An Investigation into the Environmental Impacts of Container Choices on the UBC Farm

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Abstract

The UBC farm uses plastic Rubbermaid totes and InterCrate crates for a variety of tasks such as harvest, storage, and shipping. However, they were concerned with the containers' economic, social, and environmental costs. This report presents the evaluation of the environmental costs of using reusable plastic containers which need to be continually washed in comparison to four other possible alternatives: cardboard boxes, wax-lined cardboard boxes, wooden boxes, and cardboard boxes with biodegradable liners. Due to food safety considerations and lack of structural practicality, cardboard boxes, wooden boxes and biodegradable liners were eliminated as options. Therefore, wax lined cardboard boxes were left as the most favorable alternative. Closer investigation of plastic containers versus waxed cardboard boxes was then done through comparative analysis of the environmental impacts on a scale based on solid waste, water emissions, air emissions, water usage, and CO_2 emissions. This analysis showed that the plastic containers yielded far better environmental results in all factors except water usage by a factor of about 15. Overall, the recommendation presented is to continue with the current practice of plastic containers, favouring lighter local ones where possible.

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Glossary

CO_2eq The amount of carbon dioxide that would have to be released to cause the equivalent amount of global warming from some effect

Low Density Polyethylene A solid recyclable plastic used by Rubbermaid for their totes

Paraffin An oil byproduct useful for repelling water, used in waxed cardboard as a liner

Polypropylene A solid recyclable plastic used by InterCrate to make their crates

List of Abbreviations

LDPE Low Density Polyethylene

MJ Megajoule

PP Polypropylene

RCP Rubbermaid Commercial Products

Section 1.0 Introduction

The UBC Farm is the last working farm in Vancouver, growing nearly 60,000 pounds of fruits and vegetables annually as of 2014, which are sold and distributed through a number of markets. They have expressed concerns about the social, environmental, and economic impacts of their current method of harvesting, transporting and storing produce: using plastic containers from Rubbermaid and InterCrate. Instead, they wished to explore alternative containers and methods of achieving these tasks.

This report presents an assessment of several alternative containers for use in their current system, including wooden boxes and a few kinds of cardboard boxes. In order to provide a focused analysis of the issue, the different choices were assessed only for their environmental impact. These environmental concerns were quantified based on the life cycle of the materials (from manufacturing, transportation, use, and disposal) on a scale based on energy consumption, water consumption, air emissions, water emissions, and CO_2eq.

The evaluation of the life cycle of the plastic containers on this scale is presented first. Then, the analysis of the best alternative among some possible options based on practicality and broad environmental effects will be shown, followed by the life cycle analysis of this alternative. Finally, the comparative analysis of the plastic containers to the best alternative shows the conclusions and recommendations of this report.

Section 2.0 Plastic Tote Life Cycle

The UBC farm had two main kinds of containers in use: Rubbermaid totes, and InterCrate crates. The methodology used to analyze these containers' life cycle was to divide the life cycle up into the manufacturing, usage, and disposal stages, and evaluate each stage's environmental impact on a scale using energy, solid waste, air emissions, water usage, water emissions, and CO_2eq. As well, each companies' practices were considered for their environmental effects.

2.1 Manufacturing

The Rubbermaid totes were made from low density polyethylene (LDPE) and the InterCrate crates were made from polypropylene (PP) (Rubbermaid, 2014; InterCrate, 2011). Each plastic was found to have a different impact, as summarized below.

2.1.1 Low Density Polyethylene (LDPE)

The process that was considered for manufacturing LDPE is shown in Figure 2.1 (Franklin Associates, 2011). The plastic begins with the processing of crude oil and natural gas to make ethylene, a necessary component of LDPE. Then, a high pressure (300 MPa) and temperature (300 °C) process causes the ethylene coalesce into long random chains. These polymer chains (which are now known as LDPE) are then extruded into pellets (Boustead, 2005a), which can then be heated and formed into a large variety of plastic products.

