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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 of Asheville's foundational identities—its environmentally mindful community and the craft brewing industry. The goal was to quantify CO_2 emissions from the fermentation process of brewing beer at local breweries in Asheville. Additionally, this project determined whether emissions from fermentation were substantial compared to CO_2 emissions from the breweries' electricity usage. Data from three breweries were analyzed. Our results show that the emissions from fermentation were not substantial in relation to electricity usage. Total CO_2 emissions from electricity usage from all three breweries were slightly over 31,000 tonnes compared to just under 70 tonnes of CO_2 from fermentation. Emissions from fermentation were less than 0.5% of emissions from electricity usage at all three breweries. While 70 tonnes of CO_2 may not seem substantial, this study was limited to just three of the more than 35 breweries in Asheville as of 2016. Given the size of the brewing industry, it is too soon to dismiss fermentation emissions as being unimportant to Asheville's carbon footprint.

1. Introduction

It is well known that greenhouse gas (GHG) emissions have steadily increased since the start of the Industrial Revolution. Reducing these emissions have become a global priority as outlined in the United Nations Sustainable Development Goals[1]. 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[2]. In order to reduce CO_2 emissions, first, it is important to quantify those emissions. One such method to measure GHG emissions 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 combustion of fuels, emissions from physical and chemical processing, as well as indirect sources of electricity[3,4].

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 2008-2015[5]. 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[6]. Asheville is also home to the Collider, a co-working space for dozens of market-based climate businesses including the National Environmental Modeling and Analysis Center, which developed the U.S. Climate Resilience Toolkit[7]. Additionally, Asheville is home to the National Oceanic and Atmospheric Administration's National Centers for Environmental Information headquarters, which holds the largest database of climate, weather, and environmental information globally[8].

In addition to its environmental identity, Asheville has deep roots in the craft brewing industry. It is home to the third most microbreweries per capita in the nation[9], 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 output as of 2016[10].

To unite these two identities, some breweries, like New Belgium Brewing Company, have incorporated many environmental efforts such as calculating their carbon footprints into their industry practices[11]. New Belgium follows the Beverage Industry Environmental Roundtable (BIER) Beverage Sector Guidelines. BIER guidelines do not calculate emissions totaling less than one percent of CO_2e (CO_2 equivalent), 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 CO_2e, fermentation emissions may be considerable when looking at the extent of Asheville's brewing industry.

There is a potential dissonance between these two foundational identities that Asheville holds. Yeast action during fermentation inherently creates ethanol and CO_2 and yet is a missing piece within Asheville's carbon footprint[13]. Therefore, our study aims to quantify the CO_2 emissions from the fermentation process of brewing beer and determine if they are a substantial amount compared to the breweries overall coal-based electricity CO_2 emissions.

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 in a monthly breakdown or annual sum.

Approximately twenty breweries in Asheville were approached to be a part of this study. Brewery representatives were met in person, called, emailed, and given a letter that detailed the intent of the project, the data needed, and the importance of the study. When asking breweries to participate, it was made clear that breweries identities would remain anonymous. About ten breweries responded, but only three decided to participate in this research. Brewery A's fermentation and electricity data was reported from the entire 2016 calendar year (12 months), Brewery B's data was collected for the 2017 calendar year (12 months), and Brewery C's fermentation data was from March to November 2017 (9 months), while Brewery C's electricity data was from March to October 2017 (8 months). Note that Brewery C's electricity is one month shorter than its fermentation data.

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).

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

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 determined 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 energy consumed from LJPP was proportional to the CO_2 emissions of LJPP. For example, if a brewery used one percent of LJPP's total energy output, we can apportion one percent of LJPP's CO_2 emissions to that brewery's electricity usage. Data on LJPP's total electricity production was obtained from the U.S. Energy Information Administration (EIA)[12] 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 Environmental Protection Agency's (EPA) Facility Level Information on Greenhouse Gases Tool[13]. It is important to note that electricity usage from the three breweries studied had differing timeframes. Only Brewery A's electricity data match the emissions data 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.

