International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:14, No:6, 2020

# Energy Recovery Potential from Food Waste and Yard Waste in New York and Montréal

T. Malmir, U. Eicker

***Abstract*****—**Landfilling of organic waste is still the predominant waste management method in the USA and Canada. Strategic plans for waste diversion from landfills are needed to increase material recovery and energy generation from waste. In this paper, we carried out a statistical survey on waste flow in the two cities New York and Montréal and estimated the energy recovery potential for each case. Data collection and analysis of the organic waste (food waste, yard waste, etc.), paper and cardboard, metal, glass, plastic, carton, textile, electronic products and other materials were done based on the reports published by the Department of Sanitation in New York and Service de l'Environnement in Montréal. In order to calculate the gas generation potential of organic waste, Buswell equation was used in which the molar mass of the elements was calculated based on their atomic weight and the amount of organic waste in New York and Montréal. Also, the higher and lower calorific value of the organic waste (solid base) and biogas (gas base) were calculated. According to the results, only 19% (598 kt) and 45% (415 kt) of New York and Montréal waste were diverted from landfills in 2017, respectively. The biogas generation potential of the generated food waste and yard waste amounted to 631 million $m^3$ in New York and 173 million $m^3$ in Montréal. The higher and lower calorific value of food waste were 3482 and 2792 GWh in New York and 441 and 354 GWh in Montréal, respectively. In case of yard waste, they were 816 and 681 GWh in New York and 636 and 531 GWh in Montréal, respectively. Considering the higher calorific value, this amount would mean a contribution of around 2.5% energy in these cities.

***Keywords*****—**Energy recovery, organic waste, urban energy modelling with INSEL, waste flow.

## I. INTRODUCTION

LOOKING through the current practices and opportunities of megacities in developed countries, sustainable waste management is still a challenge. The world's largest 27 megacities contribute to 12.6% of waste production of the total global quantity [1] and landfilling is still the predominant waste management method. Efforts have been done globally in order to reduce landfilling of biodegradable fraction of waste, but the reduction amounts were not satisfying so far. An example can be Food Waste (FW) which is an easily biodegradable Organic Waste (OW) [2]. It contributes almost half of the total municipal wastes in most countries [3] and has a great potential to be used for energy purposes. However, it is directly landfilled in many cases. For instance, landfilling of over 97% of FW in the USA was reported in 2010 [4] and the situation did not improve significantly later. In 2014 and 2015, FW accounted for 38 [5] and 39 million tons [6] in the USA respectively and three quarters of these amounts were landfilled [5], [6]. In the last years, different strategic plans for waste diversion from landfills were developed to increase energy generation and material recovery from waste.

In New York City (NYC) as the most populous and the most densely populated city in the USA with around 8.5 million inhabitants [7], it is planned, by 2030, to achieve 75% diversion of solid waste from landfills [8] and a 90% reduction in total waste disposed in landfills relative to 2005 [9].

A second case study is the agglomeration of Montréal (AMTL), which is made up of 16 cities including the City of Montréal, which in turn is divided into 19 boroughs. The City of Montréal is the largest city in the Canadian province of Québec (24% of the population) [10] and the second-most populous municipality in Canada with around 2 million inhabitants [11], [12]. Currently most of the OW in Québec is landfilled or incinerated and it is planned to ban the disposal of OW and reach 60% diversion from landfill [13], [14]. Moreover, the AMTL has a Waste Management Master Plan firmly anchored in the targets of the Quebec Residual Materials Management Policy - 2011-2015 Action Plan of the Government of Québec. According to this plan, the recovery target for recyclables, OW, and construction and demolition (CD) waste is 70%, 60% and 70%, respectively [11]. It is also planned, by 2030, to increase the bioenergy production by 50% through various methods such as bio-methanization of OW [15].

Currently most waste in NYC is disposed in landfills [16], [17] and mishandling of OW in MTL or Québec has been reported by several studies [10], [14], [18]. In this paper we carry out a statistical survey on waste flow in NYC and MTL and theoretically estimate the energy recovery potential from FW and yard waste for each case.

