Chapter 4
Circular Brewery: A Transformational Journey to the Circular Economy

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Abstract This chapter examines the integration of circular economy principles in the brewing industry, focusing on the transition from linear to circular production and resource-efficient models. Through a literature review and the analysis of different brewing companies, the research analyzes how the brewing industry implements circular practices and to what extent these approaches align with established theoretical principles.

Key findings reveal significant potential of revalorizing brewery by-products, transforming these into animal feed, human food, bioactive compounds, or bioenergy. Innovative approaches such as wastewater recycling and biogas production further showcase the industry's ability to close resource loops. Notable examples include a Swiss brewery, which implements advanced heat recovery systems and utilizes biogas for energy needs.

Despite these advances, financial constraints, technical challenges, and regulatory barriers hinder widespread adoption, particularly for small breweries. This chapter underscores untapped opportunities, including Scope 3 emission reductions and enhanced by-product utilization. Achieving a fully circular brewing industry requires long-term investment, stakeholder collaboration, and consumer engagement.

Keywords Circular economy · Business transformation · Supply chain transformation · Brewing industry · Value networks

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Introduction

Beer production has been on the rise in recent years, and the use of linear economic models in production is very common (Amienyo & Azapagic, 2016). This is associated with some environmental damage. Beer production consumes a lot of water and produces a high volume of wastewater (Simate et al., 2011). In addition, the high energy consumption, which is mostly based on fossil fuels, is associated with carbon dioxide (CO_2) emissions. Furthermore, a considerable amount of waste and by-products are produced, which are discarded and not utilized further (Ortiz et al., 2019). Therefore, a transformative shift toward sustainability, driven by the principles of the circular economy (CE), is needed. At its core, circularity reimagines the brewing process, turning waste into resources, optimizing energy use, and reducing environmental impact. This approach is vital for addressing the industry's significant challenges (Rachwał et al., 2020).

One of the key aspects of circularity in brewing is the repurposing of by-products such as spent grain and yeast. Brewery by-products have valuable properties that make them suitable for use in the food industry, but their potential is currently underutilized (Rachwał et al., 2020). Traditionally considered as waste, these materials can be upcycled into animal feed, bioenergy, or even sustainable food products. Similarly, water management strategies, such as advanced filtration and wastewater recycling, play a critical role in minimizing water usage, a pressing issue given the large quantities required in brewing (Pasquet et al., 2024). Moreover, renewable energy integration and waste heat recovery contribute to reducing the industry's carbon footprint while lowering operational costs (Ortiz et al., 2019). By understanding the potential of these by-products, researchers and industry professionals can design innovative ways to utilize what was previously considered waste, contributing to sustainability and resource efficiency in the brewing and food industries (Rachwał et al., 2020).

However, implementing circular practices is not without challenges. Breweries, especially smaller ones, may face financial and logistical barriers in adopting advanced technologies for waste management and renewable energy. Establishing closed-loop systems also requires collaboration across the supply chain and significant upfront investment (Cimini & Moresi, 2021; Pasquet et al., 2024).

To study the transition from linear to circular models in the brewing industry, a qualitative research method is employed to conduct a comparative analysis of theory and practice. For this purpose, a literature review was carried out, and an interview with a beer producer was conducted. Relevant studies in the fields of CE and the brewing industry were systematically searched for. The search involved the use of multiple databases and specific search terms to identify relevant studies. The databases searched included Swisscovery, Google Scholar, ScienceDirect, and PubMed. Each database was queried using a combination of keywords related to the topic. To identify relevant studies, the process began with an examination of the titles of all retrieved studies to assess their relevance to the research. Subsequently, the abstracts of the remaining studies were read and analyzed for their alignment with the research objectives. Studies selected for use were chosen based on their relevance to the research question and their quality. For the interviews, a large beer producer in Switzerland was selected to investigate their CE strategies (Velenturf & Purnell, 2021).

In order to achieve a more profound comprehension of the principles of CE in the context of the beer industry and to support companies in the implementation of relevant strategies, this study will address the following research question: How does the brewing industry implement circular practices, and to what extent do these approaches align with established theoretical principles? The results of the literature review and the interview are reviewed in this chapter to identify common patterns, success factors, and differences in the approaches to circularity among the companies studied.

