Environmental Audit of Beertzinut Beer Brewery in the Southern Arava

by

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ABSTRACT

Three functional environmental audits were performed on the Beertzinut brewery to collect data on the brewery's water use, waste generation, and electricity consumption. This report compiles the results of those environmental audits. The main takeaways from these audits were that a significant amount of water is used at the brewery for wort cooling, electricity usage is more efficient on days that handle larger processes, and the waste management practices are already environmentally sustainable. With these main takeaways, suggestions were made to decrease these environmental impacts and allow for Beertzinut to improve environmental sustainability.

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CHAPTER 1: INTRODUCTION

Environmental sustainability is defined as the advancements of economic and social development while minimizing damage to local ecosystems and the climate from emissions, waste, and harvesting of natural resources. Many businesses look for ways to improve their economic development while monitoring their business's sustainability practices. Sustainability impacts every business, no matter the size, and should be monitored to reduce nonrenewable resource consumption, save money, and reduce environmental impact.

The Beertzinut brewery operates in the extremely arid Southern Arava valley of Israel on Kibbutz Ketura. This region has limited resources, and as such, environmental sustainability is a priority for all that live there. This concern is a priority for Beertzinut as they hope to gain more concrete statistics about their environmental impacts.

The scope of the three audits focuses on the inputs and outputs of the brewery's processes in terms of electricity and water usage, as well as waste output in the form of solid waste and carbon dioxide emissions. These three factors must be fully documented, analyzed, and validated by comparing with previous audits to understand the brewery's current environmental impact. This data can be used to highlight areas of improvement both environmentally and economically through a cost analysis. Final suggestions can then be made that address all the aspects considered in this report. The goal of this project is to audit the water, electricity, and waste of the Beertzinut brewery in order to provide data for future environmental improvements. The objectives of this project are the following:

1. Map the business and manufacturing process of the Beertzinut brewery
2. Outline the inputs and outputs of a full cycle of beer production that affect the environmental impact of the brewery
3. Establish a framework to connect to previous reports and validate our data
4. Create a costing analysis to compare with the sustainability report
5. Suggest future improvements with both environmental sustainability and economic viability in mind.

CHAPTER 2: BACKGROUND

2.1 The Southern Arava Valley

The Arava region is in the southernmost tip of Israel and is known for its year-round high temperatures and lack of rainfall, as seen in Figure 1. Despite these harsh conditions, many communities live and thrive through environmentally sustainable living practices. Solar panels are used to collect energy, water is recycled, and waste is composted. Additionally, new practices are created and adopted daily to make life here the best it can be. These communities strive to be more sustainable, not only because of the conditions they have learned to live in, but also because of a collective will to give back to the Earth.

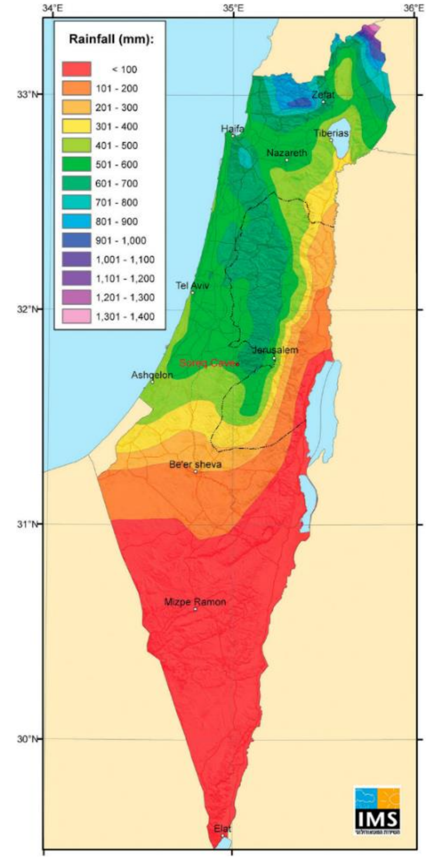

Figure 1: Israel Rainfall Figure

The annual rainfall in various regions of Israel highlights the lack of rainfall in the Southern Arava region. The entire region gets less than 100mm a year (Ackermann 2019).

2.2 Beer Brewing at Beertzinut

Beertzinut brewery is a microbrewery that calls the small desert community of Kibbutz Ketura home. Here, the business has grown from a small homebrewing setup developing experimental brews to a substantial 100L brew system with five fermentation tanks supporting the 15 unique craft beers that Beertzinut currently offers. As the brewery expands, it is interested in understanding and reducing its impact on the environment.

2.2.1 Brew Process

Beer brewing at Beertzinut is a complex mechanical and biochemical process with a variety of inputs and outputs. Figure 2 visually outlines the process. The first input in the brew process is malt, which consists of several types of roasted grains. The ratio of grains and other ingredients depends on the desired flavor of the product. In all cases, these grains are de-husked in the milling process to expose their grist, the part of the grain which contains sugars. The water and grist are combined and heated in a mash tin, allowing them to hydrolyze and become wort, the base liquid of beer. This wort is filtered, which leaves behind spent grain, the first output of the system. Spent grain consists of husks and grist that did not hydrolyze in the mashing stage. These spent grains, once removed, are no longer needed for the brewing process and can be used as animal feed or thrown away.

Following the disposal of the spent grains, the wort is ready to be boiled and the next input, hops and/or various flavoring spices and ingredients, can be added. Hops can be added at different ratios, times, and temperatures to add flavor and texture to the beer. It also functions as a preservative, which is useful for shipping and storage in warmer climates. The boiling process uses energy to raise the temperature of the wort to nearly boiling. This gradual application of heat releases more flavor from the ingredients. Once the brew has been heated for the required time, the whirlpooling stage can begin. The hop solids and proteins, known as trub, are removed, as well as any other particulate matter. This waste output is often a small amount of plant material that is too bitter to be used as animal feed and is composted. The strained wort can be cooled in preparation for fermentation. Water is needed to draw the heat away from the wort during the cooling stage by being pumped through the boiling tin’s jacket. The cooled wort is added to the fermenter along with the final input, yeast, and left to begin the fermentation process. After fully fermenting, the final product is transferred to the bottling and packaging stage.

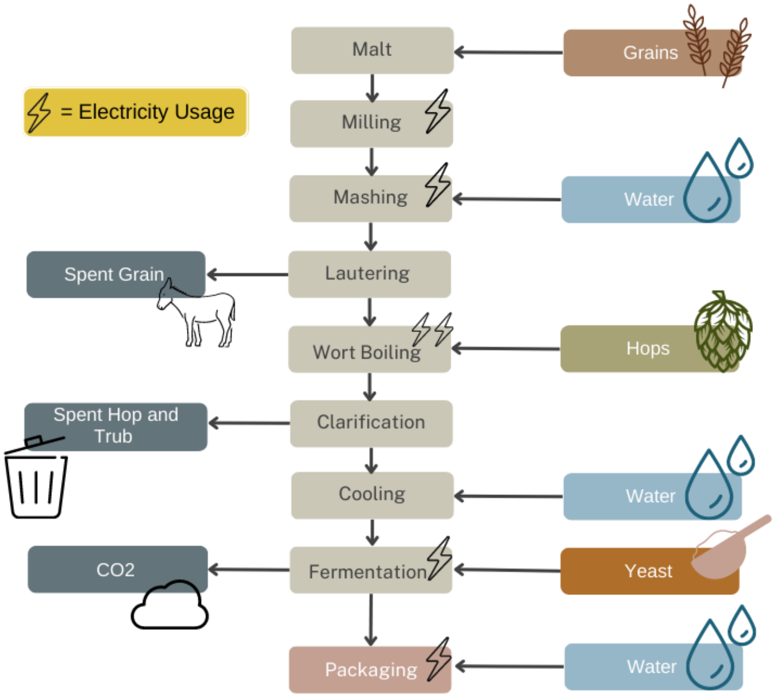

Figure 2: Brew Process Flowchart

A flowchart breakdown of the relevant inputs and outputs in the brewing process at Beertzinut.

2.2.2 Bottling Process

The bottling process handles the filling and packaging of the beer, and the inputs and outputs of this process must also be considered for the audit. Figure 3 outlines the inputs and outputs of this process. Bottling begins with the sanitization of the bottles using water. This water is recycled for all bottles being filled that given day. Once sanitized, the bottles are filled with beer, then carbonated with compressed carbon dioxide. The bottle caps are sterilized with concentrated ultraviolet light and guided into position to be crimped onto the filled bottles. Next, the bottles are labelled, and this process requires no electricity or water, but it does produce waste. During labelling, bottles are individually labelled on a label roller, which applies a sticker to the circumference of the glass bottle. This sticker leaves behind a wax paper backing which must be disposed of. Labeled bottles are then packaged and shipped out in recycled carboard boxes.