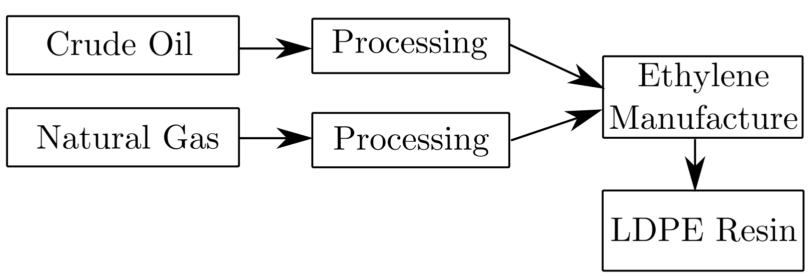

Figure 2.1: The LDPE manufacturing process (Franklin Associates, 2011).

Table 2.1: Environmental effects of LDPE manufacturing per kilogram produced (Boustead, 2005a; Franklin Associates, 2011)

Environmental Indicator	Effect
Energy	80.8 MJ
Solid Waste	61.3 g
Air Emissions	1740 g
Water Use	47200 g
Water Emissions	11.0 g
CO_2eq	2460 g

The net environmental effects per kilogram of LDPE produced is summarized in Table 2.1 (Franklin Associates, 2011; Boustead, 2005a). It takes into account the environmental effects arising from a variety of processes in the manufacture: the energy sources (ie: electricity, natural gas), the transportation of materials, the energies in the materials, and the actual manufacturing process.

2.1.2 Polypropylene (PP)

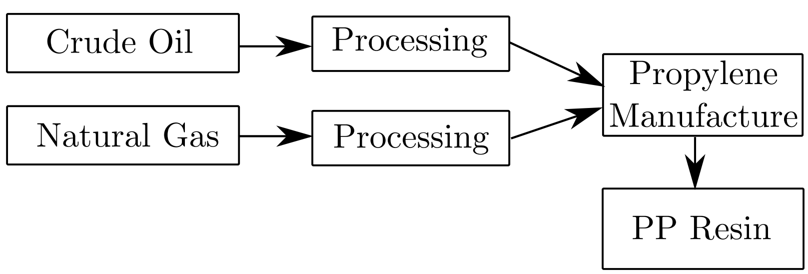

Figure 2.2: The PP manufacturing process (Franklin Associates, 2011).

The PP manufacturing process considered was similar to LDPE, as shown in Figure 2.2 (Franklin Associates, 2011). Crude oil and natural gas are processed to produce a material known as propylene, the base unit of PP (its 'monomer'). Then, the propylene is used in a gas phase reactor (which passes gas at high speed through the polymer) to cause the monomers to chain together to form a polymer, polypropylene. This process uses lower temperatures and pressures than the corresponding LDPE process.

Table 2.2: Environmental effects of PP manufacturing per kilogram produced (Boustead, 2005b; Franklin Associates, 2011)

Environmental Indicator	Effect
Energy	75.2 MJ
Solid Waste	57.2 g
Air Emissions	1600 g
Water Use	42600 g
Water Emissions	10.0 g
CO_2eq	2140 g

The overall effect of this manufacturing, along with energy sources and transportation effects, is summarized in Table 2.2 (Boustead, 2005b; Franklin Associates, 2011). Notably, this plastic had better environmental performance in all environmental effects considered, probably due to the less temperature and pressure intensive manufacturing process.

2.2 Company Specifics

2.2.1 Rubbermaid

Rubbermaid had a variety of initiatives in place to minimize environmental impact and increase the sustainability of their manufacturing processes. Rubbermaid Commercial Products (RCP) was based in Atlanta, Georgia and largely manufactured 80% of its products in the United States, with all of its U.S. locations having zero net emissions and acid rain production through their recycling

Table 2.3: Reduction in waste achieved by RCP practices (Rubbermaid, 2014)

Substance	Description
Heavy Metal	Rubbermaid does not use any colorants containing heavy metals
Water	Closed water loop, 12,000 gallons used and recycled continuously
Hydraulic Oil	60,000 gallons recycled every year
Waste Plastic	Collects and regrinds plastic scraps to be used, reduction of 98%

programs (Rubbermaid, 2014). As this fact was only claimed and no reports were available to confirm with actual numbers, the basis of factoring in RCP's practices with the manufacturing part of the life-cycle (from Section 2.1) will be the actual numbers the company provides, such as the recycling of water and plastics or the reduction of material use. Table 2.3 outlines this information on various recycled or reduced materials and their effect from the baseline, current as of this report.

