UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Streamlined LCA of Paper Towel End of Life Options for UBC SEEDS Recycling vs. Composting

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Recycling vs. Composting

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CEEN 523: Energy and the Environment

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Executive Summary

This study was performed for the University of British Columbia Alma Mater Society (AMS) as part of the Sustainable Ecological Economic Development (SEEDs) program. Although paper towel is proven to be an environmentally damaging method for drying hands, relative to other methods such as hand dryers, many buildings on the UBC campus must still provide paper towel for technical or sanitary reasons (Gregory, 2011). In particular, the AMS is concerned with how to minimize the environmental footprint of paper towels used in the Student Union Building (SUB). This streamlined LCA provides a comparison between end-of-life options for paper towel used in SUB bathrooms, in particular for recycling and composting. The study used a closed loop process for recycling, and an open process with avoided burdens for composting. Overall it was determined that when considering impact categories of solid waste, electricity use, water depletion, fossil fuel depletion, climate change, and human toxicity, composting is the better option for all categories except for electricity consumption. Avoided burdens calculated to not change this result. For example, the Climate Change impact for Recycling was 1,039 kg CO_2 eq while for composting it was 734 kg CO_2 eq (874 kg CO_2 eq without avoided burdens). Additionally, a basic life cycle cost analysis was completed, and composting costs to the university are less than those for recycling. Annual costs for composting were estimated at $5,070, while those for recycling were $16,120.

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1 Introduction

This Life Cycle Assessment compared disposal methods for paper towel used in the Student Union Building at the University of British Columbia. The project was completed for the UBC Sustainability Office as part of the Sustainable Ecological Economic Development Studies (SEEDS) Program. Recycling and composting options were considered. The assessment framework can be seen in Figure 1.

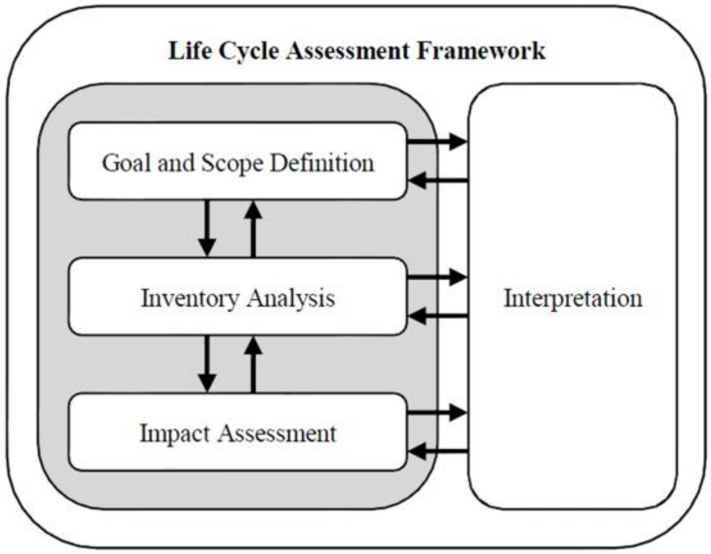

Figure 1.The Life Cycle Assessment framework (International Organization for Standardization, 2006).

Despite paper towels being an environmentally costly method of drying hands in campus bathrooms, for sanitary and technical reasons, most bathrooms must still make them available at the very least to allow users to avoid touching bathroom doors on the way out. In order to decrease the negative impacts associated with paper towel use, the Alma Mater Society (AMS) proposed this LCA comparison.

1.1 Background

1.1.1 Recycling

Recycling involves several processes. The system considered in this study takes in wood chips which must be heated to high temperatures in water and chemicals, and blended to break it down into pulp. Paper towels to be recycled come into the system and are shredded, then soaked in water and chemicals in order to break them down into pulp as well. The two pulp streams are combined, with the wood chip pulp having a higher quality fibre content. The pulp mixture is then poured onto flat screens on a conveyor. Water drains through the screens and the mixture begins to dry. The fibres begin to bond together to form a sheet. The sheet passes through rollers to squeeze out more moisture. Heated rollers complete the drying process, and the finished paper product is wound around rolls in preparation for packaging (The Leading Technical Association for the Worldwide Pulp, Paper, and Converting industry, 2001).

1.1.2 Composting

Composting in this report refers to the facilitated process of organic material decay. This study considers emissions from an aerated static pile facility with biofiltration, where organic material is mixed to optimal moisture content and then covered for an extended period of time. During the decay period, a vacuum pulls air down through the pile, which oxygenates the natural decay reactions occurring. As organic materials decay in contact with oxygen, CO_2 and organic compounds are emitted (Harvest Power, 2012).

2 Goal and Scope

The purpose of this Life Cycle Assessment was to compare the environmental impacts of two different paper towel disposal options: composting, and recycling. The study was performed to aid UBC SEEDS in their paper towel recycling projects, with a focus on paper towel use in the Student Union Building (SUB) bathrooms.

The goal of this study is to propose recommendations regarding the best end-of-life option for paper towels in SUB bathrooms, and to produce further recommendations for UBC regarding opportunities to decrease environmental costs of paper towel use on campus. The study focused on the following major components of the paper towel life cycle:

1. Production of the type of paper towel currently used in the SUB
2. Transportation between the university and production or disposal facilities
3. Energy usage in disposal options
4. Emissions during disposal processes

This simplified LCA will examine the emissions due to each process to determine whether recycling or composting is the more environmentally friendly disposal method.

2.1 Functional Unit

This study requires that a functional unit be selected to provide equivalency between the two disposal systems for direct comparison. The exact quantity of paper towel which is disposed of specifically in SUB bathrooms is unknown, but an exact purchased quantity is easily accessible. The difference between these two quantities is equal to the amount of paper towel dispensed in SUB bathrooms, but thrown out in a different location (for example, if someone carries the paper towel out of the bathroom and throws it in a cafeteria garbage bin). Assuming that the proportion of paper towel ordered for the SUB but disposed of elsewhere is constant, the quantity disposed of in the SUB will be directly proportional to the quantity ordered. Therefore the functional unit used was per tonne of paper towels purchased.

2.1.1 Impact Categories

This assessment will focus on the following indicators, as required by the AMS (UBC Alma Mater Society (AMS), 2008):

1. Global Warming Potential (kg CO2 eq)
2. Electricity (kWh)
3. Solids waste (kg)
4. Water resource depletion (m^3)
5. Cost ($)

Additionally, the following impact categories were calculated.

1. Human toxicity (kg 1,4-DB eq)
2. Fossil fuel resource depletion (kg oil eq)

Eutrophication, ecotoxicity, and biodiversity will be left out of this analysis, but should be considered for future work and decision making.

2.1.2 System Boundary

The boundaries for this LCA will begin with the production of the recycled paper towels of the type ordered by the AMS for the SUB. They will end with the completion of the recycling or composting process. For recycling, this will be when the paper towel has been processed into a new usable paper product. For composting this will be when the paper has fully degraded into compost that can be used as fertilizer. The simplified system boundary diagram can be seen in Figure 2.

