Crafting a Handbook for Sustainable Brewing: Recommendations for Water Treatment, Fermentation, CO2 Capture, and Biodegradable Packaging

Includes:

Final Report

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Introduction

The brewing industry is a vital component of Canada's social and economic identity and has evolved dramatically in recent years to become a thriving sector, contributing significantly to the nation's economy. Canada now offers a diverse array of breweries that cater to a wide range of tastes and preferences. The industry has flourished with breweries large and small dotting across the country. Canada's brewing industry mirrors its vast and diverse geography, with regional variations in brewing traditions, ingredients, and consumer preferences. Canada's multicultural society has established the brewing landscape with a variety of influences, resulting in a vibrant selection of styles and flavors that reflect the country's cultural diversity.

Alongside its growth and success, the brewing industry faces pressing environmental challenges that demand the attention of those in the industry. As concerns over climate change, resource depletion, and pollution escalate, breweries in Canada are increasingly under scrutiny for their environmental impact. The brewing process is resource-intensive, requiring significant amounts of water, energy, and raw materials such as barley, hops, and yeast. In addition to this, the production, packaging, and distribution of beer generates greenhouse gas emissions, contributing to climate change and environmental degradation. In response to these challenges, breweries can embrace sustainable practices to minimize their ecological footprint and promote environmental stewardship. Our research has delved into the fermentation and water treatment processes, as well as packaging solutions and methods to incorporate CO_2 capture within the brewing industry, so that breweries can take proactive steps to reduce their environmental impact.

Although Canada certainly leads in many aspects of sustainable brewing, it is essential to recognize that these efforts are part of a broader global movement towards environmental responsibility in the brewing industry. Breweries in the United States are also increasingly prioritizing sustainability, driven by consumer demand, regulatory pressures, and a growing awareness of the urgent need to address environmental challenges. Like Canada, American breweries are also implementing a wide range of sustainable practices. The idea of community engagement and the sharing of sustainable practices is the driving force behind Karbon Brewing, a sustainable brewery located in Toronto, Ontario. Founded in 2020 by Stephen Tyson, Karbon Brewing is striving to become a carbon-negative brewery and is eager to share its ideas with breweries worldwide. As students studying at Trent University partnering alongside Karbon Brewing, we have been tasked with identifying areas in the brewing industry that can be adapted to reduce impacts on ecosystems while remaining socially and economically viable. Our research is focused on carbon capture technologies, fermentation, water treatment methods, and biodegradable packaging and will contribute to the crafting of a sustainable brewing handbook.

By examining the brewing industry's sustainability journey in Canada, the United States, and other countries with a dense population of breweries, we have gained valuable insights into the shared challenges and opportunities between brewers and their practices. Through our research, we have been able to identify best practices across a brewery's value chain to advance sustainability efforts. The future of brewing lies in embracing sustainable practices that not only minimize environmental impact but also enact a more resilient and inclusive industry that benefits both present and future generations. Karbon Brewing is certainly a pioneer in this nature, but we hope our research will establish some innovative ideas to make their overall social, environmental, and economic practices more established.

Methodologies

Description of Study Area

Karbon Brewing, based out of Toronto, Ontario, is owned and operated by Stephen Tyson. The scope of this project is to assist Karbon Brewing with their work in researching sustainable technologies and alternatives within the beverage industry to guide companies that are wanting to decrease their environmental impact while optimizing their value chain. While the headquarters for Karbon Brewing is based in Toronto, they work with breweries across the province that have the facilities to brew Karbon’s beer and sell it locally, working towards their carbon-negative goals. Our study area has extended further into the industry to gather data and research alternative methods of sustainable brewing.

Description of Data Collection & How It Will Be Interpreted

Each member of our team is responsible for a specific area of focus and has researched and collected their data individually. Our team has researched and analyzed various aspects of the industry using both a micro and macro lens, to develop better solutions for the following areas of Karbon Brewing's value chain: *CO_2 capture*, *fermentation*, *water treatment*, and *biodegradable packaging*. The information collected through secondary research will inform recommendations for each topic, which will be compiled into a 'handbook on sustainable brewing', to be easily accessible to professionals in the brewing industry. Each topic will be referred to Appendix A, Figure 1, to determine which section of the value chain results in the largest impact in terms of indirect and direct emissions.

The scope of this assignment did not include obtaining information from primary sources within the brewing industry, instead we focused our research on secondary sources and combined them to determine best recommended practices. The research into each topic consisted of examining stakeholders in the industry. This included but was not limited to companies in the industry, governments, scientists who have already conducted similar research, and consumers.

This data will include public documents consisting of government reports, company reports, records from other researchers that have already broken ground on similar research, recorded interviews with those at the forefront of sustainable brewing, and market research that has already been conducted on consumers and organizations in the industry. The sources used to discover this data were Trent Omni, Google Scholar, Research rabbit, and news outlets such as CBC and New York Times.

Our final recommendations will be determined based on the credibility of sources, ability for different sized breweries to make adaptations, and by finding a balance between the environmental and economic benefits. Our research focused around the three pillars of sustainability (social, environmental, and economic), to ensure consistent values and to optimize benefits to guide sustainability trends.