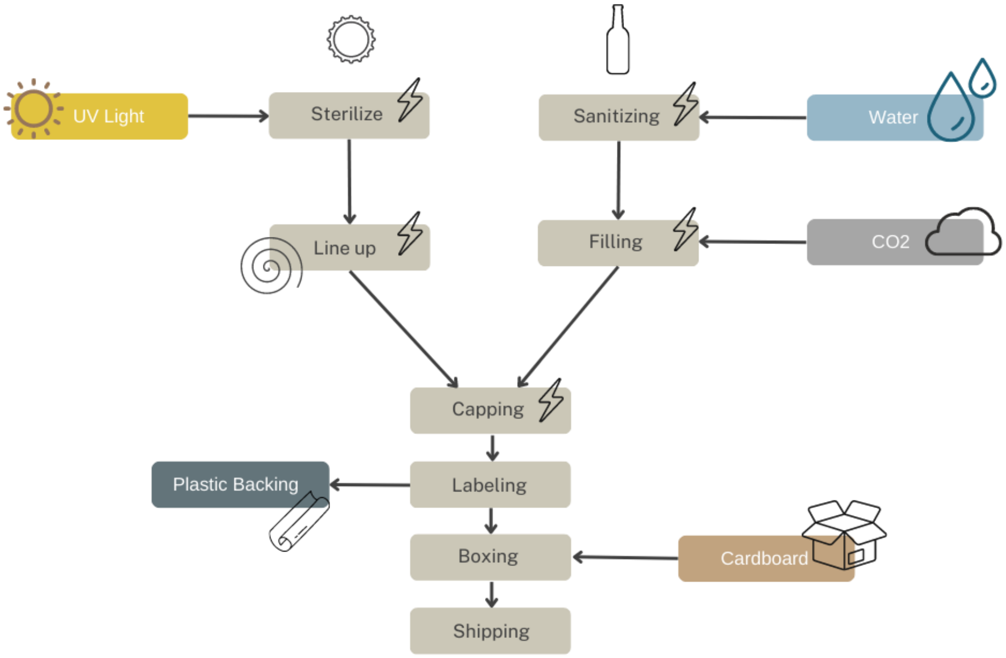

Figure 3: Flowchart of Bottling Process

A flowchart breakdown of the relevant inputs and outputs in the bottling process at Beertzinut.

2.2.3 Cleaning Process

The Beertzinut brewery distributes consumable products and is required to thoroughly clean and sanitize all equipment for the safety of their customers. For a brewery, this means using a significant amount of water to sanitize, clean, and rinse all components in the process which come into contact with the beer. This includes, but is not limited to, the bottling machine, boiler, mash tin, fermenter, and all hoses. At Beertzinut for sanitization, one liter of water is combined with three milliliters of peracetic acid to properly sanitize equipment. To sanitize a 100-liter fermenter, roughly twenty liters of water, or 1/5 of the total size of the tank, and sixty milliliters of peracetic acid is needed. For cleaning at Beertzinut, one liter of water is combined with ten milliliters of caustic cleaner. To clean a 100-liter brew pot, roughly twenty liters of water and two hundred milliliters of caustic is needed. Additionally, a significant amount of water is needed before and after cleaning and sanitization to rinse off the equipment in the facility. While Beertzinut is aware of the specific cleaning cycle measurements, the audit aims to understand how each cleaning cycle fits into their overall water use.

2.3 Functional Environmental Audits

A functional environmental audit is a type of audit that focuses on one environmental impact as opposed to other audits which have broader focuses. Additionally, functional environmental audits provide suggestions on avenues to reduce these impacts (National Registry of Environmental Professionals, 2020).

The functional environmental audit process consists of three phases: the pre-audit, audit, and the post-audit. The pre-audit phase focuses on the process leading up to the audit, through preparatory information gathering. Here, the information gathered should focus on gaining background for the audit prior to arriving on-site to maximize the time spent on data collection. Additionally, this portion of the audit should be used to research and determine benchmarks and expectations for the upcoming audit. Following the completion of the pre-audit, the audit phase can begin, which focuses on data collection on-site as well as gathering any final documentation, and background information that was left out of the pre-audit phase. The documents reviewed here cover more in-depth information regarding permits, inspections, inventories, environmental procedures, and other relevant audit information. In the post-audit, the collected data is analyzed, and the main environmental impacts are identified, often backed up by the research done in the pre-audit phase. With the main environmental impacts identified, solutions can be researched and presented in the final audit report. Once the final report and suggestions are presented, the functional audit process is complete (National Registry of Environmental Professionals, 2020).

2.4 Audit Protocol Review

Environmental audits of a business should follow a protocol that appropriately considers the relevant elements of the manufacturing process. Therefore, beer brewing must be audited with the complexity of the fermentation process in mind. Some of these factors include the water, the energy required to regulate the temperature, and the CO_2 emitted from the fermentation process.

Designing a protocol that is applicable to small and medium enterprises (SMEs), such as craft breweries, has been attempted throughout the last two decades and has produced 22 energy audit programs in 15 countries (Price and Lu 2011). Some existing protocols that apply to beer brewing are the 2019 European Union Best Available Techniques (BAT) Reference Document for the Food, Drink, and Milk Industries, The Swedish Energy Audit Policy Program (SEAP), the EINSTEIN software and audit protocol, The United Nations Carbon Emission Calculator. Each of these audit protocols is implemented primarily in Europe, the U.S., and Australia. Each of these audits looks at the same problem through different lenses. However, having multiple audit procedures is an obstacle to establishing a global standard. The key to quality in an audit is detailed quantitative data which uses globally standardized units that can be understood by others (Olajire, 2020). Ultimately, the success of an audit is determined by the implementation of more environmentally sustainable and economic business practices by the organization undergoing the audit. The audit is designed to be an informational tool that quantifies current resource usage and cost, then provides an estimate of how cost and usage would change with the implementation of more environmentally conscious methods.

2.4.1 European Union Policy

The European Union has published and consistently updated “Best Available Techniques (BAT) for Food, Drink and Dairy” since 2002, with the most recent update in 2019. This audit protocol dedicates an entire chapter to beer brewing. The published protocol is designed to function as a reference document educating its audience on current overall energy and water consumption in participating breweries. After establishing current usage levels and the impact that carbon emissions, waste, water, and energy usage will have on environment, the EU BAT protocol outlines changes that should be made to brewing procedures and specifies how each change can minimize environmental impact. The protocol maintains standard units such as Kilowatt hours and percent usage. Furthermore, for every proposed procedural adjustment there is a reference to its implementation in a pilot brewery. The European Union also works closely with the Brewers of Europe, a conglomerate organization of 29 national brewers' unions throughout Europe (Santonja, 2019).

2.4.2 Swedish Energy Audit Policy

The Swedish Energy Audit Policy (SEAP) is a stand-alone audit program. Between its implementation in 2010 and 2014, “the program resulted in annual net energy efficiency savings equivalent to 340 GWh/year or 6% of the 713 participating companies' energy end use.” However, “the implementation rate of the recommendations in the audit program was 53%”. The program aims to include more small and medium enterprises (SMEs) like Beertzinut because they can usually implement improvements in manufacturing support processes at very low costs. The estimated potential for energy savings for SMEs as of 2015 is above 20% (EC, 2006; Thollander et al., 2013; Thollander et al., 2015a; Svetland et al., 2016). The SEAP protocol has an emphasis on providing free energy audits through public policy as this increases implementation in SMEs that may have fewer resources at their disposal to do on their own. There is also a qualification requirement for those performing the audit that they have a background in engineering, as this ensures more concrete, quantitative results (Paramonova, 2016).

2.4.3 EINSTEIN Software

The EINSTEIN software and audit protocol takes a more digital approach and performs an analysis of thermal energy transfer instead of overall carbon emissions. The primary objective of the EINSTEIN software is to determine inefficiencies in the heating and cooling processes to decrease needlessly high energy costs. The open-source software model is accompanied with resources that explain how to use the software and implement the audit methods, which makes it a protocol that can be used anywhere and has the potential to be more widely standardized. EINSTEIN also publishes reports of audits performed on other breweries, which makes it easier to directly standardize resource usage on an individual basis. EINSTEIN is best accompanied by the "black box” method, which focuses on the inputs and outputs of the system without getting caught up on the more complex inner workings of beer fermentation (Olajire, 2020). This helps define the scope of the audit according to management in the brewery and the feasibility of the scope considering available manpower, time, and cost.

2.4.4 United Nations Carbon Emissions Calculator

The United Nation’s Carbon Emissions Calculator is a tool that helps businesses determine their carbon footprint. The calculator uses three different "scopes” to describe the different sources of carbon emissions. The first scope, Scope 1, encompasses any direct emissions that are owned or controlled by the company. These include items like nonrenewable fuel sources, toxic gases released into the atmosphere, and cars powered by fossil fuels for transportation.