## II. METHODOLOGY

### *A. Data Collection and Analysis*

Fig. 1 shows a typical waste flow. As can be seen, generated waste divides to two categories of recyclables and non-recyclables. Non-recyclables are disposed directly into landfills or used for energy recovery (e.g. by incineration). Recyclables which are comprised of OW (FW, yard waste, etc.), paper and cardboard (PC), metal, glass, plastic and carton (MGP), textile and electronic products (E-waste) and other materials have two routes. One is the same as non-recyclables, and the other route is being used for energy and

T. Malmir is with the Canada Excellence Research Chair Next Generation Cities, Gina Cody School of Engineering and Computer Science, Concordia University, Montréal, Canada (corresponding author, phone: 819-437-0401; e-mail: tahereh.malmir@ mail.concordia.ca).

Professor Dr. Habil. U. Eicker is with the Canada Excellence Research Chair Next Generation Cities, Gina Cody School of Engineering and Computer Science, Concordia University, Montréal, Canada (e-mail: ursula.eicker@concordia.ca).

material recovery, or in case of OW, being composted or recovered for energy (e.g. by anaerobic digestion, gasification, etc.).

Data collection and analysis for the waste flow of NYC and MTL were mainly done based on the reports published by the Department of Sanitation in NYC [16] and Service de l'Environnement in MTL [11], [19].

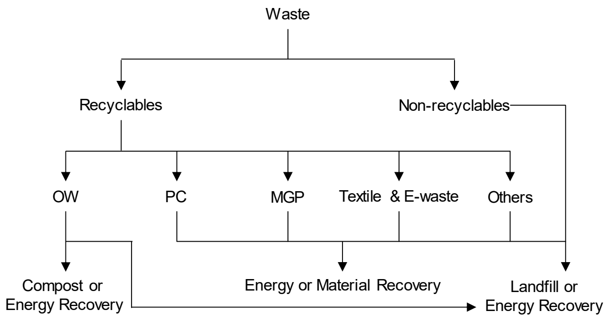

Fig. 1 Typical waste flow

### B. Case Study of NYC

According to DSNY [16], the report characterized waste collections from residential properties of all sizes and styles, and a small number of institutional and agency costumers. The residential characterization included four residential curbside collection streams including OW (FW, yard waste and food-soiled paper), PC, MGP and refuse (non-recyclables in Fig. 1). Samples were selected randomly from trucks identified by DSNY collection route and tonnage data to reach a 90% confidence of statistical significance. 45 kg (100 lb) of material per sample for OW, PC and MGP, and 91 kg (200 lb) per sample for refuse were collected for sampling. Totally 660 samples were collected (79 OW, 148 PC, 187 MGP and 246 refuse). Samples were hand sorted by the study team into 70 main sort categories and all of them were fully sorted into the same set of categories.

### C. Case Study of MTL

According to the Service de l'Environnement in MTL [11], the report characterized waste collections from three sources including residential, institutional and commercial ones. The generated waste included OW (FW, yard waste and mixed residue), PC, MGP, residential CD, harmful household products (e.g. paint, pesticide, mercury devices, etc.), textile, e-waste, and household waste. Collection and disposal of waste is handled by the municipalities in MTL in different ways and separation of materials is done in sorting centers. Curbside collection service collects the household waste and recyclables and partially OW. OW consisting of FW and yard waste is collected in most of the buildings of 8 or less dwellings in MTL and then transformed into compost. Seven ecocenters in MTL collect CD, wood, metal, tire, polystyrene and textile, harmful household products, e-waste, yard waste (gardening and weeding residues, leaves and Christmas trees) and other reusable materials. CD is also collected on street or as a result of resident calls. Household waste and non-recyclable CD are sent to the landfills.

### D. Waste to Energy Calculation Method

The biogas generation potential from biodegradable OW depends on the composition of the OW which is characterized by proximate and ultimate analyses. The characteristics of FW have been reported in many studies, and their values do not differ markedly from each other [20]. Zhang and Matsuto assumed 75.0% moisture, 10.0% ash, 40.0% C and 2.0% N in FW [20]. Sharma reported 44.2% C and 49.8% O in raw yard waste [21]. As stated before, OW in NYC is comprised of FW, yard waste and food-soiled paper and in MTL is made of FW, yard waste and mixed residue. Samples of OW were not obtained in this study, and their characteristics were assumed as 42.7% C, 9.1% H, 1.97% N and 46.2% O in FW and 46.2% C, 5.8% H, 1.03% N and 47.0% O in yard waste [22]. The percentage of sulphur, S, was assumed to be zero. Moreover, the moisture content of FW and yard waste was assumed to be 75% [20] and 63% [23] respectively.