Table 1. Keywords input within search engines to obtain research informing final recommendations.

Topic areas	**CO_2 capture**	**Fermentation**	**Water treatment methods**	**Biodegradable packaging**
Search engine keywords	• Carbon capture in beer fermenting • Carbon capture in beer hops • Carbon dense areas of brewing • CiCi carbon capture	• Sustainable fermentation • Brewing sustainably • Sustainable alternatives in brewing fermentation • Optimizing brewing fermentation	• Sustainable water treatment methods • Cost effective water treatment • Water recycling methods for breweries • Wastewater reuse	• Biodegradable beer packaging • Reusable beer packaging • Cost efficient packaging • Biodegradable plastics

Results

Through secondary research exploring the current state of the brewing industry in relation to environmental impact, it was determined that extensive resource use and carbon emissions are the main points of concern. The information and results compiled are organized in terms of specific categories (CO_2 capture, fermentation, water treatment methods, and biodegradable packaging) and include a price range for implementation. For a brewery to be successful, they need to follow the three pillars of sustainability to ensure that there is still an economic incentive, while working towards sustainable opportunities and prioritizing a level of organizational ambidexterity between the business and the environment as they intertwine.

CO_2 Capture

A concern throughout the brewing process is the emission of carbon dioxide released into the atmosphere, increasing global greenhouse gas concentrations. To minimize the effects, CO_2 capture can be established as an environmentally friendly and cost-effective method throughout the brewing process. Capturing it can lower atmospheric CO_2 levels and create a more sustainable planet. The brewing industry is a heavy emitter of carbon dioxide, but there are areas where carbon capture technology can be incorporated to help brewers and suppliers reduce their carbon footprint.

Table 2. Options for introducing CO2 capture into the brewing industry, as well as the price range and social, environmental, and economic results of doing so

Method	**Price Range**	**Results**
CiCi CO_2 Capture Machines incorporated **During Fermentation** This machine allows CO_2 to be captured by a brewery during the fermentation stage of brewing. CO_2 that is produced can be captured and reused, instead of staying as an unused by-product (Chart Industries, 2024). **Scope 1 - Internal Reporting**	~$165’000 USD	**Social:** Enables breweries that have incorporated this technology to differentiate themselves from others using traditional carbonation practices (Scudder, 2023). **Environmental:** Eliminates CO_2 from entering the atmosphere from the fermentation stage of brewing, lowering overall emissions (Chart Industries, 2024). **Economic:** Depending on the size of the brewer, some brewers no longer must buy CO_2 to carbonate their beer as they can simply use the CO_2 they have captured instead. Larger breweries may still have to buy some CO_2 , but they can purchase far less than prior to having CO_2 capture technology, lowering their overhead costs (Scudder, 2023).
CiCi CO_2 Capture Machines incorporated **During Hop Processing** This machine can be used during the hop processing phase by suppliers of breweries. The machine is the same as the one mentioned above but can be successfully integrated into this aspect of the industry also. The machine uses CO_2 to extract the oils and resins from hops. These oils and resins are turned into an extract that can be added to beer during the fermentation stage, just like you would add hops in. The CO2 can be captured and reused repeatedly for hop processing (Yakima Chief Hops, 2021). **Scope 3 - Upstream Activity**	~$165’000 USD	**Social:** Incorporating CiCi CO_2 Capture Machines during the hop processing stage can give suppliers the ability to take charge of their emissions more effectively, ensuring they are responsible for their carbon footprint and helping lower emissions overall in a brewery's value chain (Big Grove Brewery). The technology also allows for breweries to alter the taste of their beer more effectively and efficiently (Yakima Chief Hops, 2021). **Environmental:** Lowers emissions as less heat is required to dry the hops this way, compared to traditional drying methods. Also allows for the CO_2 to be used, captured, then reused, in an ongoing cycle (Yakima Chief Hops, 2021). **Economic:** Savings over long term as CO_2 no longer needs to be purchased. It takes 5-7 years to start seeing the savings, as this will be the break-even point between investing in the machine and saving enough money from buying excess CO_2 as a heat source. As the technology allows for hops to be incorporated into beer in the form of an extract, shipping fees will also drastically be reduced given the ease of shipping concentrated liquid instead of cumbersome hops. Shelf life will also be increased, allowing for less wastage (Big Grove Brewery).

Fermentation

The fermentation process is the key to producing beer which reveals areas within the value chain that can be improved in both environmental and economic practices. Cooled wort (malted barley) is added to the fermentation vessel along with yeast, which converts the glucose in the barley into ethyl alcohol and carbon dioxide gas. Hops can be added to increase flavour throughout the process, resulting in multiple harvested crops and external resources needed for completion.

It was determined through secondary research that the main points of concern in the fermentation process are the sourcing of sustainable ingredients, disposing of waste, offsetting emissions generated by sourcing, transportation, mixing of ingredients, and the integration of fermentation monitoring systems (Table 3).

Table 3. Description of sustainable methods derived from secondary sources, price range and results in terms of social, environmental, and economic benefits in the fermentation process.

