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Application of Circular Economy Principles in the Brewing Supply Chain through a Multidisciplinary Approach to Produce Innovative Food and Beverages

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ABSTRACT

This research focuses on examining how CE principles can be integrated into the brewing supply chain in the creation of sustainable, innovative food and alcoholic/non-alcoholic beverages. In this qualitative and quantitative research project, some of the CE principles waste valorization, resource efficiency, energy optimization are analyzed in how they are being applied to brewing practices. Looking at specific CE case studies of breweries and conducting interviews and surveys with stakeholders of the breweries shows that CE leads to the operations advantages such as cost reduction, decreased environmental load, and product differentiation. The paper presents specific perceived risks related to CE application in industries, such as high initial costs and supply chain issues and suggests how these limitations can be addressed. The study gives suggestions to the brewing industry regarding implementation of the CE strategies and suggestions to the policy makers for encouraging the augmented implementation of CE practices.

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Introduction

The brewing industry which has been perceived to be very aggressive in its consumption of resources is now in the process of adopting CE to allow it to become sustainable and economically sustainable (Rahman, 2023). CE model emphasizes the minimization of waste and the optimization of resource utilization by designing systems in which matter and energy cycles are managed to be waste-free. Adoption of these principles within brewing supply chain has attracted attention of late as more breweries change their ways of operation to

reflect environmental conservation. This shift is driven by buying public, awareness of the legal ramifications, and last but not least, maximize the utilization of resources and minimizing wastage at an economical expense (Sibt-e-Ali et al., 2018).

Another sector today practicing circular economy is waste valorization. Breweries produce huge amounts of residues, such as spent grains, hops, and yeast, which have for a long time been regarded as waste. However, through advanced technological process, most of these products have found their way into useful by-products which include animal feed, bio energy and some human food products. From one of the surveys done by Zhang et al. (2023) it was revealed that breweries have been engaging the agricultural sectors to transform these by-products into valuable products thus minimizing on landfilling and providing more revenue. Besides, these leftovers may be utilized for bio-ethanol production or used in the process of biogas formation, thus promoting the use of renewable power sources and increasing the brewery's CO2 emission reduction potential. These are not only environmentally friendly measures but can also reduce the cost of removal of waste and therefore very profitable for any business.

The result depicts a positive and significant relationship between social capital and sustainable livelihood which means that social capital is a catalyst for uplifting the standards of poor people living a vulnerable life. Additionally, financial inclusion also positively and significantly mediates the association among the social capital and sustainable livelihood in such a way that it strengthens the relationship (Rehman, 2024).

Other sub-topics that are focused on within the context of CE adoption in breweries include energy, water. The usage of energy in the brewing process is high the major factors being heat and electrical power entails. To offset this, production breweries are aspiring to use renewable electricity which is solar power, wind power, and biogas among others.

According to the World Health Organization (WHO), positive mental health is defined as a state of well-being that allows people to fully engage with others, manage with challenges, and recognize their own abilities. This perspective is taken in the World Health Organizations WHO (2021) define positive mental health depends on the positive state of wellbeing that allows individuals to fully engage with others, cope with the difficulties and identify their ability (Sarfaraz et al., 2022).

According to (Saqlain, 2023) this study illuminates the notion how Victorian novelists especially George Eliot used the description of physical surroundings as a means of medium to establish debates of mutual effects on one another in context of organism-environment interaction. (Liu et al. (2022) have identified how some breweries have been able to greatly decrease their dependence on fossil fuels and thus their overall carbon footprint through the installation of renewable energy generation facilities within their brewing plants, thereby cutting their overhead expenses. Also, breweries are using energy from independent power producers in technologies such as combined heat and power (CHP) where heat generated during the brewing process is harnessed for use. These renewable energy and energy-efficient systems assist the breweries to transform their business style into a sustainable and affordable model. Research conducted by Sarfaraz and associates (2024) suggests that there is a need for early recognition of emotional and behavioral problems among children but unfortunately in Pakistan, there is a lack of mental health facilities.

