Assessment of the Waste-to-Energy Potential from Alberta's Food Processing Industry

Mohammad Ullah[1], Mahdi Vaezi[1], Amit Kumar[1,*] and Jeff Bell[2]

[1]*Department of Mechanical Engineering, University of Alberta, Edmonton, AB T6G 1H9, Canada*
[2]*Bioindustrial Opportunities Branch, Alberta Agriculture and Forestry, Edmonton, AB T6H 2V8, Canada*
**Email: amit.kumar@umanitoba.ca*
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Ullah, M., V. Mahdi, A. Kumar and J. Bell. 2017. **Assessment of the Waste-to-Energy Potential from Alberta's Food Processing Industry.** Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **59**: 8.1-8.9. Alberta's food processing industry is the second largest food waste producer after the household sector. Most of the waste currently produced from the food processing industry is landfilled. Decomposing landfill waste, moreover, emits greenhouse gases (GHG), which contribute to global warming. In this paper, we estimated the amount of food waste produced by Alberta's food processing industry by developing a geographical information system (GIS)-based model with data from food processing companies in the province. The companies were selected such that all sizes, types, and geographic locations were considered. The information was gathered on the amount and characteristics of food waste, the location of the processing facilities, and the food waste disposal method and then the total amount of food waste generated in Alberta was estimated. In addition, GIS maps were created to show the distribution of food waste throughout the province and the availability intensity. Finally, we estimated the potential energy that could be produced in the form of biogas and electricity using Alberta's food processing waste and mapped it as well. There is a potential to generate 852 GWh of electricity per year from Alberta's food processing waste, which is about 1% of the province's total electricity generation. This potential capacity could help in the development of waste-to-value-added facilities in Alberta. **Keywords**: food processing; food waste; Alberta; GIS; electricity

L'industrie de la transformation des aliments de l'Alberta vient au deuxième rang des producteurs de déchets alimentaires après les ménages. La plupart des déchets qui sont produits par les industries de transformation sont enfouis. La décomposition de ces déchets enfouis produit des gaz à effet de serre (GHG) qui contribuent au réchauffement climatique. Dans cette étude, nous avons estimé la quantité de déchets alimentaires produits par l'industrie de la transformation alimentaire de l'Alberta en développant un modèle basé sur le système d'information géographique (SIG - GIS) et des données provenant des entreprises de transformation de la province. Les compagnies ont été sélectionnées de manière à ce que toutes les tailles, tous les types et tous les emplacements géographiques soient considérés. Les informations recueillies incluaient la quantité et les caractéristiques des déchets alimentaires, l'emplacement des installations de traitement et la méthode d'élimination des déchets. Ensuite, la quantité totale de déchets alimentaires produits dans la province de l'Alberta a été estimée. De plus, des cartes SIG ont été créées pour montrer la distribution des déchets alimentaires à travers la province ainsi que leur volume. Finalement, nous avons estimé l'énergie qui pourrait être produite sous forme de biogaz et d'électricité par ces déchets de transformation alimentaire et nous avons également cartographié ces données. Ces déchets ont un potentiel de production d'électricité de 852 GWh par an, ce qui représente environ 1% de la production totale d'électricité de la province. Cette capacité pourrait aider au développement d'installations de valorisation des déchets en Alberta. **Mots clés:** transformation des aliments; déchets alimentaires; Alberta; GIS; SIG; électricité

INTRODUCTION

Accrding to the Food and Agriculture Organization (FAO) of the United Nations, one-third of the food produced globally for human consumption is wasted (Gustavsson et al. 2011). The wastage occurs at different stages of the supply chain, which starts with farm production and continues through food processing, transportation and distribution, retail shops, restaurants and hotels, and finally to household consumption. A study estimated the percentages of food waste that occur at different stages in Canada, as shown in Fig. 1 (Gooch and Felfel 2014). Household consumers and food processing industries generate the highest (47%) and second highest (20%) percentages of food waste. Although household consumers produce the highest portion of food waste, it is difficult to separate and collect food waste alone, since it is mixed with municipal solid waste. Food waste produced in food processing companies, on the other hand, is easier to separate and collect. The food processing industry, the second-largest food waste-producing sector, requires a comprehensive study of its waste potential.