Method	**Price Range**	**Results**
FSA, Farm Service Agency sustainability platform (SAI, 2024).	Free for initial assessment, < $1000 for membership	**Social:** Working alongside local communities and learning from the experiences of global farming groups will increase community engagement and discussion on sustainable practices. **Environmental:** The more farms that are following a sustainable mindset, the lower the emissions will be across all steps in production and fewer resources will be extracted. **Economic:** The FSA platform will allow companies to be informed on the most cost effective, sustainable practices and technologies associated with brewing. Being labeled as a sustainable brewer will increase profit through reaching the consumers making the earth conscious choice.
Reuse of spent hops as fertilizer for crops (Colby, 2024).	Free	**Social:** Foster relationships with local farmers that can utilize spent hops on property. **Environmental:** Reuse of materials to offset GHG emissions at local agriculture level. **Economic:** Potential to sell spent hops to farm to make profit or reduce overall spending. Strengthening a circular economy.

Sourcing local ingredients (Sustainable agriculture initiative) (SAI, 2024).	Low - Mid price range (Dependent on size of brewery from regional to macro, and location)	**Social:** Working alongside local communities to source materials and enhance relationships. **Environmental:** lowering transportation emissions by purchasing local **Economic:** Local economies can benefit from the use of local grains through employment creation, incomes for local farmers, reduced transportation costs and overall economic benefits
Fermentation monitoring system (Precision Fermentation, 2024).	~ $300/unit (Precision Fermentation, 2024).	**Social:** Consistent and reliable yield will allow for a solid consumer following and strong ties with community members. **Environmental:** Monitoring systems will increase efficiency and utilization of ingredients with lower waste and higher yield. **Economic:** Increased successful batches will reduce loss spending and optimize yield and revenue.
Fermented yeast to replace aroma hops (Bryce, 2022).	No current estimate on pricing due to novice practicing and dependent on the extent of replacement the company can afford. Cheaper alternative to current crops.	**Social:** Will branch out from only working alongside farmers but also local scientists cultivating the yeast. Will put less stress on local farmers struggling to match required yields. **Environmental:** Decrease reliance on cultivated crops that are damaging ecosystems and degrading habitats. Reducing pressure on farming yield and monocultures that degrade agricultural soils. **Economic:** Long Term cost benefits when utilizing lab-based enzymes that have the same sugars as agriculturally grown barley. Consistent yield with no threat of changing climate conditions.
Malternatives + lab produced enzymes use sorghum, maize, rice and cassava. These require enzymes to be added to facilitate brewing process (Kerry Group, 2022)	No current estimate on pricing due to novice practicing and dependent on the extent of replacement the company can afford. Cheaper alternative to current crops.	**Social:** Will increase local relationships when sourcing from multiple farming operations. Work with farmers for harvest and scientists for sourcing enzymes. **Environmental:** By replacing malted barley with adjuncts like sorghum, maize, rice, and cassava, it reduces pressure on agricultural systems that are being damaged by climate change. Reduced need for monocultures and degradation of soil. Sourcing any of these alternatives locally will reduce transportation emissions and increased reliance on external inputs (fertilizer, water, pesticides)

		Economic: Long Term cost benefits when utilizing lab-based enzymes that have the same sugars as agriculturally grown barley. Consistent yield with no threat of changing climate conditions.

Water Treatment

The issue with water and the environment within breweries stems from the significant amount of wastewater generated in the brewing process. Water consumption in beer production ranges from 4 to 11 liters per liter of beer, with smaller breweries tending towards higher ratios. ⅔ of water are allocated to the brewing process, while ⅓ is used for cleaning operations (Pettigrew et al., 2015). This wastewater contains highly concentrated pollutants such as chemical oxygen demand (COD), biochemical oxygen demand (BOD), and total suspended solids (TSS) like proteins, far exceeding levels typically found in domestic sewage (Government of Connecticut, n.d.).

Various sources contribute to this high-strength wastewater, including spent grains, mash runoff, hops, trub, bad batches of product, first rinses of process tanks, and waste product from fill stations and bottling lines (Government of Connecticut, n.d.). These contaminants result in high levels of BOD, COD, TSS, wide pH swings, high temperatures, and slug loading from batch discharges (Government of Connecticut, n.d.). It is important to address the substantial wastewater generated within water treatment plants themselves. As such, recycling water through various filtration systems should be of consideration to help brewers reduce their water usage costs, as well as their environmental impact.

The challenge arises due to wastewater having the ability to damage the biological balance at wastewater treatment plants if certain limits are exceeded. Thus, breweries must implement effective wastewater management strategies to mitigate their environmental impact and ensure compliance with regulations. Monitoring wastewater production and water use volume on a monthly and yearly basis is an essential tool that will help determine what size of system is needed, and how they can improve their business from an economic, environmental and social standpoint. Three methods of well recognized effective water treatment and management were identified, which provide various cost points for the different sizes of breweries depending on their financial ability to implement these methods (Table 4).