Scope 2 encompasses emissions that a company creates indirectly when the energy it purchases is used and subsequently produces emissions. These emissions are from purchased electricity, heat, steam or cooling. However, if the electricity used by the company was under a renewable energy contract, there would be no emissions. These purchased energies are an indirect form of emissions but have a large effect on the environmental impact of the business.

Scope 3 encompasses emissions that are not produced by the company itself, instead, are emissions produced down the value chain. An example of this is materials that were produced by an external company and bought for internal use, like bottles in the brewery. This audit protocol is much more qualitative and spans many other industries. This provides more context for how Beertzinut’s carbon emissions relate to other companies globally, however it does not directly account for the difference in manufacturing process. There is also a lack of published information on other beer breweries who have utilized the UN calculator (National Grid 2023).

2.4.5 Literature Synthesis

Each audit protocol or tool has elements that apply to parts of the audit performed on Beertzinut. The BAT protocol considers environmental impact in terms of water, electricity, and carbon emissions, which is mostly comparable to this audit. However, each of these components comes together and is discussed in terms of total energy usage, while the Beertzinut audit analyzes the components further in terms of environmental sustainability. The SEAP protocol does not specifically discuss beer breweries; however, it does discuss energy auditing methods that can be best applied to small businesses. One of the benefits outlined by SEAP is that when new ideas are suggested, SMEs have the potential to implement them much faster than larger companies. The UN Carbon Emissions calculator also investigates energy usage and describes overall impact in terms of CO_2E emissions. It allows any business to evaluate its current CO_2E emissions and then re-evaluate once changes have been made to determine if those changes have improved the business's environmental impact. However, the UN calculator lacks information on beer breweries that have used the calculator, so other participating small businesses must be used to compare the results produced by the CO_2E calculator. The EINSTEIN protocol has similar recommendations to our audit for preliminary steps of a functional environmental audit and has a similar focus on electricity usage in terms of temperature regulation. Each of these elements can be used to standardize parts of the data collected in this audit as well as determine potential areas of focus for future audits on Beertzinut.

2.5 Cost Analysis

Cost analysis is a tool used by businesses to understand their management costs and help predict potential savings for future opportunities. It is used to create a baseline for a process, or business costing, and compares the cost to estimated financial benefits. Most businesses use cost analysis to find the baseline for the business, compare environmental impact with cost management, and calculate profits for potential new projects. Cost analysis reviews identify which factors have a major impact and how they can be reduced (Indeed Editorial Team). It also helps identify financial problems and discover solutions.

2.5.1 Direct and Indirect Costs

When performing a cost analysis of a business, costs are typically divided into two categories: direct and indirect costs. The first and more straightforward factor is direct cost. This is the cost of materials, both fixed and variable. Variable costs are elements that are correlated with a material cost and increase with the amount of input. Fixed costs are the opposite. For example, the equipment and its cost remain constant with increasing output. For example, buying more grains would be a variable cost, while buying and operating a single fermenter is a fixed cost.

Indirect costs are not directly associated with the manufacturing process, but the company needs them to operate the business. These expenses are colloquially known as "overhead" costs, and include items like rent, labor, shipments, and marketing. These expenses have no impact on the production of the product but are fixed expenses that need to be included in the analysis of the overall company cost. These costs do not change as much as the direct costs, however they do somewhat scale with the growth of the business.

CHAPTER 3: METHODS

3.1 Water Audit Methods

To perform the functional environmental audit for water, water usage data was collected using a *RainPoint* flow meter. The meter was used to track single instance water use and total water usage for each day. Water usage in liters was recorded using an Excel spreadsheet, along with the category that the function of water was associated with. The categories for water use are outlined below in Table 1.

Table 1. Water Usage Categories

Brewing	Water used directly in the brew
Sanitizing	Water mixed with peracetic acid to sanitize equipment
Cleaning	Water mixed with caustic to clean used equipment
Rinsing	Water used to rinse equipment
Cooling	Water used during brewing to cool off the boiling tin
Miscellaneous	Water used outside of the brew & bottling process

Describes water usage categories in the brewing process.

The miscellaneous data category includes water data collected from atypical cleans and other random water sources. This data is not included in daily averages, so it doesn't introduce irregularity, however, it was still recorded and analyzed. In addition to the categorization of the data in each sheet, the days were also categorized as either brewing or bottling days. This is in line with Beertzinut's business practices where days are split into brewing and bottling days. These days have unique needs for water usage and were looked at separately. With this data, the Beertzinut brewery's water per liter beer ratio (WB) was derived to identify the primary contributors to the brewery's inefficiencies.

3.2 Waste Audit Data Method

We identified carbon dioxide gas emissions, spent grains, and packaging waste as a part of our functional environmental audit for waste. These elements also tie into the energy and water audit but are separated to distinguish between inputs and outputs.

3.2.1 Carbon Dioxide Fermenter Emissions

Fermentation produces carbon dioxide (CO_2), which contributes to the brewery's overall emissions. To estimate the amount of CO_2 produced per batch of beer the Ideal Gas Law was used and is shown below.

The first step of the calculations was to convert specific gravity (SG) to degrees Plato (°P), which was derived from the ASBC (American Society of Brewing Chemists). Specific gravity is a measure of density relative to the density of a reference substance, in this case sugar to wort. The reason for the use of this equation is because 1°P is 1% sugar weight. The specific gravity of the wort is assumed for this calculation as a hydrometer is needed to find the sugar weight of the wort, which was not available. This sugar weight was then used to calculate the mass of sugar in each wort. This was done by multiplying the volume of the batch by its density.

$$°P = 135.997SG^3 - 630.272SG^2 + 1111.14SG - 616.868$$
$$°P = Degrees\ Plato$$
$$SG = Specific\ Gravity$$

The second assumption, the apparent attenuation in the wort, is used to find how much sugar is consumed. Alcohol’s density is lower than water, meaning the solution is not uniform. Hydrometers measure the density of the solution from a specific point, so when alcohol is first created, the hydrometer’s reading tends to be flawed. To calculate the actual attenuation of the solution, apparent attenuation is multiplied by a factor of 0.814. This calculation gives us the amount of sugar consumed in the fermentation process.

Using the amount of sugar in the solution, we can calculate how many mols of sugar are in the assumed wort. single mol of glucose weights 180.156 grams, or 0.180156 kg, but it is not feasible to know how much sugar turns into glucose. We estimated the amount of sugar consumed and divided by the weight of one mol of glucose, which gave us the number of mols of glucose consumed in the wort. This is then multiplied by two as for every mol of glucose consumed, two mols of CO_2 are produced.

Once the total mols of CO_2 produced are calculated, the Ideal Gas Law is used to predict the volume of the gas. Rearranging the ideal gas law equation, PV = nRT, we input the known values to solve for the volume (V).

$$\boldsymbol{PV = nRT}$$
$$P = Pressure$$
$$V = Volume\ of\ Gas$$
$$n = Number\ of\ Mols$$
$$R = Gas\ Constant$$
$$T = Temperature\ of\ Gas$$

Importing the known values into the equation will calculate the volume of one mol of CO_2. Multiplying by the number of mols produced in the process will present the total CO_2 produced in a 130L batch of beer.

3.2.2 Spent Grains

After the lautering process, the spent grains are separated from the wort and fed to livestock. The disposal of the spent grains without squeezing any extra liquid out results in a loss of water. To calculate the amount of wastewater that remained in the spent grains, we weighed the dry grains prior to the brewing process, then measured the grains after they were taken out after lautering. The difference in weight provides an estimate of the quantity of remaining liquid in the spent grain. The proportions of grains for each beer are different for every batch, so multiple calculations were conducted to determine the average amount of wastewater in the spent grains.

Figure 4. Spent Grains

Image of spent grains being removed from the brew pot into a bucket to be weighed.

3.2.3 Packaging

The unpackaging of the bottles generates plastic waste, such as packing tape and sticker backings, that is collected and thrown away. This waste was calculated by measuring both the plastics' weight and length. The weight was calculated per barrel of plastic waste. Each batch of beer produces an amount of plastic waste that can be converted to the number of waste barrels per batch of beer. The total length of the plastic packaging that was used to label each individual bottle was calculated by measuring one strip of plastic waste used on one bottle and multiplying by the number of bottles in a batch of beer. The weight and length of produced plastic waste are then used for further environmental and economic analysis.

Cardboard waste is created when unloading the shipments of bottles. Cardboard waste was calculated by the weight of waste produced per batch of beer. We calculated how much beer was bottled in each kind of batch, which translates to how much waste cardboard was produced for that specific amount. We then measured the weight of waste cardboard and calculated how many kilograms of cardboard waste is produced from the process.

3.3 Electricity Audit Data Methods

The goal of the electricity audit was to provide the Beertzinut brewery with an understanding of their electricity usage, as well as guide our recommendations to reduce their environmental impact. There were three sources of data that were relevant to the electricity audit: the past brew archives, the electrical bill, and the regional temperature data. These were obtained from Ardom (the Beertzinut archival software), the kibbutz power center, and from the Israel Meteorological Service (IMS) respectively. The IMS own a Thaller Shelter Model 6, a type of weather probe, nine kilometers from Kibbutz Ketura on Kibbutz Yotvata. This automatically takes the measurements and uploads them to their website.