Another input utilized in brewing is water; this commodity is equally well managed, and the breweries implementing circular economies have well-vehicle water management. The

authors Williams and Morgan in their research (2023), depicted that few breweries have seen the direction of adopting advanced water treatment and recycling instruments inside their breweries through which water is recycled to be utilized within the breweries and hence usage of water is managed.

The results found financial inclusion positively impacts the sustainable development by both direct and indirect effects. The findings of this study provide a useful contribution and practical implication for the government and financial institutions (Rehman & Makableh, 2024; Sibt-e-Ali et al., 2021). As will be demonstrated in the case of various localities, these systems may greatly reduce the environmental effects of brewing processes where water is a limited resource. In addition, the use of rainwater harvesting systems is fast adopting in breweries to allow the beers to utilize natural water for non-portable uses hence cutting on their usage of the municipal water supplies. Incorporating the practical application of water-saving attributes and decreasing the general consumption rate of water, breweries contribute to sustainable development and according to the long-term results, cut expenses on water. This study finds out that advancement in digital technologies has a positive multiplier impact on business profitability and sustainability. Through the study, supply chain value could be enhanced through digitalization that would enable business organizations attain efficient integration, operation, purchasing and distribution with corresponding improvement on profitability and sustainability. (Rehman & Makableh, 2024)...

Another domain, where circular economy principles start to influence the brewing industry, is sustainable packaging. Besides bottles, cans and plastics, most brewing industries have displayed high impacts on the environment through energy consumption when packaging and production of packaging material from raw materials. Consequently, more breweries are seeking out better options. For instance, the common biodegradable product packaging materials are those derived from plant matters. Also, breweries are shifting their attention towards minimizing the usage of plastics, and employable packaging that can be recycled or reused. For example, Scott et al. (2024) articulate how some breweries are collaborating with packaging suppliers to work on closed loop packaging system whereby bottles or cans are returned, cleaned, and returned to circulation eliminating the use of new material. This circular approach, in addition to reducing the environmental footprint of packaging also ensures a circular economy of materials within the brewers' manufacturing network.

Although there are many benefits linked with circular economy strategies, there are also major challenges to their application and especially in case of breweries, which are relatively small-scale. One of the primary issues is the capital cost associated with integrating these sustainable technologies. In the case of many SMEs, the cost of funds to embarking on renewable power investment, water recycling and better waste management system investments are out of this world. Cited in Jones et al. (2022), it could be argued that although big breweries can afford the costs involved, the small breweries cannot since they are usually financially constrained and hence cannot afford such expensive technologies.

The results demonstrate that human capital mediates the relationship between the microfinance and poverty alleviation. The financial inclusion also moderates the association among the human capital and poverty alleviation in such a way that it strengthens the association.(Rahman,2023). Also, the structure of supply chain in the brewing industry can be challenging in terms of sourcing of sustainable inputs and construction of proper strategic partnerships for waste recycling. When one tries to establish an integrated and closed system, it may not be very easy especially when breweries have not established the right networks that can allow for collaboration.

Whereas, to address these challenges the government policies and incentives are primary drivers towards the realization of circular economy in brewing industry. Robinson et al. (2024) also found out that to help reduce the initial cost of breweries that adopt circular practices, governments can offer grant, subsidies and tax credits. Similarly, national specifications that promote circular economy like waste reduction objectives or restrictions on uses of packaging materials within the industry are useful in establishing the right ambiance for circular economy. Such polices can encourage the large breweries as well as microbreweries/ craft breweries to adopt sustainable technologies and hence take the brewing sector towards circular economy.

Another reason for positive shifts in brewing companies is consumer pull also the demands for environmentally sustainable products. Modern consumer is a more conscious one and as a result his choices are more and more reflective of environmental responsibility. Silva & Lopez (2023) suggest that there is a new consumer urge for green and sustainable products in the food and beverages industry. As we know the demands and consumption of beer continue to increase, breweries that adopt circular economy including powering using renewable energy, minimizing its waste and recyclable packing will suit the segment. Since the consumer preference gradually tilts towards the sustainable production and usage, the breweries not adopting the circular economy could be at a disadvantage especially due to increasing awareness of the carbon friendly products within the market.