Table 4. Comparison of effective methods of water treatment and management with associated price ranges

Method	**Price Range**	**Results**
Rainwater harvesting and process optimization (Water recycling)	Low > $100 - $3000 (Cellucci, 2024; RainHarvest Systems, n.d.)	**Social:** Rainwater harvesting promotes reliability during water scarcity, fosters responsibility, and raises awareness for sustainable brewery practices (Rahman et al., 2014; Landcaster, 2010). **Environmental:** Rainwater harvesting provides pure water with fewer minerals, requiring less processing and meeting high environmental standards (Rahman et al., 2014; Landcaster, 2010). **Economic:** Rainwater harvesting offers economic benefits with low installation costs, long-term water bill savings, and reduced energy expenses when integrated with existing water systems (Rahman et al., 2014; Landcaster, 2010).
Reverse Osmosis	Medium > $1500 - $10 000 (Scale and size of brewery is the determinant of cost) (Crail & Tynan, 2024)	**Social:** Reliable and well-known process for treating wastewater, which ensures the safety and well-being of the brewery process, while reducing pollution and contaminants (Crail & Tynan, 2024). **Environmental:** RO efficiently treats wastewater, reducing strain on water supplies and preserving ecosystems, while also cutting down on energy use and carbon emissions (Simate et al., 2011; Crail & Tynan, 2024). **Economic:** Despite higher upfront costs, reverse osmosis systems offer long-term savings by reducing expenses on water treatment and disposal (Crail & Tynan, 2024).
Anaerobic Digestion	High >$1,000,000 (Alberta Agriculture and Rural Development, 2008).	**Social:** Anaerobic digestion provides an environmentally friendly method for managing brewery waste, potentially enhancing community perceptions and support for sustainable practices (Alberta Agriculture and Rural Development, 2008). **Environmental:** Anaerobic digestion reduces organic substances in brewery wastewater, promoting environmental sustainability by minimizing pollution, recycling water, and producing methane for renewable energy, thereby reducing reliance on fossil fuels and carbon emissions (Shah-Ganai, 2011). **Economic:** Anaerobic digestion systems produce biogas for energy, cutting costs and generating revenue, and increasing the ability to recycle water by removing biomaterials and reducing the cost (Alberta Agriculture and Rural Development, 2008).

Biodegradable Packaging

Since this sustainable handbook is targeted at all breweries of varying sizes looking to improve their total carbon footprint, we decided to focus on small steps regarding biodegradable/reusable packaging which can be easily attained by breweries while still making an impact on their total environmental and carbon footprint.

Plastic beer rings are widely used within the beer industry. However, they have been proven to be environmentally unsustainable as they are made from single use plastic which ends up in our landfills and does not efficiently breakdown. They are also harmful to wildlife and in 2025, they will be officially banned in Canada (Wirsig, 2022). There have been new sustainable innovations being sold such as biodegradable, cornstarch plastic labels for beer cans and bottles which could be a helpful guide for brewers wanting to switch to more sustainable alternatives (Creative Direction, 2022). Therefore, we have included some recommendations for more environmentally sustainable alternatives which brewers can utilize for their products.

Within our research, we have also composed more recommendations to make small steps in the direction of sustainable brewing such as considering what one can do to contribute to the sustainable and biodegradable packaging industry. Recent studies have shown experiments regarding brewers' spent grain, a common waste product within breweries, being used to make biodegradable and sustainable packaging (Qazanfarzadeh, 2023).

Lastly, eco-labels are a great way to communicate with consumers the conscious sustainable efforts the brewery is making to cut back on carbon emissions as it justifies price increases and established respect and communication with the customer base. However, these labels should be used to communicate exactly what efforts are being made and only if they are being made (Staples, 2020).

Table 5. Description of methods and recommendations for small steps toward biodegradable and reusable packaging within a brewery

Method	**Price Range**	**Results**

E6PR Biodegradable beer rings - 1st compostable beer rings - Varying size options (E6PR, n.d.)	Low >200$- 400 per case (Depending on brewery size as prices vary depending on the size of each order) (E6PR, n.d.)	Social: Encourages consumers to compost their packaging within breweries and other places in their communities. **Environmental:** Depending on the product, there are less greenhouse gases emitted during manufacturing as well as there is less single use plastic ending up in the landfill (E6PR, n.d.). **Economic:** These switches can occur slowly over time depending on the scale of the brewery and can be closely compared in cost with other commonly used packaging (E6PR, n.d.)
Hard Plastic reusable beer rings - Durable and can be reused multiple times (Pak-it Products, 2024)	Low >200$- 400 per case (Depending on brewery size as prices vary depending on the size of each order) (Pak-it Products, 2024)	Social: Encourages consumers to reuse and/or compost their packaging within breweries and other places in their communities. **Environmental:** These products are still made from plastics however, because they are durable and can be reused multiple times, they are less likely to be disposed of as frequently as single use plastics are and therefore preventing less plastic beer rings in the landfill. **Economic:** Reusable products can cut costs overtime due to customers returning their packaging.
Biodegradable, cornstarch plastic self-adhesive labels - There have been many companies experimenting with biodegradable cornstarch plastic which could potentially be used for biodegradable labels for beer cans (Creative Direction, 2022).	Low > $200- 400 per case (Depending on the company and their label/case sizing) (Creative Direction, 2022)	**Social:** The spread of awareness to consumers and businesses within the community of new sustainable innovations and companies. Environmental: The biodegradable labels help limit single-use plastic manufacturing and their presence in the landfills. **Economic:** Costs may vary depending on the company as well as order sizes, however with time and more traction of the product as it is newer, it may be comparable to other commonly used brewery products.

