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Article

Environmental Priorities, Drivers and Barriers in the Craft Beer Sector: Insights from Massachusetts Breweries

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Abstract This article provides empirical research about the environmental priorities, drivers, and barriers in the craft beer sector. It is based on a survey of 43 Massachusetts craft breweries. The authors found that the top three environmental drivers for the industry include: being an environmental steward (81%), saving money (67%), and maintaining a good reputation with the community (63%). The most significant challenges preventing craft breweries from adopting pollution prevention and environmental sustainability strategies include: lack of financial resource (74%), limited knowledge about their opportunities (67%), and lack of time (67%). The top three pollution prevention areas of interest to Massachusetts craft breweries include energy efficiency (88% of participants), water efficiency (76%), and using safer chemicals (67%). In addition, over 80% of participants expressed interest in a "Green Brewery" recognition, obtaining information about state and other incentives and grants, and preventing waste through reuse or recycling. Spent grain management, recycling, and waste prevention are the three areas where craft breweries perform best presently. Wastewater reduction and reducing the use of hazardous chemicals are the most challenging areas for them. The research also found some differences in the priorities and drivers when comparing nanobreweries (with a production of fewer than 1000 beer barrels (bbl)/year) and larger craft breweries (with a production over 1000 bbl/year). The study findings provide valuable insights for devising effective policies and actions to support the sector's adoption of pollution prevention.

Keywords environmental priorities, drivers, and barriers; pollution prevention; craft beer sector; sustainable production and consumption; circular economy

1. Introduction

Business has a major role to play in transforming consumption and production systems through innovation in product and service offerings, value chain collaborations, circular business models, and consumer education [1]. Such transformation, however, requires a major paradigm shift in our society and economy, and the collaboration of many societal actors and disciplinary boundaries on "devising and testing unconventional, dynamic and adaptive solutions" [2]. The coronavirus pandemic of 2020–2021 created unprecedented changes in society and business operations globally, many of which are here to stay. With the widespread disruptions of global supply chains, an increasing number of companies are looking to shift to local or regional sourcing. In addition, consumers are increasingly seeking local and more sustainable products [3].

Small businesses are often best positioned to respond to such societal changes and experiment with environmental strategies as they do not face the shareholder pressures to deliver quarterly profits and thus often prioritize their commitment to support their local community and the environment [4–6]. In 2023, ninety-six percent of B-Corps [7] [1] were small companies with fewer than $100 million in annual revenues [8]. Small companies also represent the majority of businesses and create most of the jobs. In 2022 small businesses with less than 500 employees represented 99.9 percent of all companies in the U.S. and employed half of all workers [9]. At the same time, research has found that small and medium-sized enterprises (SMEs) are responsible

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[1] According to B Labs, B-Corps or Benefit Corporations are "mission-driven businesses that balance purpose and profit", https://usca.bcorporation.net/about-b-corps

for about 60% of the carbon dioxide emissions and 70% of pollution globally [10]. SMEs are less efficient and have limited knowledge and resources to adopt environmental strategies that can help reduce their impacts and costs. They also tend to receive less attention in research and technical assistance. This, however, is beginning to change. Since the COVID-19 pandemic, governments around the world have begun to enact major policies to support the financing of more sustainable economic development, including subsidies for renewable energy, electric vehicle (EV) deployment, and infrastructure upgrades. In the United States, the Bipartisan Infrastructure Bill and the Inflation Reduction Act, for example, enabled the Environmental Protection Agency (EPA) to advance the adoption of pollution prevention by providing technical assistance to entire industries [11].

One sector that has benefitted from this government support is craft beer, an industry represented almost entirely by SME companies. The sector has experienced rapid growth in the U.S. and globally in recent years. The U.S. had over 9700 craft breweries in 2022, compared to 2616 in 2012: a 370% growth over a decade [12]. In Massachusetts, the number of craft breweries increased from 34 in 2007 to over 230 in 2022 [13]. The industry is very committed to environmental and social responsibility, with many small entrepreneurial players focused on local sourcing, reducing energy, water, and chemical use, preventing waste, and promoting social justice and community well-being [14,15]. At the same time, beer manufacturing is water- and energy-intensive, generating a significant amount of waste (both liquid and solid) and uses toxic chemicals for cleaning and sterilizing. Beer manufacturing is also associated with significant greenhouse gas (GHG) emissions, from raw materials production, transportation, and packaging.

Many stakeholders have been working with the craft brewery industry in the U.S. to support the adoption of pollution prevention practices, including state and federal policy makers, the national Brewers Association, state brewers' guilds, universities, and other partners along the value chain. While research and academic studies about the craft beer industry have been growing, a gap in understanding remains with respect to the environmental priorities, drivers, and barriers faced by small craft breweries in adopting various environmental strategies [8,10,16]. Yet, understanding these factors is critically important for devising effective policies and actions to transition the entire industry towards more sustainable production and consumption.

This paper aims to address this gap and provide empirical research about the environmental priorities, drivers, and barriers in the craft beer sector. The authors aim to examine the following questions. What are craft breweries' top environmental priorities and needs? What are the key drivers for craft breweries to pursue pollution prevention and other environmental strategies? What are the main barriers to greater adoption of such practices? How do breweries assess their current environmental performance? The study is based on a survey of 43 Massachusetts craft breweries. It is part of a larger New England initiative to develop a common environmental assessment and recognition program for craft beverage manufacturers.

The paper is organized as follows. It begins with a literature review, followed by the study design and method. Next are presented the main research findings, followed by a discussion of the key results and implications for future research, policy, and practice. The paper concludes with a discussion of the research limitations, main contribution, and future prospects.

2. Literature Review

2.1. Pollution Prevention and Sustainable Consumption—Key to Addressing the Current Environmental Crisis

According to the U.S. EPA, pollution prevention (P2) is "any practice that reduces, eliminates, or *prevents* pollution at its source before it is created" [17]. It is also known as "*source reduction*" and is more effective than recycling, treatment, and disposal because it prevents the generation of waste, GHG emissions, and other negative environmental impacts. It also often reduces costs as it improves material, water, and energy efficiency. Examples of P2 practices in the craft beer sector include: reducing water consumption through reuse and recirculation, reducing energy use through the implementation of LED lights, better insulation, adopting on-demand hot water heating, switching to renewable energy, and use of non-toxic cleaners and sanitizers. Recycling, for example, is not considered a pollution prevention strategy because it does not *prevent* waste but instead aims to reduce it after it is generated. Increasing recycling rates will not solve the climate and environmental crisis as recycling still generates negative environmental and health impacts (e.g., from transportation and processing) and does not fully eliminate the impacts of extraction. To effectively address the problem of climate change and waste, "there needs to be a move beyond recycling into the largely unchartered territory of the higher end of the waste management hierarchy, to reuse, reduce and prevent waste" [18].

While many people agree that climate change is the biggest environmental crisis that humanity is facing presently, few realize how significantly consumption (of energy, water, and raw materials) and waste generation contribute to it. Increases in pollution and effects on human health are additional unrecognized outcomes of consumption and waste. More than thirty years since the concept of sustainable consumption was first introduced [19], limited progress has been made by businesses and governments. One recent approach to reducing consumption and preventing waste is the Circular Economy (CE) which is seen as an alternative to the linear "take-make-waste" economy. Circular business models have been reported to help reduce costs and environmental impacts, increase revenues and brand differentiation, and manage risks [20,21]. Within just a few years CE principles have been adopted by policy makers around the world—in the European Union (EU), China, Africa, and the U.S. [22]. Yet, despite these developments, most companies have not made radical changes to their traditional, linear business models [23]. Researchers have reported a range of barriers such as technological, economic, and financial limitations, supplier relationships, information, market and networking, human resource challenges, social and cultural, regulatory and institutional, and organizational pressures [23,24]. Policy makers have also been reluctant to advance radical measures to address consumption and waste and have continued to rely on Gross Domestic Product (GDP) as the key policy indicator, which directly promotes consumption by individuals and businesses.