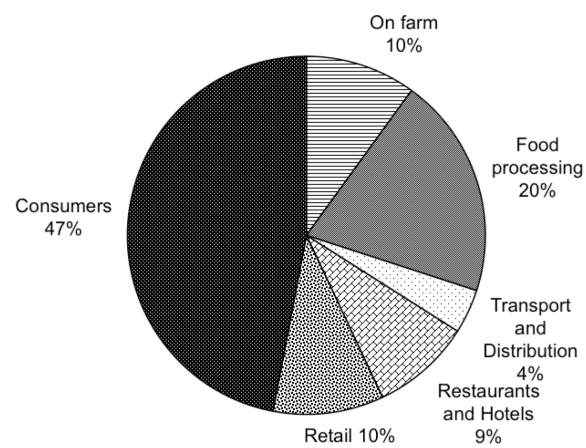

Fig. 1. Food waste production along Canada's food value chain.

The province of Alberta in Canada has over five hundred food processing companies (Bates 2015). Food processing facilities in Alberta process and produce a wide variety of food such as meat, fish, vegetables, fruit, cereal products, baked goods, confectioneries, beverages, etc., which generate an equally wide range of waste through the loss of raw materials during processing, unused leftovers, and by-products of processes (Bell 2015). The disposal of this food waste causes wastage of energy, labour, and other resources that have been invested to produce and process the food. Environmentally speaking, when landfilled, the decomposition of food processing waste emits methane (CH_4), which is a greenhouse gas (GHG) 25 times more powerful than carbon dioxide (CO_2) and contributes significantly to global warming (Alberta Government 2015). In addition, the transportation cost of waste to landfills and tipping fees (i.e., disposal fees) impose immense costs to food processing companies. Landfill tipping fees vary from one county to another and depend on the county's waste management policy and regulations. Some notable landfill tipping fees in 2015 were \$110/t in the City of Calgary (Bell 2015; The City of Calgary 2015), \$110/t in Taber (Municipal District of Taber 2015; Bell 2015), \$70/t in the City of Edmonton (Bell 2015; The City of Edmonton 2015), \$65/t in Red Deer County (Bell 2015; The City of Red Deer 2015), and \$60/t in Lethbridge County (Bell 2015; The City of Lethbridge 2015). The environmental concerns and the costs indicate the need to manage food-processing waste efficiently.

Food processing waste can be used as a source of energy. Electricity can be produced from food waste by anaerobic digestion (AD) technology (Kiran et al. 2014; Moriarty 2013; Pham et al. 2015; Zhang et al. 2014). In this process, food waste is decomposed in a digester with the help of anaerobic bacteria in absence of air to produce biogas. This biogas can be combusted in a combined heat and power (CHP) unit to generate electricity. There are a number of food waste conversion facilities in North America that produce electricity through AD technology, e.g., the 40,000 t/y AD facility in Toronto, Canada (Moriarty 2013), the 35,000 t/y AD facility in East Bay Municipal Utility District (EBMUD) Oakland, USA (Institute for Local Self-Reliance 2010), and the 40,000 t/y AD facility in Everett, USA (Moriarty 2013). There are also AD facilities where food waste is co-processed together with other residues. Examples of those are food and yard waste AD facilities at the University of Wisconsin, USA (Moriarty 2013), in Richmond, Canada (Natural Resources Canada 2016), in San Jose, USA (Institute for Local Self-Reliance 2010), and in Lethbridge, Canada (Lethbridge Biogas LP 2013).

There are several approaches to estimate food waste from food processing industries. Common approaches are collecting information by conducting surveys among food manufacturers (Moriarty 2013) and calculating per capita food waste generation (Abdulla et al. 2013) by measuring the waste sent to landfills, composting, etc. (Moriarty 2013). Food waste is also estimated by identifying the sectors where the wastage takes place (e.g., agricultural production, processing and packaging, transportation and distribution, hotels and restaurants, etc.) and associating a certain percentage of the total food waste to every specific sector. In another study, 20% of total food waste produced in Canada was assumed to be associated with the food-processing sector (Gooch and Felfel 2014). Except for a comprehensive survey approach (i.e., collecting accurate data from all food processing companies), none of the approaches ensures an accurate estimate of produced waste. Such a survey has never been conducted across the province of Alberta before. This study was an effort to address this gap.

The specific objectives of this study were:

- To assess the total amount of food waste produced in the province of Alberta, Canada;
- To find out the geographical locations where food processing waste availability is comparatively higher;
- To find out the type and characteristics of food processing waste and how it is managed at present;
- To estimate the potential energy from food processing waste; and
- To develop region-wise (GIS) maps to illustrate corresponding energy distribution across Alberta.