The brew archive was relevant because it outlined what processes had occurred on a given day e.g., brewing, fermenting, and bottling. We aligned this data by date with the electrical bill to see what processes were taking up the most power, as well as the weather data to measure the impact the temperature had on the electricity used.

The combined brew archive and electricity bill were split by process. Three different processes are recorded in Ardom: brewing, fermentation, and bottling. Brewing and fermentation happen consecutively on the same day, and fermentation happens passively over the course of a week, so the data was split into three different groups: brew days, bottling days, and no process days. The days with no processes are vital as they form a baseline for electricity usage from the air conditioning, which is constantly running at 24° C year-round, as well as the fermenters constantly chilling the wort.

The kibbutz power infrastructure and transmission systems often fail due to aging equipment, and this introduced a source of error in our data. The system is comprised of meters across the kibbutz which communicate with a central computer via analog modem calls every six hours. This means that when the phone lines failed, which happened nearly three dozen times, there was no communication. While the electricity used is still recorded locally on the meter, for multi-day outages, there is no record of how much electricity was used each day, which interferes with the daily average calculations. To solve this problem, the sum of electricity that was unaccounted for was averaged over the period of days that were not recorded.

3.4 Carbon Emissions Equivalency Calculator

The waste generated from the brew process is converted into carbon emissions using the United Nations CO_2E Carbon Emissions Calculator. Data is imported into specific emissions source categories, and using the factors built into the system, carbon emissions are calculated for the brewing process. This shows how many harmful emissions the process emits into the atmosphere and is then compared to other companies' reports for an analysis of their carbon emissions (United Nations, 2023).

3.5 Cost Analysis Methods

3.5.1 Water Cost Analysis Methods

To determine the cost for water, the monthly water bill was collected to determine the set price for water. The price for water is determined by how much water was used over the kibbutz quota. The amount of water that the kibbutz is allowed to use before being charged is ten thousand shekels per cubic meter. Once the quota is met, the kibbutz is then charged 1.983 shekels per cubic meter.

The water used from the bill is converted from liters to cubic meters and is then multiplied by the cost per cubic meter. The amount of water during a brew day, bottling day, brew cycle, and cooling cycle are used to calculate the cost per each process. The total water usage for each process (in cubic meters) is multiplied by 1.983 shekels per cubic meter, to calculate the cost of water usage during each process.

3.5.2 Electricity Cost Analysis Methods

The kibbutz power center charges for power at different rates based on the time of day, the day of the week, and the season. Each day has a “clock” that determines the rate based on the time and the estimated system load. Then, each season has three different “clocks” based on the day of the week: one for weekdays, one for Fridays and the days before holidays, and one for Saturdays and other holidays. The months in the “summer” pricing group were July and August, the winter months were December, January and February, and the remaining seven months were combined into a third category. To determine the total cost breakdown, each hourly kilowatt usage was given identifiers in Excel based on the three necessary criteria (time, day, season) and then attached to each one of the nine different rates.

CHAPTER 4: RESULTS & ANALYSIS

4.1 Water Audit Results & Analysis

Between January 17th and February 6th, a total of twelve days of water data were collected at the Beertzinut brewery (See Appendix A for data). Of these days, six were brew days and six were bottling days. The data collected for these days is displayed in Figure 5 below.

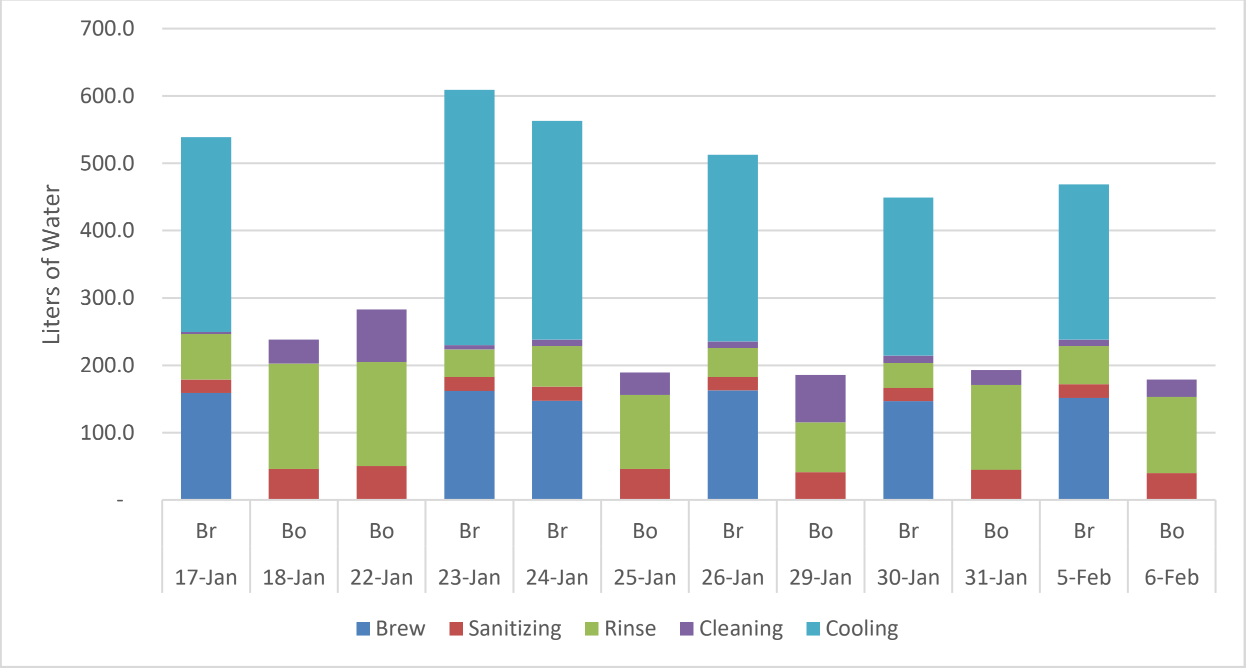

Figure 5. Daily Water Usage at Beertzinut Brewery

Daily water usage at the Beertzinut brewery split into brewing and bottle days and categorized by water use in liters. Each bar is also divided into the categorical uses of water that day.

With this data, a water per liter beer (WB) ratio can be derived for the Beertzinut brewery by averaging both brewing and bottling days along with the amount of beer produced. Combining these two averages gives the average water used, 735.0 liters, along with the average amount of beer produced, 111.8 liters, per batch of beer. Dividing the average water used by the average beer produced gives a WB ratio of 6.6, which is above most breweries in the European Brewers' Union, which have a ratio below 6.0 (Santonja, 2019).

Table 2. Water per Liter Beer Ratio Data Table

Beer	Avg. Beer (L)	Avg. Brewing (L)	Avg. Bottling (L)	Total Water (L)	W/B
Overall Average	111.8	523.6	211.3	735.0	6.6

Water per liter beer ratio data table with average brew and bottling water used and amount of beer produced.

Given the brewery’s high WB ratio, the water usage is then further analyzed by examining the brew and bottle day percentile data.

4.1.1 Brew Day Water Use

Six brewing days of water data were collected over the data collection period at the Beertzinut brewery. Using this, the average brew day water use was calculated to be 523.6 liters. Additionally, the percentile makeup of this average daily water use was calculated and can be seen in the table below.

Table 3. Brew Day Water Data

Date	Total Water (L)	Brew (%|L)		Sanitizing (%|L)		Rinse (%|L)		Cleaning (%|L)		Cooling (%|L)	
17-Jan	539.2	29.4%	158.7	3.7%	20.1	12.6%	68.1	0.4%	2.2	53.8%	289.9
23-Jan	609.1	26.6%	162.2	3.4%	20.6	6.7%	40.6	1.0%	6.1	62.3%	379.6
24-Jan	562.9	26.2%	147.6	3.7%	20.6	10.7%	60.3	1.7%	9.8	57.7%	324.6
26-Jan	512.9	31.7%	162.7	3.9%	20.0	8.4%	42.9	1.9%	10.0	54.1%	277.3
30-Jan	449.3	32.6%	146.6	4.5%	20.0	8.1%	36.6	2.6%	11.5	52.2%	234.6
5-Feb	468.4	32.4%	151.9	4.3%	20.0	12.1%	56.6	2.1%	9.8	49.1%	230.1
Average Brew Day Water Usage											
523.6		29.8%	156.3	3.9%	20.4	9.8%	51.1	1.6%	8.5	54.9%	287.3

Brewing day water use categorized and displayed as a percentage of the daily total and number of liters. Cooling takes up most of the water usage.