One positive development in recent years is the rapid decline in the cost of renewable energy accompanied by substantial government subsidies. Together they create strong incentives for clean energy adoption by companies, including craft breweries [14,25]. Another development is the "rapid increase in sustainable-packaging regulations beyond a focus on shopping bags and selective food-service items" [26]. A study of 30 countries found that in 29 of them, governments have begun to discuss and advance sustainable packaging regulations, involving restrictions of certain materials, adopting extended producer responsibility, setting up infrastructure to support recycling, and in some cases like the European Union, banning the use of single-use plastic packaging [26]. In Massachusetts alone, more than a dozen bills were in consideration in 2023 aimed at banning, reducing, or better recycling plastics [27].

These developments, however, are insufficient to address the current climate and environmental crisis and the data are clear: 2023 was reported as the warmest year on record and global GHG emissions continued to increase [28]. In addition, circularity in supply chains declined from 9.1 percent in 2018 to 8.6 percent in 2021 and 7.2 percent in 2023 [23]. More radical actions and inclusive and transparent transformation of entire industries and their value chains are needed, to reduce resource consumption and *prevent* waste.

In such a transition, companies play a key role by experimenting with new products, services, technologies, and business models. Companies continuously innovate to gain competitive advantage, and entrepreneurs are best positioned to take risks and launch new products and services with both environmental and social value. Business experimentation for sustainability, however, is still a new field and largely underexplored according to Bocken et al. [29]. Blank [30] has called start-ups "one big experiment" as they are crucial for advancing sustainability. Entrepreneurs' niche experiments can provide valuable insights and social learning about the challenges and opportunities in advancing sustainability [1], as well as help build momentum towards enacting government policies that "change the rules of the game" to reward sustainable businesses [31,32]. A growing number of researchers are examining business model experimentation[2] [33,34]. Studies have analyzed "the learning, signaling, and convincing as key approaches for experimentation by startup businesses" [35]. For instance, a small but growing number of craft breweries are experimenting with sourcing malt and hops locally, taking back and reusing plastic can carriers, switching to compostable can carriers or adopting reusable wrap [36,37]. More research is needed to understand the main barriers faced by startups in this process.

Hernandez-Chea et al. [38] examine the role of sustainable business models in sustainability transitions and offer a new conceptual framework, looking at the short-term (operational), medium-term (tactical), and long-term (strategic) levels. At the operational level, companies establish

[2] A *business model* is about how an organization creates, delivers, and captures value (or in simple words, how it makes money).

a vision and activities that aim to change the dominant practices at the firm level. At the tactical level, firms collaborate with key stakeholders to change the value creation opportunities along the value chain. At the strategic level, companies pursue changes in the dominant practices and cultures at the societal level. The authors argue that "non-technological business model changes at the micro level of the firm create multiple niche innovations that generate radical changes in the system". Thus, firm-level research is key to understanding the "specific steps required for transition" [38]. Using business model innovations, companies can influence consumers and suppliers to move towards environmental sustainability. The authors reported three success factors: a) shared vision and strategic partnerships among firms in different sectors; b) creation of an interdependent network of the green supply chain and collaboration with stakeholders, and c) in the short term adopting sustainable practices, controlling daily operations, conducting awareness campaigns and experimenting with collaborations to deliver values based on sustainable practices" [38].

George et al. [39] proposed a framework to study grand challenges from an organizational and management perspective. The authors argue that "the core of beginning to address a grand challenge lies in its articulation". Organizations with purpose are able "to inspire others to contribute effort and resources with a sense of purpose". The framework also calls for researchers to examine the societal barriers, organizational constraints, and institutional contexts for addressing grand challenges, before moving to multilevel action such as regulation and government interventions.

2.2. Craft Beer Industry: Environmental Impacts and Initiatives

Beer is the most consumed alcoholic beverage in the world and the third most popular beverage after water and tea. The global beer market is projected to reach $989.29 billion by 2028 from $768.17 billion in 2021, mostly driven by the increasing demand for premium and craft beers [40]. Craft brewing began to take off in the 1970s, when consumers started to place higher importance on what they were buying and began to look for local options rather than their traditional macrobrew [41]. Globally, the industry experienced rapid growth in recent years. The United States had over 9700 craft breweries in 2022, compared to 2616 in 2012: a 370% growth over a decade [12] (see Figure 1). Massachusetts had 34 craft breweries in 2007 when the Massachusetts Brewers Guild (MBG) was formed; that number increased to 230 by the end of 2022 [13]. The industry contributed $1.6 billion to the state in 2021 (not including the indirect economic impacts) and employed about 6500 people [12].

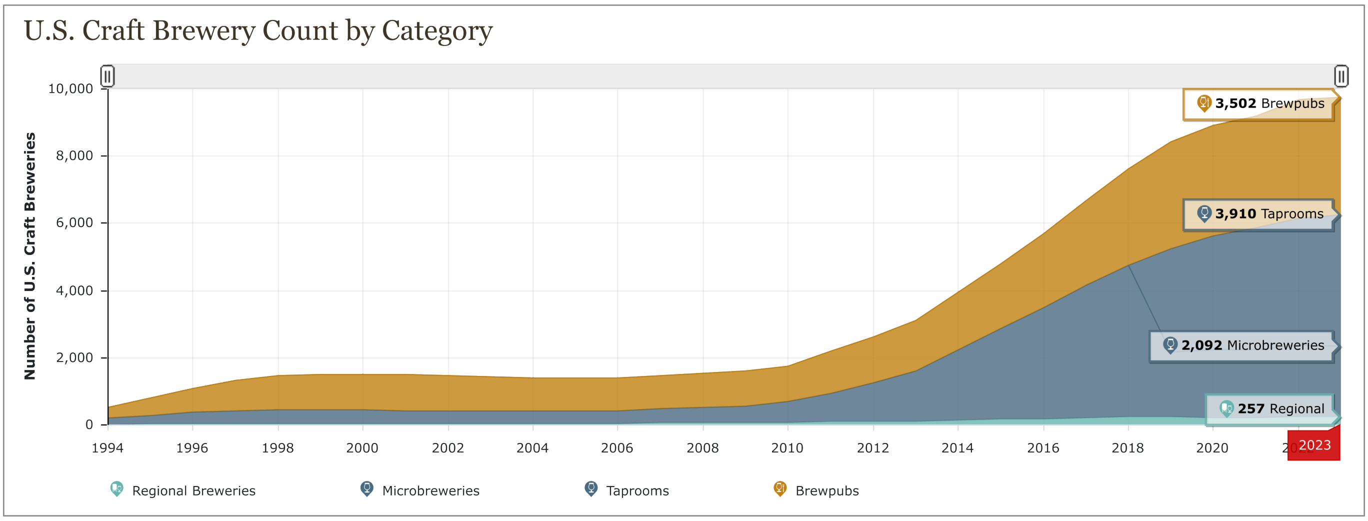

Figure 1. U.S. Craft Brewery Count by Category. Source: [42].

Since the COVID-19 pandemic, however, craft beer volume has been down. It declined drastically in 2020 due to the closure of restaurants and pubs and then recovered modestly in 2021. The 2023 volumes were still lower than in 2019, before the pandemic [42]. Thus, while the number of craft breweries has increased (more modestly as the industry matures), overall beer volume has been down in recent years. In addition, supply-chain disruptions caused by the pandemic, the war in Ukraine, and inflation have led to significant increases in the cost of raw materials, energy, and water. At the same time, climate change is advancing at an unprecedented rate, increasing the urgency for companies, governments, and individuals to act. As a result, many craft breweries see environmental sustainability as a crucial strategy to reduce costs, minimize environmental impacts, and differentiate from competition.