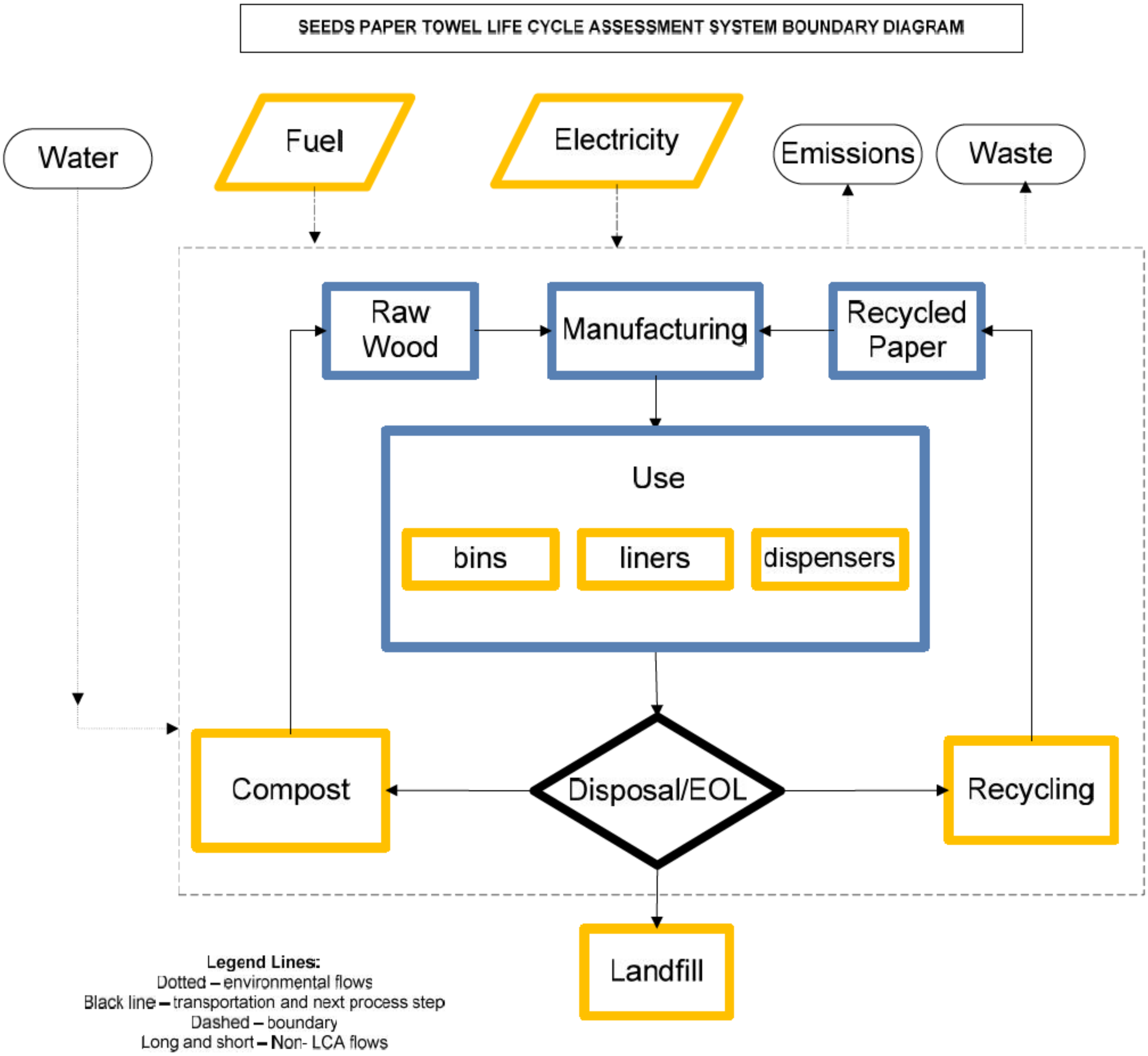

Figure 2 – The generalized process system overviewed by the LCA of Paper towel including three disposal options: compost, landfill, recycling.

Paper towel currently used at the SUB contains 100% recycled content. Therefore, production of prior virgin forms of the material (including land use change) has been left out of the LCA according to best practices for open loop recycling (Clift, 2012). However, the impacts of this should be considered in future studies and will be discussed on a high level in this paper. Impacts of building, construction, and infrastructure requirements for processing and shipping have also been omitted but should be examined in future studies. Landfill as a disposal option was also scoped out because it is unlikely to be chosen by the AMS as UBC strives to be waste neutral.

2.1.3 Sources of Data

The information assessed was found on SimaPro using the Ecoinvent database (2007). Further information and clarification was compared through various journal articles, and other reports where referenced. The SimaPro software made notes on unit processes and full LCI.

The following were gathered from interviews with current and potential suppliers:

1. Paper towel manufacturing through recycling
2. Composting energy consumption

The following were taken from SimaPro:

1. Electricity use
2. Fuel use
3. Truck and train transportation intensity
4. Recycling process impacts

The following were taken from journal articles and estimates of inventory intensity:

1. Use phase
2. Composting emissions

3 Method

3.1 Manufacturing

The paper towel used in SUB bathrooms is 100% recycled content (Cook, 2012). Therefore, impact category values for the upstream portion of the LCA were determined using a generic paper recycling process in SimaPro. The software assumed paper input materials to be a free stream, allocating no values to the transportation of the wood. However, the supplier indicated that 20% of materials were post-industrial, so additional raw material (waste wood chips) streams were added (Cook, 2012). The major energy inputs included fossil fuels for machinery and electricity using the Quebec supply mix, since the paper towel is produced in Gatineau. The manufacturer indicated that the amount of material in the packaging is equal to approximately 2.3% of the paper towel mass, so this value was used to attribute manufacture of a small mass of corrugate (Cook, 2012).

3.2 Transportation

It was assumed that paper travelling from Quebec would be shipped by train to a rail depot in Delta, and then driven by truck to the university. To complete the cycle, the used paper towel would also be transported by truck from the university either back to the Gatineau recycling facility or to the major local organics composting facility (depending on the alternative being analysed). Transportation emissions were determined in SimaPro by applying the emissions per tonne-kilometre for each type of transport to the appropriate distances travelled, and multiplying by one tonne (as per the functional unit).

3.3 Use

Use emissions were minimal as no electricity is required at the time of use. Bin liners, dispensers, and disposal bins were considered. However, due to the much longer useful life of the dispensers and bins compared to the paper towels (a decade as opposed to a day), emissions from these aspects were negligible. Liners also have no emissions during the use phase, but their manufacture contributed a small amount to upstream emissions.

3.4 Disposal

3.4.1 Option 1: Recycling

Because paper towel coming into UBC is composed of recycled content, a loop was assumed wherein the emissions due to recycling disposal are included in the recycling emissions generated when the paper is produced. A diagram illustrating the complete process can be seen in Figure 3.

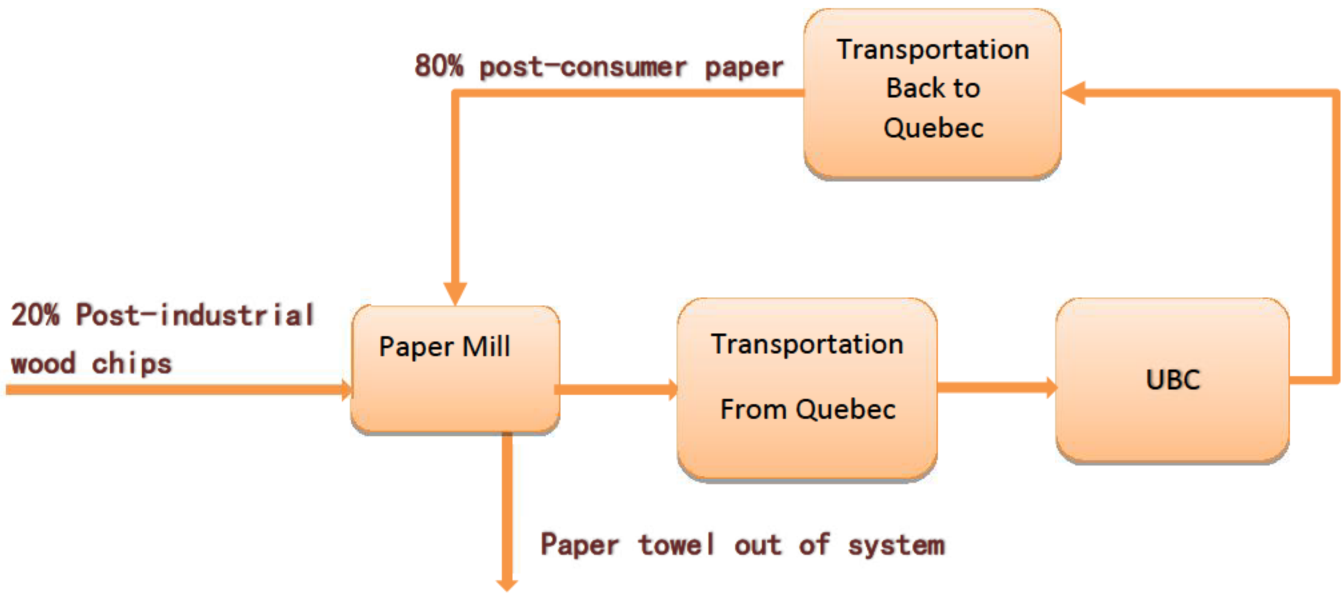

Figure 3. Recycling system process diagram

As such, avoided burdens were built into the process and did not need to be calculated separately. Emissions due to recycling were already accounted for during the manufacturing process so no additional calculations were required.

3.4.2 Option 2: Composting

The data for these processes did not exist in Gabi or SimaPro, so values from literature and conservative estimates were used to create a generic composting process in SimaPro. The system process diagram can be seen in Figure 4.