This study could help to select the location of future food processing waste conversion facilities in Alberta.

METHODOLOGY

Data collection

Gooch and Felfel (2014) assumed that 20% of Canada's food waste is generated in food processing facilities. However, no organized survey conducted so far has estimated the amount of food waste produced by food processing facilities in Alberta. The initiative was taken for the first time here to collect data on food waste from all of Alberta's food processing facilities. Fig. 2 shows the data collection and waste estimation steps taken for this research.

Out of 503 food-processing companies in Alberta, 200 companies were selected so as to include a range of facility sizes (small with 1-25 employees, medium with 26-100 employees, and large with 100+ employees), food types (meat, fish, vegetables, fruits, cereal products, baked goods, confectioneries, beverages, etc.), and geographic locations. Surveys and data collection were completed with the help of Alberta Agriculture and Rural Development. The survey questionnaires were sent out to these companies to ask about the types of products, the types of waste or underused by-products, the characteristics of the waste, the volume of the waste produced per day/week/month, the current use for the waste and/or the disposal method, the waste disposal cost, and anything else the company wanted to add. In the end, responses were received from 181 companies.

The waste data provided by the companies were reported in different units such as kg/month, dumpster/week, etc. Some companies provided the waste

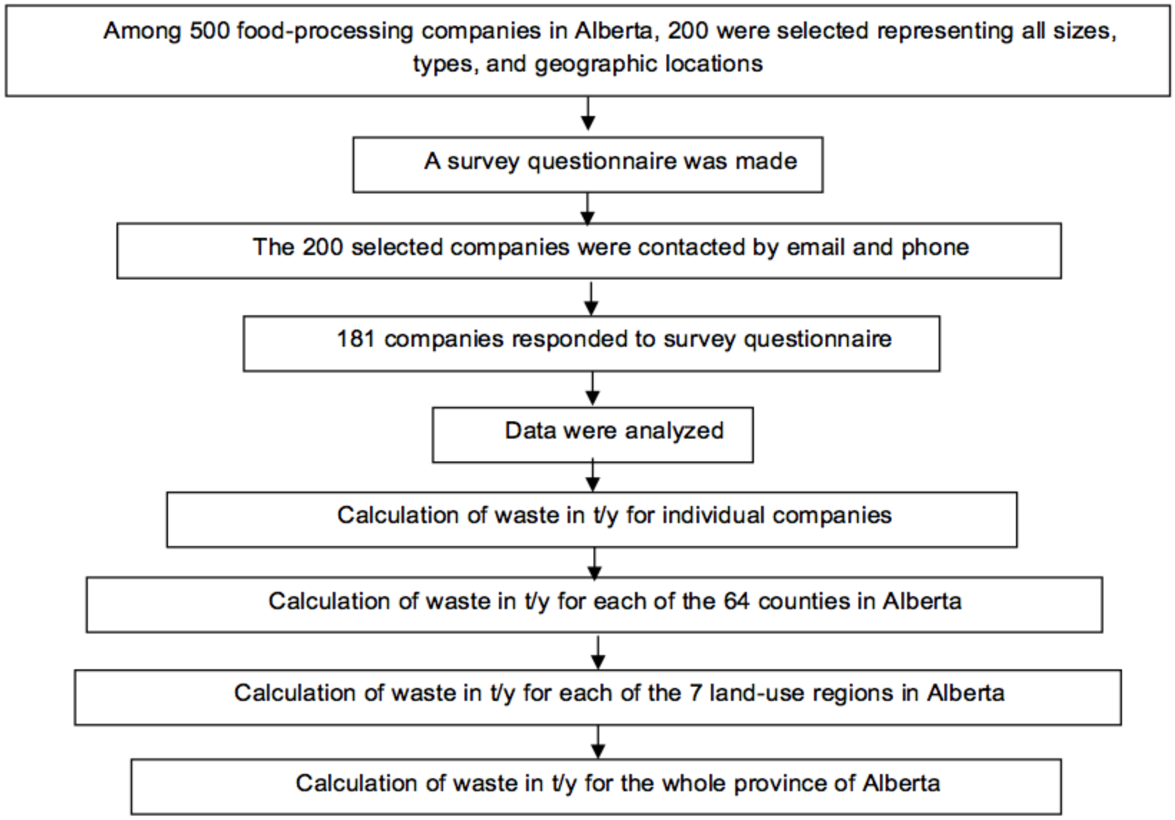

Fig. 2. Flow chart of data collection process and waste estimation.