The industry is very sustainability-committed; many industry events include sessions on environmental impacts and best practices, and since 2015 the national Brewers Association has offered numerous environmental resources and a Sustainability Benchmarking Tool for members [43]. At the same time, beer manufacturing is a water- and energy-intensive process, which generates a significant amount of waste (both liquid and solid). Larger breweries with more than 10,000 beer barrels (bbl)[3] per year are significantly more efficient in the use of water and energy than smaller breweries with fewer than 1000 bbl/year (see Table 1). Beer has been made traditionally from malted barley, hops, water, and yeast. Brewers typically purchase malt from suppliers (*malting* is the process of soaking barley to germinate and then drying it to stop the process, which activates enzyme production necessary for converting the starches). Conventional brewing consists of four main processes: a) *mashing*, during which enzymes hydrolyze starch into fermentable sugars and proteins into amino acids; b) *boiling*, during which resins undergo thermal isomerization and yield bitter taste; c) *fermentation*, during which sugars are converted into ethanol; and, finally, d) *maturation and bottling* [44]. Brewers may add some supplements known as adjuncts to achieve a unique beer flavor. In addition to these four steps, raw materials (barley, hops, and yeast), malting, packaging, and transportation (upstream and downstream of the value chain) are significant sources of GHG emissions and pollution. Research has found that Scope 3 GHG emissions (upstream and downstream along the supply chain) represent between 46% and 75% of a beer's carbon footprint [45].

Table 1. Comparison of small and mid-size breweries, energy, and waste metrics [46].

Resource	Nano Brewery (<1000 barrels/year)	Micro Brewery (1000–10,000 barrels/year)	Regional Brewery (10,000–100,000 barrels/year)
Electricity use per bbl	182 kWh/bbl	65 kWh/bbl	27 kWh/bbl
Water use per bbl	607.6 gal/bbl	269.7 gal/bbl	179.8 gal/bbl
Cost for liquid waste disposal/bbl	\$2.31/bbl	\$3.38/bbl	\$1.97/bbl
Cost for solid waste disposal/bbl	\$6.20/bbl packaged	\$0.80/bbl	\$0.23/bbl
Cost of CO_2/bbl	\$3.67/bbl packaged	\$2.46 bbl	\$1.90/bbl

Energy use: Breweries use significant amounts of propane, electricity, and natural gas for processes like heating, cooling, and refrigeration. This generates Scope 1 and Scope 2 GHG emissions according to the WBCSD and WRI GHG Protocol [47]. In addition, raw materials (barley, hops, yeast), packaging, and transportation all include embodied energy and contribute to a beer's carbon footprint (Scope 3 GHG emissions). A study by Francis [48] found that a typical brewery using fossil fuels emits around 250 g CO_{2e} per six cans of beer. Another study from the UK reported that craft breweries' carbon footprints ranged from 760 g to 1900 g CO_{2e} per liter of beer (or from 6.3 pounds to 15.8 pounds of CO_{2e} per gallon of beer)[4] [49]. An increasing number of breweries are reducing energy use and related costs by improving insulation, using programmable thermostats and LEDs (which can reduce energy use by 90% over incandescent bulbs), installing on-demand hot water heaters, and shutting down equipment when not used. Some breweries are sourcing electricity from solar or wind energy by either installing them on their facility (when they own it) or subscribing to community solar. Due to generous federal and state subsidies in the U.S. and the European Union, using renewable energy can help significantly reduce both GHG emissions and costs [17]. For instance, in Massachusetts, switching to community solar can help reduce a brewery's electricity bill [50]. Shifting to local suppliers, selling beer locally and as draft or in reusable kegs, can further reduce a brewery's Scope 3 GHG emissions.

Water use and wastewater: Water represents about 90% of the weight of beer and is used in high quantities by breweries in the brewing process, for cooling, and for cleaning. As a result, a significant amount of water is discharged through the drains. Research has estimated

[3] One beer barrel is 31 gallons or 117,348 liters (one gallon is 3.785 liters).
[4] One gallon is equal to 3785 liters, and 1 pound is equal to 454 grams.

that 3–10 liters of waste effluents are discharged while producing one liter of beer (or 3–10 gal of waste effluent for each gallon of beer) [16,51]. Both water supply and water treatment use energy and thus contribute to a beer's carbon footprint. Improvement in breweries' efficiency through water reuse or closed system for cleaning, installation of high-pressure low-flow spray nozzles, low-flow aerators, and other strategies, can reduce the environmental impacts and brewery costs. Some breweries have switched to using ionized air rinsing systems for can cleaning, which further helps reduce water use and costs [16]. Such proactive water conservation measures are especially prevalent in areas such as California, where water shortages have impacted business operations and policy makers have implemented restrictions [52].

Raw materials: Grain, hops, and yeast are the main solid ingredients in craft beer manufacturing. Grain can be malted or unmalted (malt is partially germinated grain) and may include a variety of crops, which explains the large flavor differences between craft beers on the market. While local grain and malt may be available in some cases, they tend to be more expensive and do not always meet brewers' needs. Yet, some breweries aim to purchase at least some local grain/malt for a special release beer to support their local farmers [16]. Hops are essential in craft beer production but are also expensive, with most U.S. suppliers located in the states of Washington, Oregon, and Idaho. Some breweries use hops from Germany which are seen as superior in quality. Yet, the transportation of grain and hops from long distances is associated with additional GHG emissions.

Fermentation and carbonation: The process of fermentation (where yeast metabolizes the sugars in the wort to ethyl alcohol and carbon dioxide to give beer its alcohol content and carbonation) releases CO_2. The amount of CO_2 varies based on how long the fermentation stage lasts, the ingredients used, and the alcohol rating. Research has found that each barrel of wort can produce on average10 pounds (or 4.536 kg) of carbon dioxide [53]. At the same time, breweries purchase CO_2 to carbonate their beer before packaging. A growing number of breweries have begun using carbon recapture technology to capture the CO_2 from late-stage fermentation and use it for carbonation. This circular business model not only leads to cost reductions (by reducing the amount of CO_2 they must purchase) and a decline in GHG emissions but also reduces business risks from supply-chain disruptions (the industry experienced such disruptions during the COVID-19 pandemic of 2020–2022).

Waste generation: The main types of waste generated by a typical brewery include: brewer's spent grains (BSG), hops, sludge, spent yeast, and packaging (e.g., grain bags, can carriers, stretch wrap, empty bottles from cleaners and sanitizers). BSG is the largest source of waste and represents about 85% of the total by-products by weight in the brewing industry [54]. It is estimated that every 6-pack of beer uses about one pound of grain; approximately 20 million pounds (or 9 million kilograms) of BSG are generated in the U.S. each year [55]. Discarded BSG can pollute water, soil, and air (in the case of waste incineration) and thus negatively impact human health and the environment. Disposal of BSG also represents a significant cost for brewers. In states such as Massachusetts, where disposal of organic waste is banned [56], breweries typically have three main options to manage spent grain: a) send it for composting where they typically pay by weight; b) send it to local farms for animal feed (a zero cost or revenue-generating option where farmers remove BSG from the property and may even pay for it); and c) provide it to startups which are upcycling it into products such as flour, dog biscuits, and energy bars for human consumption [14,57,58]. Such circular business practices have become increasingly common for the industry due to their financial and environmental benefits. A study of 90 craft breweries in England found that "the primary method for recycling spent grain was its use as animal feed by local farmers by both rural and urban breweries" [59]. In addition to BSG, the packaging of beer is associated with a significant amount of waste and related GHG emissions (e.g., from canning and use of can carriers, labels, and cardboard boxes for shipping). The use of silos and grain trailers help reduce costs and environmental impacts of packaging (e.g., avoids the use of single-use grain bags) [16]. Most breweries aim to maximize recycling. Some reuse can carriers or order pre-printed cans to reduce cost and waste, and improve recyclability. A study of 70 craft breweries' websites by Ness [14] found that one-third reported the reuse of spent grains by others, and about one-third of participants implemented some solid waste handling or recycling program [14].

