan a better and fuel efficient route, according to the conditions of waste bins in a city area. In this way, unnecessary visits are avoided and resources are not wasted. An illustrative scenario is shown in Figure 4, which shows routing on the basis of waste-bin statuses.

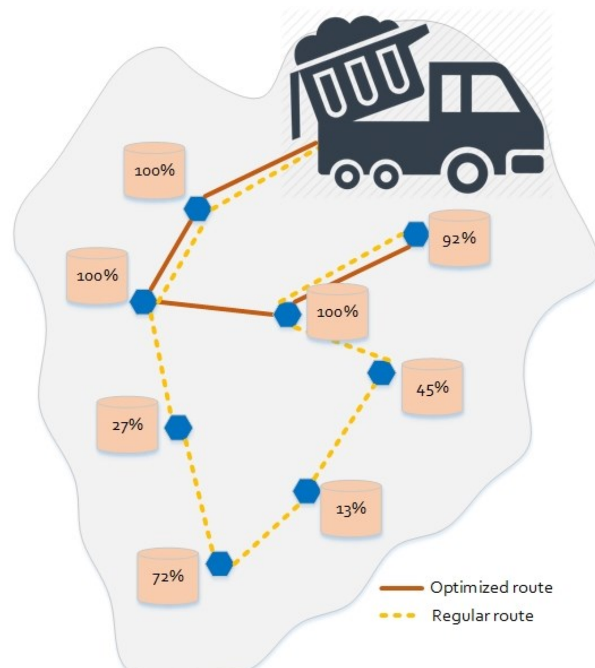

Figure 4. Route optimization and planning.

C. *Recycling and disposal*

Better ways of recycling and disposal are dependent upon each type of recyclable waste and its quantity. With smart bins, separate for each type of waste, the stakeholders will be able to see through the cloud and analyze what type of waste is coming up and in what magnitude. In this way, better arrangements can be done and efficient ways of recycling are adopted in a dynamic way.

D. Resource management

The overall waste management process involves a lot of resources. Starting from the waste collection bins, vehicles, human resource, separation and dumping locations, disposal locations, etc. Based on the waste generation trends of a particular city and/or area, resources can be effectively managed since the data is available live through the cloud.

E. Food industry planning

Most of the waste generated is either organic or comes from food/organic items. For example, a lot of waste is generated because of packaged food and fast food, like cans, beverage containers, Styrofoam packs and cups, etc. In UK, fast food litter makes up more than 31% of the total garbage [17]. It is costly and time taking to dispose them off properly. Food industry can plan according to the trends of a certain locality. In this way, not only waste material can be minimized, but also, food trends and habits of an area can be coped in a much more operative way. In addition to that, food industry will be able to plan better regarding when and where to open restaurants based on waste quantity in a particular area. For instance, considering any particular residential area in a city, if it is unknown that what are the waste generation trends, it would be difficult to judge whether opening a restaurant there is going to work or not. It has to be analyzed first that what is the population of that area and of what age group and overall financial status. However, with waste data, it would be easy to know that if a particular quantity of waste (according to its category as well) is being generated per particular period, then there is a scope of opening a restaurant there. CloudSWAM can help achieve this in practical ways.

F. Taxation

According to the UN, one third of all food produced is wasted [18]. Food waste results in greenhouse gas emissions and is a reason of lot of health issues also giving birth to several insects and bugs. The city of Seattle in USA has already imposed fines on food waste. According to Seattle Municipal, a household will be fined for $1 if their trash contains more than 10% of food waste [18]. In France, more than 7m tons of food is wasted annually [19]. With CloudSWAM keeping track of each kind of waste, better taxation and fine imposition can be performed on unnecessary waste generation. This can be on pay-as-you-throw basis.