In these calculations, cooling takes 54.9%, or 287.3 liters, and brewing takes 29.8%, or 156.3 liters, of the 523.6 liters of water used on an average brew day. The remaining 15.3% of water use contributes to cleaning, sanitization, and rinsing water. This shows cooling water use is significant not only to the total water use of brew days, but also the whole brew cycle which impacts the WB ratio. The brew water use category is also significant, however reducing water usage here would counterproductively reduce the amount of beer produced which could further impact the WB ratio negatively. That being the case, cooling should be focused on to reduce the WB ratio. If an alternative to water cooling was implemented, thereby reducing the water for cooling to 0, the WB ratio would drop from 6.6 to 4.0.

4.1.2 Bottle Day Water Use

Six bottling days of water data were collected over the data collection period at the Beertzinut brewery. From this the average bottle day water use was calculated to be 211.3 liters. Additionally, the percentile makeup of this average daily water use was calculated and can be seen in Table 4 below.

Table 4. Bottle Day Water Data

Date	Total Water (L)	Brew (%|L)		Sanitizing (%|L)		Rinse (%|L)		Cleaning (%|L)		Cooling (%|L)	
18-Jan	238.1	0.0%	-	19.4%	46.1	65.8%	156.6	14.9%	35.4	0.0%	-
22-Jan	373.1	0.0%	-	11.9%	44.3	58.2%	217.0	18.6%	69.3	0.0%	-
25-Jan	189.5	0.0%	-	24.3%	46.0	58.2%	110.3	17.5%	33.2	0.0%	-
29-Jan	186.1	0.0%	-	22.0%	41.0	39.8%	74.1	38.2%	71.0	0.0%	-
31-Jan	192.8	0.0%	-	23.3%	45.0	65.1%	125.6	11.5%	22.2	0.0%	-
6-Feb	178.7	0.0%	-	22.3%	39.8	63.3%	113.2	14.4%	25.7	0.0%	-
Average Water Usage											
211.3		0.0%	0.0	21.5%	45.4	57.8%	122.2	20.7%	43.7	0.0%	0.0

Bottling Day water use at Beertzinut categorized and displayed as a percentage of the daily total and number of liters. Rinsing used the most water, however, it was about half of what cooling used on brew days.

In these calculations, rinsing takes 57.8%, or 122.2 liters of the 211.3 liters of water used on an average bottle day. In addition to this the sanitization and cleaning categories made up the rest of the water demand at 21.5% and 20.7% respectively, as no water is used in the brewing and cooling categories on bottling days. The water drain from rinsing, sanitization, and cleaning is essential to ensuring that the brewery does not contaminate their product, and therefore must be carefully considered. Some solutions to this would be utilizing more water efficient cleaning products or increasing the production rate of the brewery. Although increasing the production rate would linearly increase the water usage on brew days, it would not increase the water drain on bottling days as the bottling machine would not need to be scaled up, they would just spend more time bottling. As such, if the production of beer were to be doubled, the brew day average would also double, while the bottling day average would stay the same. With these rough factors in place, the WB ratio would drop from 6.6 to 6.3.

4.1.3 Miscellaneous Water Use

Amongst the twelve days of water use recorded at the brewery, three days had a miscellaneous contribution to the water data, which are shown in Table 5 below. Here the significant causes of miscellaneous water usage are keg and deep bottling machine cleaning. Keg cleaning is a necessary water drain for the functions of the brewery; however, it takes anywhere from 13 to 33 liters of water to clean and sanitize a twenty-liter keg. This water consumption could potentially be reduced with a keg cleaner. Deep bottling machine cleaning represents a larger water consumption at around 90 liters per occurrence, however it occurs less frequently. Regardless, this is a necessary process and can neither be avoided nor sufficiently reduced without replacing the current bottling machine.

Table 5. Miscellaneous Water Usage

Date	Day	Amount (L)	Purpose
17-Jan	Brew	33.4	Keg Cleaning
22-Jan	Bottle	48.0	2 x Keg Cleaning
		90.4	Deep Bottle Machine Clean
5-Feb	Brew	12.9	Keg Cleaning

Miscellaneous water use data collected. These only occurred four times in the twelve data collection days.

4.2 Waste Audit Results & Analysis

4.2.1 Carbon Dioxide Fermenter Calculations

This section describes the calculations conducted to determine the approximate amount of CO_2 produced in the fermentation process. The calculations begin with two assumptions: the specific gravity (SG) of wort and the apparent attenuation of the solution. In this calculation, a 1.048 SG wort and 75% apparent attenuation of the solution was used.

$$°P = 135.997SG^3 - 630.272SG^2 + 1111.14SG - 616.868$$
$$°P = 135.997(1.048)^3 - 630.272(1.048)^2 + 1111.14(1.048) - 616.868$$
$$11.91°P,\ or\ 11.91\%\ sugar\ by\ weight$$

The average liters in a batch of beer are 130L, so (2896.59 lbs.) * (0.11912 sugar weight) gives us 34.17 lbs. or 15.49 kg sugar in each wort. Apparent attenuation is multiplied by 0.814. The assumed attenuation is 75% so the calculation that was made is the following:

$$(34.17lb) * (0.75 * 0.814) = 20.86lb\ or\ 9.46kg$$

This calculation gives us the amount of sugar consumed in the fermenting process. We took the amount of sugar consumed and divided by the weight of one mol of glucose: (9.46 kg) / (0.1801 kg/mol) = 52.51 mol glucose consumed in this wort. This is then multiplied by two as for every mol of glucose consumed, two mols of CO_2 are produced. (52.51 * 2) = 105.02 mol of total CO_2 produced from fermenting a 1.048 wort to 75% apparent attenuation.

$$V = \frac{(1mol)*(0.821)*(273°K)}{1atm}$$

$$V = 22.41$$

This means that every mol of gas occupies 22.41 L. (105.02 mol) * (22.41 L) = 2353.49 L or 2.35 m^3 of CO_2 produced in a 130 L batch of beer.

This calculation is the general amount of CO_2 produced in a 130 L batch of beer with two assumptions (specific gravity of wort and apparent attenuation), that cannot be calculated without additional equipment. For comparison, the average person breathes around 500L of CO_2 into the atmosphere per day. Fermenting beer, which is a week-long process, produces only five times as much CO_2 as a human does in a single day.

4.2.2 Process By-Products

This section describes the data collected from waste by-products, and the analysis for this data. Below is a table showing all the by-products of the brewing process per month.

Table 6. Waste Data Calculations Per Month

	Plastic and Cardboard Waste	Spent Grains	Sticker Waste	Bottles
Number of Containers	1	1	1	N/A
Average Pickup/Month	4	12	4	N/A
Container Sizes (liters)	400	50	240	N/A
Estimated Percent Reused	10%	100%	0%	100%
Weight of Material/Pickup (kg)	11.79	37.95	.18	N/A
Total Weight Material/month (kg)	47.16	455.4	.36	N/A

Waste data collected per month with estimated percentage of waste products reused. Spent grains produce most of the waste by-products.

The amount of waste was recorded weekly. Bottles were labelled as “Reused” as the “waste” bottles were either reused to bottle other beers or stored in the fridge for later consumption, creating no waste during the process.

Table 7. Waste Data Collections Per Week

Week	1/22/2023	1/29/2023	2/5/2023
Beer(s)	3-Way IPA	Date Beer/Medjool	Arava
Cardboard and Plastic Waste	1 Barrel	1 Barrel	1 Barrel
Spent Grains (Barrels)	3 Barrels	2 Barrels	Total Weight: 42.2kg
Bottles	Reused	Reused	Reused
CO2 Fermenter Emissions	130L - 2.3m^3 CO2 Emissions	130L - 2.3m^3 CO2 Emissions	130L - 2.3m^3 CO2 Emissions
Sticker Waste (Batch)	22.5m	22.5m	22.5m

The different types of waste produced from the brewing process. This shows the weight of waste products per week.

These waste products include plastic and cardboard waste, spent grains, sticker waste, and bottles. This table includes the weight of material per pickup by using the standard volume-to-weight reference card from the South Carolina Department of Health and Environmental Control (DHEC) Office of Solid Waste Reduction and Recycling. Each material is picked up a certain number of times per month with an estimated percentage filled for each pickup. The total weight of the material per week is recorded in the table above in kilograms.

Empty waste bottles are already being reused in the process by being saved for later bottling. This creates zero bottle waste for the brewing process, helping with the CO_2E facility emissions. Products that are not suitable for sale are saved and consumed at the brewery for tasting and quality control instead of being discarded, and afterwards, the bottles are sanitized and reused. This allows for zero bottle waste in the process and improves the waste reduction of the brewery.

4.2.3 Carbon Dioxide Equivalency Emissions Calculator

This section describes the carbon emissions emitted from the brewing process at Beertzinut. Below is the current CO_2E calculated from the UN Carbon Emissions Calculator for each scope of the brewing process in the year 2022.