amount by dumpster size (i.e., small, medium, large) and filling schedule (daily or weekly). In such cases, the average volume of a standard dumpster was considered and the corresponding mass of the waste was then calculated by multiplying the volume and the waste density. The value of the waste density was mainly provided by the processing companies. However, in some cases, it was collected from the literature (Krokida et al. 1998; Krokida and Maroulis 1997). Similarly, the waste moisture content was collected from both the companies and the literature. In cases of mixed waste, since it was not possible to determine the dominant waste in the mixture, 70% moisture content was assumed as this is considered to be typical for food waste (Miller 2000). The moisture contents for different waste streams are shown in Table 1.

We then estimated county- and region-wise food processing waste for the province. Alberta has sixty-four counties and seven land-use regions (Alberta Environment and Parks 2011; AltaLIS 1998). The 181 companies that responded were allocated to their own counties and the total amount of food processing waste in each county was calculated. The estimates of the counties were used to estimate the respective potential in the different land-use regions and the total amount of food processing waste produced in every region, as well as the potential for the entire province of Alberta.

Table 1. Average moisture content of different waste streams.

Waste type	Moisture	Reference
Vegetables	90%	(Bastin and Henken 2011; Sipahioglu and Barringer 2003)
Fruit	85%	(Bastin and Henken 2011; Sipahioglu and Barringer 2003)
Potato	76%	(Bastin and Henken 2011; Krokida and Maroulis 1997; Sipahioglu and Barringer
Wet distilled grain	70%	(Leu 2011)
Mixed food waste	70%	(Miller 2000)
Meat	60%	(Yalçın and Şeker 2016; USDA 2011)
Unusable bread	60%	(Estimated)
Syrup (stillage)	60%	(Cardona et al. 2009)
Filter grain or	50%	(Provided by companies)
Bean hulls	50%	(Estimated)
Oat hulls	20%	(Clarke 2011)
Flour	14%	(Canadian Grain Commission 2013)

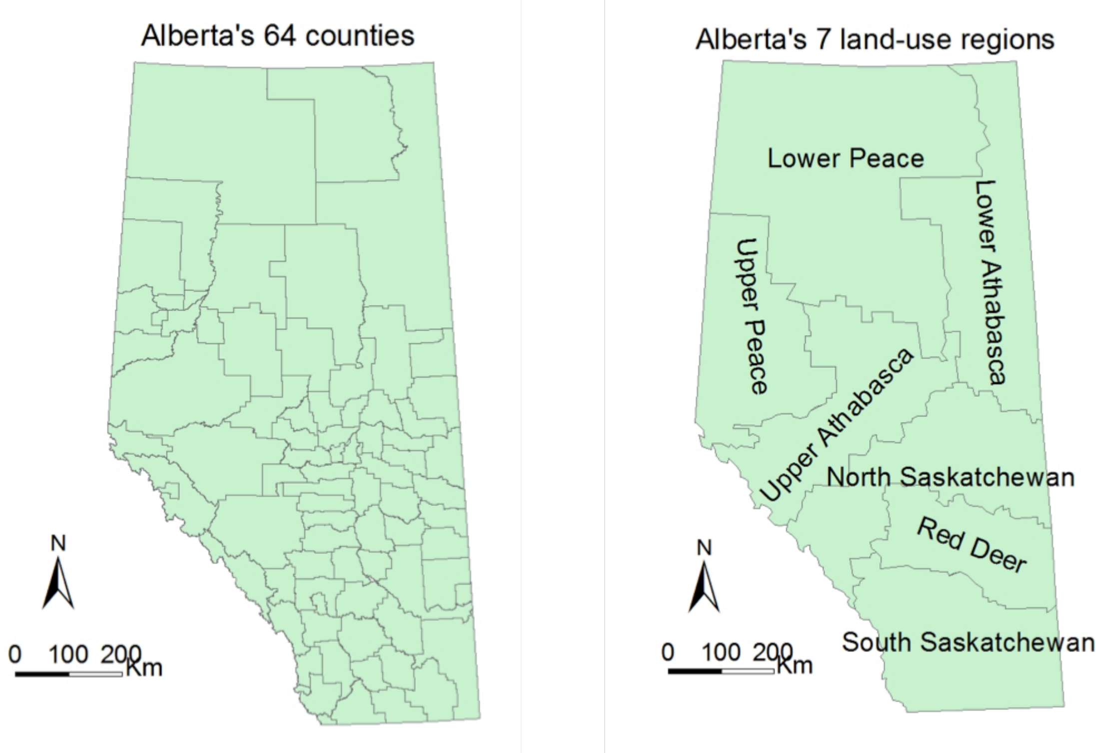

Fig. 3. Shape file boundaries for Alberta's counties (left) and land-use regions (right).

