The Future of Organic Waste Management at UBC

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Chemical and Biological Engineering
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Executive Summary

In 2004, UBC initiated an on-site composting facility for the organic wastes collected on campus. Currently, sorting of the contaminants from the waste and seasonal variations in the incoming feed are posing threats to proper handling by UBC's Waste Management. UBC's on-site system is recognized in this report as the *"On-campus Option"* which includes the following processes from start to end: collection, transport of the rejected waste to landfill, landfilling, composting with energy input, and land application of compost. This option assumes a rejection rate of 20% because of the lack of sorting, therefore only 80% of the collected waste goes into processing. This report also considers an alternative option, which takes the waste outside of UBC for processing. The *"Off-campus Option"* comprises of the following operations: collection, transport to sorting facility, transport to landfill, landfilling, transport to processing, anaerobic digestion (AD), composting, transport of compost, and land application of compost. This option assumes a rejection rate of only 5% because of the existence of sorting. A model considering an average annual amount of 650 tonnes of organic waste is used in a life cycle analysis tool SimaPro 8™ with the database Ecoinvent 3.0. Essentially, three indicators, climate change, ecosystem quality and human health, are chosen in order to compare the two options and also a third scenario where the *"On-campus Option's"* rejection rate is reduced to 5%.

It is found that the *"On-campus Option"* with 20% rejection rate has the greatest impact on climate change. The impacts on human health and ecosystem quality are similar to the *"Off-campus Option"*. However, if the rejection rate can be reduced to 5% (minimum assumed value), impact on climate change would become smaller than the *"Off-campus Option"*, though the effects on human health and ecosystem quality increase.

The numbers and results presented should however not be taken as absolutely accurate. Limited options in the database for different variations in a process operation and the region selection leads to results that can deviate from the true values to different extents.

SEEDS Project Final Report

Introduction

The current situation (*"On-campus Option"*) of organic waste management at UBC comprises the operations "collection, transport of the rejected waste to landfill, landfilling, composting with energy input, and land application of compost". Approximately 650 tonnes/year of food waste is composted by the in-vessel system located on South Campus of UBC. Struggles with sorting and seasonal variations in the incoming waste are posing threats to proper handling by UBC's Waste Management. Recently, a four-bin system has been adopted that separates the garbage from the organics, paper recyclables, and plastic recyclables at the source. Although it represents a large step towards implementing a zero waste action plan and becoming a leader among North American universities, problems can still occur as segregation of organic and inorganic wastes in the green bins becomes a difficulty.

An alternative, the *"Off-campus Option"* is being considered. It comprises the operations "collection, transport to sorting facility, transport to landfill, landfilling, transport to processing, anaerobic digestion (AD), composting, transport of compost, and land application of compost".

Objectives and Methodology

The objective of the SEEDS project was to compare the two options using the Life Cycle Analysis (LCA) approach. LCA requires that the system boundaries and a functional unit be defined. The functional unit for this study was chosen to be 650 tonnes of food waste processed per year. Simulation was performed using the LCA software, SimaPro 8^{TM}, which includes the following *midpoint life cycle impact indicators* - global warming potential, acidification potential, human toxicity (carcinogenic and non-carcinogenic emissions), and respiratory inorganic emissions. The midpoint indicators predict the environmental problems and impact raised during the cycle of the process. The intermediate results (midpoint impacts) were further processed within the software to generate results pertinent to the three *endpoint life cycle impact categories* - climate change, ecosystem quality and human health. The endpoint indicators on the other hand display the overall damage as a result of the emissions.

Emissions associated with production, transportation, and energy consumption in each processing stage over the entire life cycle are calculated by multiplying each energy or material consumption value by the intensity or emission factor for each pollutant of interest. The midpoint indicators display impacts based on the chemical substances emitted, and they can truly reflect categories such as climate change and acidification. However, for categories such as human health there is no middle ground in the life cycle chain; hence endpoint indicators which display the damage caused by the emissions to living organisms or the environment may be more readily understood.