Chemical use: Chemicals such as caustic sodium hydroxide, powder keg, liquid metal safe, and Star San are used in the cleaning and sanitizing processes and can create risks to workers, air and water quality. These chemicals also contribute to a beer's carbon footprint as a result of their manufacturing, transportation, packaging, and treatment (when discharged with the wastewater). In addition, to reduce the negative impacts on sewer pipes, many breweries dilute the chemicals before disposing, which increases their water use and costs. The Toxics Use Reduction Institute (TURI) in Massachusetts has identified safer alternatives to toxic chemicals which meet the industry quality standards and help reduce a brewery's environmental impact and carbon footprint [60]. For example, with help from TURI, Merrimack Ales in Lowell, Massachusetts, explored safer alternatives to caustic sodium hydroxide. It switched to Brewers Wash, effective at a lower temperature and volume, to clean, and to NADCC tablets to sanitize [61]. As a result, Merrimack Ales improved its worker safety and reduced the use of energy, water, and its Scope 3 GHG emissions without increasing its costs.

2.3. Environmental Drivers and Priorities in the Craft Beer Sector

While there is limited academic research on craft breweries' environmental priorities and initiatives, Ness [14] examined the websites of 70 small and medium size craft breweries in the U.S. and Europe and found that "a wide array of sustainability priorities is important to craft beer producers". These included environmental issues such as water and energy use, climate change, and solid waste generation. The author also found that "being a positive and active member of the community" was a strong priority for many brewers [14]. The study reported that for craft breweries sustainability encompasses both environmental and social issues, including energy and climate, water efficiency, spent grain reuse, and community support [14].

The **sustainability values** of brewery founders are a key driver for producing sustainable beer. Westman et al. [6] examined the factors that shape the sustainability actions of SMEs and reported that such firms are "social actors" and their actions are shaped by "individual values, internal and external interpersonal relationships". Earlier research on SMEs has also reported the importance of social drivers of sustainability, such as the ethical convictions of owners and managers and their strong engagement in local communities [62–66]. Examining sustainability strategy development at two craft breweries in Canada, Luederitz et al. [4] report that "collective agency and interpersonal relationships are central in forming strategic sustainability orientation". A recent study of U.S. craft breweries' motivations found that top management (typically founders and owners) is the most significant factor in adopting environmental practices [67]. The researchers concluded that "the owner's attitude toward and knowledge of environmental issues and practices are reflected in the brewery's overall stance in terms of the cost considerations and the level of employee engagement in the implementation of sustainable practices" [67].

Cost savings is a key driver for adopting environmental practices in a variety of industries [67] and craft breweries are no exception. Most expenses for a brewery come from its production operations, the ingredients, cans, water, and energy that goes into making the beer. The U.S. Bureau of Labor Statistics (BLS) reported a 15.8% increase in energy bills in 2022 [68]. Some states like Massachusetts faced much greater increases in 2022 [69]. Such cost increases in energy and water rates make it difficult for brewers to stay competitive without raising the price of their beer. As a result, it is in a brewery's best interest to pursue energy and water efficiency as well as renewable energy sources to reduce costs.

A brewery's **reputation within the community and its customers** is another important driver for implementing environmental sustainability practices. Research has examined the role of customers as a driver of sustainable business practices through their expectations, demands, and purchasing habits [10]. A 2018 study reported that 59% of 1094 respondents to a survey would be **willing to pay more for sustainable beer**, specifically about $1.30 per six-pack of beer [70]. Craft breweries are deeply connected to their community and other stakeholders along the supply chain—farmers, maltsters, suppliers, customers, employees, and local charitable organizations, each of which can also become a driver for sustainability adoption. Del Giudice et al. [71] found that due to their limited resources SMEs "learn about sustainability through their interactions with their network of contacts". Such networks lead to innovative collaborations and joint value creation. Beyond breweries, research has found that public image is an important driver for green business practices among SMEs [5].

Regulation is typically an important driver for adopting environmental initiatives by businesses [72,73]; however, presently SMEs are often not significantly affected by regulatory pressures. For example, many craft breweries discharge their wastewater directly into the sewerage because they are considered too small of enterprises to be inspected and subjected to fines. At the same time, stricter regulations may be playing a more important role in the future, similar to the

Massachusetts Organic Waste Ban which reduced the threshold for mandatory organic waste diversion from one ton/week to 0.5 tons a week [56]. As the U.S. population increases, wastewater treatment facilities are looking for ways to cut the cost and volume of wastewater. There have been major efforts by the U.S. EPA with their Municipal Separate Storm Sewer System (MS4) to reduce the amount of flow going to wastewater facilities by constructing storm drainage mains to separate stormwater from wastewater [74]. The MS4 program has made major efforts and a growing number of wastewater authorities have started to consider **stricter wastewater regulations**; for breweries, this could mean being required to treat their wastewater on-site before it can flow to the MS4 system. Side-streaming (or reducing the waste going to the sewer system) has the potential to reduce both costs and business risks.

2.4. Barriers to Adopting Environmental Initiatives by the Craft Beer Sector

While in theory, efficiency improvements provide strong incentives for all brewers to switch to more environmentally sustainable practices, craft breweries face several barriers to implementing such strategies. The **upfront costs** of implementing these measures are a hindrance to small breweries with limited resources (both capital and human) [10,75–77]. More broadly, the lack of capital has been identified as a major barrier to implementing green business practices by SMEs [5].

Breweries who **lease their land and facilities** are also restricted to the terms of their lease and may not be able to implement some infrastructure improvements such as installing solar panels or wastewater treatment technology [78]. Larger breweries may have more difficulty in implementing sustainability changes as these may disrupt their production lines and require more capital, compared to a smaller or newer operation which has more flexibility in their day-to-day operations [79].

Product quality and safety are of paramount importance for all craft breweries. If **green cleaning products are ineffective**, a brewery may choose to use a more toxic, conventional product if it means that cleaning is up to the standard for producing their high-quality beer [79]. This is equally important when considering ingredient sourcing; local farmers may be able to produce ingredients needed for beer production, however, if they are **inconsistent, of limited quantity, or prohibitively expensive** a brewer may continue to source products from further away [80]. In addition, local barley and hop producers may be less efficient in their operations, thus having a higher carbon footprint than larger producers located far away [81].

Lack of awareness and information about best practices and available state and federal incentives for reducing environmental impacts is a common barrier for craft breweries in any country [75,76]. Brewers guilds, the national Brewers Association, and state programs have been working to address this challenge by providing up-to-date information, technical assistance, and resources such as examples of best practices [15,82–84]. **Lack of technical capacity** in identifying and carrying out complex energy efficiency or water efficiency projects, analyzing performance data, or evaluating alternatives, is another key barrier to adopting sustainable beer production practices [45].

Local codes and regulations of the municipal, state, and federal governments can create an additional barrier. Some sustainability practices are so new and radical that the governments have not had time to fully evaluate the impacts. As a result, laws may preclude the implementation of certain environmental practices. For example, in Massachusetts breweries are allowed a license for only one business activity; if they produce and sell beer, they may not simultaneously operate a farm to produce their ingredients [79]. This is a lost opportunity to be more sustainable and reduce their carbon footprint (Scope 3 GHG emissions).

More broadly, researchers have highlighted the lack of support from external stakeholders such as government, supply-chain partners, and customers, as a barrier for SMEs to adopt green practices [85].