Beertzinut - 2022 GHG emissions report

Category		Emission source category		t CO2e
GHG Protocol Standards: Corporate Scope - 1 and 2, Value Chain - Scope 3	Scope 1	Direct emissions arising from owned or controlled stationary sources that use fossil fuels and/or emit fugitive emissions	Fuels	-
			Bioenergy	-
			Refrigerants	-
		Direct emissions from owned or controlled mobile sources	Passenger vehicles	-
			Delivery vehicles	-
		Total Scope 1		-
	Scope 2	Location-based emissions from the generation of purchased electricity, heat, steam or cooling	Electricity	1.92
			Heat and steam	-
			Electricity for Evs	-
			District cooling	-
		Total Scope 2		**1.92**
	Scope 3	Fuel- and energy-related activities	All other fuel- and energy related activities	-
			Transmission and distribution losses	0.14
		Waste generated in operations	Waste water	-
			Waste	0.98
		Purchased goods	Water supplied	0.02
			Material use	7.88
		Business travel	All transportation by air	-
			Emissions arising from hotel accommodation associated with business travel	-
			All transportation by sea	-
			All transportation by land, public transport, rented/leased vehicle and taxi	-
		Upstream transportation and distribution	Freighting goods	49.56
		Employees commuting		-
		Food		-
		Home office		-
		Total Scope 3		**58.59**
Total Emissions				**60.51**

Figure 6. UN Emissions Calculator

Greenhouse gas emissions calculator for Beertzinut. This shows most emissions come from freighting goods in Scope 3.

The Arava Power Company (APC) is the local power company and is fully solar energy powered; however, they sell it to the national power grid and the kibbutz buys it from the national grid rather than directly purchasing it from the APC. However, we assume that the kibbutz is fully powered by the APC because it would be more efficient than sending all the power somewhere else farther away. Because of this, we assume the brewery uses fully renewable energy during the day, which generates no CO_2E, and buys power from the grid at night, which is assumed to be nonrenewable, as there is no solar energy being generated at night. The brewery used 7,447.5 kWh during the night, and using the UN conversion factor of 0.0188, we can estimate that they generated 140kg or 1.92 tons of CO_2E in 2022. However, if we assume the brewery uses no renewable energy the entire day, then they would generate 3.89 tons of CO_2E in 2022.

4.2.4 Carbon Emissions Analysis

In Scope 1 of the CO_2E analysis, zero tons of CO_2E were recorded in the year 2022. This is because the brewery does not use any fuels or company vehicles that produce carbon emissions. Scope 2, however, encompasses 1.9 tons of carbon emissions as the brewery only has renewable energy during the day. During the nighttime, solar panels are no longer used for energy consumption, and the grid is used instead. During the period of January 17th to February 6th, 2022, 487 kWh of energy was used at night, resulting in 0.13 tons of CO_2E being produced during that period. The data was used from the year 2022 because energy data had yet to be recorded for 2023. Scope 3 produces 58.59 tons of CO_2E, which comprises about 95% of the total carbon emissions for the process. Freighting goods make up most of the carbon footprint in Scope 3, which is 49.56 tons of CO_2E.

The Beertzinut Brewery produces an estimated total of 60.51 tons of CO_2E annually. For a microbrewery, the carbon emissions produced are low compared to other companies. Most companies that reported data to the UN CO_2E Carbon Emissions Calculator had much larger total CO_2E emissions. Alpha Male Grooming, which is a smaller company and uses 100% renewable energy, is the only company that was found to have less CO_2E produced for a full period of data recording. Larger companies that use non-renewable sources of energy produce on average 90 tons of CO_2E in a year of data collection (United Nations, 2021). The difference in emissions is due to Scope 3 calculations as many companies have company cars for delivery of their products. These use non-renewable energy sources for energy and heat consumption and produce larger amounts of waste products that contribute to a larger carbon footprint.

Beertzinut's beer brewing process compared to its freighting goods has a much smaller carbon footprint. Scope 3, however, cannot be directly reduced, as it is required for the brewery to operate. There are ways, however, to reduce the carbon footprint of freighting goods. Finding ways to reduce the carbon footprint of Scope 3 is essential to reduce the impact Beertzinut has on the environment.

4.3 Electricity Audit Results

In 2022, the brewery used 15,045 kilowatt hours (kWh), meaning there was an average of 41.2 kWh used each day. As seen in Figure 7, May through September had above average electricity usage, peaking at an average of 53.9 kWh in August, while the remaining months had below average, bottoming out at an average of 31.7 kWh in March. The temperature data gives us the daily highs and lows, and these can be averaged to create an approximate daily average temperature. When comparing the average daily temperature per month and the average daily electricity used per month, we can see that the temperature ranged from 27 to 33 degrees Celsius during the higher usage months, and 12 to 26 in the lower usage months. When plotted, these two datasets have a correlation of 0.839, confirming the strong positive linear relationship between kilowatt hours used and outside temperature.

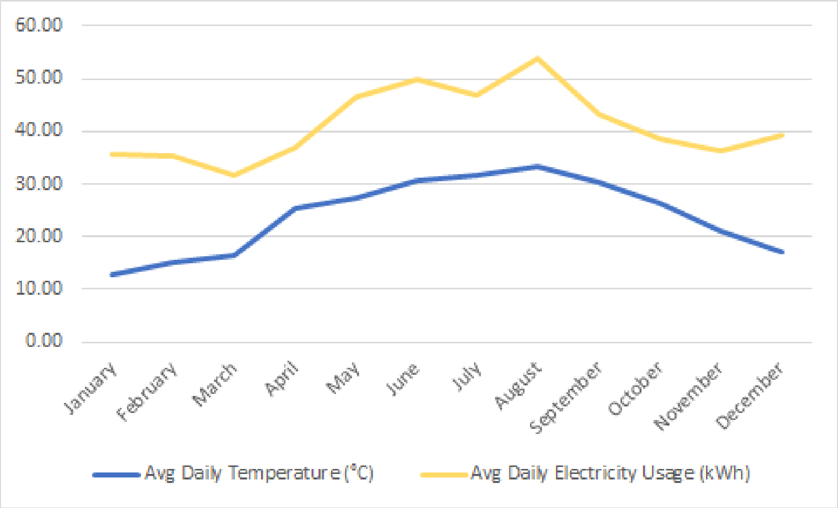

Figure 7: Average Daily Temperature vs Electricity Usage per Month

Daily temperature data averaged per month plotted with daily electricity usage data averaged per month in 2022. These two items have a strong correlation.

During 2022, 109 different batches of beer were brewed, fermented, and bottled. By splitting days into either a “brew day”, a “bottle day”, or a “no process” day (a day where no work was done and the only electricity used was from the air-conditioning and fermenters), trends become apparent. The average brew day used 61.50 kWh of electricity, the average bottling day used 48.32 kWh, and the average day with neither process used 28.76 kWh. Electricity usage changes with temperature throughout the year, and Figure 8 also shows that the ratio of all three categories of days increases during the warmer months, further highlighting the importance of environmental sustainability in the summer. There does appear to be a pattern with the Bottle Day Averages, potentially related to the regional temperature. However, with our time and resources we were unable to find the reason for this pattern, so further investigation should be conducted.

Most days would have a single process, however there were a few exceptions, which show some areas for significant increase in efficiency. Out of the 103 days spent brewing, there were five days where two batches of beer were brewed. The average electricity used during a brew day was 61.50 kWh, however the average electricity used during a double brew day was only 74.20 kWh. Out of the 97 days spent bottling, there were 18 days where multiple batches of beer were bottled. The average electricity used during a bottling day was 48.32 kWh, however the average electricity used during a multi-bottle day was 43.80 kWh.