The total amount of CO_2 produced from fermentation for Brewery A was 68.2 tonnes (Table 1).

Table 1. Fermentation Data And CO_2 Emissions For Three Breweries in Asheville

	Alcohol by volume (%)	Volume in barrels	Mass of CO_2 (tonnes)	Total CO_2 (tonnes)
Brewery A				68.2
Beer A_1	6.2	5668.8	31.1	
Beer A_2	5.5	2856	13.9	
Beer A_3	6	1975.9	10.5	
Beer A_4	6	231	1.2	
Beer A_5	6	90.4	0.5	
Beer A_6	6	1032.1	5.5	
Beer A_7	5.2	407.1	1.9	
Beer A_8	4.8	87	0.4	
Beer A_9	9.3	50	0.4	
Beer A_{10}	9.5	57	0.4	
Beer A_{11}	5.7	488	2.5	
Brewery B				0.78
Beer B_1	5.2	22.6	0.10	
Beer B_2	5.4	27.1	0.13	
Beer B_3	6.7	29.4	0.17	
Beer B_4	6.5	24.8	0.14	
Beer B_5	5.6	25.8	0.13	
Beer B_6	5.6	9.0	0.04	
Beer B_7	7.5	6.5	0.04	
Beer B_8	7.3	2.6	0.02	
Brewery C				0.88
Beer C_1	5.8	171	0.88	

Brewery B produced 0.78 tonnes and Brewery C produced 0.88 tonnes of CO_2. The stark difference in the amount of CO_2 created by Brewery A compared to Breweries B and C is due to the greater volume of beer made by Brewery A since ABV does not vary much between the three breweries. Brewery A made just under 13,000 barrels of beer compared to Brewery B's 147.8 barrels, and Brewery C's 171 barrels.

CO_2 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. As such, CO_2 emissions vary by beer type. Just under half of the CO_2 created by Brewery A is attributed to Beer A_1. This beer generated 31.1 tonnes of CO_2 from slightly over 5,600 barrels of beer and an ABV of 6.2%. The next highest volume of beer made from Brewery A was 2,856 barrels from Beer A_2 which had an ABV of 5.5%. This beer created far less CO_2 than Beer A_1 at 13.9 tonnes. The top three beers made from Brewery A, Beers A_1-A_3, accounted for 81.4% of total CO_2 emissions. Out of eleven beers made by Brewery A, these three were responsible for the majority of CO_2 produced from fermentation.

Brewery B had less variety of beer types compared to Brewery A. Beers B_1-B_5 were all produced in relatively similar volumes, had ABVs that ranged from 5.2- 7.5%, and generated close results in terms of tonnes of CO_2. Beer B_3 (29.4 barrels), created the largest amount of CO_2 at 0.17 tonnes. The last three beer types, Beers B_6-B_8 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. Brewery C, having made a little over 20 more barrels of beer than Brewery B, output just under one tonne of CO_2. It is important to note that this quantity is artificially low because Brewery C only reported data for 9 months as opposed to 12 months compared to Breweries A and B. So, Brewery C's CO_2 emissions would likely be greater than 0.88 tonnes if they were given for a 12-month period. To account for these differing time spans, calculations for fermentation and electricity emissions were made for a monthly average and per gallon of beer (Tables 2 and 3).