3. Study Design and Method

To conduct the study the research team designed a 12-question survey to benchmark current environmental practices and priorities, key drivers, and main barriers reported by craft breweries in Massachusetts. The survey was based on a literature review, feedback from the Massachusetts Brewers Guild executive director, and two brewery owners. Questions were formulated to reflect key areas of environmental impacts outlined in previous craft beer research and surveys such as

[14,15,76], among others. The survey included separate questions about pollution prevention practices (focused on source reduction and *preventing* pollution) and other environmental practices (e.g., recycling and reuse of BSG). It was pilot-tested by a couple of breweries and revised accordingly to ensure the terminology was aligned with the industry understanding (e.g., bbl packaged, BYOF, or bring your own food). Questions about the size of the brewery in terms of beer barrels packaged annually and the number of employees were also included. The team used Likert scale questions to examine how breweries assess their performance in nine categories from "very poor" to "excellent". The categories included energy efficiency, water efficiency, reducing the use of hazardous chemicals, solid waste prevention, wastewater reduction, recycling, spent grain management, composting, and sourcing organic or local ingredients. To ensure data quality, the team provided additional information for each environmental practice (e.g., graywater recycling, high-pressure/low-flow cleaning, animal feed, upcycling, etc.). The participants were also familiar with the Brewers Association environmental benchmarks (see Table 1), which were used as the basis for the self-assessment. Another question explored how craft breweries communicate their environmental/sustainability practices externally (e.g., on their website, social media, or do not communicate at all). The authors included questions to gauge the drivers and challenges to greater adoption of pollution prevention and other environmental practices. The survey was sent out in October 2022 to all members of the Massachusetts Brewers Guild (137 in total out of 230 craft breweries in Massachusetts as of October 2022). The survey was included in the MBG newsletter twice, shared in the MBG Facebook group twice, and mentioned at its December 2022 meeting, attended by 60 craft breweries. A total of 43 responses were received as of 17 May 2023 (a response rate of 31%). As an incentive for participation in the survey, respondents were offered a free environmental assessment and technical assistance by the University of Massachusetts Boston team, which received funding from the U.S. EPA to provide pollution prevention technical assistance to Massachusetts craft breweries.

The team used descriptive statistics to analyze the data—frequency distributions, pie and bar charts. Due to the small sample size, it was not possible to conduct more sophisticated inferential statistics, except for 95% confidence intervals. To examine potential differences based on craft brewery size the team created two groups of craft breweries for additional analysis: a) nanobreweries (with fewer or equal to 1000 bbl/year) and larger craft breweries (with production of over 1000 bbl/year). The binomial confidence intervals were applied; 95% CI indicates that we are 95% confident that the interval constructed from the sample will contain the true population proportion. There are several ways to compute a confidence interval for a proportion. If the sample size is small as in the present study, symmetrical confidence limits that are approximated using the normal distribution may not be accurate enough for this application. The method that provides a more reliable confidence interval with small samples is the Clopper-Pearson interval. The Clopper-Pearson interval is an "exact" interval since it is based directly on the cumulative probabilities of the binomial distribution rather than any approximation to the binomial distribution [86].

4. Results

The majority (53%) of survey participants were nanobreweries with a production of less than 1000 beer barrels per year. Just one brewery had production over 100,000 bbl (see Figure 2). Thirty percent of participants did not have a kitchen but instead hosted food trucks or offered some snacks on side; 28% percent had an on-site kitchen but did not provide full service; and just 14% had a restaurant or a brew pub. Most participating breweries (58%) had less than 10 employees.

The research revealed that craft breweries have been most successful in addressing environmental sustainability issues in the areas of *spent grain management* (95% assessing their performance as "good" or "excellent"), *recycling* (77%), and *composting* (65%), These areas are all related to waste management and CE business practices, not pollution prevention. The most challenging areas for them include *wastewater reduction* (12% assessing their performance as "excellent" or "good") and *reducing the use of hazardous chemicals in cleaning and sanitizing* (24%) (see Table 2).

The study found that the top drivers for adopting environmental sustainability practices for Massachusetts craft breweries are the *desire to be an environmental steward* (81% of respondents), *saving money* (67%), and *maintaining a good reputation with the community* (63%). In addition, *marketing/appeal to environmentally conscious consumers* was reported among the top three most significant drivers by 49% of participants, followed by *improving employee health and safety* (44%). Just 23% included *compliance with local ordinances/standards* among the top three drivers for adopting pollution prevention/sustainability (see Figure 3).

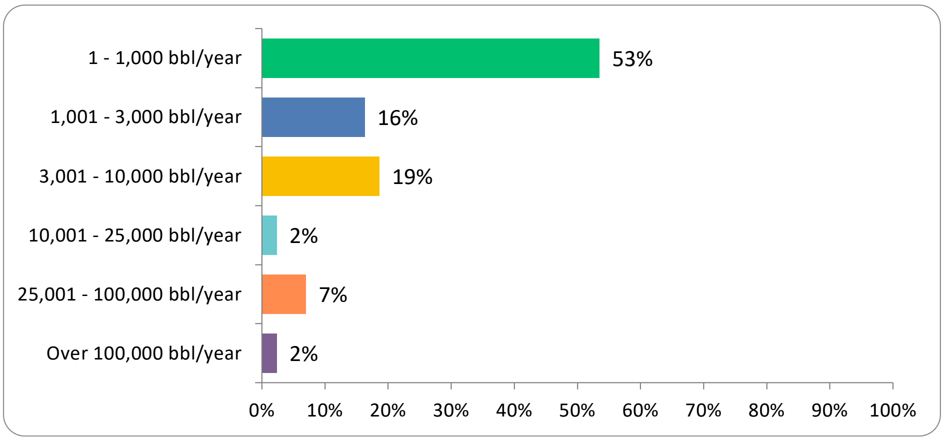

Figure 2. Participating breweries' annual production in barrels of beer packaged (bbl).

Table 2. Craft breweries self-assessment of sustainability performance in different areas, in percent[5]; Question: "*Please indicate how do you rate your operation in each area below*".

	Area/Rating	Very Poor	Poor	Fair	Good	Excellent	Good + Excellent
1	Energy efficiency/conservation (e.g., Energy Star appliances, heat pumps)	0%	12%	49%	33%	7%	**40%**
2	Water efficiency/conservation (e.g., high pressure/low flow cleaning)	0%	14%	35%	47%	5%	**52%**
3	Reducing the use of hazardous chemicals in cleaning & sanitizing (e.g., using GreenSeal or EPA Safer Choice products)	0%	24%	52%	17%	7%	**24%**
4	Solid waste prevention (e.g., reducing packaging, reuse)	0%	9%	33%	49%	9%	**58%**
5	Wastewater reduction (e.g., greywater recycling)	9%	44%	35%	7%	5%	**12%**
6	Recycling (e.g., cardboard, plastic can carriers, grain bags, stretch wrap)	0%	2%	21%	58%	19%	**77%**
7	Spent grain management (e.g., as fertilizer, for animal feed, upcycling into four)	0%	2%	2%	12%	83%	**95%**
8	Composting (of food, spent grain, etc.)	2%	14%	18%	12%	53%	**65%**
9	Sourcing organic or local ingredients	5%	7%	40%	30%	19%	**49%**

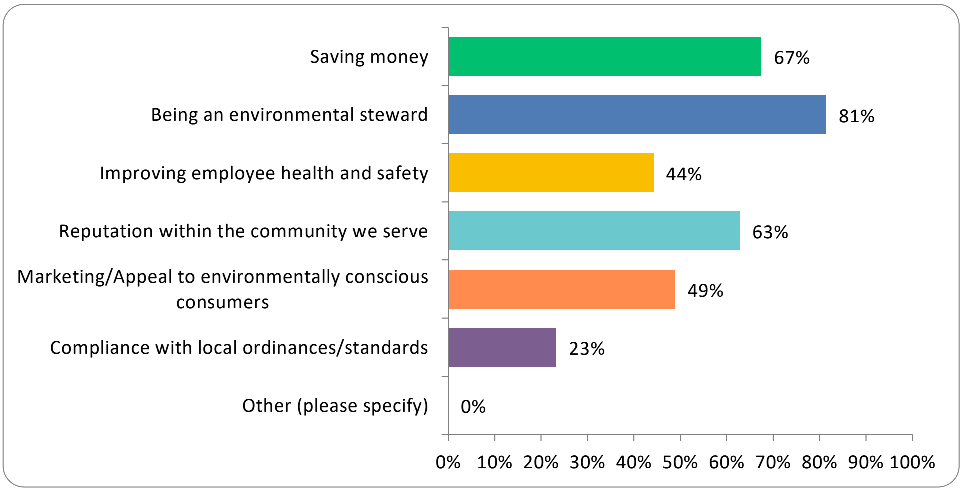

Figure 3. Main drivers for implementing P2/sustainability practices by craft breweries in Massachusetts (43 responses).