In order to calculate the gas generation potential of OW, Buswell equation [24] was used in which the molar mass of the elements (C, H, N and O) was calculated based on their atomic weight and the amount of FW and yard waste in NYC and MTL (1).

$$\begin{aligned} C_nH_aO_bN_c + \left(n - \frac{a}{4} - \frac{b}{2} + \frac{7c}{4}\right) H_2O \rightarrow \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4} - \frac{3c}{8}\right) CH_4 \\ + \left(\frac{n}{2} - \frac{a}{8} + \frac{b}{4} - \frac{5c}{8}\right) CO_2 + cNH_4^+ + cHCO_3^- \end{aligned} \tag{1}$$

The higher calorific value (HCV) and lower calorific value (LCV) of the FW and yard waste (solid base) and biogas (gas base) were calculated using (2) and (3) [25] and (4) and (5) [26].

$$\begin{aligned} HCV\ (MJ/kg\ TS) = (34.1 \times C + 102 \times H + 6.3 \times N \\ + 19.1 \times S - 9.85 \times O)/100 \end{aligned} \tag{2}$$

$$\begin{aligned} LCV\ (MJ/kg\ TS) = high\ heating\ value - 2.454 \\ \times (W + 9H) \end{aligned} \tag{3}$$

where C, H, N, O and S refer to carbon, hydrogen, nitrogen, oxygen and sulphur content (%TS) in the feedstocks, respectively, and W represents the moisture in fuel (wt.%).

$$\begin{aligned} HCV\ \left(\frac{MJ}{m^3} biogas\right) = 0.3989 \times methane\ content\ (\%) \\ + 0.0213 \end{aligned} \tag{4}$$

$$\begin{aligned} LCV\ \left(\frac{MJ}{m^3} biogas\right) = 0.3593 \times methane\ content\ (\%) \\ + 0.0192 \end{aligned} \tag{5}$$

All simulation models are implemented as modular blocks in the integrated simulation environment Insel4D, which is under development at Concordia University (www.insel.eu). The goal is to develop scenarios, where biogas generation from OW is integrated into the urban energy system via a gas network or cogeneration strategy.

## III. RESULTS AND DISCUSSION

### A. Trend in Waste Generation

Fig. 2 illustrates the generated waste in NYC (2005 to 2017) and MTL (2012 to 2017). In NYC, total waste generation was 3418 kilotons (kt) in 2005 and around 3095 kt in 2013 and 2017 which may be due to changes in consumption patterns, such as the decline in print newspaper sales, and to the evolution in product design to favor more lightweight packaging. MGP and PC had the highest amount in 2005 (1213 kt) but OW dominated from 2013 (976 kt) to 2017 (1062 kt). Non-bottle rigid plastics were added to the MGP recycling program in 2017 which led to an increase in their recovery rate. Glass packaging was declined as it was replaced by lighter weight plastic options. Less printed matter and more online shopping accounted for the decline and grow in recyclable PC respectively. Moreover, small quantities of cartons and aseptic boxes were misplaced which caused recycling of 8% of cartons with paper instead of with MGP. CD was 178 kt in 2005 and decreased to 138 kt in 2017. Textile, e-waste & harmful household product increased from 196 kt in 2005 to 218 kt in 2017.

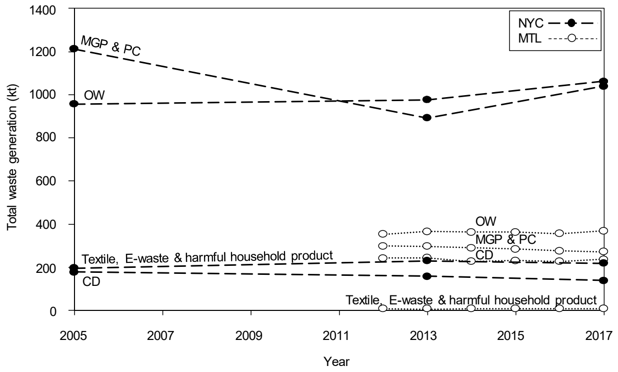

Fig. 2 Total waste generation in NYC [16] and MTL [11], [19]; CD: construction, renovation and demolition waste and bulky materials

In MTL, total waste generation decreased from 970 kt in 2012 to 931 kt in 2017. The average amount of OW, MGP and PC, CD, and textile, e-waste & harmful household product was 361 kt, 286 kt, 234 kt and 8 kt, respectively. Various factors affected the decrease in waste quantities such as replacement of printed newspapers by digital editions, eco-design of products which reduces the weight of containers, reduction of over-packaging and reduction of consumption.