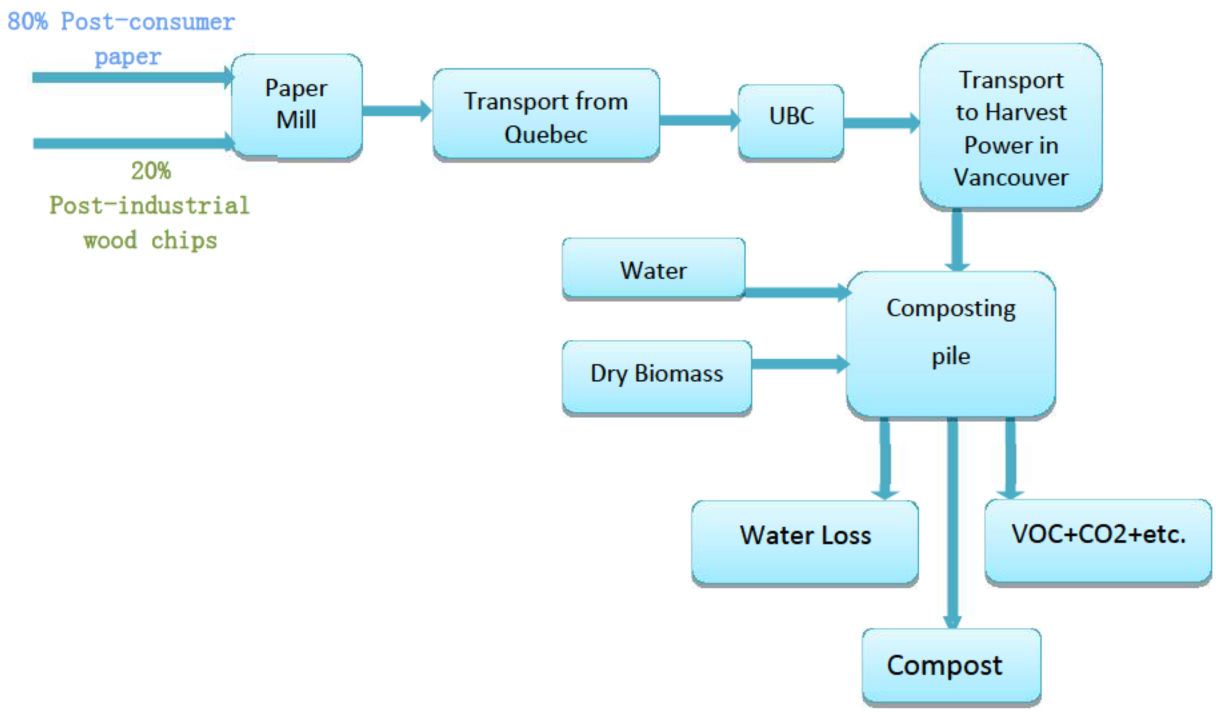

Figure 4. Composting system process diagram

According to a detailed composting study, under optimal conditions a static aerated pile with biofiltration can eventually break down organic emissions almost entirely into CO_2, water, and compost biomass (Gray, Rosenfeld, & Sellew, 2004). Furthermore, this type of composting has negligible methane emissions because the airflow oxygenates the carbon to create CO_2 instead (Shelton, 1997). The values taken from studies to determine composting emissions can be seen in Table 1.

Table 1. Values taken from studies to determine emissions

Value	Quantity	Source
Volumetric flow of air	$60\ \frac{m^3}{min}$	(Gray, Rosenfeld, & Sellew, 2004)
Duration of air flow	8 weeks	(Harvest Power, 2012)
Tonnage in study	522 t	(Gray, Rosenfeld, & Sellew, 2004)
Percentage of paper towel in compost mix	0.32	(Allen, 2012)
Moisture content in pile (optimal conditions)	50%	(Gray, Rosenfeld, & Sellew, 2004)
Electricity use per tonne of compost	6.4 kWh	(Roxby, 2012)
Diesel use per tonne of compost	0.726 L	(Roxby, 2012)
Shrinkage	50%	(Shelton, 1997)

Paper is composed mainly of wood fibres, which means that during the lifetime of the tree, carbon was sequestered and stored in the cellulose fibres. Therefore, CO_2 emissions are negated by the sequestration that occurs throughout the life of the tree, and the decay that occurs in composting is considered carbon neutral. For this reason no contribution of paper mass decay to CO_2 emissions was included.

However, because the compost heap is a complex system in which the presence of paper towel will contribute to the decay of other materials, emissions other than CO_2 had to be taken into consideration, particularly those of VOCs. Gray, Rosenfeld, and Sellew (2004) give detailed VOC emission concentrations for an aerated static pile with biofiltration, which is the type of facility located outside of Vancouver (Harvest Power, 2012). Both the study and the local composting site claim to keep the mix fractions optimized for minimal emissions and fast decay so it was concluded that the study values could be scaled to predict the required values. This scaling is detailed in Section 4.3.2.

The emission quantities and mass flow were used to create a generic composting process in SimaPro. In order to apply the burdens avoided by replacing fertilizer with compost, a stream was created for the mass of fertilizer replaced by 1 tonne of paper towel.

4 Life Cycle Inventory

Data was assessed for the LCA of Paper towel upstream processes and two end-of-life scenarios. The emissions values used are detailed in this section

4.1 Paper Towel Manufacturing through Recycling

The paper towel used at UBC is 100% recycled content where 80% is post-consumer waste (such as office paper) and 20% is post-industrial waste (Cook, 2012). Therefore, the inputs for the process included 80% post-consumer mixed paper and 20% post-industrial waste wood chips. The post-consumer mixed paper was considered to be 100% recycled paper towel (as a result, no deinking of paper was considered in the recycling process), and the 20% post industrial waste wood chips were considered as an allocated waste stream from wood processing. The recycling process including mass balances can be seen in Figure 5 below. Note that a closed-loop process is used, which assumes that paper towel from UBC is returned to the recycling facility for reprocessing.

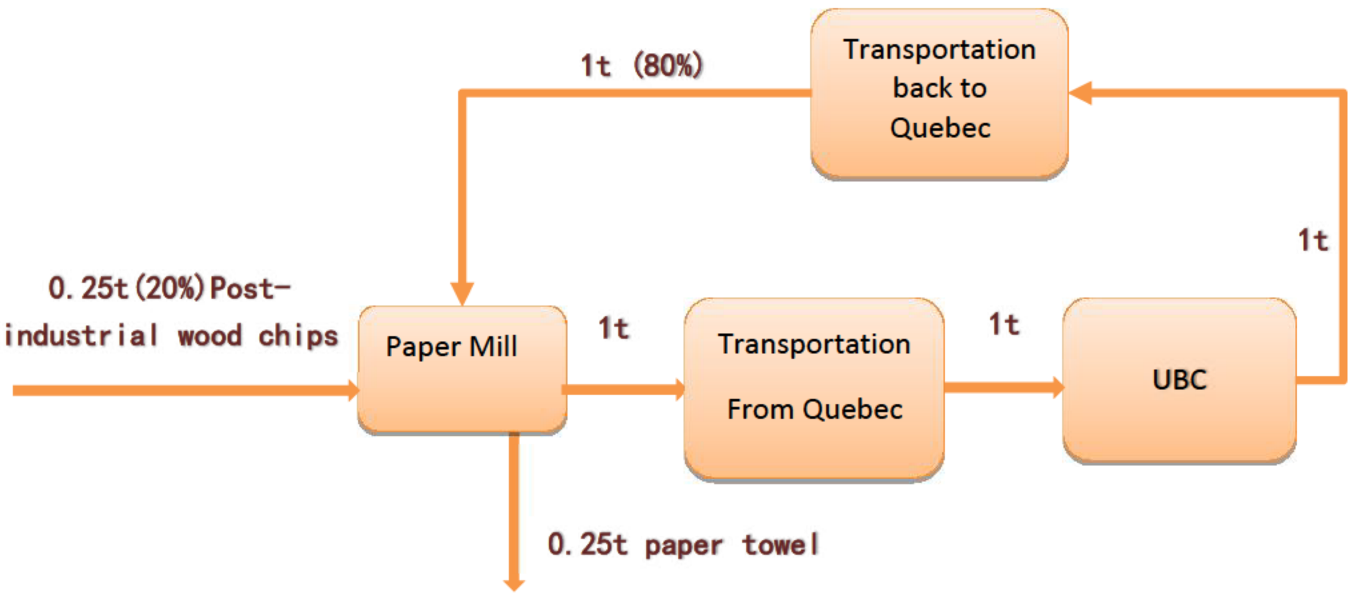

Figure 5. Paper towel recycling manufacturing process

The inventory table for the system shown in Figure 5 is shown in Table 2.

Table 2: Summary of major inputs to the paper towel recycling manufacturing process (Ecoinvent Centre 2007, 2007)

Inputs	Unit	Quantity per Tonne of Paper towel	Per Case	Per Year
Water, natural origin	m3	23.5	0.2	2,165.5
Waste paper, sorted	kg	1,013	9.8	93,348.0
Electricity	kWh	62.8	0.6	5,787.0
Natural gas	MJ	8,710	84.5	802,626.5
Transport, rail	t-km	8,886	86.2	818,844.9
Transport, lorry	t-km	47	0.5	4,331.1
Corrugated board	kg	23	0.2	2,119.5

Table 3. Summary of major outputs from the paper towel recycling manufacturing process (Ecoinvent Centre 2007, 2007)

Outputs	Unit	Quantity per Tonne of Paper towel	Per Case	Per Year
Recycled paper	kg	1,000	9.7	92,150.0
Plastics, mixture, 15.3% water	kg	20.3	0.2	1,870.6
Disposal, packaging paper	kg	6.46	0.1	595.3

Process-specific burdens	kg	2.1	0.02	193.5
Disposal, wood untreated	kg	1.13	0.01	104.1
Disposal, steel	kg	2.26	0.02	208.3
Suspended solids	kg	0.13	0.00	12.0
Total Solids waste	kg	32.4	0.3	2,985.7

4.2 Transportation

Transportation emissions are integrated into the processes defined in SimaPro. The following distances were used. SimaPro then multiplied the emissions per tonne-kilometre for each type of transportation by the respective distance travelled. The distances can be seen below in Table 4.