[5] Due to rounding the total for the category may not add to 100%.

However, when comparing nanobreweries with larger breweries, the study found some differences. While being an environmental steward is the top driver to adopt environmental practices by all breweries, reputation is more important for nanobreweries (70% compared to 55% for larger ones), and marketing is a more important driver for larger breweries (65% vs. 35% for nanobreweries) (see Figure 4).

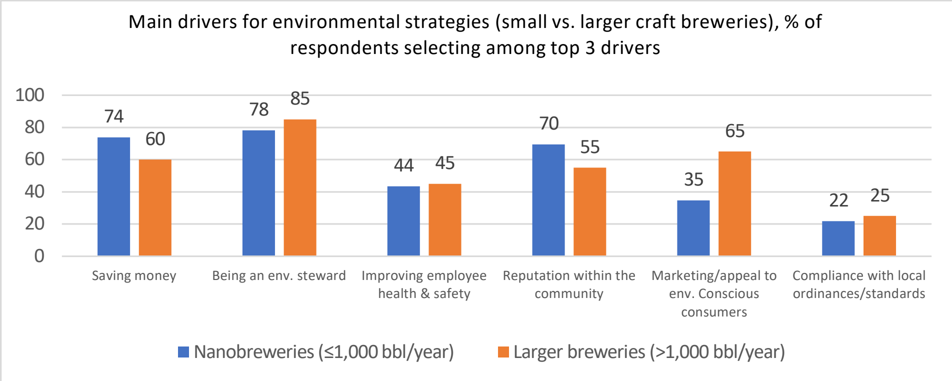

Figure 4. Main drivers for adopting P2/sustainability strategies (small vs. larger craft breweries).

Not surprisingly, *lack of financial resources* is the most significant barrier preventing Massachusetts craft breweries from adopting more environmental practices reported by 74% of the survey participants (see Figure 5). Two out of three participating breweries reported *not having time* or *knowledge about their opportunities* (each at 67%). Forty percent are unable to calculate the Return on Investment (ROI) for a specific technology they were interested in. Twenty-three percent reported the lack of enough employees among their top three sustainability challenges. In this question, "finding the time" relates to the owner's capacity to identify and prioritize potential environmental measures, and therefore is different from "not having enough employees".

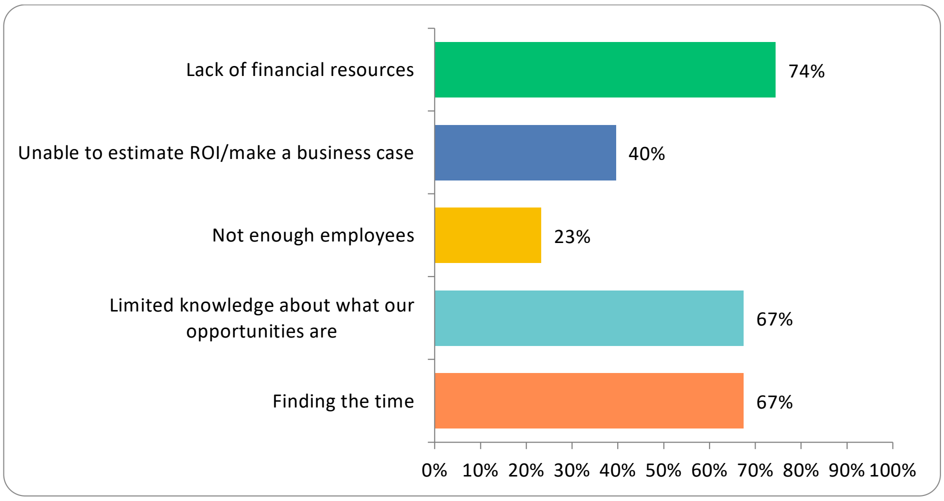

Figure 5. Main challenges preventing craft breweries from implementing P2/environmental sustainability measures (top three challenges, 43 responses).

Understanding an industry's priorities is important for any successful sustainability intervention. Figure 6 depicts the pollution prevention areas which Massachusetts craft breweries are most interested in addressing. *Energy efficiency* tops the list with 88% of participants interested in receiving technical assistance, followed by improving *water efficiency* (76% of participants). Two out of three participating breweries are interested in receiving free assistance in *reducing their use of hazardous chemicals in cleaning and sanitizing*. Fifty-seven percent reported interest in *reducing wastewater*. Slightly more than half (55%) were interested in preventing solid waste and using the Brewers Association (BA) sustainability benchmarking tool (available only to members of BA). Improving water efficiency was also identified among the top priorities by over half of the participants (52%). These priorities align closely with the areas in which breweries did not perform well, according to their self-assessment (see Table 2). One exception is the reusing and recycling of plastics. While 77% of participants assessed their performance as "good" or "excellent" in recycling (see Table 2), 83% reported interest in "reusing or recycling plastics like can carriers, grain bags, stretch wrap" (see Figure 7). This high priority could be related to greater awareness of the environmental impacts of plastics and the emerging regulations to ban single-use plastic packaging in Massachusetts. *Spent grain management* and *food waste and composting* were of less interest (selected by 19% and 33% of participants, respectively) (see Figure 7), most likely because they already have implemented various CE strategies (see Table 2).

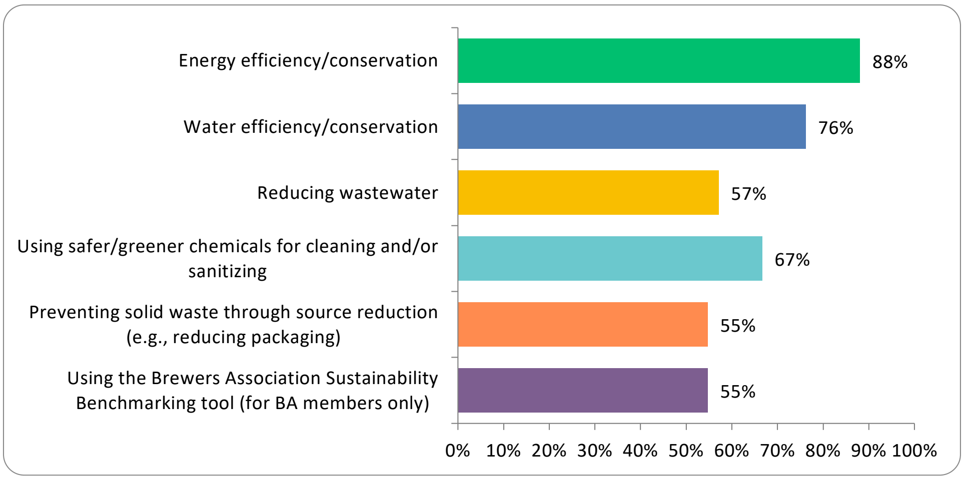

Figure 6. Massachusetts craft breweries' interest in pollution prevention technical assistance by category (top three areas; 42 responses).

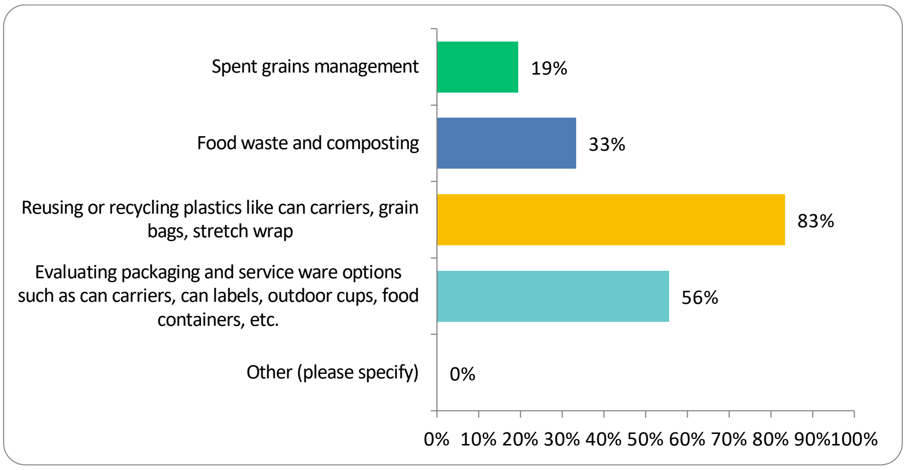

Figure 7. Massachusetts craft breweries' interest in additional waste management/circular economy options (36 responses).