Many products that used to be made from recyclable materials changed to multi-layered flexible packaging that are not accepted for recycling in NYC and MTL. For example, rigid plastics are designated as recyclable in NYC, but film, flexible or foam plastics are not. In MTL plastic #6 (polystyrene), different kinds of plastic bags and films are not considered as recyclable items. Worldwide efforts have been done to develop the public policies on plastic carrier bags [27]. Introducing the degradable plastics as the environmentally friendly alternatives to the market can decrease the huge amounts of plastics that are landfilled. For instance, Malmir used solvent casting method to prepare biodegradable films of poly (3-hydroxybutyrate-co-3-hydroxyvalerate) with cellulose nanocrystals which has capability for applications in the industry of food packaging [28] and achieved well-dispersed bionanocomposites with improved mechanical and barrier properties [29].

### B. Waste Flow

The waste flow of NYC and MTL in 2017 is shown in Fig. 3. Based on this figure, from a total of 3090 kt generated waste in NYC (comprising 77% recyclables including OW, PC, MGP, textile, plastic shopping bags, harmful household product and e-waste, and 23% non-recyclables including CD and other materials) only 19% was diverted and 81% was mainly landfilled. OW with one third contribution to the total generated waste accounted for 1062 kt from which approximately 13 kt was recovered and the vast majority was landfilled. Curbside OW collection to collect source separated food scraps, yard waste and food-soiled paper was planned to be introduced to all the neighborhoods in NYC, but it could not reach this target [30]. Plastic films and foam made up 7.5% of the waste stream including garbage and recycling bags (2.5%) and smaller plastic shopping bags (1.9%). Contractors or fee-for-service workers are responsible to dispose their commercial CD; however generated CD from do-it-yourself projects can be disposed in DSNY refuse collection. Therefore, CD is considered as non-recyclable in Fig. 3 and records a small quantity (4.5%).

In MTL, 931 kt waste was generated. This amount is comprised of 95% recyclables (OW, PC, MGP, CD, textile, e-waste and harmful household product) and 5% non-recyclables (non-recyclable CD and other materials) and the portion of diverted and landfilled waste was 45% and 55%, respectively. OW in MTL accounted for 369 kt from which around 85 kt was recovered. The recovery ratio of OW increased from 11% in 2012 to 23% in 2017 but is still far from the 60% recovery target in *2011-2015 Action Plan of the Government of Québec*. The recovery ratio of PC and MGP, and CD was 60%, and 68%, respectively. To compare, household waste collected from urban and rural sectors of Saguenay in the Canadian province of Québec comprised of 53% to 66% OW, 4% PC, 15% MGP and 5% textile [31]. The waste composition of Tokyo comprised of 27% OW, 48% PC and 20% MGP in 2018. The waste flow of Tokyo in 2018 is shown in Fig. 4 as an example. According to that, from 2.7 million tons waste, 88% was incinerated, 2% was recovered and 11% was landfilled in Tokyo in 2018.

The waste flow also shows the percentage of FW and yard waste for the OW of NYC and MTL. In case of MTL, this percentage was not available for 2017 and we assumed the same percentage in 2016 [11]. Accordingly, FW accounted for 21% (641 kt) and 9% (81 kt) and yard waste was 6% (170 kt) and 14% (133 kt) in NYC and MTL, respectively. The rest of the OW was 8% (251 kt) food-soiled paper in NYC and 17% (155 kt) mixed residue in MTL.