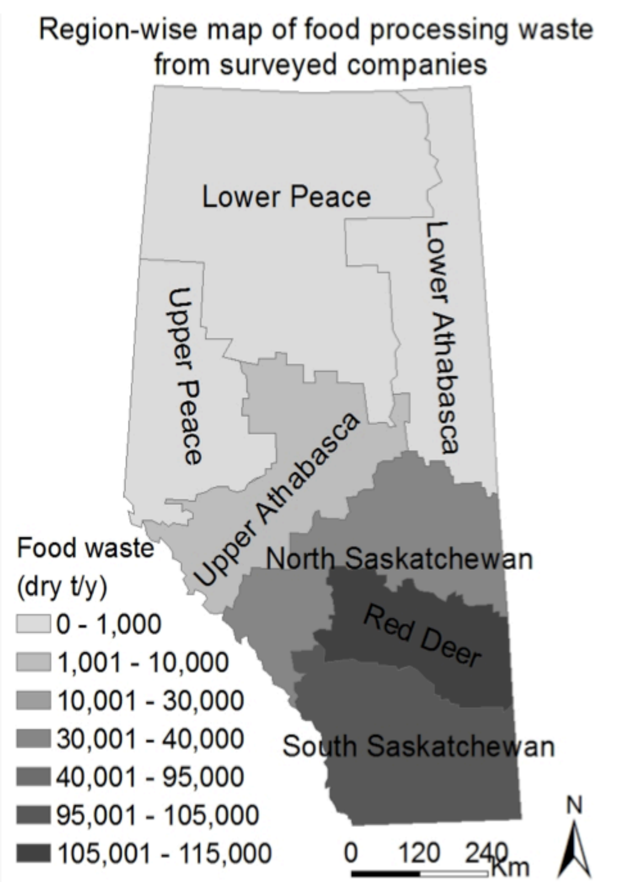

Fig. 4. Land-use region-wise GIS map of Alberta's food processing waste.

GIS mapping

A geographic information system (GIS) can store, retrieve, and display spatially referenced data (Noon and Daly 1996). The GIS software ArcGIS 10.1, released in 2011, developed by the Environmental Systems Research Institute (ESRI 2011), was used in this study to develop GIS maps. Geospatial information for the processing facilities is available in both GCS North American 1983 and GCS North American 1983 CSRS, which are databases found in the Canadian Spatial Reference System (Sultana and Kumar 2012). A map was prepared for Alberta showing land-use region boundaries and county boundaries (Fig. 3) based on collected standard shape files for land-use regions and counties from AltaLIS (1998) and Alberta Environment and Parks (2011).

Extrapolation of data

After collecting data from 181 companies, the amount of food waste was estimated for the remaining 322 companies based on the data from the facilities surveyed. Those companies that provided data were categorized into three size classes (small, medium, and large) based on the number of employees: 1-25 is small, 26-100 is medium, and 100+ is large. The average amount of food processing waste produced by each size class was calculated. The 322 companies not surveyed were also categorized into small, medium, and large size classes using same criteria, and the corresponding amount of waste produced was estimated by multiplying the size class with the corresponding average waste production. Thus, the total amount of food processing waste was estimated for the entire province.