Effects of Rubbermaid's Transportation

The emissions resulting from the transportation of the totes used by the farm to a retailer in Vancouver was estimated by looking at the emissions from RCP's selected transportation methods over the distance from the most likely export destination. Since 80% of RCP products were manufactured in the United States and Rubbermaid's base operation was in Atlanta, Georgia, an estimated route starting in Atlanta and ending in Vancouver was used to asses the impact of transportation (Rubbermaid, 2014). Rails routes were chosen when possible, since Rubbermaid prefers their use for efficiency.

A map of Canadian National rails terminals showed the closest city to Atlanta is Memphis, Tennessee at 616 km (Canadian National Railway Company, 2014). From there, the approximate path of the train from Memphis to Vancouver was 4668 km. Table 2.4 shows the estimated emissions from the route. Distance was estimated using Google Maps, which was combined with train fuel

Table 2.4: Emissions from transporting 0.62 tons from Atlanta, Georgia to Vancouver, BC

Route	Distance (km)	Fuel Efficiency (tons·km/L)	Fuel Consumed (L)	Emissions (kg)
Truck Transport (Atlanta, GA to Memphis, TN)	616	79.2	5.06	13.36
Train Transport (Memphis, TN to Vancouver, BC)	4668	182.81	16.60	43.82
Totals	5254	N/A	21.66	57.18

efficiencies (Tolliver, Lu, & Benson, 2013), a shipping weight per tote of 1.8 kg (K. Menzies, personal communication, March 21 2014), and CO_2 emitted per litre of fuel burned (Ecoscore, 2014) to calculate the total emissions of moving 350 totes (a shipment weight of 0.62 tons) from Atlanta, Georgia to Vancouver, BC. Per tote, there were overall 163 g of CO_2 emissions.

2.2.2 InterCrate

InterCrate was a local company, so their products essentially had no emissions resulting from transport from the company to a purchasing location for the farm. This elimination resulted in a cut in the environmental costs of the product equivalent to what it took to transport totes from Rubbermaid's main location in Atlanta, Georgia to Vancouver, BC.

Apart from the reduction in transportation costs, use of InterCrate products provided some benefits that were hard to quantify but are worth mentioning as they factored in to the benefits of using them. First, InterCrate's products were specifically designed to reduce water use when washing them, making them more environmentally friendly in the washing stage in comparison to Rubbermaid totes. Also, they had ideal ventilation for the food products, requiring no modification to create ventilation (unlike the totes, which had holes drilled into them for this purpose). These crates also had folds in handles for superior ergonomics and were designed to reduce possible damage to goods when stacking for transporting. The design also made the crates take up significantly less space when stacking empty as opposed to full crates, therefore reducing the cost of returning them by possibly lowering the amount of trips needed to retrieve them.

2.3 Farm Usage

The containers were used on the UBC farm for gathering produce, storing produce, and transporting produce to consumers (K. Menzies, personal communication, February 4, 2014). They were also washed on a weekly basis. The impact of each of these processes is discussed below.

Gathering and storing the produce has very little environmental effect, since this process was done by human labour. As well, since the farm only picked up the reusable plastic containers when they were going back to a location to ship more produce, they were already doing the minimum trips possible. Therefore, since this report is comparative, the environmental effects of transportation to consumers were ignored. So, only water usage was found to be important during the life cycle, and only that effect was considered.

In order to asses the water usage of 150 totes and 52 crates, a proportionate sample of the totes and crates at UBC farm were washed. The total water consumption was recorded as 386.9 gallons (Millar, 2013). More detailed information about this data can be found in Appendix A. Since the average frequency of tote washing at the farm was once per week, the total water usage on average for each container was calculated as:

$$\frac{386.9 \text{ gallons}}{202 \text{ washings}} \cdot \frac{52 \text{ washings}}{\text{year}} \cdot 2.5 \text{ years} = 250 \text{ gallons} = 946000 \text{ g.}$$

This value was the only relevant environmental effect during use at the farm.