Table 4. Transportation distances used for LCI

Transportation phase	Distance	Source
Gatineau, QC to Richmond, BC by rail	4,443 km	(Google, Inc., 2012)
Richmond, BC to UBC by truck	22 km	(Google, Inc., 2012)
UBC to Harvest Power (composting only)	15 km	(Google, Inc., 2012)

4.3 Disposal Options

4.3.1 Recycling

As previously discussed, the impacts of recycling emissions are included in the manufacture of 100% recycled content paper towels. Therefore, no additional calculations were required for this process.

4.3.2 Compost

The process diagram for composted paper towel including mass balances is shown in Figure 6. An open-loop process was used.

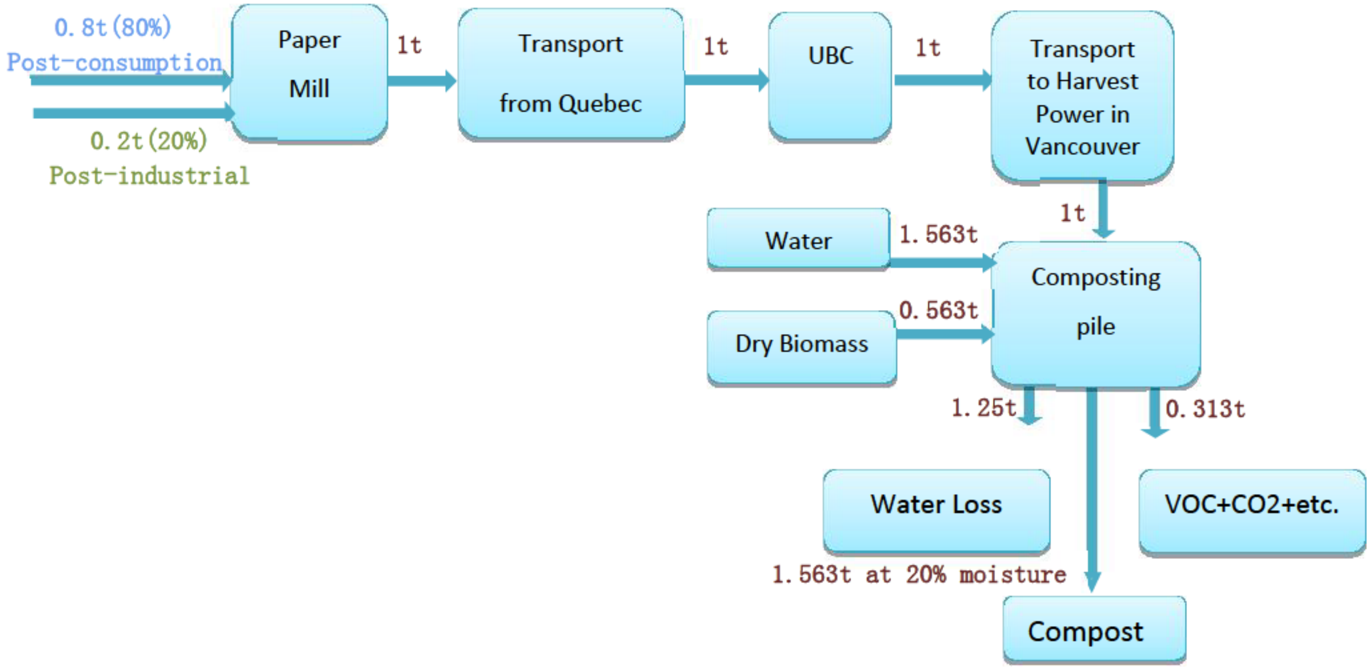

Figure 6. Process diagram for composted paper towel

As previously discussed, both the study and the local facility employ optimal conditions for minimal emissions and fast decay (Harvest Power, 2012) (Gray, Rosenfeld, & Sellew, 2004).The values used for these conditions are shown below, in Table 1. VOC emission concentrations in this study were scaled by tonnage to the functional unit quantity, given the emissions concentrations shown in

Table 5.

Table 5. VOC emissions from an aerated static pile with biofiltration

Odorant	Concentration [ug/m3] (Gray, Rosenfeld, & Sellew, 2004)	Total emission (in study) [kg]	Emission per tonne compost [kg]
Ammonia NH3	1658	8.0221	0.03074
Dimethyl disulfide (CH3)2S2 ^	961	4.6497	0.01781
Carbon disulfide CS2	1305	6.3141	0.02419
Formic acid HCOOH ^	60	0.2903	0.00111
Acetic CH3COOH	6600	31.9334	0.12235
Sulfur dioxide or carbonyl sulfide SO2 or COS^	131	0.6338	0.00243

^Emissions were below the detection limit. To be conservative, the limit is used.

Where:

$$Total\ emission\ (in\ study) = concentration\ \times volumetric\ flow\ of\ air \times duration\ of\ air\ flow\ \times 10^{-9}$$

$$Total\ mass\ of\ compost\ mix\ (including\ paper\ towel) = \frac{mass\ of\ paper\ towel}{percentage\ of\ paper\ towel\ per\ one}$$

$$= \frac{1}{0.32} = 3.125\ t$$

$$Percentage\ of\ dry\ mass\ made\ up\ by\ paper\ towel = \frac{(1\ t\ paper\ towel)}{mass\ of\ mix\ in \times (1 - moisture\ content)}$$

$$= \frac{1}{3.125 \times (1 - 0.5)} = 0.64$$

$$\begin{aligned} Emission\ per\ tonne\ compost \\ &= Total\ emission\ in\ study \div tonnage\ in\ study \\ &\times mass\ of\ compost\ per\ one\ tonne\ of\ paper\ towel \\ &\times percentage\ of\ dry\ mass\ made\ up\ by\ paper\ towel \end{aligned}$$

The inventory table for the composting process as determined by SimaPro can be seen in Table 6 (inputs) and Table 7 (outputs). Because the goal of this study is to report back to UBC SEEDs, impacts have also been converted to values for each case of paper towels, and per one year's consumption of paper towels at the SUB.

Table 6. Summary of major inputs to the composting process (Ecoinvent Centre 2007, 2007)

Inputs	Unit	Quantity per Tonne of Paper towel	Per Case	Per Year
Waste paper, sorted	kg	1,013	9.8	93,348.0
Water, natural origin	m3	23.5	0.2	2,165.5
Potato starch, at plant/DE	kg	30	0.3	2,764.5
Electricity	kWh	62.8	0.6	5,787.0
Natural gas, industrial	MJ	8,710	84.5	802,626.5
Transport, freight, rail	t-km	4,443	43.1	409,422.5
Transport, lorry	t-km	22	0.2	2,027.3
Corrugated board, recycling fibre	kg	23	0.2	2,119.5
Machine diesel for process	L	2.27	0.0	209.2

Table 7. Summary of major outputs from the paper towel composting process (Ecoinvent Centre 2007, 2007)

Outputs	Unit	Quantity per Tonne	Per Case	Per Year

		of Paper towel		
Dry Biomass	kg	1,250	12.13	115,187.50
Disposal, plastics, mixture, 15.3% water	kg	20.3	0.20	1,870.65
Disposal, paper, 11.2% water	kg	6.46	0.06	595.29
Process-specific burdens	kg	2.1	0.02	193.52
Disposal, wood untreated, 20% water	kg	1.13	0.01	104.13
Disposal, steel, 0% water	kg	2.26	0.02	208.26
Suspended solids	kg	0.13	0.00	11.98
Total solids waste	kg	32.4	0.31	2,985.66

4.3.2.1 Avoided Burdens

The avoided burdens from replacing fertilized soil with compost were determined by the difference between the composting impacts and those of an equivalent quantity of fertilizer production. It is important to note that fertilizer is much more concentrated and is distributed in a garden per unit of area, as opposed to compost which is distributed by volume. Therefore, a simple mass equivalence could not be used to determine avoided burdens.

A typical garden fertilizer was found to contain about 8% nitrogen, 8% phosphorous, and 8% potassium (Premier Tech Home and Garden, 2012). These percentages are called NPK values and are summarized on packaging as 8-8-8, for example. Because compost can have a range of NPK values from less than 0.5-0.5-0.5 or less to over 2-2-2, a moderate assumption of 1-1-1 was used for the compost produced (Pfeiffer, 1984). Therefore, using 1-1-1 compost in a garden will cause the owner to require that much less nitrogen, phosphorous, and potassium in the form of fertilizer. For example, to reach 8-8-8 concentration in the garden with 1-1-1 compost the gardener would need fertilizer to make up only 7-7-7. This method provided the quantities needed to determine fertilizer production emissions using SimaPro. The impacts of these avoided burdens were subtracted from the composting impacts discussed in section 5.

Table 8. Avoided burdens associated with replacing compost with fertilizer (Ecoinvent Centre 2007, 2007)

Avoided Burden - Fertilizer	Quantity replaced	Unit
Diammonium phosphate, as P2O5, at regional storehouse/RER U - AB	10	kg
Potassium nitrate, as K2O, at regional storehouse/RER U - AB	10	kg
Potassium nitrate, as N, at regional storehouse/RER U - AB	10	kg

4.3.3 Comparison

For ease of comparison, the LCI quantities for both processes can be seen below.