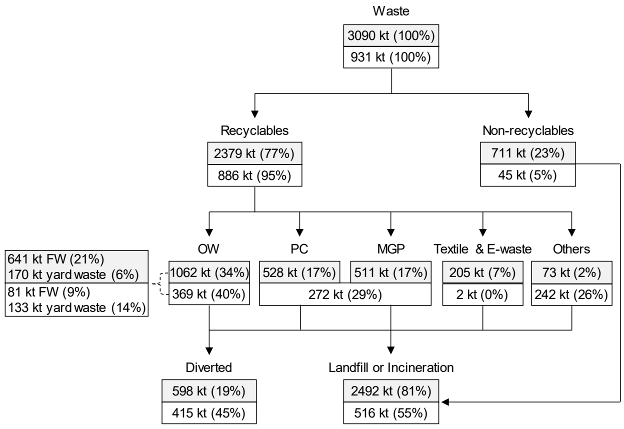

Fig. 3 Waste flow of NYC (upper values) [16] and MTL (lower values) [11], [19] in 2017

### C. Energy Recovery, Conversion and Benefits

Using the Buswell equation and the molar ratios assumed, the biogas generation potential from 641 kt FW and 170 kt yard waste in NYC and 81 kt FW and 133 kt yard waste in MTL was calculated. According to the result, the biogas generation is 487 million m$^3$ from FW and 143 million m$^3$ from yard waste in NYC and 62 million m$^3$ from FW and 112 million m$^3$ from yard waste in MTL. Table I shows the HCV and LCV of FW and yard waste (solid base), and biogas (gas base) in NYC and MTL. According to that, HCV and LCV from FW are 3482 and 2792 GWh in NYC and 441 and 354 GWh in MTL respectively. In case of yard waste, HCV and LCV are 816 and 681 GWh in NYC and 636 and 531 GWh in MTL respectively. Gas base calculation of HCV and LCV results are close the mentioned solid base values. Totally, HCV from FW and yard waste or biogas is more than 4000 GWh in NYC and more than 1000 GWh in MTL. The total electricity consumption in NYC was 156,370 GWh in 2017 [32] and in MTL was about 41,613 GWh in 2016. Considering the HCV, this amount would mean a contribution of around 2.5% energy in NYC and MTL.

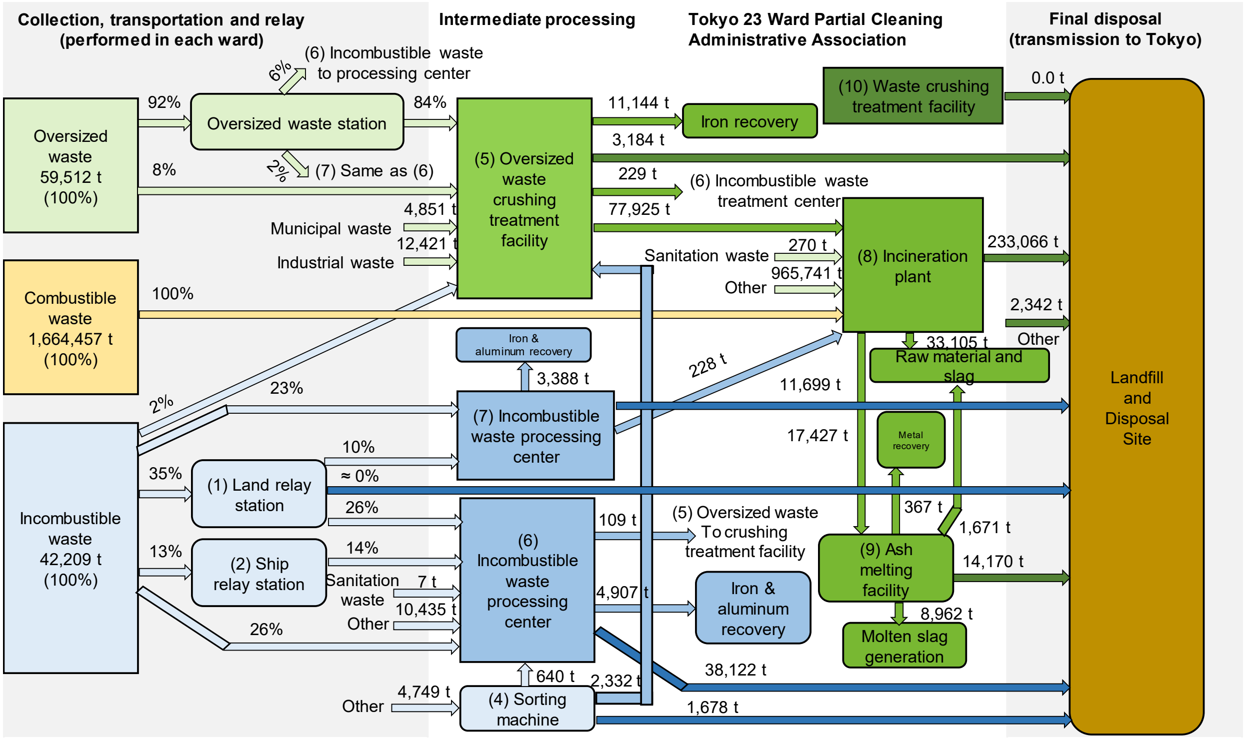

Fig. 4 Waste flow of Tokyo in 2018 [33]