G. Big Data analytics

A plethora of Big Data analytics can be applied on the data gathered from waste management. Big Data practices can be used to reduce waste generation and improve its management. Big Data analytics applied on waste management related data, combined with geographic and socio-economic data, can help in understanding spatial distribution of waste. Data being stored in the cloud helps in creating further services from it and analyzing it in a more in-depth way. Relevant stakeholders can be attracted and given opportunities to work further in mitigating waste disposal and other issues. Moreover, additional stakeholders can also be found out in this way. Figure 5 shows an example of Big Data analytics being applied on the data gathered from all over the city, country, or region, which helps in creating several other services.

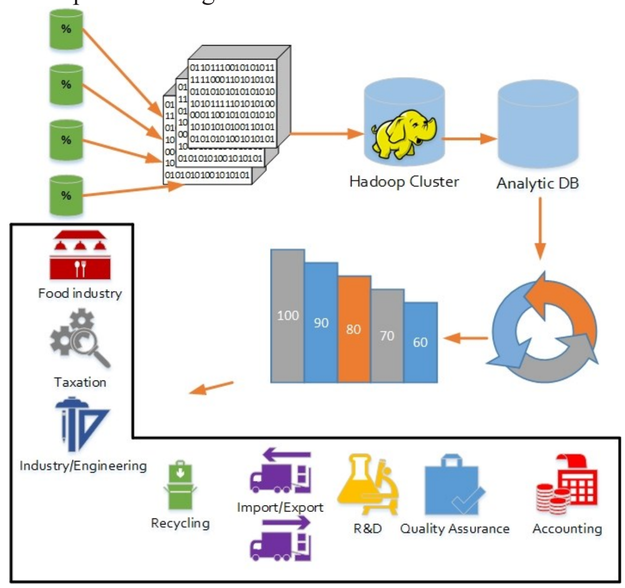

Figure 5. Big Data analytics applied on the gathered data resulting in various additional services.

H. Healthcare

Various healthcare stakeholders, like medical universities and research centers, pharmacies, hospitals and clinics, etc., can take benefit from the gathered waste management data and foresee what type of diseases a particular locality is more prone to and how to prevent from certain types of insects and bugs from breeding.

I. Waste-based energy production

Waste-to-Energy (WtE) or also known as Energy-from-Waste (EfW), is a process of generating energy from waste in the form of electricity or heat. Waste is treated through combustion process to produce heat or electricity or combustible fuel commodity, such as methanol, ethanol, or methane. In the perspective of energy technology, waste is categorized as either wet or dry. Wet waste comes from food wastes, manures, biosolids, etc. On the other hand, dry waste is a result of non-recyclable plastics, wood-based biomass, crop stubble, etc. Wet waste is treated through biological processes, like anaerobic digestion and fermentation, which results in methane gas and ethanol. Dry waste is treated through thermal processes, like combustion, gasification, and pyrolysis [20]. With waste having different types and characteristics, it is necessary to make sure that the selected technology for WtE/EfW is fully compatible with the waste stream. Many WtE projects have been unsuccessful because of poor feedstock-technology match [20]. Availability of detailed data in the cloud on each type of waste helps in achieving state-of-the-art planning and technology-matching.

V. CONCLUSION AND FUTURE WORK

Advancements in technology in various sectors of life has created avenues of sophisticated service delivery. With the increasing population and changes in the lifestyle, waste management is another sector where current technological repertoire can be applied in a more operative way. Different environmental entities and stakeholders are involved in the waste management process. It is very important to have a robust way of managing the waste, so that not only the whole process becomes efficient, but also, the disposal of waste is done in a productive way. Besides, food industry, healthcare, tourism, and other such departments can take benefit from the available resources related with waste management. With the proposed cloud-based waste management, a smarter way of handling and disposal of waste is created, which also helps in various futuristic research problems related with food, hygiene, environment, socio-cultural traits, lifestyle, etc.

In the future, this work can be extended in the context of case or country specific waste generation trends. Big Data analysis can be done on the gathered data from different municipalities.

REFERENCES

[1] Daniel Hoornweg and Perinaz Bhada-Tata, What a Waste, The World Bank, March 2012

[2] Guerrero, Lilliana Abarca, Ger Maas, and William Hogland. "Solid waste management challenges for cities in developing countries." Waste Management, 33, no. 1, 220-232, 2013.