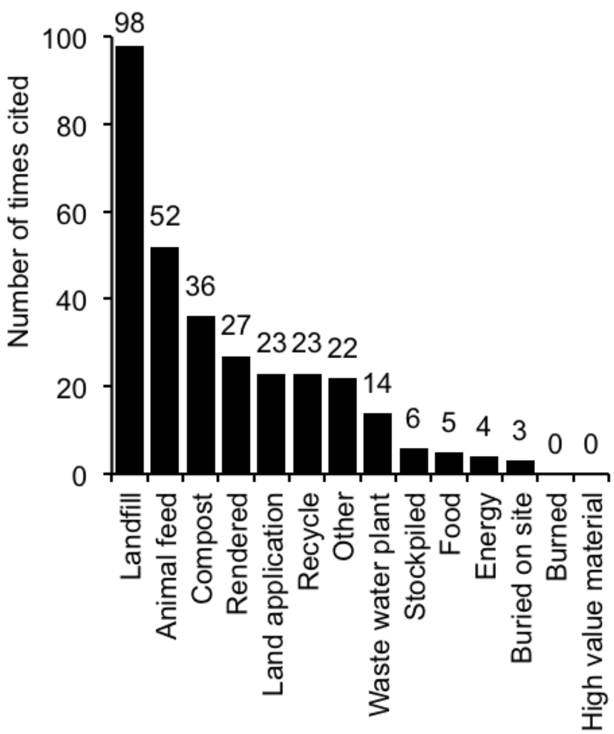

Fig. 5. Types of disposal methods and number of times cited by the companies.

RESULTS AND DISCUSSION

Estimation of the potential of food processing waste

The total amount of food waste in the 181 surveyed companies was 250,530 dry t/y. The amount of food waste for each land-use region was calculated for these companies and is shown in Table 2. The Red Deer and South Saskatchewan regions produced the most food processing waste.

Estimation of total waste

The waste from the remaining 322 companies was calculated by extrapolation. The estimated total amount of food processing waste from all 500 companies in Alberta was 503,171 t/y (dry) and is shown in Table 3. Based on provincial waste disposal data, the food wasted by food producers with more than 50 employees all of Canada is estimated at 4,222,000 t/y (Saville 2014). Among all provinces, Ontario produced the highest amount (2,513,000 t/y), followed by Alberta (369,000 t/y) and British Colombia (332,000 t/y).

Development of GIS maps

We used GIS software to create maps showing the locations of food processing waste generating regions and the distribution of waste throughout the province. Fig. 4 shows a land-use region-wise GIS map of Alberta's food processing waste based on 181 surveyed companies. Most of the waste is concentrated in southern Alberta, primarily in Red Deer County, Taber County, Lethbridge County, Sturgeon County, the City of Calgary, Parkland County, and the City of Edmonton. It also shows the intensity of the food waste availability for different regions. The higher intensity regions are favourable for the establishment of a waste-to-value-added facility.

Disposal of waste

The surveyed companies provided information on how they handled their waste. Some companies have several waste streams and many waste disposal methods including landfilling, animal feeding, composting, land application, rendering, recycling, etc. The different disposal methods and the number of times they are cited by the companies are shown in Fig. 5.

The disposal of waste may be a cost to the company or may be a revenue stream. Table 4 shows some comparative values based on various disposal methods. It shows that some disposal methods such as landfilling, supplying to waste water plant, and stockpiling yield negative values for food processing companies since food processing companies pay the hauling and tipping fees. On the other hand, some disposal methods such as animal feeding and composting yield low value for companies since food processing companies may or may not pay for hauling, and may or may not receive payment. The table also shows that the companies practice negative value and low value disposal methods most of the time.

Potential application of food waste diverted from the landfill

Food waste can be used to produce biogas through conversion technologies such as AD and fermentation and thus can be diverted from landfills. AD of food waste yields higher volumes of biogas than other organic wastes such as animal manure, organic fraction of municipal solid waste (MSW), and garden waste (Zhang et al. 2014). AD of food waste can generate 0.936 m^3 of biogas for every kilogram of volatile solids destruction (Moriarty 2013). Assuming 88% volatile solids in total food waste (Moriarty 2013), 824 m^3 of biogas can be produced from each tonne of solid food waste. Hence, Alberta has the potential to generate 412 Mm^3 of biogas per year from 500,000 dry t food waste. Considering the heating value of biogas to be 20.7 MJ/m^3 (Ghafoori 2007), 8.528 PJ energy would be available in Alberta each year. If electricity is produced from the biogas using a combined heat and power (CHP) unit with 40% electrical efficiency and 90% capacity, Alberta has the potential to generate 852 GWh

Table 2. Food processing waste by land-use region.