Table 2. Breweries Electricity and Fermentation Emissions Per Month

	Fermentation CO_2 emissions (tonnes/month)	Electricity CO_2 emissions (tonnes/month)	Total CO_2 emissions (tonnes/month)
Brewery A	5.7	1957.8	1963.5
Brewery B	0.1	305.3	305.4
Brewery C	0.1	450.9	451.0

As anticipated, Breweries B and C emitted much less CO_2 per month than Brewery A because B and C make less beer. Brewery A had a total monthly average of 1963.5 tonnes of CO_2 emissions. Brewery B had a much lower total monthly average of 305.4 tonnes of CO_2 emissions and Brewery C was a little higher at 451.0 tonnes of CO_2 emissions per month. This data suggests that there might be a linear relationship between CO_2 emissions from electricity usage, which could indicate a direct proportionality between two emission sources. Figure 1 shows this linear relationship, but more breweries are needed to determine if this relationship is robust. It is interesting how stark the difference between fermentation emissions and electricity emissions per month are. This is true for all three breweries, which demonstrates that electricity usage is responsible for substantially more CO_2. Again, Brewery C's electricity data is one month shorter than its fermentation data as described in the methods section. But, because this is a monthly average, the shorter time span most likely does not make a large impact on the fermentation and electricity emissions.

Table 3. Breweries Electricity and Fermentation Emissions Per Gallon of Beer

	Fermentation CO_2 emissions (tonnes/gallon)	Electricity CO_2 emissions (tonnes/gallon)	Total CO_2 emissions (tonnes/gallon)
Brewery A	0.000170	0.058599	0.058769
Brewery B	0.000171	0.800083	0.800254
Brewery C	0.000147	0.680439	0.680586

Table 3 allows for a direct comparison of CO_2 emissions between the three breweries per unit of beer produced. All breweries had relatively similar fermentation emissions per gallon. This was expected because the chemical process of beer production and the inherent byproduct of CO_2 is consistent from brewery to brewery. The small variance in CO_2 emissions from fermentation between breweries were a result of the differing alcohol contents of the beers produced by each brewery. When calculating the rate of CO_2 from fermentation per gallon at Brewery C, an average rate of production over an eight-month period was used to match the eight months of electricity data. If the volume of beer for all nine months was used, the result would be an artificially low amount of CO_2 emissions from electricity for Brewery C.

While fermentation emissions between breweries were similar, there was substantial variance in the electricity emissions per gallon of beer. As shown above, Brewery A produced far less CO_2 emissions from electricity per gallon of beer than either Brewery B or C. This implies that larger breweries may be more efficient utilizing their electricity per gallon of beer produced.

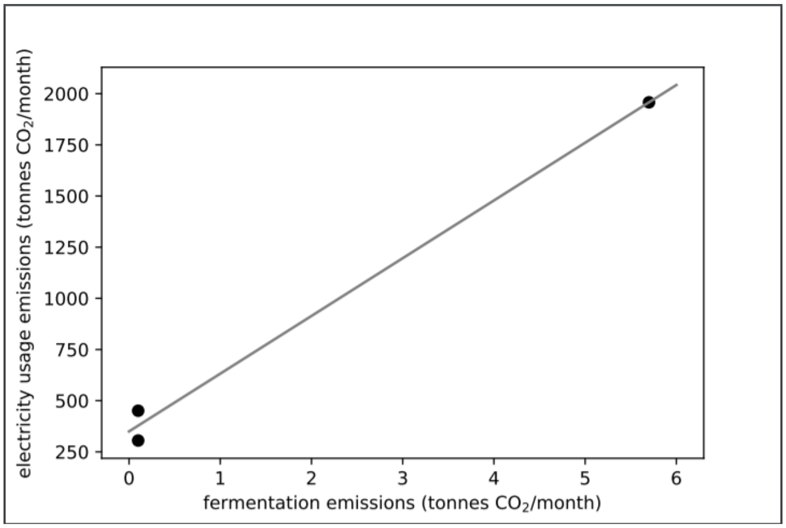

Figure 1. Relationship between CO_2 emissions from brewery electricity usage and fermentation

Figure 1 There is an apparent linear relationship between CO_2 emissions from fermentation and CO_2 emissions from electricity usage. $y = 282.09x + 349.89$, $R^2 = 0.9937$.