2.4 Disposal

Table 2.5: Environmental effects of recycling 1 kg of plastic by mechanical recycling, and incineration of resultant waste products (Arena et al., 2003).

Environmental Indicator	Effect
Energy	−1.88 MJ
Solid Waste	36.2 g
Air Emissions	0.468 g
Water Use	1276 g
Water Emissions	0.055 g
CO_2eq	553 g

After the 2-3 years of use, the plastic totes were recycled, generally due to breakage of handles or cracking of the walls (K. Menzies, personal communication, February 4, 2014). The most common technique of recycling plastics such as LDPE and PP was mechanical recycling, where the plastics are ground, washed, dryed, and re-formed into resins by application of heat. Assuming that the City of Vancouver's recycling facilities employed this common technique, Table 2.5 shows the net environmental impacts that arise from recycling the average 1 kg of plastic (Arena et al., 2003). The negative energy in the table indicates that energy was recovered from the process instead of being consumed.

2.5 Totals

2.5.1 LDPE Rubbermaid Tote

Table 2.6: Net environmental effects of one Rubbermaid tote

	Manufacturing	Use	Disposal	Total
Energy	106 MJ	N/A	−2.47 MJ	104 MJ
Solid Waste	80.6 g	N/A	47.6 g	128 g
Air Emissions	2230 g	N/A	0.62 g	2230 g
Water Use	30000 g	946000 g	1680 g	978000 g
Water Emissions	14.4 g	N/A	0.073 g	14.5 g
CO_2eq	3400 g	N/A	730 g	4130 g

The total environmental impact found for a Rubbermaid tote is shown in Table 2.6. The manufacturing values were calculated by scaling the raw manufacturing impacts of LDPE (Table 2.1) by the mass of the totes in use at the farm, 1.3 kg (K. Menzies, personal communication, March 21 2014) with the addition of the transport effects and RCP environmental practices (Table 2.3, which resulted in water use reduction). The disposal stage was calculated by a simple multiplication of the recycling impact given in Table 2.5 by the mass of a tote.

2.5.2 PP InterCrate Container

The total environmental impact of an InterCrate crate is tabulated in Table 2.7. The average InterCrate container had a mass of 1.8 kg (InterCrate, 2011), and each environmental category was weighted by this value. The assumption that these crates take about the same about of washing as the totes was also made (since the washing data was for a representative sample of crates and totes), causing the use data to be the same as for the Rubbermaid totes. Since the exact environmental practices of InterCrate were unavailable, the manufacturing portion of this table has no reductions in environmental impact due to company practices, unlike the previous Rubbermaid table.

Table 2.7: Net environmental effects of one InterCrate Crate

Environmental Indicator	Manufacturing	Use	Disposal	Total
Energy	135 MJ	N/A	−3.39 MJ	132 MJ
Solid Waste	103 g	N/A	65.1 g	169 g
Air Emissions	2880 g	N/A	0.842 g	2880 g
Water Use	76700 g	946000 g	2300 g	1030000 g
Water Emissions	18.3 g	N/A	0.10 g	18.4 g
CO_2eq	3860 g	N/A	1000 g	4860 g

Section 3.0 Alternatives

Considered next were several alternatives to plastic containers: cardboard boxes, waxed lined cardboard boxes, wood boxes, and biodegradable plastic liners. Each option had their merits and drawbacks placed on a qualitative scale, and the overall best choice was selected based on primarily on practicality and broad environmental effects.

3.1 Cardboard Boxes

Cardboard was found to be widely used around the shipping industry for many tasks, and in the food industry for transportation of dry products, such as apples or bananas. Cardboard was cheap, readily available, strong for its weight and could also be custom ordered into many different shapes and sizes. Environmentally, the main advantage of this material was its ability to be recycled, and that it was biodegradable when it eventually loses that ability. For the UBC farm, cardboard boxes also entirely removed the necessity of intensive washing every week.

However, cardboard had some critical drawbacks. Moisture from wet materials (such as produce like leafy greens) would cause warping and loss of structural integrity of the material (Verghese, Crossin, & Jollands, 2012). As well, it offered less protection from pests and wildlife than a plastic alternative.