Land-use region	t/y (dry)
Lower Peace	-
Upper Peace	-
Lower Athabasca	-
Upper Athabasca	4,000
North Saskatchewan	36,114
Red Deer	113,184
South Saskatchewan	97,231
Total	250,530

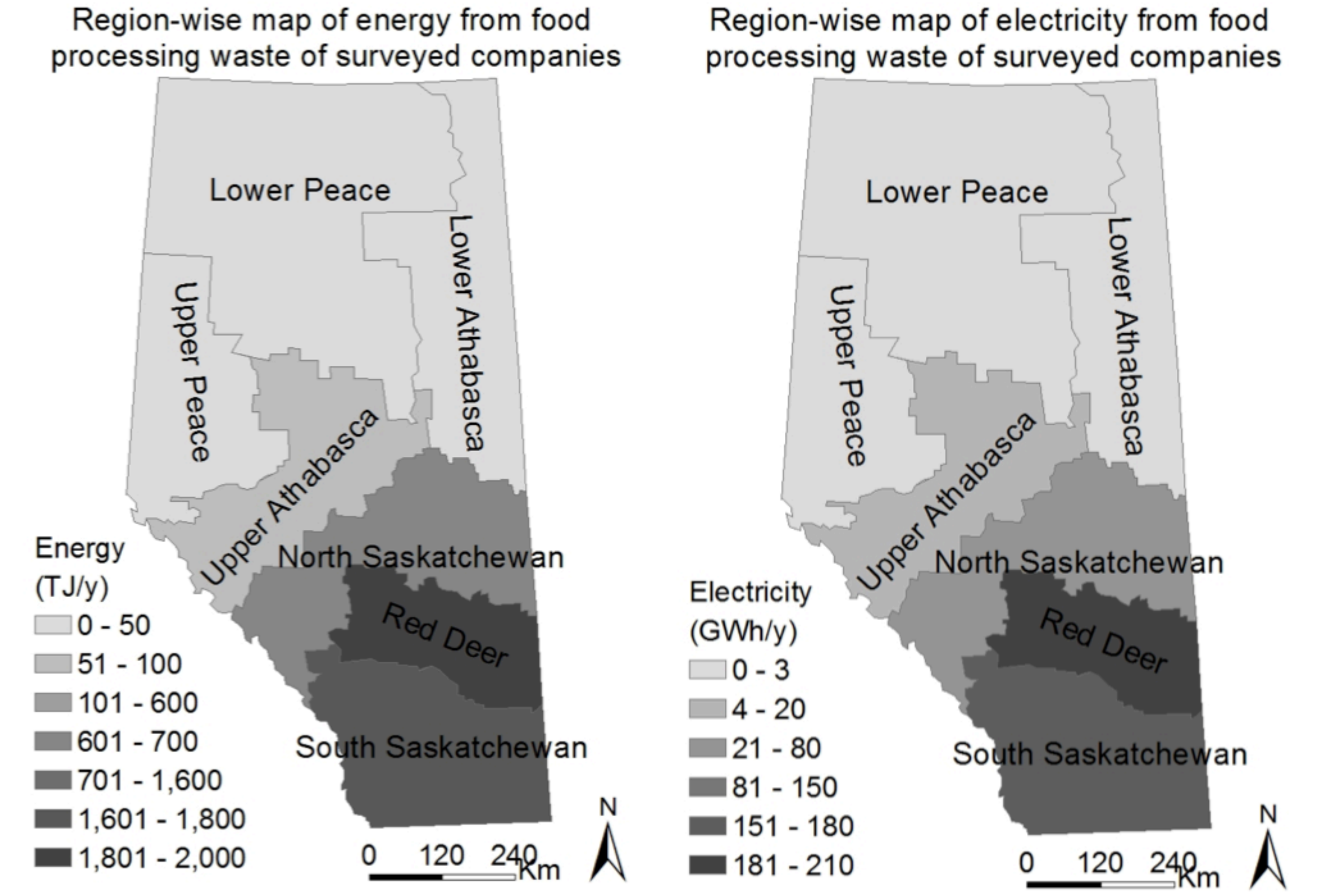

Fig. 6. Region-wise GIS map of available energy (million MJ/y) and electricity production (million kWh/y) from the food processing waste of surveyed companies.

Table 3. Potential of total waste by food processing industries across Alberta.

	Small companies	Medium companies	Large companies	TOTAL
Surveyed companies	85	69	27	181
Collected amount (dry t/y)	28,874	135,287	86,408	250,569
Companies not surveyed	252	46	24	322
Extrapolated amount (dry t/y)	85,603	90,191	76,807	252,602
Total number of companies in Alberta	337	115	51	503
Total amount of waste (dry t/y)	114,478	225,479	163,215	503,171

Table 4. Net value of different disposal methods.