Additional analysis comparing nanobreweries with larger craft breweries found some notable differences (see Figure 8). First, energy efficiency was identified as a top priority by 96% of nanobreweries, compared to 75% of larger craft breweries. Second, using safer/greener chemicals for cleaning and sanitizing is much greater priority for nanobreweries (78% vs. 50% for larger breweries).

The study also aimed to examine craft breweries' interest in additional environmental opportunities such as: sourcing more local/sustainable ingredients, implementing pollution prevention technologies such as carbon capture, getting information on state incentives and grant opportunities, and being recognized as a "Green Brewery". As demonstrated in Figure 9, a clear majority of participating breweries reported interest in a "*Green Brewery*" recognition and *receiving information on state incentives and/or grant opportunities* (each at 83%). Sixty-two percent reported interest in *switching to nitrogen for cleaning to decrease the use and dependence on* CO_2. About half of the participants were interested in *sourcing more local and/or sustainable ingredients* (52%) and *adopting carbon capture technology* (50%).

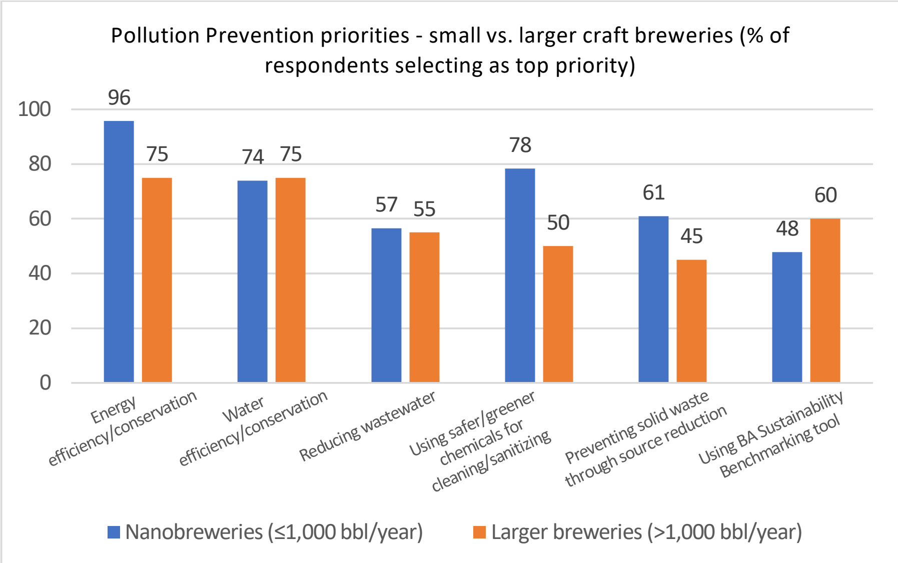

Figure 8. Interest in pollution prevention technical assistance-small vs. larger craft breweries.

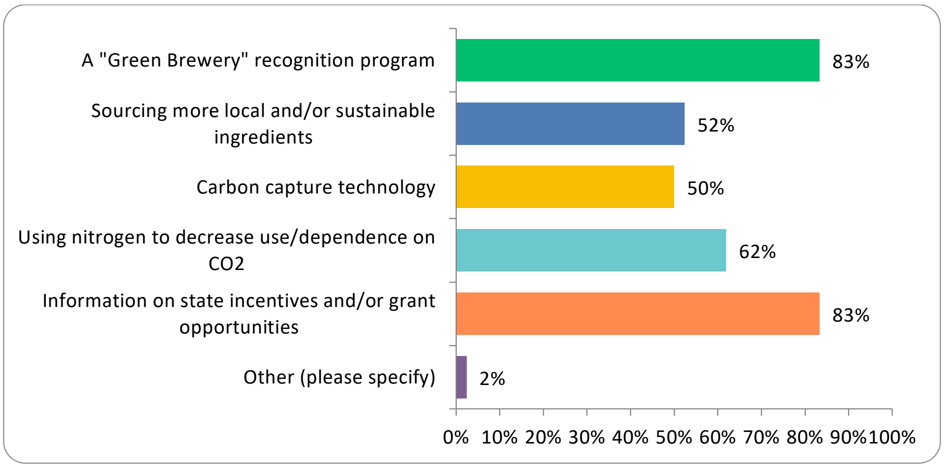

Figure 9. Massachusetts craft breweries' interest in additional environmental opportunities (42 responses).

While most participating breweries have implemented some environmental measures (just 9% reported not having any environmental sustainability initiatives), 37% of them do not promote these publicly (see Figure 10). About one in three participating breweries promote their efforts both on their website <u>and</u> on social media (30%), 14% promote just on social media and 5% promote only on their website (see Figure 8).

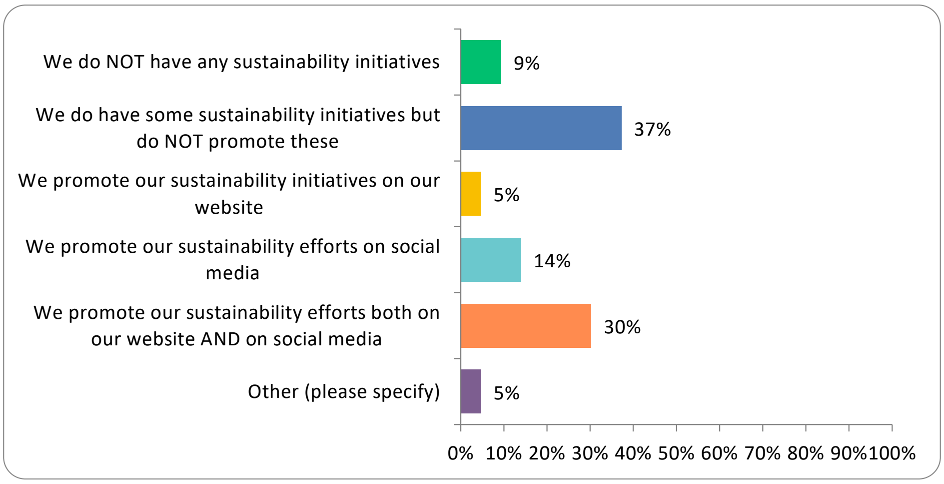

Figure 10. Craft breweries' strategies to promote their environmental sustainability initiatives (43 responses).

5. Discussion

The current study aimed to understand the environmental priorities, drivers, and barriers for craft beer manufacturers. It found that the most important reason for the industry to adopt P2 and environmental sustainability is the desire to be an environmental steward, which confirms previous research by Purwandani & Michaud [5] who reported that internal motivations were the most significant driver for SMEs to adopt green business practices. This result also aligns with Sozen et al. [67] findings that brewery owners' and founders' attitudes and knowledge about environmental issues, are the most significant factors for the adoption of environmental practices. The finding confirms previous research about the importance of social drivers of sustainability such as the ethical convictions of owners and managers and their strong engagement in local communities [10,62–66]. Maintaining a strong reputation within their community was the third most important driver for adopting sustainability by Massachusetts craft breweries (63%), confirming prior studies about the importance of reputation for these businesses [5,10,71].