[3] "Municipal solid waste: Is it garbage or gold?" UNEP Global Environmental Alert Service (GEAS), October 2013.

[4] Caniato, Marco, Mentore Vaccari, Chettiyappan Visvanathan, and Christian Zurbrügg. "Using social network and stakeholder analysis to help evaluate infectious waste management: A step towards a holistic assessment." Waste Management, 34, no. 5, 938-951, 2014.

[5] Yang, Rebecca Jing. "An investigation of stakeholder analysis in urban development projects: Empirical or rationalistic perspectives." International Journal of Project Management, 32, no. 5, 838-849, 2014.

[6] Greene, Krista L., and David J. Tonjes. "Quantitative assessments of municipal waste management systems: using different indicators to compare and rank programs in New York State." Waste Management, 34, no. 4, 825-836, 2014.

[7] Kollikkathara, Naushad, Huan Feng, and Eric Stern. "A purview of waste management evolution: special emphasis on USA." Waste Management, 29, no. 2, 974-985, 2009.

[8] Zhang, Xiaodong, and Gordon Huang. "Municipal solid waste management planning considering greenhouse gas emission trading under fuzzy environment." Journal of Environmental Management, 135, 11-18, 2014.

[9] Moh, Yiing Chiee, and Latifah Abd Manaf. "Overview of household solid waste recycling policy status and challenges in Malaysia." Resources, Conservation and Recycling, 82, 50-61, 2014.

[10] Al-Jarallah, Rawa, and Esra Aleisa. "A baseline study characterizing the municipal solid waste in the State of Kuwait." Waste Management, 34, no. 5, 952-960 2014.

[11] Bing, Xiaoyun, Jacqueline M. Bloemhof, Tania Rodrigues Pereira Ramos, Ana Paula Barbosa-Povoa, Chee Yew Wong, and Jack GAJ van der Vorst. "Research challenges in municipal solid waste logistics management." Waste Management, 48, 584-592, 2016.

[12] Zhang, Qiannan, Tian Huang, Yongxin Zhu, and Meikang Qiu. "A case study of sensor data collection and analysis in smart city: provenance in smart food supply chain." International Journal of Distributed Sensor Networks 2013, 2013.

[13] Hong, Insung, Sunghoi Park, Beomseok Lee, Jaekeun Lee, Daebeom Jeong, and Sehyun Park. "IoT-based Smart Garbage System for efficient food waste management." The Scientific World Journal 2014, 2014.

[14] Chowdhury, Belal, and Morshed U. Chowdhury. "RFID-based real-time smart waste management system." In Telecommunication Networks and Applications Conference, 2007. ATNAC 2007. Australasian, pp. 175-180. IEEE, 2007.

[15] Glouche, Yann, and Paul Couderc. "A smart waste management with self-describing objects." In The Second International Conference on Smart Systems, Devices and Technologies (SMART'13). 2013.

[16] "Smart Waste Management", Citibrain 2016, available at: www.citibrain.com, accessed on: 13 June, 2016.

[17] "Fast food litter at record levels on Britain's streets - and experts blame the wrong type of BINS", published: 13 Nov., 2014, available at: http://www.dailymail.co.uk/news/article-2832794/Fast-food-litter-record-levels-Britain-s-streets-experts-blame-wrong-type-BINS.html, accessed on: 13 June, 2016.

[18] "Seattle to fine residents and businesses for food in rubbish", published on: 24 Sept., 2014, available at: http://www.bbc.com/news/world-us-canada-29336968, accessed on: 13 June, 2016.

[19] "French law forbids food waste by supermarkets", published on: 04 Feb., 2016, available at: https://www.theguardian.com/world/2016/feb/04/french-law-forbids-food-waste-by-supermarkets, accessed on: 13 June, 2016.

[20] Sanderson, John. "Waste to energy." Proceedings of the Royal Society of Victoria 126, no. 2, 32-33, 2014.