For the on-campus option, initially the scenario with an assumption of maximum 20% rejection rate was considered. Thus, 130 tonnes of the waste are inorganics and get diverted to the Vancouver landfill while the remaining 520 tonnes are delivered to an AD and composting plant in Richmond. The compost product will then be sent back to UBC for landscaping purposes. Subsequently, a sensitivity analysis was performed whereby the 20% rejection rate was reduced to 5% (32 tonnes), which was deemed to be the minimum value.

For the off-campus option, it was assumed that approximately 95% of renewable organics can be separated from the contaminants, based on the findings from an off-campus sorting site (Annacis Island). Hence, 32 tonnes of the waste are sent to the Vancouver landfill.

Results and Discussion

Results in terms of the endpoint life impacts are presented in Tables 1-5. Table 1 shows the components of total emissions for the off-campus option. Tables 2 and 3 show the components of total emissions for the on-campus option, at 20% rejection rate and 5% rejection rate, respectively. The intensity or emission factors of the various processes on a "per tonne" basis are indicated in Table 4. A comparison of the total (full) emissions relevant to the off-campus and on-campus options is presented in Table 5.

The endpoint indicators Human Health, Ecosystem Quality and Climate Change are expressed in units of DALY, PDF and T $CO_{2\text{-eq}}$, respectively. DALY "Disability Adjusted Life Year" means the amount of years lost as a result of the toxic materials released. PDF "Potentially Disappeared Fraction" is pertinent to the fraction of species over an area of land in a certain amount of time. T $CO_{2\text{-eq}}$ is the tonnes of carbon dioxide equivalent.

For the off-campus option, anaerobic digestion has the lowest amount of GHG emission, as expected (Table 1). A reduction of GHG from composting is obtained. Land application of compost sequestrates carbon dioxide, resulting in negative values of GHG emission and offsetting total GHG emissions. Transportation and electricity was found to have the lowest impacts on human health, ecosystem quality and climate change. In terms of impacts on ecosystem quality (acidification potential) and human health effects, the composting process is the highest, followed by anaerobic digestion and land application of compost. This is attributed to the windrow method of composting, whereby the machinery involved burns fossil fuel that can release a fair amount of air pollutants including sulfur dioxide (SO_2), nitrogen oxides (NO_x), and ammonia (NH_3) that have impacts on ecosystem quality. Untreated particulate matter smaller than 2.5 μm ($PM_{2.5}$), ammonia (NH_3) and volatile organic compounds (VOC) emission from composting, or, hydrogen sulfide (H_2S) from anaerobic digestion will also pose threats to human health.

For the on-campus option, impacts due to composting on human health, ecosystem quality and climate change are smaller with a 5% rejection rate versus a 20% rejection rate (Tables 2 and 3). Landfilling of the rejected materials has lower impacts on human health and ecosystem quality, but greater impacts on climate change. Composting leads to higher GHG emission and human health effects when compared to land application of compost.

By comparing the on-campus option (Tables 2 and 3) with the off-campus option (Table 1), on-campus composting is seen to have greater impacts on human health, ecosystem quality and climate change than off-campus composting. This is primarily due to the smaller amount of UBC organics (food waste) being composted at the off-campus facility after the AD process which induces 50% degradation of the food waste. Although an equal amount of yard waste is mixed with the digestate for composting, emissions from the composting of yard waste are not included in the calculations as yard waste is not co-composted with food waste on campus.

Even though the emission factors for composting are considered to be the same for the on and off-campus options, they are different in reality. The on-campus composting system uses the in-vessel method. This is achieved by forced aeration with blowers and agitation with motor-operated spinners. Both operations involve mainly electrical power. Emissions associated with hydropower generation (in the case of Vancouver) and hence the impacts on environment and health are expected to be very low. In contrast, the off-campus composting option uses the windrow method, which requires fossil fuel-operated machinery and equipment. Air emissions, which contain typical air pollutants, are expected to be higher. Thus the impacts on environment and health are also expected to be greater. Unfortunately, the database used in the software, Ecoinvent 3.0, is unable to distinguish between the two composting methods.

When the impacts are compared between the on-campus and off-campus options in terms of total emissions (Table 5), we found that the on-campus option with 20% rejection rate (processing less food waste) has much greater impact on climate change, whereas impacts on human health and ecosystem quality are similar to the off-campus option. However, as the rejection rate is reduced to 5%, the impact on climate change becomes smaller than the off-campus option, though the effects on human health and ecosystem quality are somewhat higher.

