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CO_2 Emissions from Asheville's Craft Brewing Industry

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Abstract

This study examined the relationship between two foundational identities of Asheville, North Carolina — its environmentally mindful community and the craft brewing industry. We quantified CO_2 emissions from the fermentation process of brewing beer at several local breweries in Asheville. Additionally, this project determined whether emissions from fermentation were substantial compared to CO_2 emissions from the breweries' electricity usage. We analyzed data from four breweries of varying size. Our results showed that the emissions from fermentation were small compared to emissions from electricity usage. Total CO_2 emissions from electricity usage from all four breweries were slightly less than 180,000 tonnes compared to just over 600 tonnes from the fermentation process. Emissions from fermentation were less than 0.5% of emissions from electricity usage at all four breweries. While 600 tonnes of CO_2 may not seem substantial, this study was limited to just four of the more than 35 breweries in Asheville as of 2016. Given the size and rate of growth of the craft brewing industry in the region, it is too soon to dismiss fermentation emissions as unimportant to Asheville's total carbon footprint.

Keywords: fermentation, carbon footprint, greenhouse gas, carbon dioxide, craft brewing

1. Introduction

It is well known that greenhouse gas (GHG) emissions have steadily increased since the start of the Industrial Revolution. Carbon dioxide (CO_2) is the primary GHG emitted through human activities and accounts for the vast majority of all GHG emissions from anthropogenic sources in the United States (US EPA, 2019). In order to reduce CO_2 emissions, it is necessary to first quantify those emissions. One method of estimating GHG emissions from a region is by calculating a carbon footprint. A carbon footprint is a measurement of total greenhouse gas emissions. It is a quantitative estimate that assesses direct and indirect sources of pollution, GHG emissions from stationary and mobile sources, emissions from physical and chemical processing, as well as indirect sources of electricity (Al-Mansour and Jejcic, 2017; Institute for Local Government, 2009).

Asheville is a mid-sized city in western North Carolina that prioritizes reducing CO_2 emissions. The city achieved a reduction in CO_2 emissions from 2008-2016 (Weaver, 2017). Asheville's environmental identity is reinforced by its Sustainability Management Plan, which commits the city to reducing GHGs, reducing total energy consumption of city facilities, and increasing renewable energy use for water consumption and distribution (City of Asheville, 2009). Asheville is also home to the Collider, a co-working space for dozens of market-based climate businesses as well as the National Environmental Modeling and Analysis Center (NEMAC), which developed the U.S. Climate Resilience Toolkit. Additionally, Asheville is home to the National Oceanic and Atmospheric Administration's National Centers for Environmental Information headquarters, which holds one of the largest database of climate, weather, and environmental information globally.

In addition to its environmental identity, Asheville has deep roots in the craft brewing industry. It is home to the second most microbreweries per capita in the nation (Pomranz, 2019), and there are more than 35 brewing businesses that provide over 2,500 jobs, add a collective $111 million in labor income, and generate $934 million in total economic output in 2016 (Economic Development Coalition, 2017). To unite these two identities, some breweries, like New Belgium Brewing Company, have incorporated environmental efforts such as calculating their carbon footprints into their industry practices (New Belgium, 2017). New Belgium follows the Beverage

Industry Environmental Roundtable (BIER) Beverage Sector Guidelines (BIER, 2018). BIER guidelines do not calculate emissions totaling less than one percent of all GHGs, therefore, CO_2 emissions from the fermentation process of brewing beer are not accounted for. Alcoholic fermentation inherently creates CO_2 as a byproduct, and, while the emissions from fermentation are likely to be smaller than one percent of lifecycle GHGs, fermentation emissions may be considerable when looking across the extensive Asheville's brewing industry. The brewing industry has been looking to improve its sustainability practices (Betts, 2010; Saxe, 2010). In fact, breweries across the globe are recognizing that CO_2 capture from the fermentation process is viable and have installed systems for recovery and reuse in their facilities (e.g. Sierra Nevada, 2016; Craft Brew Alliance, 2016).