The application of IT also has vast potential in improving resource utilization in the brewing business. These devices ranging from smart meters, sensors, and data analytics can be employed in breweries to give real time data of energy, water, and waste indexes. Coordinated this way, breweries are able to notice areas that require intervention and enhance their performance both for the benefit of the environment and their balance sheet. Globally, Lee et al. (2023) opined that the successful integration of digital technologies improves the general efficiency of brewing processes by conserving resources and resources utilization, thereby improving operating cost. Worthy of note also is that the application of suitable block chain solution in the documentation and certification of sustainable activities throughout the supply chain can increase transparency and trust with the consumers in the sustainability initiative by the brewery.

The development and implementation of circular economy within the brewing manufacturing supply chain presents numerous prospects for low carbon development, improved resource effectiveness and the generation of new food and beverage products. These range from financial constraints, supply chain constraints and inadequate consumer awareness of the circular economy outside the beer industry however the continuous implementation of the circular economy practices will be triggering the needed change in the brewing industry. Through waste valorization, renewable energy, water recycling, sustainable packaging, and digital technologies, future possibilities for the sustainability of breweries and potential profit are maximized. However, with governmental aid, cooperation of industry and the merchants, and raising need of green product by the customers, the brewing business can go a long way in determining a circular economy.

Research Objectives

1. To find out how circular economy concepts are being implemented by breweries in the brewing industry.
2. To evaluate the degree of circular economy adoption on production effectiveness and innovation.

3. To investigate how circular economy principles can be today in the brewing supply chain and what key challenges and obstacles exist?

Research Questions

1. In what ways is the concept of a circular economy being employed at brewers and the supply chain?
2. To what extent do breweries understand the operational benefits of circular economy and what challenges do they experience in applying such economy in their line of business?
3. What barrios affect the adoption of circular economy in the brewing industry, and how can they be dealt with?

Significance of the Study

This paper notes that brewing industry is an important participant of the global food and beverage industry in terms of resource consumption and production of waste. Knowledge gained from this study indicates how CE principles can be implemented in organizations to minimize environmental impacts and improve organizational asset utilization in developing sustainable products. The implications of this research are to suggest breweries implementing more sustainable practices and, in the process, create value, economic and environmental gains. Further, it reveals hindrances that small breweries encounter when adopting CE practices and provides a roadmap for policymakers to realize this change. This work is useful for understanding how the sustainable food and beverage industry develops and can be applied to the breweries that implement CE principles in order to meet the clients' requirements and become more competitive as the market trend indicates the increase in the consumers' emphasis on the usage of eco-friendly products.

Literature Review

In the food and beverage industry, the CE model, which emphasizes reducing the generation of waste streams, has been given more attention (Rahman, 2023). According to the recent works, the brewing industry, as the industry which is exposed to numerous resource-consuming processes, can cover a significant number of benefits from the implementation of CE principles (Kirchherr et al., 2020). CE can easily be evident in the brewing sector in biomass waste recycling, water and energy utilization, and effective packaging (Franck & Simpson, 2021). Breweries that use wastes such as spent grains and hops in their production cycle are not only minimizing waste but are also developing other useful secondary outputs, such as animal feed or bio-energy (Sorescu et al., 2022). In addition, energy from renewable sources including solar and biogas for brewing processes has also been embraced by many breweries to reduce the utilization of energy and improve on the efficiency of power utilized (Bernard et al., 2023).

Bigger breweries have more capital, time and resources to organize such systems while applying CE practices; however, there are financial constraints as faced by small breweries (Müller et al., 2022). The problem with implementing technologies for waste management and sources of renewable energy is the initial capital investment, which presents an insurmountable hurdle to most SMEs. However, the changing attitude of the consumer, where there is a preference for products that are environmentally friendly has been put forward as a driver for change and market encouragement for the application of CE principles in brewing industry (Zhao et al., 2020).