Discussion

CO_2 Capture

The process of capturing carbon was developed to capture the gas before it can be emitted into the atmosphere. Capturing it can lower atmospheric CO_2 levels and create a more sustainable planet. The brewing industry is a heavy emitter of carbon dioxide, but there are areas where carbon capture technology can be incorporated to help brewers and suppliers reduce their carbon footprint. Recommendations, price range, and the social, environmental, economic implications are included within results section Table 2.

CiCi - Fermentation Stage

Incorporating CiCi carbon capture machines during the fermentation stage of brewing drastically cuts greenhouse gas emissions from entering the atmosphere. This move mitigates climate change and air pollution, aligning with global efforts to reduce carbon emissions. CiCi machines can be installed at a brewery's fermentation tanks, and capture the carbon generated during fermentation, when yeast converts sugars into alcohol and CO_2. CiCi machines capture the CO_2 emitted during this process before it is released into the atmosphere. The CO_2 is then separated from the other gases to isolate the CO_2, making it usable for beer carbonation (Chart Industries, 2023).

This method of incorporating carbon capture stands out as, rather than simply capturing the carbon before it enters the atmosphere and selling or storing it, the technology promotes resource efficiency and helps develop a circular economy, minimizing environmental impact (Chart Industries, 2023). Breweries that incorporate CiCi machines during their fermentation stage demonstrate a commitment to their social and environmental responsibilities, enabling community trust and loyalty. Addressing consumer demand for sustainability enhances brand reputation, appealing to environmentally conscious consumers and supporting a healthier future for the business (Scudder, 2023).

While initial investments are required and are high, integrating CiCi machines during the fermentation stage offers long-term economic benefits. Reduced operational costs, enhanced efficiency, and improved market competitiveness are all outcomes of incorporating the technology, and lead to significant cost savings and profitability over time (Big Grove Brewery, 2024).

CiCi - Hops Processing

CiCi machines incorporated during the hop processing phase offer a revolutionary approach to hop extraction that significantly enhances efficiency and sustainability in the brewing industry. By utilizing CiCi machines, hop farmers can streamline the extraction process, yielding a high-quality hop extract that is superior to conventional hop incorporation methods. One of the key advantages of CiCi machines is their ability to process hops in cylindrical chambers rather than traditional indoor drying beds. This innovation allows for a more compact and space-efficient operation. In addition, hop pellets, rather than whole hops, can be loaded into the machine, enabling a higher volume of hops to be processed simultaneously (Yakima Chief Hops, 2018).

During processing, CO_2 is introduced to the hop pellets, triggering the release of oils and resins that form the extract. This extract can be added into the beer during the fermentation process, eliminating the need for whole hops and enhancing the flavor profile of the final product (Yakima Chief Hops, 2018). A notable aspect of a CiCi machine's process is its sustainability. The CO_2 used in extraction can be recycled for subsequent batches, minimizing the environmental impact by preventing its release into the atmosphere. Additionally, this method requires less heat compared to traditional drying techniques, resulting in reduced energy consumption and lower production costs (Yakima Chief Hops, 2018).

The CiCi machine's vertical processing approach also optimizes commercial space utilization, as it utilizes vertical space rather than surface area. This not only saves space but also enhances operational efficiency. Overall, CiCi machines incorporated into the industry's hop processing represent a significant advancement in hop extraction technology and carbon capture, offering brewers a more efficient, sustainable, and cost-effective solution for producing high-quality hop extracts (Yakima Chief Hops, 2018).

Fermentation

The fermentation process can be adapted to better represent a sustainable framework while still benefiting the value chain of beverage manufacturing. The recommendations included within this section range from low pricing/free to more costly options. A brewery interested in improving their fermentation strategies will have the ability to reflect on their needs, current environmental footprint, and price range and choose a recommendation that will match set goals. Recommendations, price range, and the social, environmental, and economic implications are included within results section Table 3.

SAI Platform

Starting with options at the lower price ranges, The Sustainable Agriculture Initiative Platform, is an organization that brings together companies and organizations at a global level to construct sustainable agriculture frameworks (SAI, 2024). Currently they have brought together over 180 members to better understand current practices and ways in which farmers transform to sustainable food systems. By joining this initiative, breweries can ensure the farmers they are sourcing ingredients from are following sustainable cultivation practices, and by doing so can move towards establishing themselves as sustainable brewers. This platform is free to join, but for long-term membership there is a monthly cost to remain updated on the forum's discussions and frameworks. The pricing is dependent on the size of brewer and location, so specific values were not attained for this project. Joining this platform is highly recommended for any brewery that is striving for sustainable brewing. It will connect people at a local and global level, bringing together adaptive and innovative ideas that will benefit the individuals and ecosystems involved. The SAI will benefit breweries at an economic level as well by informing organizations of the most cost-effective sustainable alternatives and having the chance to gain bursaries and grants when adapting these practices (SAI, 2024). Purchasing locally produced, sustainable beer is becoming the norm in the context of climate change, which will increase brewery revenue.