3.2 Wax-Lined Cardboard

Waxed cardboard was found to be widely used among large agricultural operations to ship large amounts of produce. The material shared many characteristics with normal cardboard, with its main advantage over normal cardboard being water resistance (Verghese et al., 2012). Therefore at the UBC farm the boxes would not lose stability when in contact with wet produce.

Naturally, the wax lining added extra environmental effects from manufacturing relative to normal cardboard. As well, the lining makes the material non-recyclable. However, waxed cardboard was found to be compostable: the paraffin used in the wax was biodegradable (Clean Washington

Center, 1993). So, waxed cardboard maybe was not as environmentally detrimental as it may have seemed at the outset.

3.3 Wood

Wooden crates were another possibility for replacing the plastic containers. The main advantages of wooden crates were the facts that they have good ventilation and could be manufactured and repaired locally. As well, wood is a naturally occurring material, which reduces the negative impacts from production of the boxes greatly.

However, there were some drawbacks. The hardness and inflexibility of wood may result in bruising of soft fruits and produce. As well, if not kept under good conditions (not sitting wet outside), wood could easily become contaminated with fungi and bacteria, making a large food safety hazard (Lelieveld, Mostert, & Holah, 2005). Given the large amount of washing that occurred on the plastic crates, it would be very difficult for farm workers to keep the wood in good conditions (that is, dry). There were treated woods that prevent fungal growths, but this option was even worse: the treatment chemicals were often biohazardous (Defra, 2012).

3.4 Biodegradable Liners

The final option considered was biodegradable plastic liners around plain cardboard boxes. These liners remove the problem that wax lined cardboard has, that it cannot be recycled and has a short lifespan. Therefore, they could have come out better for the environment than the wax lined cardboard boxes.

On the other side, these liners were more expensive. As well, the main issue with these liners was the lack of ventilation they provide. This issue was alleviated in the plastic containers with holes drilled into the sides (K. Menzies, personal communication, February 4, 2014). However, this solution was clearly not an option for plastic bags due to stability issues: they would simply tear apart if holes were cut into them. As well, the plastic bags would be probably not be in a size convenient for the cardboard boxes, causing wasted material and inconvenience while placing the liner (BioBag Canada, 2007).

3.5 Overall Comparison of Alternatives

Environmentally speaking, the wooden crates offered the least impact, due to re-usability and naturally sourced materials. The cardboard option, waxed lined or not, required much more frequent disposal (and hence waste) and the biodegradable liners were still plastic based, possibly causing detrimental environmental effects in production. As well, the plastic liners would probably end up being frequently disposed of as well due to their fragile nature.

However, from the *practical* viewpoint of the farm wooden crates were perhaps the worst option, with food safety issues due to possible fungal contamination. Thus, they were eliminated as an option. As well, the biodegradable liners did not provide sufficient ventilation for storing agricultural goods, and thus were also not suitable for use.

These eliminations left raw cardboard and waxed cardboard as the only remaining options. The raw cardboard seemed the most appealing, however, due to structural stability loss when in contact with wet materials such as freshly washed produce, it was not suitable. The remaining option that provided the most general solution was wax-lined cardboard. Thus, wax-lined cardboard is the focus of the assessment in the next section.

Section 4.0 Waxed Cardboard Box Life Cycle

Normal corrugated cardboard boxes were found as sturdy and strong containers for their mass. As shown in Figure 4.1, they consist of a few layers of paper material held together by glue. The top and bottom layers are for stability and flexural strength, and the middle 'fluting' layer provides compressive strength, support, and stiffness at low density. The fluting also makes for good thermal insulation (Verghese et al., 2012).

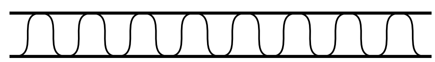

Figure 4.1: A cross section of corrugated cardboard (FEFCO, 2012).

The waxed cardboard boxes under study consisted of corrugated cardboard walls, along with paraffin wax impregnated into the wall liners to improve resistance to moisture and oils (Verghese et al., 2012). The next sections will summarize the manufacture, usage, and disposal of waxed cardboard boxes as they would be used on the UBC farm.