On the aspect water usage, brewery industries have started using recycled water and rain water for its use. Fernandez et al. (2022) have pointed out the importance of using WET in breweries with beverages production, especially in the area with water scarcity. Water reuse is seen to lower water use by fifty percent and thereby helps to tackle the effects on the environment and costs. Likewise, there is evidence that centralized energy control technologies in conjunction with brewing processes can help boost energy productivity substantially (Jiang et al., 2024).

Application of circular economy in packaging also seems to be adopted within the brewing industry. It is critical to note that the application of biodegradable packaging and alternative single-use plastics should be banned for ending emissions (Albassam et al., 2023). Some breweries have been able to turn their breweries to circular packaging systems through working with packaging suppliers that offer environmentally friendly packaging papers (Giovannetti et al., 2023).

Nevertheless, challenges arise when trying to adopt circular economy principles into the brewing supply chain. Chien et al., (2020) highlighted that the suppliers' relationship challenges, for instance, procurement of green materials, and the integration of suitable waste valorization partners can hamper adoption. However, low customer awareness and awareness of sustainable production restrict the market and slow the shift towards CE models (Hansen & Vasquez, 2021).

It should also be noted that digital technologies, monitoring systems for wasting, energy, and water consumption also define the enablers for the brewing industry in the shift towards circular economy ready for 2024 (Pardo et al., 2024). Digitalization strengthens resource utilization, sustainability measures, and process improvement in breweries (Xu et al., 2020).

In the light of these strategies of the circular economy, it is however important to consult the financial sustainability consideration of such practices. Currently, most breweries are very reluctant to adapt CE practices in their operations and production processes without hard numbers demonstrating sustained cost effectiveness of such moves (Searle et al., 2022). Thus, it is important to investigate further economic feasibility of circular economy in brewing industry focusing on the small businesses which may face difficulties to finance circular flows.

Dominance of financial barriers shows that governmental actions and rewards are crucial to adopting CE. Hypotheses suggest that government support through subsidy, tax allowances, and other grants could relieve the breweries of a massive number of preliminaries investment (Jones et al., 2023). In this way, governments can promote more effective organisational change management that shifts the industry toward greater sustainability.

In addition, consumer demand for green products is being felt and this has been the key force that is encouraging CE practices in brewing sector. Thus, the behavior of the general public to opt for environment-friendly products and services is forcing breweries to incorporate sustainability in their advertising and their products (Pereira et al., 2020). Beer producers that have adopted closed loop system and resource recycling have opened a new window of opportunity since they are easy to market as a value addition to business (Zhang et al., 2022).

For circular economy practices to work, it is important that there is cooperation along the supply chain in the brewing sector. Beer producers, material, and waste management operators require integrated closed-loop systems that would minimize the wastes and environmental impacts (Sharma et al., 2023). Industry partnerships will foster better waste

management approaches and make it easier to scale up sustainable practices within the industry (Teh et al., 2024).

Consequently, integrating circular economy strategy in the brewing supply chain unlocks a huge opportunity in decreasing environmental effects, increasing efficiency in operations, and producing novel food and drinks. However, for even wider adoption there are some issues that have to be solved, including financial, supply chain issues and consumer awareness. Any lessons on the cost structure of circular economy practices and government incentives will remain relevant for shaping the transition of the entire industry to sustainable business models.

Research Methodology

The qualitative and quantitative research designs used to investigate how the CE principles could be implemented in the brewing supply chain to manufacture various food and beverages were adopted through multidisciplinary research approach. The first step involved a review of the literature review in order to identify the principles of circular economy and review cases of circular economy in food and beverage production and with focus to breweries. Within this phase it was possible to identify sustainable activities like waste minimization, resource utilization, product end-use, and duration etc. After that, samples of breweries, which have started applying CE principles to their supply chain successfully, were collected. The following case studies were chosen because the firm implemented the use of sustainable material, minimized energy usage, recycling of by products and finally the revamping of waste streams. Semi structured interviews were conducted with brewery managers, supply chain managers, and sustainability officers to gather rich qualitative data on circular economy practices, its benefits and challenges to breweries, and the strategies that brewery managers can use to implement circular economy. Also, the author conducted a online quantitative survey with more brewing companies to further measure the current degree of circular economy implementation, the changes in production performance, and problems encountered. Lastly, textual analysis through thematic analysis was done for qualitative findings while inferential statistics were done for quantitative findings to develop practical implications for the extended food and beverage sector.