Table 9. Comparison of major inputs for recycling and composting

Input	Recycling	Composting	Unit
Waste paper, sorted	1,013	1,013	kg
Water, natural origin	23.5	23.5	m3
Electricity	62.8	82.8	kWh
Natural gas	8,710	8,710	MJ
Transport, rail	8,886	4,443	t-km
Transport, lorry	47	37	t-km
Corrugated board	23	23	kg
Machine diesel for process	0	2.27	L

Table 10. Comparison of major outputs for recycling and composting

Output	Recycling	Composting	Unit
Product	Recycled Paper Towel, 1.0t	Dry Biomass, 1.25t	-
Plastics, mixture, 15.3% water	20.3	20.3	kg
Disposal, packaging paper	6.46	6.46	kg
Process-specific burdens	2.1	2.1	kg
Disposal, wood untreated	1.13	1.13	kg
Disposal, steel	2.26	2.26	kg
Suspended solids	0.13	0.13	kg

4.4 Allocation Discussions

4.4.1 Recycling Process Emission Allocation

Through communication with the paper towel supplier, it was determined that the paper towel coming in has a post-consumer content of 80% (the remaining 20% is post-industrial wood waste) (Cook, 2012). Therefore, it was assumed that the paper towel from UBC would compose 80% of the recycling inputs, and 80% of the paper produced would be purchased by UBC. Therefore 80% of recycling emissions were attributed to paper towel from UBC.

4.4.2 Compost Process Emission Allocation

Compost emissions were allocated based on the percentage of compost pile mass made up by the paper towel. According to Harvest Power (2012), paper towel could account for up to 32% of the total mass in the pile. This includes a large amount of water. When moisture is discounted (50%wt as per Section 3.4.2), paper towel is found to contribute 64% of the dry mass in the pile. Therefore, 64% of emissions from the compost pile were attributed to the paper towel from UBC.

5 Impact Assessment

The data, input variables, and output variables were integrated in SimaPro using the Ecoinvent database and using the Recipe 2007 (H) method. The values are summarized in Table 11.

Table 11. Impact Categories for recycling and composting (with and without avoided burdens) (Ecoinvent Centre 2007, 2007)

Impact Category	Unit	Recycling Impact	Compost Impact without Avoided Burdens	Compost Impact Characterization with Avoided Burdens
Climate change	kg CO2 eq	1039.3	873.5	734
Human toxicity	kg 1,4-DB eq	38.8	36.8	29.8
Water depletion	m3	24.7	24.6	23.4
Fossil fuel depletion	kg oil eq	385.8	328	308
Solid waste	Kg	62.8	75.6	66.8
Electricity Use	kWh	32.4	32.4	32.4

The total impact per one tonne of paper towel can be seen in Figure 7.

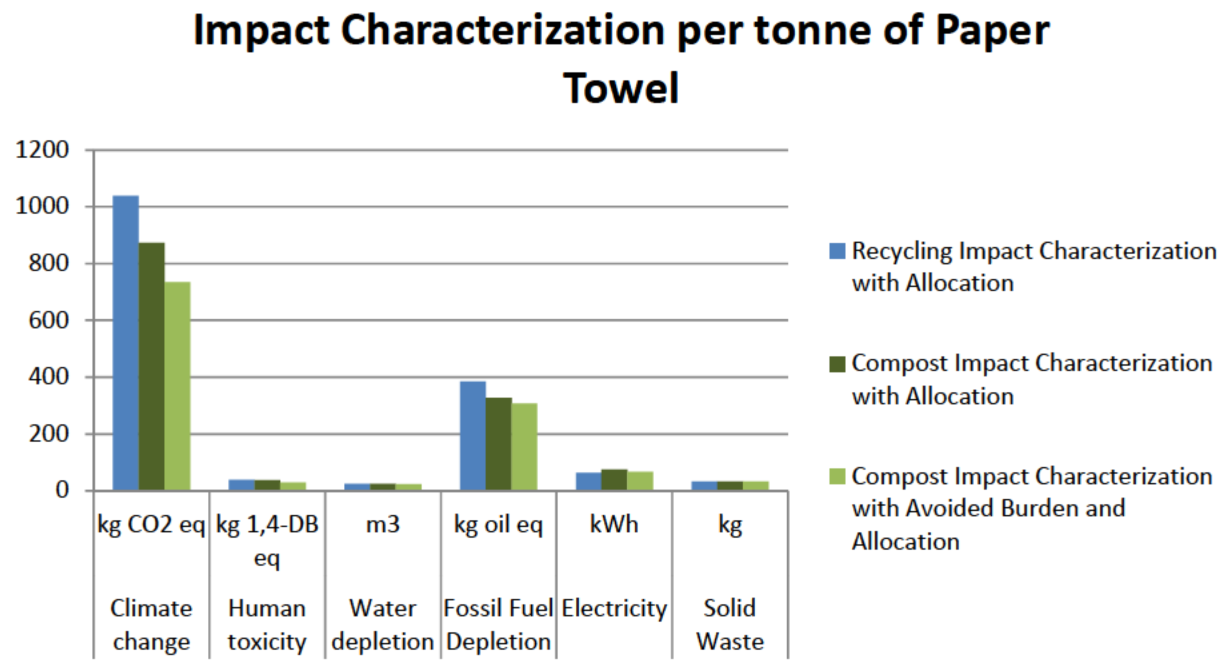

Figure 7: Impact characterization per tonne of paper towel considering the cradle to grave emissions. Also considers the allocation scheme and avoided burden scheme for the compost.

The chart indicates the impact for recycling is higher than the impact for compost. The above chart also demonstrates the reduced impact including the avoided burden for compost. As discussed, the avoided burden accounts for 1-1-1 (Nitrogen, Phosphorus, and Potassium) of compost fertilizer as a replacement for the need to include as large a quantity of inorganic fertilizer.

The normalized impacts were evaluated to demonstrate the weighted impact considering the world average. The normalization factors were used from the Recipe 2007 (H) method and were only available for the four impact categories shown in Figure 8.

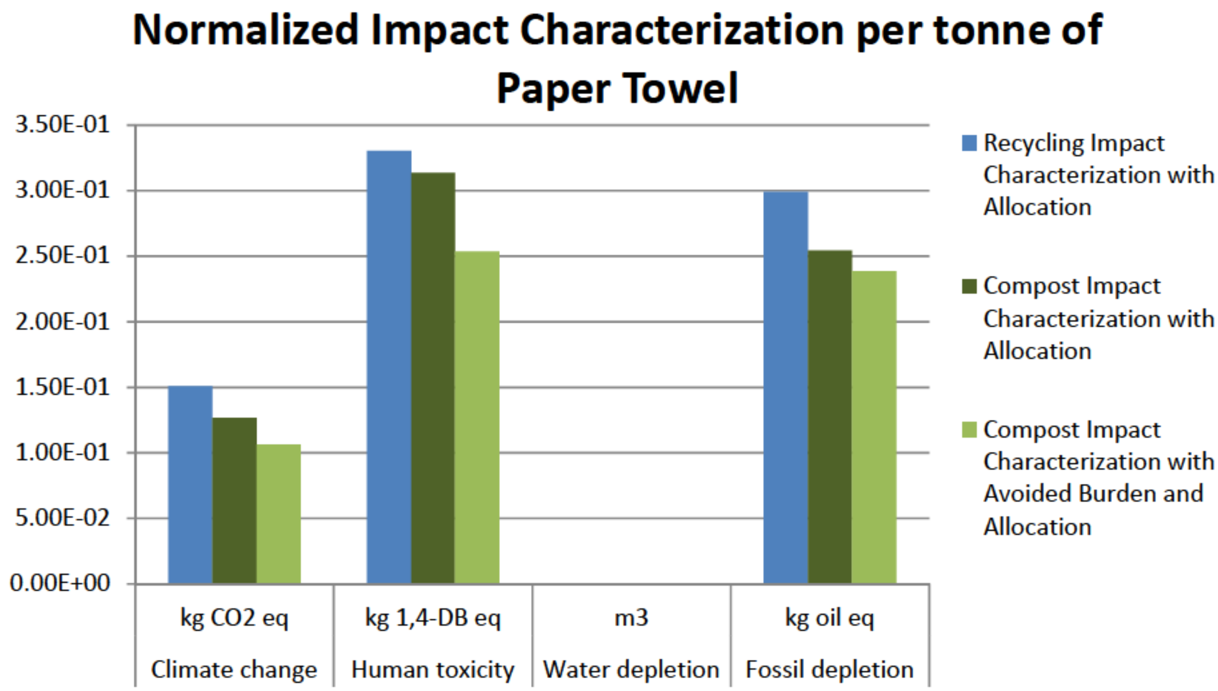

Figure 8: Normalized impact factors for total impacts for each process demonstrating the relative impact of each category based on world average.