The study also found that most craft breweries see pollution prevention and circular business models not as a cost, but instead as a way to save money (the second most significant driver for implementing environmental practices, reported by 67% of participants and 74% of nanobreweries). This finding supports a growing body of research demonstrating that resource efficiency is an important driver for SMEs and a key reason for implementing environmental sustainability practices [67,87]. Not surprisingly, regulation was the least significant driver for craft breweries as many are too small to be affected by regulatory actions. Yet, as the case of Massachusetts' organic waste ban demonstrates, this may change in the future with increasingly stringent policies to address waste, wastewater, and single-use plastics. About half (49%) of participants identified the opportunity to market sustainability to their environmentally cautious consumers, yet 37% are not sharing any information about their initiatives publicly. Just 30% of participants promote their environmental sustainability efforts on their website and social media. Future research needs to examine the factors for this gap—whether it is the lack of time and resources or concerns of being accused of "greenwashing". Previous research by Jones [88] has also reported craft breweries' reluctance to communicate their environmental accomplishments to the public.

The main challenges reported by Massachusetts craft breweries—lack of financial resources, time, and limited knowledge about available opportunities—confirm previous studies of SMEs and the importance of providing funding and technical assistance to the sector. The upfront cost of implementing environmental technologies and practices is a common barrier for SMEs reported in the literature [1,10,76]. In addition, estimating the ROI or making a business case for adopting a specific technology is a challenge (reported by 40% of the study participants). Small companies with limited resources do not have the capacity to navigate and take advantage of various state and federal environmental incentives. Yet, they are highly interested in these (83% of breweries in the study reported interest in getting information about state incentives and/or grant opportunities). The study confirms the recommendations by Rahman et al. [10] that policy makers and others need to help craft breweries overcome such challenges through sharing best practices, designing effective consultation programs, and offering other government incentives.

The research found that managing waste and especially managing brewers spent grain is the area where Massachusetts breweries perform best (95% of participants rated their performance as "good" or "excellent"). This demonstrates the attractiveness of CE business models for SMEs and confirms previous research by Ness [14] and Kerby & Vriesekoop [59]. Recycling and composting (also representing CE strategies) are two other areas of waste management where a majority (77% and 65%, respectively) of participating breweries reported good performance. The most challenging environmental area for craft breweries is wastewater prevention. Investing in side streaming or wastewater reduction currently does not provide opportunities for cost savings for small craft breweries as there is no legal requirement to do so. This finding highlights the need for new policies that help small companies capture the value of investing in such environmental initiatives.

Understanding craft breweries' priorities is key to providing effective technical assistance and support. The study found that Massachusetts craft breweries were most interested in improving their performance in the areas of "energy efficiency/conservation" (88% of participants), "reusing or recycling plastics like can carriers, grain bags, and stretch wrap" (83%), "water efficiency/conservation" (76%), and "using safer/greener chemicals for cleaning and/or sanitizing" (67%). Being recognized as a "Green Brewery" was also of high interest to participants (83% reported interest in getting such recognition). All of these areas offer opportunities for cost savings and other tangible benefits including improved brand recognition and worker health and safety. They also help reduce resource consumption and advance waste prevention.

The study identified two new insights about the industry's environmental priorities and actions. First, a craft brewery's size matters when it comes to environmental priorities. Nanobreweries with fewer than 1000 bbl/year are most interested in implementing energy efficiency measures (96% vs. 75% for larger craft breweries) and switching to using safer chemicals for cleaning and sanitizing (78% vs. 50% for larger breweries). Energy use is typically the most significant expense for a small brewery outside of labor, and such facilities lack the time and resources to identify and implement efficiency measures even when state subsidies may be available. The higher interest in switching to safer chemicals for cleaning and sanitizing by nanobreweries could be associated with the fact that owners/founders are typically directly involved in the beer manufacturing process and may be concerned about their own exposures as well as family members' exposures (as many nanobreweries are family-owned businesses). This finding also demonstrates that the smallest craft breweries are more interested in making changes and experimenting with new processes around energy efficiency and safer chemicals for cleaning and sanitizing.

Second, the study raises the question about the impact of a craft brewery location on its environmental priorities and actions. Massachusetts is well-known for its high environmental awareness, stricter environmental laws, and generous incentives for clean energy and energy efficiency. It has been rated as the #1 and #2 most energy-efficient state in the U.S. by the ACEEE for over a decade [89] and was among the first states to ban disposal of organic waste in landfills in 2014. In late 2023 it also moved to restrict some single-use plastics. Previous research has found that environmental regulatory pressures are positively linked to proactive environmental practices by SMEs [90]. Porter & Kramer [91] have also emphasized the "profound effect" of a business location on firm productivity and innovation, which still remains understudied by researchers, especially in regard to the craft beer industry. They argue that companies can create economic value by creating societal value. Such "shared value" helps "uncover new needs to meet, new products to offer, new customers to serve and new ways to configure the value chain, where the resulting competitive advantage will often be more sustainable than conventional cost and quality improvements". Future research should aim to examine the impact of a state's environmental awareness and policies on craft breweries' priorities and actions. Many craft breweries are already collaborating along the supply chain and with peers to experiment with local sourcing, can carriers reuse, and BSG repurposing, among others.

6. Conclusion

The main contribution of the present study is providing empirical research about the priorities, drivers, and barriers for craft breweries to adopt pollution prevention and other environmental practices. The results highlight several important implications for future research, policy, and practice. First, the industry is strongly committed to reducing their environmental impacts, however, they face some significant barriers such as a lack of financial resources, time, and knowledge about their opportunities. Effective interventions should incorporate access to capital, subsidies, and grants/tax reductions, educational and technical support through workshops, webinars, and on-site assessments. Second, "Green Brewery" recognition programs are of high interest to craft breweries and can provide credibility to their efforts as well as further educate consumers and promote brand differentiation. Third, providing technical support via facility assessments and ROI analysis is critically important for an industry that reports it lacks time and knowledge. Leveraging local business schools and university research centers' capabilities could be a win-win for the industry and educational institutions increasingly seeking to implement community-engaged teaching and research. Fourth, the size of a brewery matters when it comes to environmental priorities and drivers. Finally, environmental awareness and government policies in a brewery's community may be an important driver for its environmental priorities and actions.

The present study has several limitations. First, the sample of craft breweries was small and did not allow for conducting a more rigorous statistical analysis. Second, all breweries were based in Massachusetts, a state with high sustainability awareness, and numerous environmental policies and actions, which may not be representative of craft breweries in other states or countries. Third, the study did not explicitly examine craft breweries' interest in adopting renewable energy—a crucial strategy for addressing climate change and reducing energy costs. Fourth, there is a possibility of selection bias—breweries which were interested in implementing pollution prevention and sustainability initiatives were more likely to participate in the survey, so they could get free technical assistance from the project team.

Future research should consider including a larger number of breweries from several different states or countries, to examine potential similarities and differences based on the environmental policies and awareness of their location. In addition, researchers should compare breweries' self-assessment to a third-party assessment to identify potential discrepancies (due to lack of knowledge or responder's bias). It should also examine craft breweries' interest in adopting renewable energy such as solar and wind (by either installing solar panels and wind turbines or subscribing to community solar). Finally, future research should examine the reasons for craft breweries not promoting their P2 and environmental sustainability work publicly. Craft breweries are important social actors and as such play a key role in educating customers and experimenting along the supply chain with more sustainable practices to reduce their environmental impacts. Understanding their priorities, drivers, and challenges is crucial for implementing effective policies and interventions that support and recognize first movers while helping shift the entire industry towards more sustainable production and consumption.

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Data Availability

The data set used for the article is not publicly available due to confidentiality concerns (the survey included contact information for each of the participants). Researchers interested in obtaining anonymous data set can contact the lead author at vesela.veleva@umb.edu.

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Author Contributions

Conceptualization, Funding acquisition, and Writing – original draft: V.V.; Statistical analysis, Validation, and Methodology: S.T.; Writing – review & editing: K.B.; Data curation and Formal analysis: J.M.; Survey design and Project administration: R.V.

Conflicts of Interest

The authors have no conflict of interest to declare.

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