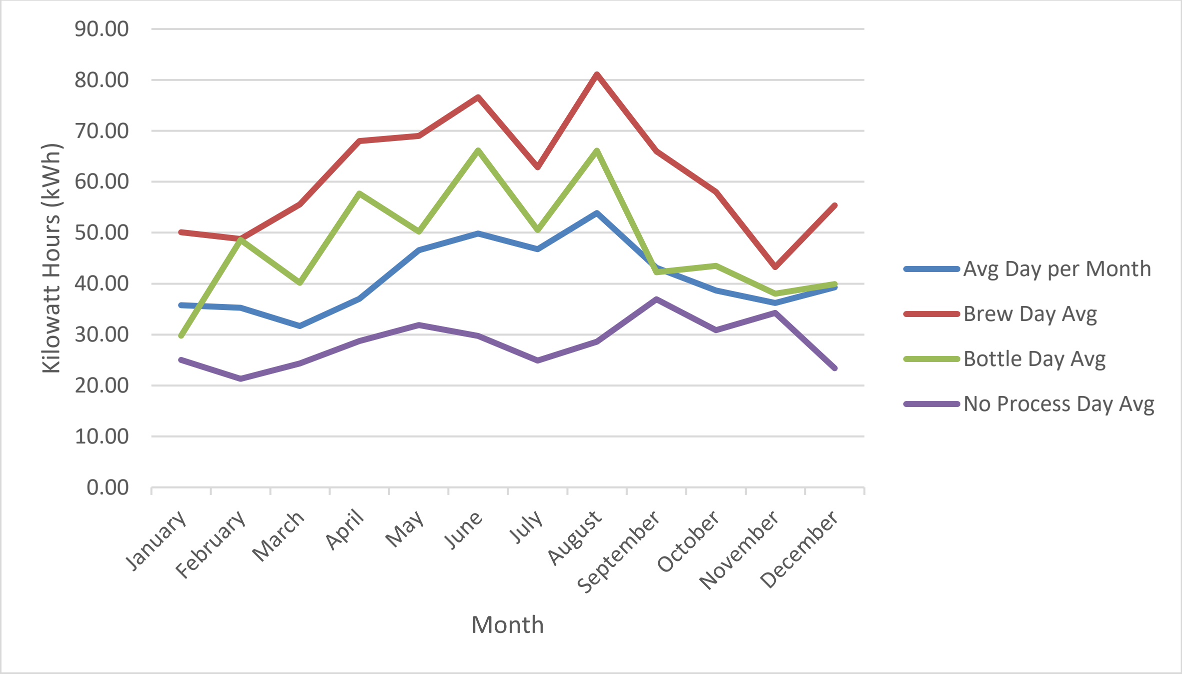

Figure 8. Average Daily kWh per Month per Process

Displays the average electricity used per process per month. It shows the difference in process usage as well as the daily baseline usage.

A well-run brewery would use from 8 to 12 kWh electricity, 5 hL water, and 150 MJ fuel energy per hectoliter of beer produced (Olajire 2020). 150 MJ is equivalent to 41.6 kWh, which means that a well-run brewery will use 49.6 to 53.6 kWh per hectoliter of beer produced. However, a brew and bottle day combination at Beertzinut uses 109.82 kWh. This does not include the couple of days the beer is sitting in the fermenter, meaning the true total kWh used per hL of beer is slightly higher than 109.82.

4.4 Cost Analysis Results

4.4.1 Water Cost Analysis

In the calculations shown below in Table 8, an average cycle of water usage, which is a brew and bottle day for any beer made, costs 1.46 New Israeli Shekels (NIS). Of this total cycle cost, 0.40 NIS, or 27% of the total, is directly from cooling. However, this is a lower bound, as the average cycle water usage will increase due to warmer weather in the Arava region directly increasing the amount of water needed to cool the wort.

Table 8. Water Cost Analysis

	Water (L)	**Cost (NIS)**
Average Brew Day	523.6	0.52
Average Bottle Day	211.3	0.42
Average Cycle	735.0	1.46
Average Cooling	201.6	0.40
Estimated Min. Yearly Cost	75,705.0	150.11
Price per Kiloliter (NIS)	1.983	
Cycles in 2022	103	

The cost of water for the average brew and bottle days, as well as a full cycle. It compares the cycle average with the current cost per Kiloliter of water in New Israeli Shekels (NIS). The estimated minimum yearly cost is 150.11 NIS.

With the cycle average known, a minimum yearly cost for water can be estimated to be roughly 150.11 NIS, which correlates to 75.71 Kiloliters of water. This assumes an average of 103 cycles performed per year and uses the average cycle water usage measured in the coldest month of the year. With this 150.11 NIS minimum per year water cost, the economic impact of water usage can be compared with other environmentally impactful costs, such as electricity usage.

4.4.2 Electricity Cost Analysis

In 2022, Beertzinut paid 6,173.35 NIS for 15,045 kWh of electricity. After categorizing all the records with their timestamped electricity cost (in shekels), the average daily cost of electricity was graphed with the average daily temperature (in Celsius) and average electricity used (in kilowatt hours). The electricity used and shekels spent have a correlation of 0.819, which is expected. The only reason that these two lines would differ is because the brewery starts early in the morning, when electricity is still inexpensive, and is finished by the afternoon, which is when prices rise. The more unique finding is that temperature and shekels spent only have a correlation of 0.634. While this is still relatively strong, it is significantly weaker than the correlation between usage and cost. This shows that while energy usage is much higher in the summer months than the winter months, costs are not as influenced by these factors as they might appear to be.

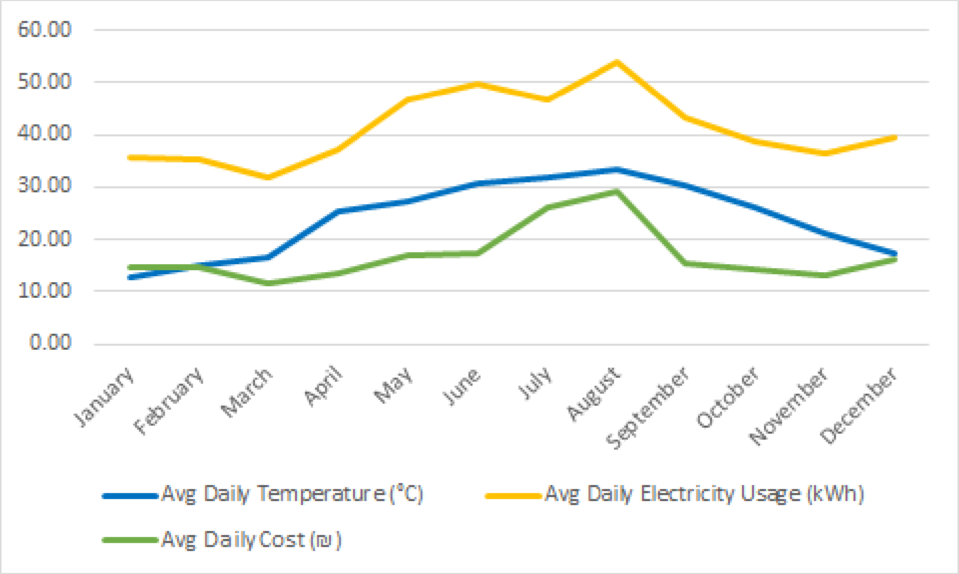

Figure 9: Average Daily Temperature vs. Electricity Usage vs. Cost of Electricity

This chart shows the strong correlation between usage and cost as well as the less strong correlation between temperature and cost.

CHAPTER 5: DISCUSSION AND RECOMMENDATIONS

This section reviews the key takeaways of the three functional environmental audits along with the cost analysis for the functions reviewed. With these considerations, recommendations can be made which consider the environmental and economic factors together to provide the best solutions for Beertzinut.

5.1 Discussion

The audit procedure most closely related to the methods implemented in this paper is the 'black box' method used in the EINSTEIN protocol and outlined by Olajire. Both methodologies quantify energy consumption through the collection of data from brewery records and direct measurements taken on-site. Furthermore, the goal of both audits is to provide data that leads to future improvements for cost and environmental impact. The scope of both audits is defined by brewery management and considers feasibility relative to available time and resources. These parameters can be visualized as a black box where only inputs and outputs are quantified while the inner workings of fermentation and heat transfer are "blacked out."

The water audit revealed that Beertzinut maintained a below average water per liter beer (WB) ratio of 6.6 during the water data collection period from January 17th to February 6th, 2023, compared to the average WB ratio for breweries of 6.0 (Santonja, 2019). Additionally, the data is limited as it was not collected year-round, meaning that water usage was not observed during warmer months where higher temperatures could negatively impact water use. This is especially the case with the leading cause of the high WB ratio, cooling water. This would be a more significant draw in warmer months that would require more water to be used to cool the hot wort prior to being added to the fermentation tank. Now, as seen in Table 9 below, removing this water usage alone would decrease the WB ratio down to 4.0.

Table 9. WB Ratio Scenario Table

	Total Beer (L)	Brewing (L)	Bottling (L)	Total Water (L)	W/B
Overall	111.8	523.6	211.3	735.0	6.6
Without Cooling	111.8	236.37	211.3	447.7	4.0
Double Brew	200	1,047.3	211.3	1258.6	6.3
Double Brew & Without Cooling	200	472.68	298.7	771.4	3.9

WB ratio for different water use scenarios at the Beertzinut brewery. Removing cooling water and doubling the brew would lead to a 4.0 WB ratio.

In addition to reducing the water needed for cooling, the WB ratio could also be impacted by increasing the amount of beer produced on any given brew day. This can also be seen in Table 9 above. Through doubling the amount of beer produced during any brew day, without changing the bottling process, the WB ratio is projected to go down to 6.3. This decrease is not significant, however when paired with no water for cooling, a WB ratio down to 3.9.