4.1 Manufacture

First, in order to make cardboard, paper must be manufactured. The manufacturing process that was considered is shown in Figure 4.2. The paper began with the harvesting of trees or by collection recycled paper products. The wood is chipped and is then cooked with water along with recycled products and other chemicals to a pulp at temperatures of around 160 °C (FEFCO, 2012). This pulp is then filtered and refined, removing large fibers, any remaining chips, inks, wax etc.

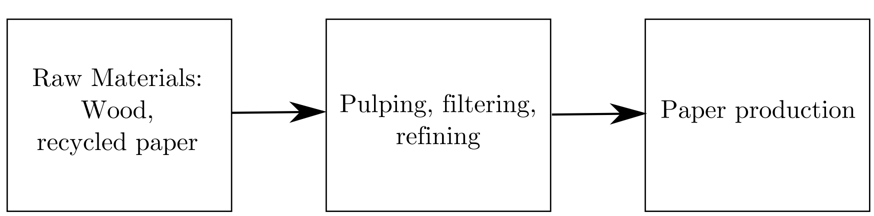

Figure 4.2: The major stages of producing paper (FEFCO, 2012).

Then, the pulp is moved to the paper mill, where it is formed and dewatered by gravity and suction action. The material, now formed into a long sheet, moves onto a series of rollers and heaters for further drying and thickness management. At the end, it is cut and rolled into large reels and sold.

To make waxed cardboard boxes, the paper for the fluting is steam heated and corrugated (folded into a wavy pattern). Glue is applied to both sides of the fluting, and the outer liners, infused with the paraffin wax, are placed. This raw cardboard is then cut and folded into the desired box shape (Verghese et al., 2012; FEFCO, 2012).

The net environmental impacts of this process for the production of 1 kg of cardboard can be found in Table 4.1. This data does not take into account waxing of the cardboard since that data was unavailable. In fact, the waxing data was not needed, which is justified in Section 5.0.

Table 4.1: Environmental effects of producing 1 kg of cardboard (FEFCO, 2012).

Environmental Indicator	Effect
Energy	8 MJ
Solid Waste	71.84 g
Air Emissions	850 g
Water Use	1700 g
Water Emissions	4.33 g
CO_2eq	849 g

4.2 Farm Usage

If implemented, the UBC farm would use waxed cardboard boxes in place of the current plastic crates and totes. In particular, they would harvest the produce into them, store the produce in them, and ship the produce out to consumers (such as restaurants). They also would not be collected again once shipped. This lack of recollection would not cut down on the net emissions in comparison to the plastic containers however, since the plastic ones were only recollected when the farm has new produce to ship to a consumer. Since these boxes would *not* be washed, they have no further environmental effect while in use (K. Menzies, personal communication, February 4, 2014).

Since the plastic totes were washed about once every week, the cardboard containers should have a similar lifetime before becoming unfit for food usage. Therefore, their expected lifetime while at the farm was estimated for this report as one week.

4.3 Disposal

Waxed cardboard, while not recyclable, was found to be compostable – the paraffin in the liner does decompose (Clean Washington Center, 1993). As such, if the farm was to use this option, they essentially produce no further environmental effects after use: any solid waste will biodegrade. In fact, disposal as composting may slightly *help* the environment, since the cardboard can be used to control certain parameters like moisture content in the compost. However, this effect was not particularly measurable and was small, and so was disregarded for the environmental impact of these boxes.

4.4 Totals

Interestingly, the environmental effects for waxed cardboard as it would be used on the UBC farm came solely from manufacturing. The mass of the boxes generally used for produce averaged around 500 g (FEFCO, 2012). Therefore, the environmental effects overall for one box was calculated by multiplying all the values in Table 4.1 by 0.5 kg per box. Table 4.2 shows the result.

Table 4.2: Environmental effects of one cardboard box

Environmental Indicator	Effect
Energy Use	4 MJ
Solid Waste	35.92 g
Air Emissions	425 g
Water Use	850 g
Water Emissions	2.17 g
CO_2eq	425 g

Section 5.0 Comparative Assessment

In order to compare the cardboard and plastic totes, the impact of removing one plastic tote and using the equivalent number of cardboard boxes over the same lifespan was considered. The cardboard box lifespan was estimated as 1 week in Section 4.2, and the plastic container lifespan was given as 2.5 years (K. Menzies, personal communication, February 4, 2014). Therefore, the number of cardboard boxes that would be used in place of a plastic tote is around $52 \times 2.5 = 130$ boxes.