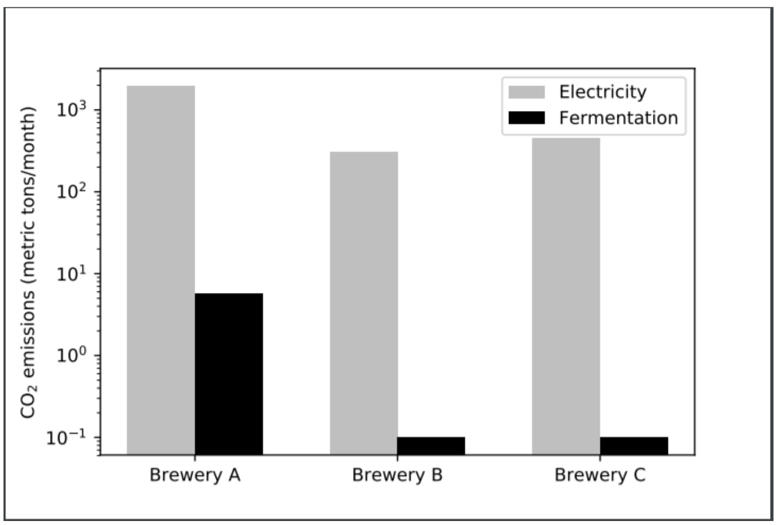

Figure 2. CO_2 emissions from brewery electricity usage and fermentation

Figure 2 CO_2 emissions from electricity usage compared to CO_2 emissions from fermentation. Note the log scale on the y-axis. Emissions from electricity usage are given in gray and emissions from fermentation are given in black.

For all three breweries, CO_2 emissions from electricity usage were substantially greater than emissions produced from fermentation (Figure 2). CO_2 emissions from fermentation were less than one percent than emissions from electricity usage for all breweries. Brewery A's CO_2 from fermentation was 0.29% that of its electricity usage. Brewery B and C had the same percentage of CO_2 from fermentation compared to their electricity usage at 0.02%. Based off of these values, it does not seem that the CO_2 produced from the fermentation process of brewing is substantial in comparison to breweries electricity usage. However, that does not mean that CO_2 emissions from fermentation are not important. The sum of all of Asheville's breweries (not just the three reported here) might be a significant contributor to carbon emissions in the region.

4. Conclusion

This study sought to quantify a missing piece of the carbon footprint within Asheville's brewing industry. Based off the information received from the three breweries that participated, two measurements of CO_2 emissions were calculated for each brewery. The first was from fermentation and was found by deriving CO_2 emissions from a brewery's ABV and volume of beer. The second measurement calculated emissions from breweries' electricity usage (kwh) into tonnes of CO_2 emissions. Based off of these three breweries, CO_2 from fermentation is not substantial compared to CO_2 created from breweries' electricity usage. However, it is important to note that only three breweries participated in this study compared to the over 35 local breweries in Asheville. While proportionally emissions from fermentation were substantially smaller than emissions from electricity at each brewery, the total emissions from fermentation of all Asheville's collective brewing community could be a substantial part of Asheville's carbon footprint. As such, what is yet to be determined is the importance of fermentation emissions in totality within Asheville.

This project served as a pilot study and will guide the next phase of research. This line of questioning will be continued and will include a larger number of Asheville's breweries. In addition to this, more in-depth analysis will be undertaken on breweries electricity usage because this study only determined emissions from coal-based electricity, but many breweries use other sources of electricity such as natural gas. Continuing this project will allow for a better representation of the CO_2 emissions from fermentation and electricity usage within the brewing industry in Asheville. Asheville commits itself to reducing GHG emissions, and the city has successfully reduced emissions from municipal operations in 2008-2015. By being able to fill-in a missing piece of Asheville's total carbon footprint, this research helps serve the city's goals of quantifying CO_2 emissions throughout Asheville, North Carolina. Calculating emissions from fermentation, Asheville can have a more complete carbon footprint. Realizing the smaller emissions of GHGs that are otherwise unaccounted for, Asheville can acknowledge and potentially address them.

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