TABLE I
HCV AND LCV OF ŞFW AND YARD WASTE (SOLID BASE) AND BIOGAS (GAS BASE) IN NYC AND MTL IN 2017 (GWH)

| | Solid base | | | | Gas base | | | |
|---|---|---|---|---|---|---|---|---|
| | NYC | | MTL | | NYC | | MTL | |
| | HCV | LCV | HCV | LCV | HCV | LCV | HCV | LCV |
| FW | 3482 | 2792 | 441 | 354 | 3337 | 3005 | 423 | 381 |
| Yard waste | 816 | 681 | 636 | 531 | 750 | 675 | 584 | 526 |
| Total | 4298 | 3473 | 1077 | 884 | 4087 | 3681 | 1007 | 907 |

## IV. CONCLUSION

The work presents a comparison on the waste flow in the two cities NYC and MTL and estimates the potential of biogas generation from their FW and yard waste. It shows the huge potential of energy recovery from FW and yard waste in these cities instead of landfilling them as is the current OW management method.

From a total of 3090 kt generated waste in NYC in 2017, only 19% was diverted and 81% was mainly landfilled. OW with one third contribution to the total generated waste accounted for 1062 kt from which approximately 13 kt was recovered and the vast majority was landfilled. In MTL in the same year, 931 kt waste was generated and the portion of diverted and landfilled waste was 45% and 55%, respectively. OW in MTL accounted for 369 kt from which around 85 kt was recovered.

Using the Buswell equation and the molar ratios assumed, the biogas generation potential was 487 million $m^3$ from FW and 143 million $m^3$ from yard waste in NYC and 62 million $m^3$ from FW and 112 million $m^3$ from yard waste in MTL.

## REFERENCES

[1] C.A. Kennedy, I. Stewart, A. Facchini, I. Cersosimo, R. Mele, B. Chen et al., “Energy and material flows of megacities,” *Proceedings of the National Academy of Sciences of the United States of America*, vol. 112, no. 19, pp. 5985-5990, 2015.

[2] T. Malmir Y. Tojo, “Municipal solid waste management in Tehran: Changes during the last 5 years,” *Waste Management and Research*, vol. 34, no. 5, pp. 449-456, 2016.

[3] R. Sindhu, E. Gnansounou, S. Rebello, P. Binod, S. Varjani, I. S. Thakur, R. B. Nair and A. Pandey, “Conversion of food and kitchen waste to value-added products,” *Journal of Environmental Management*, vol. 241, pp. 619-630, 2019.

[4] J.W. Levis, M. A. Barlaz, N. J. Themelis and P. Ulloa, “Assessment of the state of food waste treatment in the United States and Canada,” *Waste Manag*, vol. 30, no. 8-9, pp. 1486-94, 2010.

[5] USEPA, “Advancing sustainable materials management: 2014 fact sheet,” United States Environmental Protection Agency, Office of Land and Emergency Management, Washington, DC 20460, pp. 22-22, 2016.

[6] USEPA, “Advancing sustainable materials management: 2015 Fact Sheet,” United States Environmental Protection Agency, Office of Land and Emergency Management, Washington, DC 20460, pp. 22-22, 2018.

[7] DSNY, “2017 annual report,” 2017.

[8] NYC, “PlaNYC: A greener greater New York” pp. 1-202, 2011.

[9] NYC, “One New York: The plan for a strong and just city,” 2015.

[10] A. Richter, N. Bruce, K. T. W. Ng, A. Chowdhury and H. L. Vu, “Comparison between Canadian and Nova Scotian waste management and diversion models—A Canadian case study,” *Sustainable Cities and Society*, vol. 30, pp. 139-149, 2017.