Therefore, the multiplication of the overall impact of one cardboard box (as given in Table 4.2) by 130 gave a meaningful comparison to the results of the plastic crates (given in Tables 2.7 and 2.6). The results are shown in Table 5.1, and are graphed in Figure 5.1.

Table 5.1: Overall comparison of cardboard boxes to plastic containers

Environmental Indicator	Cardboard Box	Rubbermaid Tote	InterCrate Crate
Energy Use	520 MJ	104 MJ	132 MJ
Solid Waste	4670 g	128 g	169 g
Air Emissions	55300 g	2230 g	2880 g
Water Use	111000 g	978000 g	1030000 g
Water Emissions	281 g	14.5 g	18.4 g
CO_2eq	55185 g	4130 g	4860 g

Figure 5.1 clearly shows that in nearly all areas plastic containers are far better than cardboard boxes. In these areas plastic was found to outperform cardboard on average by a factor of 15. This result led to the conclusion that in order to even begin to compete with plastic, the farm would have to extend the lifetime of a cardboard box to 15 weeks, or 3.75 months, which seems very unlikely. As well, this result justifies the previous omission of the effects of wax lining: adding those effects on would only add even more negative environmental impacts to the cardboard, while it is already clear that cardboard is the worse option.

However, there was a very notable exception where the cardboard outperforms the plastic: water usage. This result was reasonable, since the totes are washed on about the same frequency as the cardboard lifetime, while using much more water each wash than making a cardboard box (about