Reuse of spent grain

Waste generated from the brewing process is a crucial point of interest when devising sustainability frameworks. Spent grains, hops, and yeast are products from the fermentation process, and there have been practices that have found benefits to utilizing these spent goods. According to current research and active practices, brewery waste can be an amazing source of nutrients for animal feed, certain plant oyster mushrooms, and can also be included within the anthropocentric diet with proven health benefits (Spent Goods Company, 2024). Spent grain and hops can be beneficial to plant growth when added within fertilizer and compost, creating a circular economy within the brewing industry (Colby, 2024). Not only will reusing these materials reduce reliance on external inputs for farmers and cost of production, but it will also strengthen the relationships between local farms and breweries while providing the chance to reap profits from selling the waste.

Locally sourced organic ingredients

Transitioning to more sustainable brewing ingredients requires sourcing from local farms. Depending on the region and size of brewery, the cost of transitioning to strictly locally based ingredients will differ. Buying locally grown grains, hops, and yeast will lower the greenhouse gas emissions that would otherwise be produced from transportation, storage, and cultivation (SAI, 2024). Opting for organic ingredients grown without synthetic pesticides and toxic fertilizers will help in conserving natural resources and reducing chemical runoff into surrounding waterways and terrestrial ecosystems, while lowering the cost of these external inputs (David Suzuki Foundation, 2024).

Fermentation monitoring system

Through secondary research, it was determined that by optimizing the fermentation process through monitoring systems, breweries can ensure a higher yield, reduced waste, and consistent products. Fermentation monitoring systems collect data on dissolved oxygen, pH, gravity, pressure, fluid temperature, ambient temperature, and conductivity. Depending on the price range, size of the brewery, and access to technology, there are different options for monitoring machines. BrewIQ precision fermentation system offers fully automated, live-stream monitoring which has helped produce a higher yield in breweries, while saving money at $300/unit (Precision Fermentation, 2023).

Fermented yeast

Fermented yeast has proven to be a viable and cost-effective option for breweries when choosing alternative ingredients. This ingredient has been studied by replacing the aroma hops that give beer the traditional taste from fermented yeast (Bryce, 2022). This has been widely implemented into non-alcoholic beer resulting in a great flavour, and is set to be an option in alcoholic beer production where resource intensive aroma hops are also used. The current use of this ingredient has resulted in a reduction in water use by 100,000-fold, and CO_2 production by 100 times (Melton, 2022). Fermented yeast is a space and resource efficient ingredient that would reduce the impacts on the environment from cultivating hops. It is also a cheaper alternative to sourcing conventional hop species (Bryce, 2022).

Malternatives

Beer production is under pressure from a warming globe and changing climate, which has put stress on the cultivation of the usual ingredients sourced for brewing. The price of barley is increasing due to external environmental and social pressures in the brewing industry, which has led many brewers to source local alternatives (Kerry, 2022). Breweries have found that alternatives to malted barley include cassava, raw barley, maize, rice, and sorghum. To initiate the fermentation process, enzymes are needed when utilizing these alternatives. These alternatives result in a cost reduction, as they do not require as many resource intensive cultivation practices compared to that of malted barley. Sourcing locally also reduces transportation and storage emissions. Finally, it allows for the broadening of community relationships when including other local farms who cultivate different ingredients (Kerry, 2022).

Water Treatment

Utilization of Rainwater

Rainwater harvesting significantly alleviates the strain on public water supplies and preserves natural water ecosystems (Rahman et al., 2014). By harnessing rainwater, breweries reduce their reliance on municipal water sources, thus conserving vital community resources. Moreover, rainwater harvesting minimizes the need for energy-intensive treatment processes, thereby lowering carbon dioxide emissions associated with electricity generation (Rahman et al., 2014). Research indicates that rainwater harvested for brewing purposes often exceeds municipal water quality standards, boasting minimal contamination and optimal purity levels (Landcaster, 2010). This not only ensures the integrity of the brewing process but also underscores the environmental benefits of utilizing rainwater. Furthermore, rainwater harvesting provides a dependable water source during periods of scarcity or emergencies, bolstering community safety and well-being (Rahman et al., 2014). Its cost-effectiveness empowers not only breweries but also households and communities to take control of their water supply, reducing expenses and fostering a sense of shared responsibility (Rahman et al., 2014; Landcaster, 2010). Increased awareness and engagement regarding rainwater collection initiatives amplify these benefits, contributing to enhanced community resilience and well-being. From an economic standpoint, rainwater harvesting offers substantial advantages. The initial investment in rainwater harvesting infrastructure is often offset by long-term savings on water bills (Rahman et al., 2014; Landcaster, 2010). Integrating rainwater harvesting with existing water infrastructure further amplifies these economic benefits, as it reduces energy consumption and related expenses over time. Thus, rainwater harvesting emerges not only as an environmentally sustainable practice but also as a financially prudent strategy for breweries aiming to optimize resource utilization and minimize operational costs.