Conclusion

The overall goal of the project is to compare the on-campus option with the off-campus option using the LCA method. It may be concluded that the on-campus option with 20% rejection rate (maximum assumed value) would have much greater impact on climate change, whereas impacts on human health and ecosystem quality are similar to the off-campus option. However, if the rejection rate can be reduced to 5% (minimum assumed value), the impact on climate change would become smaller than the off-campus option, though the effects on human health and ecosystem quality increase proportionally.

Although this report presents the quantitative analysis results as obtained from the software, these numbers shall be treated as the general average values. Shortcomings, such as the inability to distinguish between different composting methods, are present in the software. Moreover, the database used in the software is relevant to European facilities. The data may not necessarily represent the local conditions or situations, leading to results that can deviate from the true values to different extents.

Recommendations for Future Work

For future work on this project, it is desirable to obtain exact emission factors from the local facilities studied in order to manually calculate the impact categories and compare to the LCA software database. Performing an energy balance on the composting unit at the off-campus food waste recycling facility may further help the consideration of the two options. A sensitivity analysis conducted on diesel trucks versus compressed natural gas (CNG) trucks, an alternative considered by UBC, is also recommended. Lastly, analysis can be extended to additional impact categories such as smog formation and terrestrial toxicity) in order to fully understand the endpoint values for human health and ecosystem quality.

Although composting is the focus of the present study, many other technologies are used in different regions and the shortcomings in the software create issues. It is highly recommended that developers of databases such as Ecoinvent make provisions to look after details associated with different options for a wide range of technologies.

Table 1. Components of total emissions for the off-campus option

Impact	Transportation	Anaerobic Digestion	Composting	Land Application	Landfill
Human Health, DALY	0.0055	0.42	0.37	0.12	7.4×10^{-4}
Ecosystem Quality, $PDF.m^2.yr$	395	5.1×10^4	6.8×10^4	2.4×10^4	36
Climate Change, T $CO_{2\text{-}eq}$	6.2	28	35	-43	26

Table 2. Components of total emissions for the on-campus option at 20% rejection rate

Impact	Composting	Land Application	Electricity	Transportation	Landfill
Human Health, DALY	0.63	0.20	4.3×10^{-4}	8.9×10^{-4}	0.003
Ecosystem Quality, $PDF.m^2.yr$	1.1×10^5	4.0×10^4	132	64	148
Climate Change, T $CO_{2\text{-}eq}$	59	-72	4.9	1.0	97

Table 3. Components of total emissions for the on-campus option at 5% rejection rate

Impact	Composting	Land Application	Electricity	Transportation	Landfill
Human Health, DALY	0.75	0.24	4.3×10^{-4}	0.00041	0.00073
Ecosystem Quality, $PDF.m^2.yr$	1.4×10^5	4.8×10^4	132	29	36
Climate Change, T $CO_{2\text{-}eq}$	70	-85	4.9	0.46	24

Table 4. Intensity (emission factors) of the processes on a "per tonne" basis

Impact	**Transportation**	**Anaerobic Digestion**	**Composting**	**Land Application**	**Electricity**	**Landfill**
Human Health, DALY/tonne	1.2×10^{-7}	6.8×10^{-4}	1.2×10^{-3}	3.9×10^{-4}	2.15×10^{-9}	2.3×10^{-5}
Ecosystem Quality, PDF.m^2.yr/tonne	0.0088	83	220	78	0.00066	1.1
Climate Change, T $CO_{2\text{-}eq}$/tonne	0.00014	0.045	0.11	-0.14	2.45×10^{-5}	0.75

Table 5. Comparison of the total emissions relevant to the off-campus and on-campus options

Impact	**Off-campus option**	**On-campus option 20% rejection rate**	**On-campus option 5% rejection rate**
Human Health, DALY	0.92	0.83	0.99
Ecosystem Quality, PDF.m^2.yr	1.4×10^5	$1.5\ \times10^5$	1.8×10^5
Climate Change, T $CO_{2\text{-}eq}$	52	90	14

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