There is a potential dissonance between these two foundational identities that Asheville holds. Yeast action during fermentation inherently creates CO_2 and yet is a missing piece within Asheville's carbon footprint. Our study aimed to quantify the CO_2 emissions from the fermentation process of brewing beer and determine if they are a substantial compared to emissions from the breweries' overall coal-based electricity usage.

2. Methodology

This study was divided into two sections: quantifying CO_2 emissions from the fermentation process of brewing beer and quantifying CO_2 emissions from breweries' coal-based electricity usage. The fermentation data collected from breweries included the alcohol content (alcohol by volume, or ABV) and amount (volume) produced for all beer types. The electricity usage data from breweries was provided in kilowatt hours (kwh) and was received either as monthly values or an annual sum.

We approached approximately twenty breweries in Asheville to be a part of this study. Brewery representatives were met in person, called, emailed, and provided a letter that detailed the intent of the project, the data needed, and the importance of the study. When asking breweries to participate, we made clear that breweries' identities would remain anonymous. About ten breweries responded, but only four decided to participate in this research; we refer to those four breweries as Breweries A, B, C, and D. Brewery A's fermentation and electricity data were reported from the entire 2016 calendar year (12 months). Brewery B's data were collected for the 2017 calendar year (12 months). Brewery C's fermentation data span March to November 2017 (9 months), while their electricity data include March to October 2017 (8 months). Brewery D provided data for October 2018 only. The differing time frames make direct comparisons difficult, so we report annual values here. For Breweries C and D, we extrapolated the data to one full year.

CO_2 emissions from fermentation were determined by converting the ABV and volume of beer produced to a mass of CO_2 by using Equation (1):

$$C_6H_{12}O_6 + \text{yeast} \rightarrow 2\ C_2H_5OH\ (\text{ethanol}) + 2CO_2 \tag{1}$$

First, the ABV and volume of beer were converted to moles of ethanol. As given in equation (1), the molar ratio of ethanol to CO_2 is 1:1, thus, the moles of CO_2 equal the moles of ethanol. Then, the moles of CO_2 were used to obtain CO_2 emissions in tonnes.

CO_2 emissions from electricity usage were estimated by converting the energy purchased from the local power plant (Duke Energy's Lake Julian Power Plant, or LJPP) into a mass of CO_2. To do so, we assumed that the electricity consumed by a brewery was proportional to the CO_2 emissions from the power plant. For example, if a brewery purchased one percent of LJPP's total annual energy output, we can apportion one percent of LJPP's total annual CO_2 emissions to that brewery's electricity usage. Data on LJPP's total electricity production were obtained from the US Energy Information Administration (US EIA) for the entire 2016 calendar year, and the total CO_2 emissions output by the power plant, from the same time period, came from the US EPA's Facility Level Information on Greenhouse Gases Tool. It is important to note that electricity usage from the four breweries studied had differing timeframes. Only Brewery A's electricity data match the emissions year from LJPP.

To quantify CO_2 emissions from breweries' electricity usage, certain assumptions had to be made. These included steady electricity output by LJPP, steady electricity usage by each brewery, all CO_2 emissions from electricity came from LJPP, and a steady rate of CO_2 is emitted from LJPP per kwh of energy generated.

3. Results and Discussion

Knowing alcoholic fermentation inherently creates CO_2 as a byproduct, this study aimed to quantify the CO_2 emissions from the fermentation process of brewing beer and determine if it is a substantial amount compared to the breweries' overall coal-based electricity emissions.

3.1 Fermentation Emissions

The total amount of CO_2 produced from fermentation is shown in Table 1. The ABV, volume, and CO_2 emissions are provided for each style of beer (e.g A1, A2) and span the time periods mentioned in Section 2. Total CO_2 emissions are the sum of the individual styles of beer; for Breweries C and D, these values are extrapolated to one full year because the data record is less than 12 months.