Reverse Osmosis (RO) Technology

RO technology presents a viable and sustainable solution for treating brewery wastewater, effectively mitigating the strain on public water systems and safeguarding water sources. By employing RO systems, breweries can efficiently remove contaminants and pollutants from wastewater, thus upholding environmental sustainability and mitigating the adverse impact of effluent discharge on ecosystems (Simate et al., 2011). The ability to recycle contaminated wastewater not only conserves water but also minimizes the pollution load on natural water bodies, promoting an ecological balance. Despite potential challenges such as regulatory compliance and reputational risks, the long-term benefits of RO technology are substantial. Reduced water treatment expenses and potential cost savings over time underscore the economic viability of RO systems (Crail & Tynan, 2024). Moreover, the reliability of RO systems in providing clean water ensures the safety and well-being of communities, further contributing to social sustainability and public health. While the initial investment in RO technology may be higher compared to conventional wastewater treatment methods, the subsequent operational efficiencies and environmental benefits justify the expenditure. By prioritizing sustainability and investing in innovative water treatment technologies like RO, breweries can not only optimize their operations but also uphold their commitment to environmental stewardship and community well-being.

Anaerobic Digestion (AD) Systems

AD technology plays a pivotal role in enhancing environmental sustainability within the brewing industry by effectively managing brewery wastewater and harnessing renewable energy resources. By utilizing AD systems, breweries can significantly reduce the organic load in wastewater and produce biogas, primarily methane, as a valuable byproduct (Shah-Ganai, 2011). This dual benefit not only minimizes pollution and waste but also provides a renewable energy source, thus contributing to carbon dioxide emission reduction and energy sustainability. Moreover, AD systems offer advanced features such as sludge blanket systems, which enhance the treatment efficiency of brewery wastewater by polishing the effluent and removing contaminants and excessive nutrients (Ashraf et al., 2021). The resulting improvement in water quality not only facilitates reuse within the brewery but also opens avenues for utilizing treated wastewater in other production processes or agricultural applications, thereby fostering resource efficiency and circular economy principles. From a social perspective, AD technology enhances community perceptions and support for sustainable practices within the brewing industry. The utilization of renewable energy sources and the reduction of environmental impact resonate positively with stakeholders, thus strengthening social cohesion and fostering a sense of shared responsibility (Alberta Agriculture and Rural Development, 2008). Additionally, the economic benefits derived from biogas production and reduced water costs further contribute to the socio-economic sustainability of brewery operations. Despite initial implementation challenges, such as regulatory compliance and operational optimization, the long-term economic and environmental benefits of AD systems outweigh the costs. By investing in AD technology and embracing sustainable wastewater management practices, breweries can position themselves as industry leaders in environmental stewardship and pave the way for a more sustainable future.

Biodegradable Packaging

E6PR Biodegradable Beer Rings

E6PR is a company which has made the first biodegradable beer rings (E6PR, n.d.) as a solution to the single use plastic beer rings commonly found in breweries, beer stores and liquor stores which will officially be banned in Canada by 2025 (Wirsig, 2022). They are offered in various diameters to fit differing can sizes as well as being offered in four or six packs, which allows flexibility and choice for consumers. The cost per case is comparable in cost with single use plastic beer rings and depending on brewery size, the costs can be lower with larger purchases (E6PR, n.d). The rings can be reusable which can potentially lower costs over time, however they are not as durable as other alternatives.

This alternative is socially sustainable as it allows customers to be curious and excited about composting and can therefore encourage the further use of biodegradable packaging within the community. As previously stated, these beer rings are one hundred percent compostable which results in less packaging within the landfills, less waste produced and therefore, less greenhouse gases emitted from single use plastics (E6PR, n.d.).

Hard Plastic, Reusable Beer Rings

These beer rings, which can also be found in either six or four rings, are made from a durable hard plastic which allows for multiple uses for consumers and brewers (Pak-it Products, 2024). Over time, these alternatives are comparable in cost to plastic beer rings and with the encouragement of reuse to customers, orders can be smaller depending on the size of the brewery. In larger orders as well, the costs decrease, making them cost effective. To further encourage the reuse, we recommend a return/recycling program within the brewery (Pak-it Products, 2024). This alternative encourages consumers to reuse their packaging products instead of throwing them away as they are small, light, and durable. A return/recycling program would also encourage consumers to bring back their products to be reused or recycled by the brewery to avoid sending them to the landfill as they are still a plastic product.

Biodegradable Cornstarch Labels

Although this is a newer, less common packaging product used in breweries, there is still immense potential for biodegradable beer labels made from cornstarch plastic as they limit waste and as it gains more attention, the cost may begin to go down. As the price is still relatively low, they are not closely comparable in cost to more commonly used products. However, they encourage the use of biodegradable packaging and provide less waste (Creative Direction, 2022).

Conclusion/Recommendations

The research conducted highlights various opportunities for Karbon Brewing and other breweries within the industry to reduce their environmental footprint while maintaining economic viability. By focusing on key areas of the production chain, including CO_2 capture, water treatment, fermentation, and biodegradable packaging, breweries can make significant strides towards sustainability.