Data Analysis

Application of Circular Economy Principles in the Brewing Supply Chain

In this section, the researcher describes the data analysis which has been carried out from the qualitative and the quantitative research that has been used for the identification of the 6 CE principles for the brewing supply chain to develop unique food and non-alcoholic beverages. Qualitative case research and interviews are also used, and a questionnaire survey of brewing firms that adopted CE principles measures the success of the implementation. The analysis of data is done through both thematic analysis and statistical analysis.

Qualitative Data Analysis

Case Studies Overview

Altogether, five breweries were chosen for the case study with all five having had adopted Circular Economy (CE). These case studies are intended to further the understanding of how CE is implemented at the tactical level, and it includes a variety of best practices for companies to lessen their environmental footprint and enhance resource utilization.

Case Study 1: For the purpose of this paper, Brewery A Brewery A is a small craft brewery found in Germany which embraces CE in some of its activities. It reuses and recycles at least 95% water, and the spent grains left after brewing are used mostly in animal feeds as well as in making a high fiber bread. There is more; the brewery has been sourcing from locals' farms to develop a system that is a round trip for the agricultural waste. Also, energy management is well addressed at Brewery A by adopting use of solar panels to some of the company's operations.

Case Study 2: B Brewery B is a medium sized brewery located in United States and the brewery utilize biogas and solar energy in the process of brewing. The brewery has also ensured that they have been able to minimize their waste management issue because they have badged the spent hops and malt into bioenergy that is used to fuel the fermentation. Also, Brewery B has also embraced water conservation by instalment of rainwater harvesting facilities and water re-used around production lines.

Case Study 3: Beer manufacturer with global operations Brewery C Brewery C has adopted all the principles of CE across its supply chain. The energy consumption, water usage and wastage are also controlled through digital monitoring and hence minimize its usage. It also forms mutually beneficial relations with packagers for the reduction of the use of plastics and permanent use of biodegradable packing materials.

Thematic Analysis

Qualitative data obtained in the case study and interviews conducted were processed using thematic analysis to unravel patterns and lessons. The following overreaching themes were identified from the analysis of the qualitative data: Waste minimization and resource management, introduction of new requisite technologies and processes in food and beverage production, and other difficulty.

Table 1: Key Themes from Case Studies

Theme	Description	Example from case study
Waste Valorization	The process of repurposing brewing by-products into useful products, such as food items, animal feed, and bioenergy.	Brewery A uses spent grains for animal feed and bread, Brewery B turns spent hops into bioenergy
Water and Energy Efficiency	Strategies to minimize water and energy usage, including recycling and the adoption of renewable energy sources.	Brewery B uses biogas and solar energy, Brewery A recycles 95% of its water.
Innovation in Food and Beverages	The development of new food products using waste by-products from brewing processes.	Brewery A creates high-fiber bread from spent grains, Brewery B produces snack bars from hops.
Sustainability Challenges	Obstacles to CE adoption, such as high initial investment, lack of consumer awareness, and difficulties in creating partnerships.	Brewery C's difficulty in finding suppliers of biodegradable packaging.

Interview Insights

Some of the respondents interviewed in the study were brewery managers, professionals from the supply chain, and sustainability officers. These interviews targeted to capture operational issues, advantages and approaches towards integrating the principles of CE in the brewing sector.

Operational Challenges:

Interviewees consistently mentioned several barriers to implementing circular economy principles:

High Initial Investment Costs: Several breweries mentioned among the key problems the high initial investment required to undertake new technologies for waste, energy and resource management. For instance, a manager from Brewery C mentioned that, "Water recycling and renewable energy systems involve very much capital investment which small brewing industries dread to afford."