Table 1. Fermentation data and CO_2 emissions for four breweries in Asheville, NC

	Alcohol by volume (%)	Volume in barrels	Mass of CO_2 (tonnes)	Total CO_2 (tonnes/yr)
Brewery A				68.24
Beer A1	6.2	5668.8	31.09	
Beer A2	5.5	2856	13.89	
Beer A3	6	1975.9	10.49	
Beer A4	6	231	1.23	
Beer A5	6	90.4	0.48	
Beer A6	6	1032.1	5.48	
Beer A7	5.2	407.1	1.87	
Beer A8	4.8	87	0.37	
Beer A9	9.3	50	0.41	
Beer A10	9.5	57	0.48	
Beer A11	5.7	488	2.46	
Brewery B				0.78
Beer B1	5.2	22.6	0.10	
Beer B2	5.4	27.1	0.13	
Beer B3	6.7	29.4	0.17	
Beer B4	6.5	24.8	0.14	
Beer B5	5.6	25.8	0.13	
Beer B6	5.6	9	0.04	
Beer B7	7.5	6.5	0.04	
Beer B8	7.3	2.6	0.02	
Brewery C				1.17
Beer C1	5.8	171	0.88	
Brewery D				539.81
Beer D1	7.3	2400	15.50	
Beer D2	8.2	400	2.90	
Beer D3	6.5	400	2.30	
Beer D4	10.4	400	3.68	
Beer D5	8	200	1.42	
Beer D6	9	200	1.59	
Beer D7	6.8	1200	7.22	
Beer D8	5	1000	4.42	
Beer D9	7.7	200	1.36	
Beer D10	6.5	800	4.60	

Total fermentation emissions for Brewery A was 68.24 tonnes. Brewery B produced 0.78 tonnes, and Brewery C produced 1.17 tonnes of CO_2. Brewery D emitted 539.81 tonnes. The stark difference in the amount of CO_2 emitted by the breweries is explained by volume of beer produced since ABV does not vary much between the four breweries. The total annual beer production for each of the breweries is as follows: Brewery A made just under 13,000 barrels, Brewery B made 147.8 barrels, Brewery C made 228 barrels (extrapolated), and Brewery D made 86,400 barrels (extrapolated).

CO_2 production is a function of both ABV and volume of beer. A low alcohol beer can have high emissions if it is produced in large quantities, and a high alcohol beer can have low emissions if batched in small quantities. Thus, CO_2 emissions vary by beer type. Just under half of the CO_2 created by Brewery A is attributed to Beer A1. This beer generated 31.09 tonnes of CO_2 from nearly 5,700 barrels with an ABV of 6.2%. The next largest volume of beer made from Brewery A was 2,856 barrels (Beer A2), which had an ABV of 5.5%. This beer created far less CO_2 than Beer A1 at 13.9 tonnes. The top three beers made from Brewery A, Beers A1-A3, accounted for 81.3% of total CO_2 emissions. Of the eleven beers made by Brewery A, these three were responsible for the majority of CO_2 produced from fermentation.

Brewery B had fewer varieties of beer types than Brewery A. Beers B1-B5 were all produced in similar volumes, had ABVs that ranged from 5.2- 6.7%, and generated close results in terms of tonnes of CO_2. Beer B3 (29.4 barrels, 6.7% ABV) created the largest amount of CO_2 at 0.17 tonnes. The last three beer types, Beers B6-B8, generated 12.8% of CO_2 emissions, a small percentage when compared to the other five beers from Brewery B.

Brewery C only brewed one stock beer that was used to create other beer types (by adding other flavors after fermentation, for example). Brewery C, having made a similar quantity of beer to Brewery B, also had similar emissions. Fermentation of Brewery C's single beer style produced 1.17 tonnes of CO_2. As mentioned in Section 2, this annual emissions rate has been extrapolated from the shorter data window provided by the brewery.

Brewery D had the greatest range of ABV spanning 5.0% to 10.4%. It also produced the largest volume of beer, which led to the largest (extrapolated) emissions rate of 539.81 tonnes. Two beers, D1 and D7, are responsible for half of all fermentation emissions at Brewery D. Because several types of beer were produced in equal quantities, the effect of ABV on CO_2 emissions is readily apparent. During the time window that Brewery D provided, 400 barrels each of Beers D2-D4 were produced, yet, because of the differing ABV content, the emissions produced from each beer style differed. Beer D4 (ABV 10.4%) produced 3.68 tonnes of CO_2 (extrapolated to 44.16 tonnes for the year), while Beer D3 (ABV 6.5%) produced 2.30 tonnes of CO_2 (extrapolated to 27.60 tonnes for the year).