Human toxicity of the process is the largest relative impact of the process, followed next by fossil fuel depletion and lastly by climate change. Water does not have a normalization factor.

As shown in Figure 8, natural gas and the freight transportation across Canada account for a majority of the Climate Change impact category for recycling. Human toxicity is derived from a split of waste paper (20% post-industrial using wood chips)and 80% post-consumer (free impact of production process as it is waste), potato starch, inorganic chemicals at the plant, natural gas burning, transport freight to and from Vancouver from Gatineau, packaging manufacturing, and solid waste disposal of product run off from paper recycling. Water use is mainly due to the fiber re-pulping process where water, recycled paper and chemicals are combined to produce recycled pulp. The Fossil Fuel Depletion is due mainly to the natural gas use in the re-pulping process, the transportation across Canada, and the corrugated board manufacturing (packaging). The visual results of this can be seen inFigure 9. Distribution of impact categories for the paper towel recycling system Figure 9.

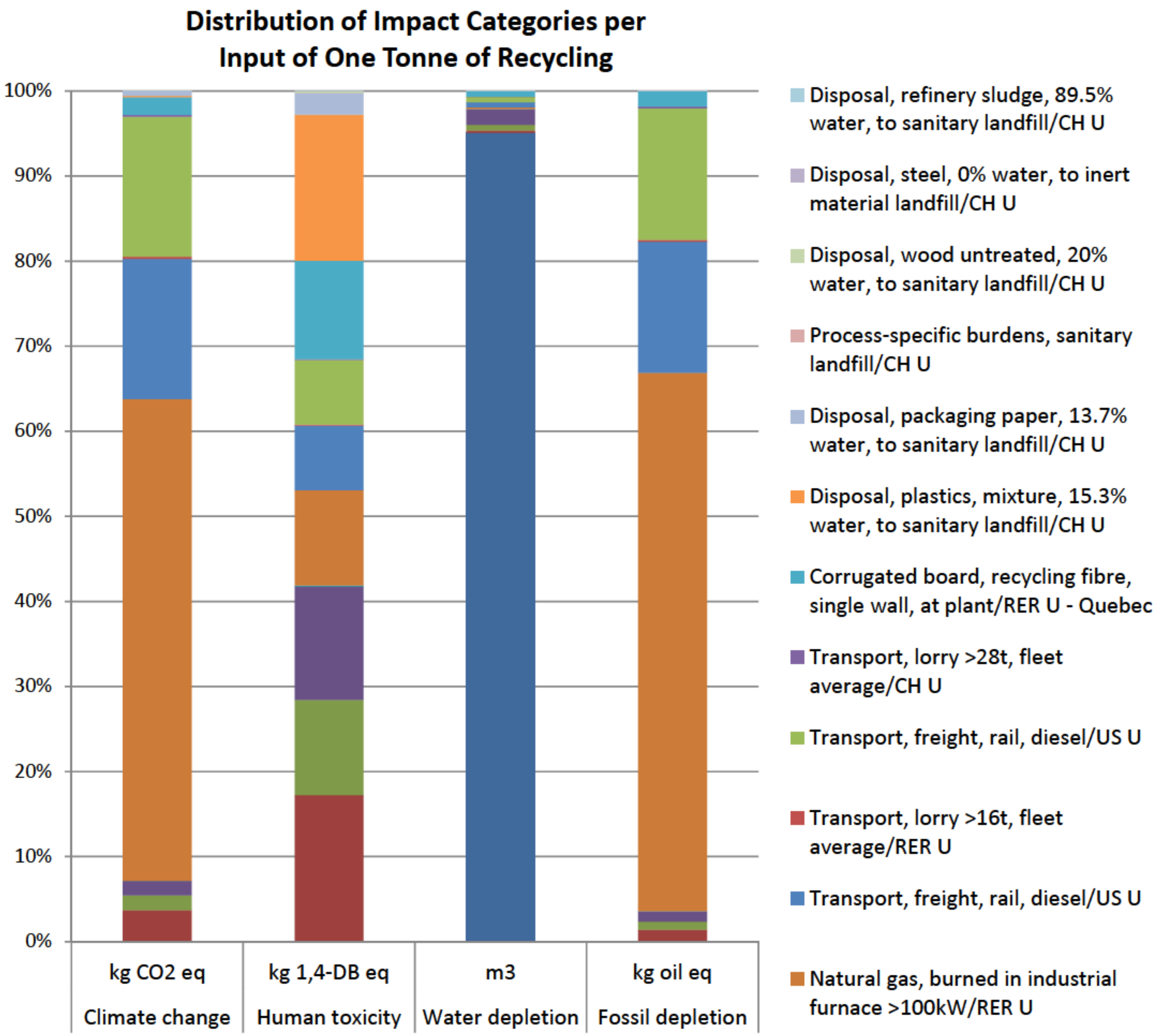

Figure 9. Distribution of impact categories for the paper towel recycling system

Examining Figure 10, it is evident that the largest portion of the process is the paper recycling.

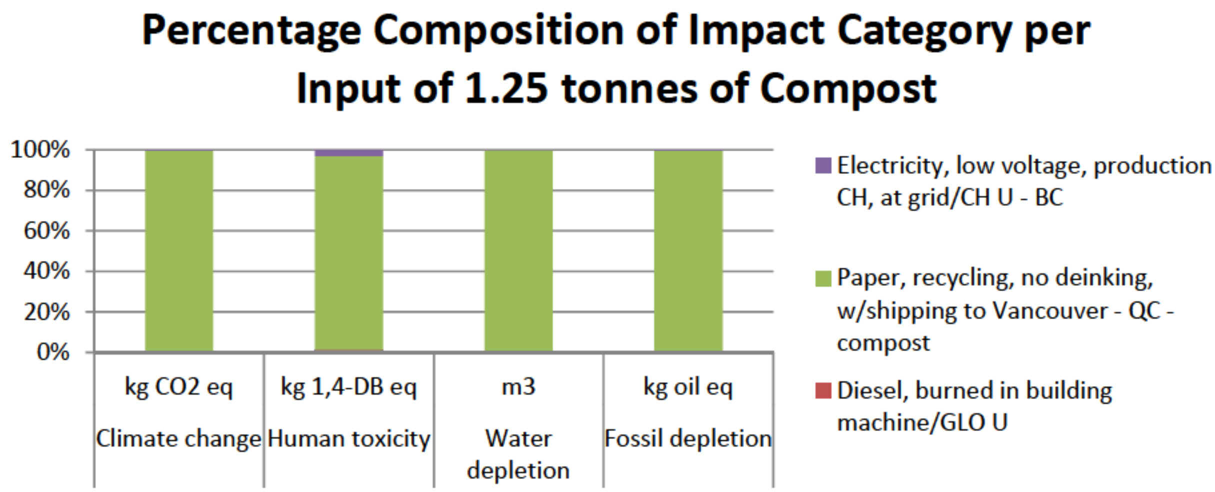

Figure 10: Percentage per impact category for 1.25 tonnes of recycling, before allocation.

The avoided burden is calculated to demonstrate the avoided equivalent inorganic fertilizer (NPK, 8-8-8). Compost is assumed to have a value of 1-1-1, which is equivalent to one eighth the mass. The values used in the one eighth mass value of equivalent organic fertilizer to inorganic fertilizer can be seen in Table 12.

Table 12: Avoided burden is calculated to subtract from emissions from compost (Ecoinvent Centre 2007, 2007).

Impact category	Unit	Total
Climate change	kg CO2 eq	139.5
Human toxicity	kg 1,4-DB eq	7.1
Water depletion	m3	1.2
Fossil fuel depletion	kg oil eq	20.0
Solid waste	kg	
Electricity use	kWh	

6 Life Cycle Cost

The valuation of the life cycle cost comparison was based on the values shown in Table 13.

Table 13. Data for life cycle cost analysis

Value	Quantity	Unit	Source
Consumption per year	57,000	rolls	(Manji, 2012)
Weight per roll	1.62	kg	(Cook, 2012)
Consumption per year by mass	92.15	t/yr	Calculated
Rolls per case of paper towel	6	Roll/case	(Manji, 2012)
Mass per case of paper towel	9.7	Kg/case	Calculated
Tipping fee for compost	55	$/t	(Roxby, 2012)
Recycling fee	175	$/t	(Grubel, 2003)

Using the values shown above, the following calculations were completed to give the costs shown in Table 14.

For 57,000 rolls of paper towel used in the SUB every year:

$$9.7\frac{kg}{case} \div 6\frac{roll}{case} = 1.6167\frac{kg}{roll}$$

$$57000\frac{roll}{yr} \div 1.6167\frac{kg}{roll} = 92.15\frac{t}{yr}$$

For composting:

$$Compost\ tipping\ fee = \$55/t = \$0.055/kg$$

$$Cost\ Composting = \frac{\$0.055}{kg} \times 1.6167\frac{kg}{roll} = \$0.089/roll$$

For recycling:

$$Recycling\ fee\ for\ the\ District\ of\ North\ Vancouver = \$174.90/t = \$0.175/kg$$

$$Cost\ of\ Recycling = \frac{\$0.175}{kg} \times 1.6167\frac{kg}{roll} = \$0.283/kg$$

Annual costs:

$$Annual\ cost\ of\ Composting = 57{,}000\ roll \times \$0.055/kg = \$5068.35$$

$$Annual\ cost\ of\ Recycling = 57{,}000\ roll \times \$0.175/kg = \$16\,117.37$$

This cost estimate shows that composting is substantially cheaper than recycling, by approximately $11,050 annually, or 69%.