[11] Montréal, “Portrait 2016 des matières résiduelles de l’agglomération,” 2017.

[12] Québec, Government of Québec, Institut de la statistique, pp. 1-1, 2015.

[13] Montréal, “Draft materials management plan,” 2019.

[14] Québec, “Québec residual materials management policy,” Chap. Q-2, r. 35.1, pp. 1-14, 2019.

[15] Québec, “The 2030 Energy Policy,” 2016.

[16] DSNY, “NYC Residential, school, and NYCHA waste characterization study,” 2017.

[17] DSNY, “Annual Report,” 2019.

[18] L. Hénault-Ethier, J. P. Martin and J. Housset, “A dynamic model for organic waste management in Quebec (D-MOWIQ) as a tool to review environmental, societal and economic perspectives of a waste management policy,” *Waste Management*, vol. 66, pp. 196-209, 2017.

[19] Montréal, “Bilan 2017 des matières résiduelles de l’agglomération de Montréal,” 2018.

[20] H. Zhang and T. Matsuto, “Mass and element balance in food waste composting facilities,” vol. 30, pp. 1477-1485, 2010.

[21] H. B. Sharma, S. Panigrahi and B. K. Dubey, “Hydrothermal carbonization of yard waste for solid bio-fuel production: Study on combustion kinetic, energy properties, grindability and flowability of hydrochar,” *Waste Management*, vol. 91, pp. 108-119, 2019.

[22] S. Panigrahi, H. B. Sharma and B. K. Dubey, “Anaerobic co-digestion of food waste with pretreated yard waste: A comparative study of methane production, kinetic modeling and energy balance,” *Journal of Cleaner Production*, vol. 243, pp. 1-9, 2019.

[23] D. P. Komilis and R. K. Ham, “Carbon dioxide and ammonia emissions during composting of mixed paper, yard waste and food waste,” *Waste Management*, vol. 26, pp. 62-70, 2006.

[24] A. M. Buswell and H. F. Mueller, “Mechanism of methane fermentation,” *Industrial and Engineering Chemistry*, vol. 44, no. 3, pp. 550-552, 1952.

[25] Y. Li, R. Zhang, Y. He, C. Zhang, X. Liu and C. Chen, “Anaerobic co-digestion of chicken manure and corn stover in batch and continuously stirred tank reactor (CSTR),” *Bioresource Technology*, vol. 156, pp. 342-347, 2014.

[26] Y. Li, H. Liu, F. Yan, D. Su, Y. Wang and H. Zhou, “High-calorific biogas production from anaerobic digestion of food waste using a two-phase pressurized biofilm (TPPB) system,” *Bioresource Technology*, vol. 224, pp. 56-62, 2017.

[27] T. D. Nielsen, K. Holmberg and J. Stripple, “Need a bag? A review of public policies on plastic carrier bags - Where, how and to what effect?,” *Waste Management*, vol. 87, pp. 428-440, 2019.

[28] S. Malmir, B. Montero, M. Rico, L. Barral and R. Bouza, “Morphology, thermal and barrier properties of biodegradable films of poly (3-hydroxybutyrate-co-3-hydroxyvalerate) containing cellulose nanocrystals,” *Composites Part A: Applied Science and Manufacturing*, vol. 93, pp. 41-48, 2017.

[29] S. Malmir, B. Montero, M. Rico, L. Barral, R. Bouza and Y. Farrag, “PHBV/CNC bionanocomposites processed by extrusion: Structural characterization and properties,” *Polymer Composites*, vol. 40, pp. E275-E284, 2019.

[30] DSNY, “NYC Organics,” 2018.

[31] J. E. Guerin, M. C. Paré, S. Lavoie and N. Bourgeois, “The importance of characterizing residual household waste at the local level: A case study of Saguenay, Quebec (Canada),” *Waste Management*, vol. 77, pp. 341-349, 2018.

[32] NYISO, “2018 Power trends - New York's dynamic power grid,” 2018, The New York Independent System Operator.

[33] Cleanup Annual Report (Tokyo 23 wards), 30 years of normalization, Business performance, Twenty-three wards of Tokyo Cleaning Office (in Japanese) available at: https://www.union.tokyo23-seisou.lg.jp/jigyo/renraku/kumiai/shiryo/documents/30seisoujigyounenpou.pdf (accessed date: 2020-05-29).