The implementation of CO_2 capture technologies during fermentation and hop processing stages presents an opportunity for breweries to reduce their carbon emissions while also realizing potential cost savings in the long term. By incorporating these technologies, breweries can differentiate themselves in the market and demonstrate their commitment to environmental stewardship. Effective water treatment and management strategies are essential for breweries to minimize their impact on local ecosystems and comply with regulations. Options such as rainwater harvesting, reverse osmosis, and anaerobic digestion, offer varying levels of investment and benefits allowing breweries to choose the most suitable approach based on their budget and size. Furthermore, improvement in the fermentation process, including the sourcing of sustainable ingredients, waste disposal, and fermentation monitoring, can lead to consistent yields while minimizing resources and emissions. By exploring alternatives such as fermented yeast and malternatives, breweries can reduce their reliance on conventional crops and contribute to the preservation of agricultural systems. Finally, transitioning to biodegradable and reusable packaging options can further enhance a brewery's sustainability profile and resonate with environmentally conscious consumers. By investing in alternatives to single-use plastics, breweries can reduce their environmental impact and promote a circular economy.

Karbon Brewing and other breweries have a significant opportunity to prioritize sustainability throughout their operations. By implementing the recommendations outlined in this paper and staying informed about emerging technologies and innovations, breweries can play a vital role in advancing the sustainability of the industry while continuing to deliver quality products to consumers. Moving forward, breweries should establish clear sustainability goals tailored to their operations, develop comprehensive action plans, and invest in research and development to explore new sustainable brewing practices. Collaborating with suppliers and partners, educating and engaging employees, and monitoring progress are essential steps to ensure success. Furthermore, breweries should communicate their sustainability efforts transparently and celebrate achievements to inspire continued commitment to sustainability within the industry. Through these collective efforts, breweries can lead the way in fostering a more sustainable future for the brewing industry and beyond.

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Appendices

Appendix A

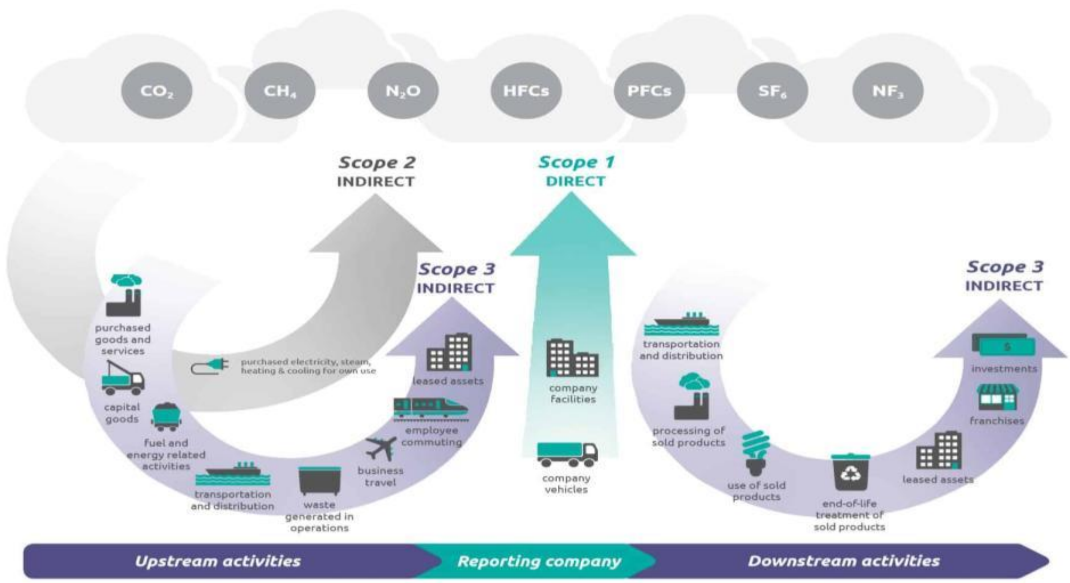

Table 1 Environmental Protection Agency. (2023, August 21). EPA. https://www.epa.gov/

Figure 1. This chart shows direct and indirect emissions through the lens of upstream activities, the reporting company, and downstream activities associated with the brewing industries value chain.

Authorship Statements

The discussion on wastewater management and treatment presented in this document reflects my original research, analysis, and synthesis of relevant literature and data. As ***Courtney Miller***, I take responsibility for conceptualizing the content, conducting literature reviews, and articulating key insights and conclusions regarding the utilization of various wastewater treatment methods in brewery operations. This authorship statement attests to my significant contribution to the development and composition of the section on wastewater management within the broader context of sustainable brewery practices.

I, ***Audrey Payne***, have contributed to the research, writing, and editing of this report. The information that I have included has helped in understanding current trends in fermentation. In addition, recommendations have been made that will improve social, environmental, and economic structures within the brewing industry as it relates to the sourcing and alterations of ingredients, fermentation monitoring, waste utilization, and community based initiatives.

I, ***Cameron Conroy,*** have contributed to the research, writing, and editing of this report. The information I have provided has helped in understanding the current methods of incorporating CO_2 capture into the brewing industry. In addition, I believe the recommendations I have made will be the most beneficial when evaluating areas across the value chain that would benefit from carbon capture technology, overall improving the social, economic, and environmental structure of the brewing industry.

I, ***Paige Nelson,*** have contributed to the research, writing and editing of this report. The information I have provided has helped in understanding the current practices, methods and products used for implementing biodegradable, reusable and overall sustainable packaging within the brewing industry. In addition, the recommendations I have made will increase the social, economic and environmental sustainability and structure of the brewing industry.