Table 14. Summary of life cycle cost analysis results

Cost of	$ per kg	$ per roll	$ per year
Composting	0.055	0.089	$5,070
Recycling	0.175	0.283	$16,120

These results are shown graphically in Figure 11.

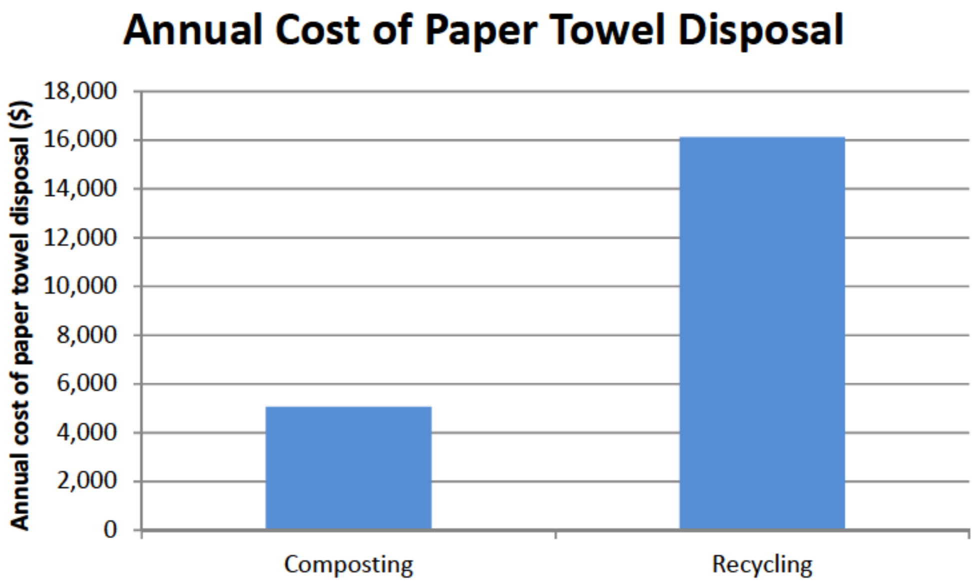

Figure 11. Annual cost of paper towel disposal for recycling and composting

7 Interpretation

Overall, it can be seen that compost has a lower environmental impact than recycling. The detailed results indicate where major opportunities exist for environmental impact reductions.

When considering the compost versus recycling with allocation and without avoided burden for compost, compost has fewer impacts across all factors except electricity. However, this is mainly due to the sensitivity surrounding the freight distance. To minimize the uncertainty in our recycling Life Cycle Analysis, the loop was closed and all material were sent back to Montreal. As a result, all of the recycling material was sent from Vancouver, to Gatineau, and back. Without the difference in distance travelled for the product, the pre avoided burden impact between compost and recycling would have been virtually the same, with compost being slightly higher. Not accounting for the avoided burden would have been unjust to the compost impact, as the compost has an avoided burden which must be accounted, as the closed loop recycling system acts as its own avoided burden.

When the avoided burden of 8-8-8 fertilizer was subtracted from the compost (assuming the compost is a 1-1-1 NPK mix, and using a mass equivalent of compost of 1/8 to fertilizer), the compost stream showed greater environmental benefit than that of recycling.

The sensitivities outlined above demonstrate the impact of the long freight distance, and the choice of avoided burden for the compost. Had the avoided burden been a larger mass or another material using a raw material the impacts would have been different.

The normalized impact demonstrates the relative importance of impacts. Human health emissions from this process are higher than relative impacts of climate change and fossil fuel depletion (water depletion has no normalization factor for the software methodology used, and was therefore left out of normalization). However, the normalization impacts are without weighting, so if UBC has a preference for climate change reductions over health impacts a weighted decision matrix would need to be constructed to find the most important variable.

Compost does output more emissions than is reported in the impact categories; about 300 kg per 1.25 t dry mass of compost produced. It also releases very small amounts of methane. However, as discussed in Section 3.4.2, these emissions are not considered a greenhouse gas as they are biogenic emissions. They are naturally produced and were sequestered over the lifetime of the tree.

To reduce the climate change impact of the manufacturing process, the amount of natural gas required in the re-pulping stage of recycling would need to be reduced. New chemical processes developed to re-pulp in low temperature water baths or other innovative ideas (solar heaters?) would need to be invented.

Human toxicity impact is a major impact throughout the system due largely to transportation emissions. This impact is also due to natural gas consumption and chemical use in the paper towel production process.

Water consumption is linked directly to the re-pulping process of paper towel. Recycled water streams or processes requiring less water would reduce the water depletion potential for paper towel manufacturing. It should be noted that there are approximately 1.56 tonnes of water within the compost mix for 1 t of paper towel. However, the water enters the stream as moisture content in the wet compost mix (as wet compost must represent 68% of the compost mix with paper towel). Although the water flows through the system, it is not considered consumed because it is waste water within the organics stream.

The electricity used and solid waste produced is difficult to mitigate. Electricity use is likely to decrease over time with efficiency increases, and as technology improves solid waste is likely to decrease as well.

8 Conclusion and Recommendations

8.1 Conclusion

Composting is the best option for many reasons. It scored lower on the vast majority of impact categories and requires less intensive sorting than recycling. It scored lower on water consumption, climate change, fossil fuel depletion and human health impact; compost was slightly higher in electricity consumption and even for solid waste disposal (as compost production is not a waste but an input).Therefore, not only are the overall impacts lower for the paper towel that goes to compost, but more of the paper towel can be allowed to go to compost than if recycling were used, decreasing emissions due to unfit paper towel being sent to the landfill.

8.2 Recommendations

8.2.1 Decreasing UBC's Footprint

Composting has great potential to aid UBC as it strives to become a waste-neutral campus. Although recycling is a viable option, it still requires significant material and energy inputs. Therefore, UBC can greatly decrease its environmental footprint by diverting as much waste as possible from recycling and landfill facilities by sending them to be composted. To increase the viability of composting by decreasing contamination, specially marked clear bins should be located in bathrooms to allow for separate disposal.

Additionally, because UBC is a very large potential client for any supplier, it has substantial buying power. One way to use this power to positively impact the environment is through Environmental Product Declarations (EPDs). EPDs are essentially purchasing standards that must be met by any supplier that would like to have the university as a client. For example, a limit could be established for the CO_2 emissions per case of paper towel purchased, and a potential supplier would have to provide data showing that the emissions for his or her product are below the limit. If the university were to develop required EPDs for its suppliers, this would encourage companies to track, quantify, and potentially decrease their environmental footprints for products sold to UBC.

8.2.2 Decreasing Paper Towel Consumption on Campus

8.2.2.1 Paper Towel used for Hand Drying

In order to avoid paper towel use on campus, it is important that UBC provide electric hand dryers in all new buildings, and in older buildings where the electrical system permits it. Additionally, in bathrooms with electric dryers where paper towel is provided as a barrier between newly washed hands and the bathroom door handle, paper towel dispensers should be near doors, not near sinks, and clear bins should be provided directly underneath to make proper disposal easy. Alternatively, a less absorbent material could be provided to dissuade people from using it to dry their hands. It would be important to include some sort of diagram or sign indicating what the material is for, and to consider the life cycle impacts of the alternate material.

8.2.2.2 Paper Towel used for Opening Doors

Airport-style doorways where a bend substitutes for a door should be planned for all new buildings on campus so no paper towel is required for door handles. Doors in older buildings should be propped open wherever it is appropriate and possible to do so. Lastly, providing hand sanitizer just outside of bathroom doors could substitute for paper towel used for opening doors.

8.2.3 Further Analyses

It was discovered in this study that because the AMS requires paper towel in the SUB to be 100% recycled content, which is very uncommon, the nearest recycling facility that can provide it is in Quebec. It is advisable that an LCA be performed comparing paper towel with a lower recycled content that could be produced locally to the current scenario to determine whether bringing in paper towel from over 4000 km away cancels the benefit of the higher recycled content. Using a local manufacturer could decrease greenhouse gas emissions from production by up to 33%.

Further analysis of the LCA should also include discussions on what the avoided burden of compost is. In particular, an examination of what products compost may be replacing (other than fertilizer) which would otherwise require raw material would be prudent. A more in-depth investigation could also include the percentage of recovery of paper towel as a recyclable material in comparison to paper towel as a compostable material. Such an analysis could also examine the percentage of paper towel in recycling that is actually used in recycling compared with that which is intentionally diverted to compost due to low grade wood fiber (as decided by the recycling plant).

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9.1 APPENDIX A: Network Diagram

SimaPro network diagrams aid in the in depth analysis to determine the highest contributors per impact category.