The results from the UN Calculator revealed that the brewery's practices were already environmentally conscious. The total tons of CO_2E produced from the brewery is far less than the CO_2E produced from other companies (relative to size). A beer distributor company was used to compare the total carbon emissions of the Beertzinut brewery. Beer 52 Limited is a wholesaler of wine, beer, spirits, and other alcoholic beverages that has 65 employees currently employed. Without the production and sale of alcohol, the company's total carbon emissions measured in 2020 was 6.77 tons of CO_2E (United Nations, 2023). Additionally, 1.8 metric tons of the total CO_2E produced is from nighttime energy usage alone in 2022, assuming all the energy used at night is nonrenewable. Even though importing materials and goods makes up most of the carbon emissions of the brewery, these goods are necessary to produce the product and cannot be directly reduced to improve the carbon emissions.

Improvements to reducing Beertzinut's carbon footprint include scaling up and switching to all diesel heavy goods vehicle (HGV) trucks which will decrease the brewery's carbon footprint from 60.51 tons of CO_2E, to approximately 33.41 tons of total carbon emissions, and harnessing renewable energy to use at night, which will make Beertzinut's electricity usage fully renewable. Renewable energy at night will decrease the carbon footprint of the brewery but increase the cost of the process due to electricity costing more than water.

The core finding for electricity is that the brewery has a substantial daily baseline of electricity usage, regardless of the work being done on that day. This is due to the constant air conditioning and temperature regulation of the fermentation tanks. On average, days with no work use 28.76 kWh, brewing days use 61.50 kWh, and bottling days use 48.32 kWh. This means that ~46% of the usage on brewing days is not from brewing, and ~59% of the usage on bottling days is not from bottling. This is further shown in the brew records, as there were a few days that Beertzinut where multiple processes occurred. Out of the 103 days spent brewing, there were 14 days where two batches of beer were brewed. On these days, electricity only increased from 61.5 kWh to 74.2 kWh. The same can be said for multiple batch bottling days, where over 97 days, 18 were multi-batch bottling days, which resulted in an average decrease in electricity usage from 48.32 kWh to 43.8 kWh. We hypothesize that this is because the fermenters can be shut off after the beer is bottled, so when multiple fermenters are shut off more electricity is saved.

While other audits were able to distinguish which stage of the brew process used what percentage of the total electricity by using an electricity meter, an electricity meter was not available, so our data was only split based on the different process that occurred that day. Based on these restraints, it was out of the project's scope to analyze the process on a granular level. However, we were still able to determine that Beertzinut uses more electricity than the benchmark set by the literature review. We found that the constant temperature regulation, both as a result of the heat of the environment as well as the heat created by fermentation, likely resulted in a higher electricity usage than standard. To better address this result, further investment in the audit is needed. An electricity meter would allow for electricity to be tracked discretely and would provide more informative data to analyze, which would make it easier to adjust smaller pieces of the current manufacturing process and increase efficiency without buying new equipment.

Through the cost analysis of the process, it was found that water was less expensive than energy. The estimated annual cost of water is roughly 150.11 Shekels, compared to an average cost of 6,173.35 Shekels annually for energy usage. Decreasing the amount of energy usage during the day would certainly decrease the energy usage cost, however, it would have no effect on the environmental impact as it would be renewable energy. Wastewater, however, may cost the brewery less than electricity, but it also produces more carbon emissions during the day. Reducing the amount of water during the day will not only decrease Beertzinut's cost, but also decrease the amount of carbon emissions produced from the process during the day. Reducing the carbon footprint of the brewery will cost the brewery more in terms of energy usage. This tradeoff of cost to environmental impact is important to understand when discussing future applications for Beertzinut.

5.2 Recommendations

In general, Beertzinut's practices are environmentally sustainable when compared to other breweries, however, Beertzinut can always improve. One of the potential next steps for improving the environmental suitability of the brewery is scaling up. If the brewery were to scale up, the water use would go down as doubling beer production directly will lower the WB ratio. Electricity would also be positively affected as making more than one batch of beer increases electricity efficiency both on brew and bottle days, as mentioned above. Although energy usage throughout the day increases, doubling the brew and bottle days would increase environmental impact. The decrease in water usage will not only decrease the brewery's cost of water but would also decrease the environmental impact of the brewery. Electricity usage does, however, increase with multiple brew and bottle days, but because renewable energy is used during the day, it does not affect environmental sustainability. Scaling up production allows Beertzinut to produce more product per daily resource usage and will therefore increase efficiency.

In addition to scaling up the brewery, the implementation of a glycol wort chiller or a solar thermal water heater has the potential to minimize environmental impact. A glycol wort chiller is predicted to decrease the WB ratio to 4.0 as this system would completely negate the need for cooling water. This cooling water would be replaced by chilled glycol fluid, which would be cooled using a significant amount of energy, however it would increase the brewery's electricity consumption. This increase in electricity could be a greater cost for the brewery, however, the reduction in water use and the renewable energy that is used at the brewery during the day would reduce the effect on the environment. Solar thermal water heating would also impact this potential increase in electricity use, however implementing a system to heat the water for the beginning of the brewing process would negate the need for electrical heating of brewing water altogether. The major drawback of this system is the initial cost and continuous maintenance of this machinery.

Overall, there are several potential solutions to improve Beertzinut's environmental sustainability. These potential solutions carefully consider the economic and environmental impacts to best provide suggestions for Beertzinut. To further strengthen these suggestions, further data collection can be performed to gain a greater understanding of year-round water and electricity usage, especially during the summer months. Additionally, a more in-depth economic analysis could be performed for the selection of future, more environmentally sustainable, equipment at the brewery.

CHAPTER 6: CONCLUSIONS

We audited the Beertzinut brewery to provide an informative report that would allow our sponsor to take the next step towards becoming a more environmentally conscious and economically efficient business. This was achieved through three functional environmental audits of Beertzinut's water, waste, and electricity, and a subsequent cost analysis.

Through the water audit, it was determined that the brewery had an above-average water per liter of beer ratio (WB) when compared with other breweries. To reduce this impact on water use, water used for cooling can be replaced with an alternative method. Scaling up the brewery would also improve this.

Through the waste audit, it was determined that Beertzinut's current practices are environmentally conscious, although, to further reduce their environmental impact they could scale up and start to use a heavy goods vehicle for shipments.

Through the electricity audit, it was determined that electricity usage was much higher than comparable businesses due to the constant year-round need for electric cooling. However, scaling up the business would also significantly improve electricity efficiency.

Through the cost analysis, it was shown that yearly energy usage costs more than water usage, although energy during the day is all renewable and does not produce any carbon emissions compared to water usage during the day.

Considering these main takeaways and the cost analysis, we determined that scaling up the brewery would lead to decreased impacts all around. Through this, water usage would drop as a result of more beer being produced, carbon emissions would be lowered as a whole, and energy would be more efficiently used with a larger process. In addition to this, other systems could also be implemented, such as a glycol chiller for wort cooling and a solar thermal water heater for water heating. Further analysis could also be performed to gain a better understanding of the brewery's environmental impacts year-round, especially in the summer, along with a more in-depth economic analysis for new potential equipment.

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APPENDIX A: BEERTZINUT DAILY WATER USE DATA COLLECTED

Date	Day	Total Water Used (L)	Brew (%|L)		Sanitizing (%|L)		Rinse (%|L)		Cleaning (%|L)		Cooling (%|L)	
17-Jan	Brew	539.2	29.4%	158.7	3.7%	20.1	12.6%	68.1	0.4%	2.2	53.8%	289.9
18-Jan	Bottle	238.1	0.0%	-	19.4%	46.1	65.8%	156.6	14.9%	35.4	0.0%	-
22-Jan	Bottle	373.1	0.0%	-	13.4%	50.0	65.6%	154.5	21.0%	78.2	0.0%	-
23-Jan	Brew	609.1	26.6%	162.2	3.4%	20.6	6.7%	40.6	1.0%	6.1	62.3%	379.6
24-Jan	Brew	562.9	26.2%	147.6	3.7%	20.6	10.7%	60.3	1.7%	9.8	57.7%	324.6
25-Jan	Bottle	189.5	0.0%	-	24.3%	46.0	58.2%	110.3	17.5%	33.2	0.0%	-
26-Jan	Brew	512.9	31.7%	162.7	3.9%	20.0	8.4%	42.9	1.9%	10.0	54.1%	277.3
29-Jan	Bottle	186.1	0.0%	-	22.0%	41.0	39.8%	74.1	38.2%	71.0	0.0%	-
30-Jan	Brew	449.3	32.6%	146.6	4.5%	20.0	8.1%	36.6	2.6%	11.5	52.2%	234.6
31-Jan	Bottle	192.8	0.0%	-	23.3%	45.0	65.1%	125.6	11.5%	22.2	0.0%	-
5-Feb	Brew	468.4	32.4%	151.9	4.3%	20.0	12.1%	56.6	2.1%	9.8	49.1%	230.1
6-Feb	Bottle	178.7	0%	-	22.3%	39.8	63.3%	113.2	14.4%	25.7	0.0%	-