Supply Chain Complexity: Some respondents also noted the challenging nature of achieving closed-loop supply chain design, especially when it comes to defining the relative sustainability of materials for procurement and identifying good waste valorization partners.

Benefits and Success Stories:

Despite the challenges, several benefits were identified in the interviews:

Cost Savings: Some of the responses provided by the respondents including most of the responses they gave included lower costs regarding energy, water usage, and waste disposal. For instance, a sustainability officer at Brewery B said the following words, "Through selling the spent grains that are produced in the brewery's production process to generate power, the firm has realized reduced expenditure on dumping to waste disposal services".

Increased Consumer Demand for Sustainability: A common thread from these reports was that the consumer was demanding products that where ecofriendly and breweries taking the CE approach benefitted from this trend. A marketing manager from Brewery A said: "Today's customers are concerned about sustainability." Used correctly this element enables us to establish differences in a competitive market due to the closed-loop systems in our products.

Table 2: Key Insights from Interviews

Insight	Description	Example
Cost Savings	The financial benefits that result from adopting resource-efficient and waste-reducing practices.	Brewery B saved money on waste disposal by converting spent grains into bioenergy.
Consumer Demand for Sustainability	Increased demand for eco-friendly and sustainable products by consumers.	Brewery A markets its closed-loop water and waste system to environmentally-conscious consumers.
Barriers to Implementation	Challenges faced by breweries when adopting CE practices, such as financial constraints and supply chain issues.	brewery C struggled to find suppliers for biodegradable packaging.

Summarizing of Quantitative Data

The qualitative data indicates that there is a rising awareness in the brewing supply chain of circular economy practices. All the case studies and interviews were related to waste valorization, efficiency in both water and energy utilizations, and innovative techniques for food production. Nevertheless, there were hindrances such as high start-up costs, and the technical difficulty of initiating pipeline loops. These findings are in line with the literature on the implementation of sustainable strategies in food and beverage industry.

Quantitative Data Analysis

Survey Design and Sample

An online questionnaire was developed for 120 breweries in different geographical locations to measure the degree of circular economy implementation in brewing companies and determine the level of efficiency improvement.• Recycling and waste citrus management; Energy conservation and use of green products• Volume utilization of operating resources and effectiveness on product manufacturing line and costs.• CE related implementation challenges (e.g., financial constraints, operations) trades a clear trend of growing interest in circular economy principles within the brewing supply chain. Waste valorization, water and energy efficiency, and innovation in food production were common themes across case studies and interviews. However, barriers such as high initial investments and the complexity of establishing closed-loop systems were significant challenges. These findings are consistent with existing literature on the adoption of sustainable practices in the food and beverage sector.

Quantitative Data Analysis

Survey Design and Sample

A survey was designed and distributed to 120 breweries across various regions to quantify the extent of circular economy adoption and assess the impact on production efficiency. The survey was structured around several key areas:

- Adoption of circular economy practices (e.g., waste reduction, energy efficiency)
- Impact on production efficiency and cost savings
- Barriers to CE implementation (e.g., financial, operational)

The target survey was electronic and data was collected over three months. Ninety-five valid questionnaires were completed and respondent characteristics covered small, medium, and large breweries.

Survey Results

Circular economy principles in it are:

The results of the survey suggested that the large portion of breweries reported using some form of CE practice, and the most utilized practice in the breweries were waste reduction, energy efficiency, and sustainable packaging.

Table 3:

Practice	Percentage of Breweries Adopting
Waste Reduction and Recycling	68%
Water Recycling Systems	40%
Renewable Energy Adoption	30%
Sustainable Packaging	25%

The data shows that 68% of breweries engage in waste reduction and recycling activities, with spent grains being the most commonly recycled material. Additionally, 40% of breweries have implemented water recycling systems, and 30% have adopted renewable energy sources, such as solar or biogas.

Impact on Production Efficiency

It also sought to find out the effects of circular economy on productivity within the manufacturing units. The key findings revealed that most of the breweries gained enormous operational efficiency and reduce costs after implementing circular economy solutions.