3.2 Comparison to Electricity Emissions

As anticipated, Breweries B and C emitted less CO_2 per month than Breweries A and D because B and C make less beer. When analyzing the breweries' electricity usage, the same pattern held. Breweries B and C used less electricity, presumably because they are smaller operations that require less electrical energy. For all four breweries, CO_2 emissions from electricity usage were substantially greater than emissions produced from fermentation (Figure 1). CO_2 emissions from fermentation were less than one percent of emissions from electricity usage. Brewery A's electricity emissions were 23,494.1 tonnes; fermentation emissions are just 0.29% of that amount. Brewery B's fermentation emissions are 0.02% of total electricity emissions, which were 3,664.4 tonnes. Brewery C had similar values. There, fermentation emissions are 0.03% of electricity emissions, which were 4,340.7 tonnes of CO_2. Brewery D's electricity emissions were 147,817.3 tonnes. Their fermentation emissions are 0.37% of that value. Figure 2 shows the relationship between each breweries' fermentation emissions and electricity emissions. These data allow the breweries to be grouped based on the ratio of fermentation emissions to electricity emissions. The ratios for Breweries A and D are an order of magnitude greater than Breweries B and C. The larger breweries produce more CO_2 from fermentation (and, thus, more alcohol) per unit electrical energy consumed.

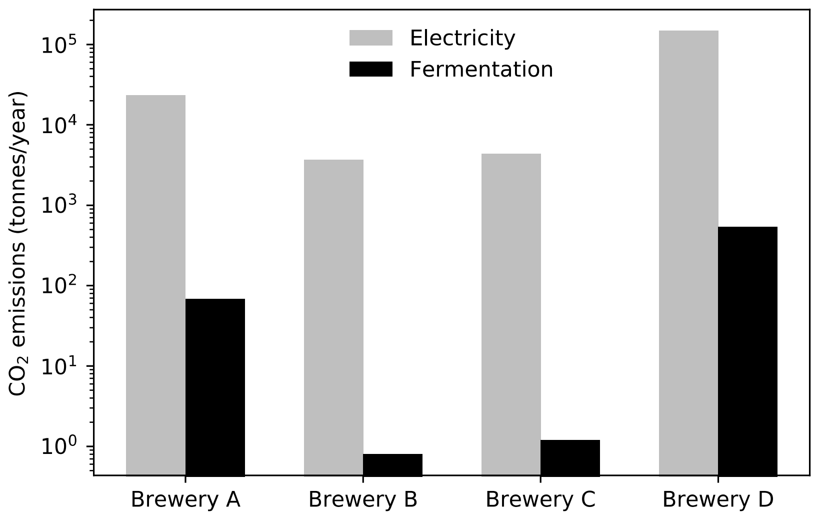

Figure 1. CO_2 emissions from brewery electricity usage and fermentation. Overall, CO_2 emissions from electricity usage were substantially greater than emissions produced from fermentation. CO_2 emissions from fermentation were less than one percent of emissions from electricity usage for all breweries