9.1.1 Compost

As demonstrated in Figure 10, the compost stream is weighted almost entirely in the paper recycling phase (manufacturing), for the purposes of the hot spot analysis, only this phase was examined.

Climate Change

Major Impacts	Percentage
Natural Gas Combustion	68.5 %
Transport freight (rail)	19.8%

Human Toxicity

Major Impacts	Percentage
Recycled and Raw Material Paper Harvesting	18.7%
Potato Starch	12.7%
Inorganic chemicals	14.4%
Natural Gas	12.2%
Transport freight (train)	8.23%
Corrugated Board	12.5%
Disposal of material	18.6 %

Water Depletion

Major Impacts	Percentage
Recycling Re-pulping	95%

Fossil Depletion

Major Impacts	Percentage
Natural Gas Consumption in Recycling Re-pulping	75.6%
Diesel consumption in rail freight	18.3%

9.1.2 Recycling

Recycling considers the collection in Vancouver; transport from Vancouver to Montreal, recycling of the product including all the process phases in Montreal, shipping to Vancouver by freight and distribution to UBC.

Climate Change

Major Impacts	Percentage
Natural Gas Combustion	57.1%
Transport freight (rail)	33%

Human Toxicity

Major Impacts	Percentage
Recycled and Raw Material Paper Harvesting	17.2%
Potato Starch	11.7%
Inorganic chemicals	13.3%
Natural Gas	11.3%
Transport freight (train)	15.2%
Corrugated Board	11.6%
Disposal of material	17.2 %

Water Depletion

Major Impacts	Percentage
Recycling Re-pulping	95%

Fossil Depletion

Major Impacts	Percentage
Natural Gas Consumption in Recycling Re-pulping	63.8%
Diesel consumption in rail freight	30.9%

9.2 APPENDIX B: Electricity Composition for Quebec Electricity

The electricity composition for Quebec was used for the majority of impacts because the paper towel is produced in Gatineau, Quebec. The composition used in this study was determined using SimaPro and is shown below in Table 15 and Figure 12.

Table 15. Electricity production composition in Quebec (Ecoinvent Centre 2007, 2007)

Power source	Percentage
Hydropower	97.0%
Nuclear	1.9%
Wind	0.3%
Natural gas	0.9%

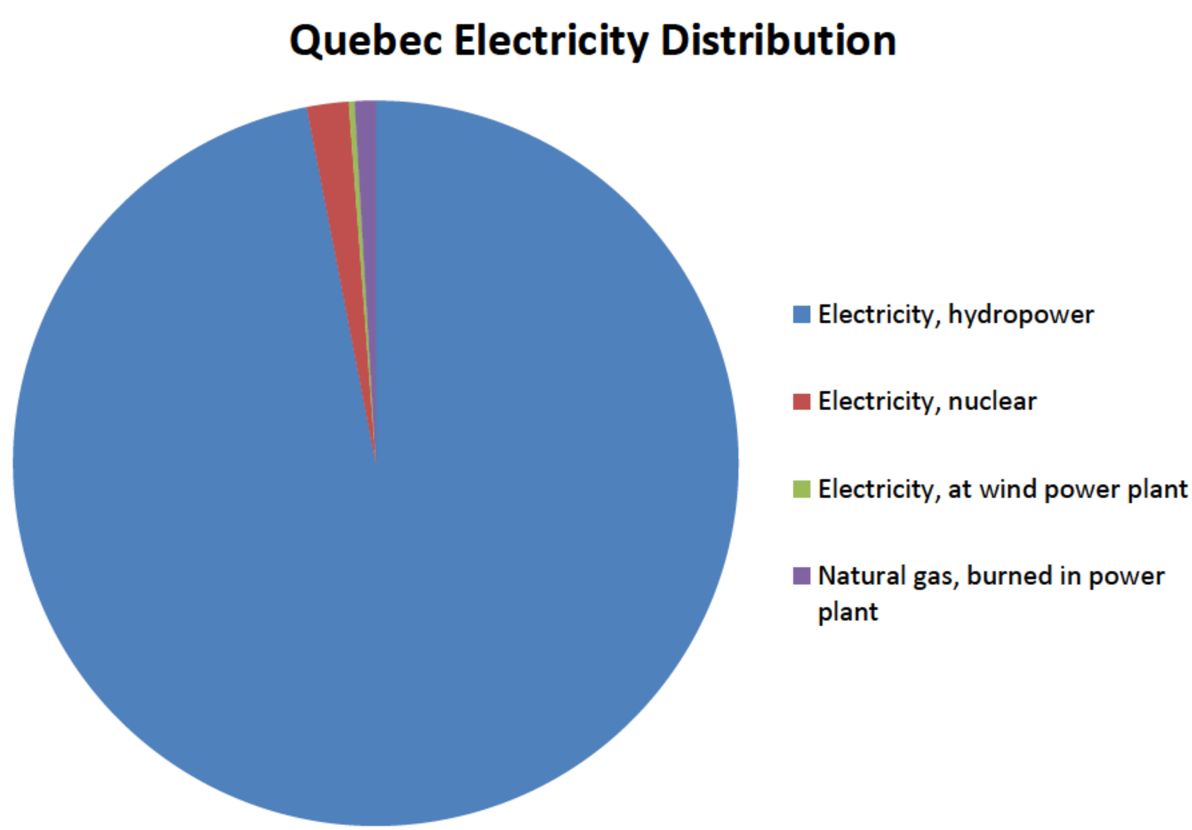

Figure 12. Quebec electricity composition

9.3 APPENDIX C: LCI for Complete System

9.3.1 Recycling LCI

Input	Quantity	Unit
Water, unspecified natural origin/m3	23.515	m3
Waste paper,mixed,from public collection, for further treatment/CH U- Q	0	kg
Waste paper, sorted, for further treatment/CH U - QC	1013	kg
Potato starch, at plant/DE U	30	kg
Chemicals inorganic, at plant/GLO U	10	kg
Electricity, medium voltage, production UCTE, at grid/UCTE U - Quebec	62.78	kWh
Natural gas, burned in industrial furnace >100kW/RER U	8710	MJ
Transport, freight, rail, diesel/US U	4443	tkm
Transport, lorry >16t, fleet average/RER U	23.5	tkm
Paper mill, integrated/RER/I U	5.4E-08	p
Transport, freight, rail, diesel/US U	4443	tkm
Transport, lorry >28t, fleet average/CH U	23.5	tkm
Corrugated board, recycling fibre, single wall, at plant/RER U - Quebec	23	kg
Heat, waste	151	MJ

Output	Quantity	Unit
Emissions to water		
BOD5, Biological Oxygen Demand	0.06	kg
COD, Chemical Oxygen Demand	0.77	kg
Nitrogen	0.03	kg
Phosphorus	0.01	kg
Suspended solids, unspecified	0.13	kg
Waste to treatment		
Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	20.3	kg
Disposal, packaging paper, 13.7% water, to sanitary landfill/CH U	6.46	kg
Process-specific burdens, sanitary landfill/CH U	2.1	kg
Disposal, wood untreated, 20% water, to sanitary landfill/CH U	1.13	kg
Disposal, steel, 0% water, to inert material landfill/CH U	2.26	kg
Disposal, refinery sludge, 89.5% water, to sanitary landfill/CH U	0.112	kg

9.3.2 Composting LCI

Categories	Quantity	Unit
Water, unspecified natural origin/m3	23.515	m3
Materials/fuels		
Waste paper, mixed, from public collection, for further treatment	0	kg
Waste paper, sorted, for further treatment/CH U - QC	1013	kg
Potato starch, at plant/DE U	30	kg
Chemicals inorganic, at plant/GLO U	10	kg
Electricity, medium voltage, at grid/UCTE U - Quebec	62.8	kWh
Natural gas, burned in industrial furnace >100kW/RER U	8710	MJ
Transport, freight, rail, diesel/US U	4443	tkm
Transport, lorry >16t, fleet average/RER U	22	tkm

Paper mill, integrated/RER/I U	5.4E-08	p
Transport, freight, rail, diesel/US U	0	tkm
Transport, lorry >28t, fleet average/CH U	15	tkm
Corrugated board, recycling fibre, single wall	23	kg
Heat, waste	151	MJ

Outputs		
Emissions to water		
BOD5, Biological Oxygen Demand	0.06	kg
COD, Chemical Oxygen Demand	0.77	kg
Nitrogen	0.03	kg
Phosphorus	0.01	kg
Suspended solids, unspecified	0.13	kg
Waste to treatment		
Disposal, plastics, mixture, 15.3% water, to sanitary landfill/CH U	20.3	kg
Disposal, paper, 11.2% water, to sanitary landfill/CH U	6.46	kg
Process-specific burdens, sanitary landfill/CH U	2.1	kg
Disposal, wood untreated, 20% water, to sanitary landfill/CH U	1.13	kg
Disposal, steel, 0% water, to inert material landfill/CH U	2.26	kg
Disposal, refinery sludge, 89.5% water, to sanitary landfill/CH U	0.112	kg