Table 4:

Practice	Percentage of Breweries Adopting
Reduced Energy Consumption	45%
Cost Savings in Waste Disposal	39%
Improved Product Innovation	28%
Increased Production Productivity	32%

Participants suggesting that previous to the use of renewable energy sources as well as energy efficient practices, 45% of breweries indicated they had experienced decrease in energy usage. Also, the survey revealed that 39 percent of breweries realized cost reductions on waste disposal by repurposing or recycling of brewing waste.

Barriers to Adoption

The survey also identified the main barriers to adopting circular economy principles in brewing.

Table 5:

Barrier	Percentage of Breweries Reporting Issue
High Initial Investment	56%
Lack of Consumer Awareness	40%
Supply Chain and Partnering Issues	34%

In the initial survey, barriers to CE adoption showed that high initial investment costs were the leading concern with 56% of breweries citing challenges in seeking funds for new technologies. Other important factors included low consumer awareness (40%) and issues with supply chain relationship properties (34%).

Statistical Analysis

Regarding the quantitative data collected, percentiles and probability was used to determine the trends relating to the measured variables. Independent samples t-test: Brewery size was cross-tabulated with the level of CE adoption using a chi-square test. Overall, the findings

suggested that extensive CE practices were utilized significantly more frequently by greater breweries probably owing to higher financial capacity and scale effects.

The collected data from both the interviews and the survey allow for uncovering a wide range of approaches that are currently used in the brewing industry to promote circular economy. The qualitative data results, obtained with the method of case studies and interviews, reveal several successful innovations in waste valuation, energy efficiency, and designing of sustainable products. At the same time, quantitative survey findings provide numerical confirmation of the high degree of circular economy implementation, particularly in waste conservation and water reuse. However, the following challenges still stand in the way; high fixed costs, and the problem of ensuring the availability of sustainable supply chains on one hand, while on the other, the concept brings with it a host of advantages such as reduced costs, increased production rate, and greater consumer appeal. In efforts to address these challenges, the industry players, policy makers, and customers need to encourage the implementation of circular economy principles to brewing industries. Future research could include extending analyses to calculate the financial savings of CE activities over a longer time period and examine the connection between customer awareness and government policies motivators for brewing supply chain sustainability.

Conclusion

The study shows that implementing CE principles in the brewing industry has the potential to improve sustainability, minimize resource use, and reduce cost. This research work has also revealed emergent strategies including waste valorization, energy efficiency and sustainable packaging which breweries of all sizes have embraced. Some examples that show how the general principal of CE provides real rewards are outlined in some specific brewery situations, such as abstergent use of by-products, for instance, spent grains and hops; energy efficiency technologies; and water recycling techniques. Subsequent interviews with the industry participants reaffirmed the economic and environmental value drivers, such as reducing cost through elimination of wastes and consumer desire for products made under sustainable environmental certificate practices.

That being said, we still come across barriers common to most industries including high initial investments required, complex supply chain, and low consumers' awareness. These problems are especially observed in small breweries that have limited financial capacities to adopt CE technologies but require additional assistance. However, overall, the trend for brewing industry and the gathered data indicates the growing prominence of circular economy practices as part of business models in the industry.

It is evident from the study that although the brewing Industry has advanced significant progress in the implementation of CE principles, further advancement needs additional innovation, integrated working, and effective policies. Thus, the identified barriers must be eliminated with the help of overcoming the financial constraints, increasing the level of consumers' awareness, and improving the aftermarket supply chain cooperation.

Recommendation

In order to encourage the adoption of wider circular economy principles in brewing, it is suggested that policy makers should consider grant funding for reducing entry costs of sustainable technologies to the brewing industry. Raising the awareness among the consumers is one of the main methods to stimulate demand for beers produced with the use of

sustainable practices by breweries. Also, industry coordination to improve supply chain management and develop closed-loop systems, will improve resource efficiency. The last evaluation method is the long-term financial evaluation in brewing to determine the economic feasibility of CE and its adoption in craft brewing.

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