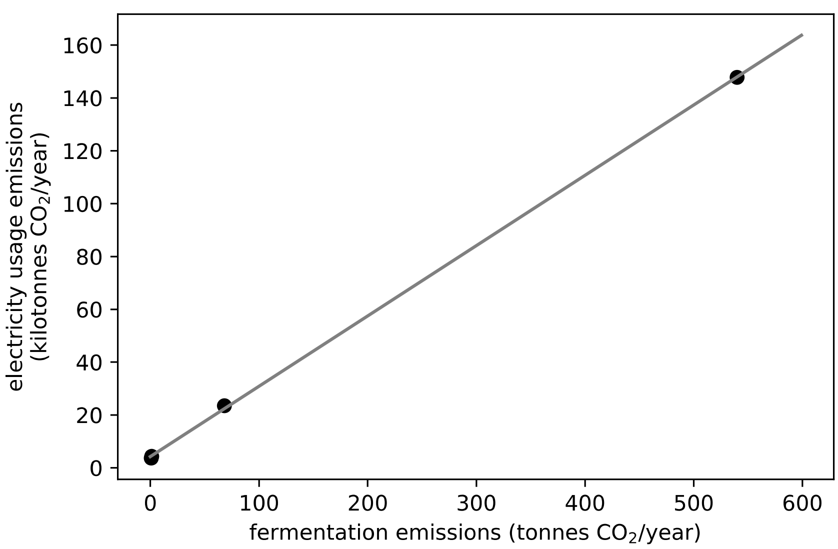

Figure 2. Relationship between CO_2 emissions from brewery electricity usage and fermentation. There is strong linear relationship between CO_2 emissions from fermentation and CO_2 emissions from electricity usage. $y = 266.27x + 4222.69$, $R^2 = 0.9999$

Table 2 allows for a direct comparison of CO_2 emissions between the four breweries per unit beer produced. All breweries had relatively similar fermentation emissions per barrel. This was expected because the inherent byproduct of CO_2 is governed by the biological process given in Equation 1 and is consistent from brewery to brewery. The variance in CO_2 emissions from fermentation between breweries was the result of the differing alcohol contents of the beers produced by each brewery. While fermentation emissions between the breweries were similar, there were substantial differences between the electricity emissions per barrel of beer produced. As shown in Table 2, Breweries A and D produced far fewer CO_2 emissions from electricity per barrel of beer than either Brewery B or C. This implies that larger breweries may be more efficient in utilizing their electricity usage per barrel of beer produced.

Table 2. Electricity and fermentation emissions

	Fermentation CO_2 emissions (tonnes/yr)	Electricity CO_2 emissions (tonnes/yr)	Fermentation CO_2 emissions (tonnes/barrel)	Electricity CO_2 emissions (tonnes/barrel)
Brewery A	68.2	23494.1	0.005	1.815
Brewery B	0.78	3664.4	0.005	24.793
Brewery C	1.2	4340.7	0.005	19.038
Brewery D	539.8	147817.3	0.006	1.711

There are several explanations for the increased efficiency at the larger breweries (A and D). First, most breweries operate tap rooms where customers can purchase and drink beer. The electricity demands for the tap rooms are essentially fixed. They all need lighting, refrigeration, and dishwashers for used glassware. This energy use does not scale with increased beer production at larger breweries because the breweries' tap rooms are of similar size. Thus, tap room electricity usage is a more substantial fraction of total electricity usage at smaller breweries. Second, most breweries likely use natural gas burners for heating at least some of the large volumes of liquid required during the initial stages of the brewing process. While total energy demands scale proportionally with increased production, this study is limited to electric energy usage. It is possible that the ratio of fermentation emissions to total utility emissions (electricity and natural gas) is similar across breweries of differing size.

4. Conclusion

This study sought to quantify a missing piece of the carbon footprint within Asheville's brewing industry. Based on the information reported by the four breweries that participated, two estimates of CO_2 emissions were calculated for each brewery. The first was from the fermentation process and was found by deriving CO_2 emissions from a given beer's ABV and production volume. The second estimate converted breweries' electricity usage (kwh) into tonnes of emitted CO_2. Our results show that CO_2 emissions from fermentation are not substantial compared to CO_2 emissions from breweries' electricity usage. However, it is important to note that only four breweries participated in this study compared to the over 35 local breweries in Asheville. While emissions from fermentation were smaller than emissions from electricity at each brewery, the total fermentation emissions from of all Asheville's collective brewing community could be a substantial part of Asheville's carbon footprint. As such, we cannot say that emitted CO_2 from alcoholic fermentation is an insignificant GHG source in the region.

This study served as an initial estimate of the carbon footprint of an important industry in Asheville. This line of questioning should be continued with a larger number of Asheville's breweries. Additionally, a more comprehensive analysis of breweries' energy usage should be conducted because many breweries use other sources of energy including natural gas and solar. Asheville has committed itself to reducing GHG emissions, and the city has successfully reduced emissions from municipal operations between 2008-2016. This research helps serve the city's goals of reducing CO_2 emissions throughout the region by quantifying size of craft brewing industry's footprint, which is a first step towards mitigating GHG emissions.

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