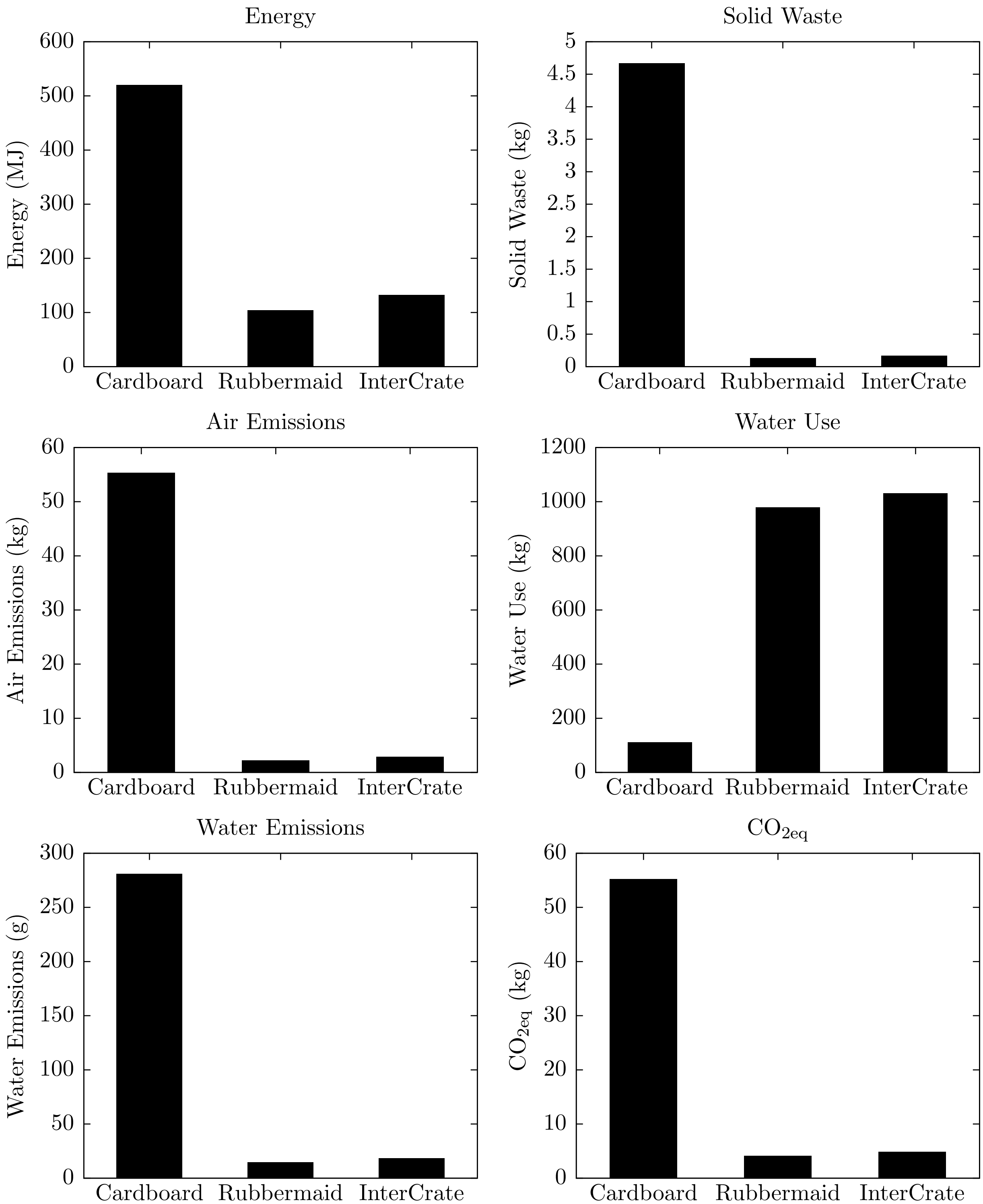

Figure 5.1: A visual comparison of the impact of replacing one plastic crate with an equivalent number of cardboard boxes

7 kg per wash, vs 850 g for box manufacture). Still, water is generally plentiful in Vancouver, and when taken in comparison to all the other negative environmental effects of cardboard, it was found that plastic was overall the better choice over cardboard.

Within the plastic choices, Rubbermaid had a slight advantage in every area. This result however was slightly deceiving: the PP used by InterCrate was actually a bit better to manufacture environmentally, but the InterCrate crates that were in use weigh more on average. Therefore, it would instead be better to choose lighter containers from InterCrate than from Rubbermaid were possible.

Section 6.0 Conclusion and Recommendations

Through extensive environmental analysis, the conclusion that was found was that the current method of plastic containers was the most viable option for harvesting, storing and transporting produce from the UBC farm. Although the wax lined cardboard boxes provided the strongest alternative, the environmental effects did not surpass those of the plastic totes and crates: plastic containers outperformed cardboard in nearly all areas by a factor of 15.

As well, the PP used in the InterCrate crates produced lower cumulative waste compared to the LDPE Rubbermaid tote and had little to no transportation because it was purchased locally. However, since the InterCrate crates were heavier, they had more impacts. This edge was slight, so overall crates should be purchased for minimum mass where possible.

Overall, the main recommendation found was for the UBC farm to continue its use of plastic totes and crates for produce transportation, handling, and storage. For optimal results, the containers should be as light as possible and should be manufactured, purchased and recycled in the same geographical area to reduce transportation effects.

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Appendix A Washing Data from the UBC Farm

The following data is a summary of the water usage and labour time when used for washing totes, provided by the UBC farm (Millar, 2013). The data was collected by UBC Farm Field Research Assistant Michael Millar on December 16, 2013, who washed a number of crates, totes, and lids while recording the time taken and water consumption with a DLJ water meter. The results are summarized in Table A.1.

Table A.1: Water usage and time spent washing at the UBC Farm

	Crates and Totes	Lids
Number	202	10
Gallons Used	247.7	6.9
Time (hrs)	4.93	0.13
Minutes per wash	1.47	0.8
Gallons/min	0.84	1.16

Extrapolation to 150 lids would lead to 139.2 gallons used over 120 minutes for washing lids. Overall, the total time and water usage for 52 crates, 150 totes, and 150 lids was 406 minutes and 386.9 gallons.

There was also additional labour in the following areas, totaling 50 minutes:

- Moving tables
- Moving stacks together
- Organizing tote/crate sizes
- Clearing space to work
- Peeling tape
- Taking down and moving stacks
- Taking down and moving tables

Overall, the total labour time was 456 minutes.