Disposal method	Total number of times cited	Possible cost/gain	Net value gain
Landfill	98		
Waste water plant	14		
Stockpiled	6	Hauling cost, staff cost, tipping fee	Negative value
Buried on site	3		
Burned	0		
Land application	23	Hauling cost by others	No value
Animal feed	52		
Compost	36	May or may not pay for material, hauling fee, may or may not receive payment	Low value
Rendered	27		
Other	22		
Energy, recycle	27	Valuable commodity	Medium value
Food	5		High value

Table 5. Biogas, energy, and electricity potential from food waste in Alberta.

	Amount of waste (dry t/y)	Biogas potential by AD (million m^3/y)	Energy potential (PJ/y)	Electricity potential (GWh/y)
Based on 181 companies surveyed				
Lower Peace	-	-	-	-
Upper Peace	-	-	-	-
Lower Athabasca	-	-	-	-
Upper Athabasca	4,000	3.3	0.068	6.8
North Saskatchewan	36,000	29.8	0.616	61.6
Red Deer	113,000	93.3	1.930	193
South Saskatchewan	97,000	80.1	1.660	166
For whole province of Alberta (for 503 companies)				
Alberta	500,000	412	8.528	852

electricity in a year. The total amount of electricity generation from all sources (i.e., coal, natural gas, hydro, wind, biomass etc.) in Alberta is 81.621 TWh in a year (Alberta Energy 2015). Hence, the amount of electricity produced from food waste would be 1% of the total generated. Table 5 shows the biogas, energy, and electricity potential in Alberta from food waste. Another important aspect of AD of food waste is the production of digestate that can be spread on farmlands as fertilizer.

Fig. 6 displays a map of available energy and electricity generation based on the waste data for different regions. The use of food waste can mitigate GHG through its diversion from landfills and its use for electricity production, which can replace coal or natural gas-based electricity. Hence, we estimated GHG reduction via the AD of waste through its diversion from the landfill as well as via electricity production from biogas and its replacement of coal or natural gas-based electricity.

The amount of GHG reduction via the AD of food waste (rather than landfilling) was estimated by ICF Consulting (2005) to be 0.9 t CO_2-eq/t of waste. The total food waste potential in Alberta is 500,000 dry t/y, which is equivalent to 1.6 wet Mt/y considering 70% moisture content. Hence, the total amount of GHG reduction in AD (compared to landfilling the waste) is estimated at 1.5 Mt CO_2-eq/y as shown in Table 6.

GHG reduction through the displacement of coal-based electricity and natural gas-based electricity by biogas-based electricity is 0.97 kg CO_2-eq/kWh and 0.3 kg CO_2-eq/kWh, respectively (Ghafoori 2007). Thus, the total amount of GHG reduction would be 820,000 or 250,000 t CO_2-eq/y, respectively, through the displacement of coal- or natural gas-based electricity as shown in Table 7.

CONCLUSION

The food processing industry in Alberta, Canada, produces around 500,000 dry t of food waste annually. The Red Deer region produces the highest amount of waste, followed by the South Saskatchewan and North Saskatchewan regions. Unlike household sector food waste, food-processing waste does not require sorting/separation. However, if the waste is not disposed of appropriately, then little or no value is gained from disposal. Such waste, however, could be converted into energy. An estimated 412 million cubic meters of biogas can be produced from these wastes through AD, and 852 GWh of electricity can be produced through combined heat and power. The potential of GHG mitigation was estimated by diverting landfill waste and displacing the coal or natural gas for electricity generation. The amount of GHG mitigation was estimated to be 1.5, 0.82, and 0.25 Mt CO_2-eq/y for diverting landfill, replacing a coal power plant, or replacing a natural gas power plant, respectively.

Table 6. Calculation of total GHG reduction in AD compared to landfilling.

Amount of waste (dry t/y)	Amount of waste considering 70% moisture (wet Mt/y)	GHG reduction in AD compared to landfill (t CO_2-eq/t waste)	Total GHG reduction in AD compared to landfill (Mt CO_2-eq/y)
500,000	1.6	0.9	1.5

Table 7. Calculation of total GHG reduction in a biogas power plant compared to coal and natural gas power plants.

Amount of waste (dry t/y)	Electricity potential of biogas plant (GWh/y)	GHG reduction in a biogas power plant compared to coal (kg CO_2-eq/kWh)	Total GHG reduction in a biogas power plant compared to coal (t CO_2-eq/y)	GHG reduction in a biogas power plant compared to natural gas (kg CO_2-eq/kWh)	Total GHG reduction in a biogas power plant compared to natural gas (t CO_2-eq/y)
500,000	852	0.97	820,000	0.3	250,000

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