Theoretical Framework

Overview of CE Principles

Conventional economic models are predicated on a linear approach, whereby natural resources are processed into saleable products, which are then utilized by consumers and subsequently discarded (Xie & Lu, 2022). Linear business models operate under the assumption that resources are infinite, resulting in their inefficient utilization. This leads to substantial levels of waste and pollution (Salvador et al., 2020). According to the principles of the CE, the transition from linear models to a closed-loop system is essential (Xie & Lu, 2022).

The concept of a CE has been defined in a wide variety of ways. Nitkiewicz and Pachura (2022, p. 384) provide the following definition: "Circular economy refers to the synchronization of forward and backward flows of goods and materials in a way to support the closure of all loops, through application of different processes, such as reuse, repair and refurbishment, remanufacturing and recycling." Geissdoerfer et al. (2017, p. 766) define CE as "a regenerative system in which resource use and waste, emissions and energy losses are minimised by slowing, closing and tightening material and energy cycles." The common denominator of the various definitions is the objective of optimizing the use of resources, although the criteria for what constitutes "optimization" remain open to discussion. The overall objective of a CE is to reduce the rate of depletion of resources, minimize their exploitation, develop waste prevention, and restore and regenerate the environment. Circular products are created with durability, repairability, and recyclability in mind. For example, modular designs allow components to be replaced or upgraded rather than discarded. Materials are preserved in use through a series of feedback loops. The objective of recyclability is to establish a closed-loop system. Biological materials are subjected to composting processes, which, in turn, are returned to the soil, while technical materials such as metals and plastics are refurbished or recycled. To minimize waste and ensure efficiency, products must be designed accordingly (Favi et al., 2017).

A CE is based on three principles: Reduce, Recycle, and Reuse (Ketenci, 2024). The CE's primary principle is the elimination of waste and pollution, contradicting the current economic models that operate on a linear "take-make-waste" system (Xie & Lu, 2022). The second principle of the CE focuses on maximizing the value of products and materials throughout their lifecycle. This principle advocates for keeping resources in active use for as long as possible, in one of three forms: as complete products, as components of other products, or as raw materials for new products. The goal is to create a closed-loop system where nothing is wasted, and the inherent value of materials is preserved. The CE's third fundamental principle focuses on regenerating nature. By transitioning from a linear economic model to a circular one, opportunities are created to support and enhance natural processes. This shift allows the reduction of pressure on natural resources, to minimize pollution and waste, restore degraded ecosystems, and enhance biodiversity (Morseletto et al., 2022).

To achieve the objectives of the CE, a variety of strategies have been developed (Alamerew et al., 2020). A significant strategy is the 9-R strategy. This framework consists of strategies that range from the most circular to the least circular. The following is a list of the strategies (Morseletto et al., 2022; Alamerew et al., 2020):

– Refuse: Avoid purchasing unnecessary or unsustainable products.
– Rethink: Reconsider consumption and production patterns to reduce their environmental impact.
– Reduce: Limit the consumption of resources and the production of waste.
– Reuse: Use products again in their current form.
– Repair: Extend the life of products by repairing them.
– Refurbish: Restore or improve existing products.
– Remanufacture: Manufacture new products from used parts.
– Repurpose: Find new uses for products or their components.
– Recycle: Transform waste into new raw materials.

The effective implementation of circularity requires a holistic consideration of the economic, environmental, and social dimensions. For a product to be considered circular, it must align with all three dimensions. In that regard, social aspects need attention to generate intergenerational equity and broader social justice issues. Most discussions on social benefits focus narrowly on job creation, neglecting to address broader issues such as social equity, resource distribution, labor exploitation, and power dynamics within value chains. It is also focused on preserving and regenerating natural capital, transitioning to restorative practices that deliver environmental net-gains. Ultimately, the viability and sustainability of circular practices depend on their profitability (Terra Dos Santos et al., 2023).

Transition from Linear to Circular in the Brewing Industry

The transition to a circular model holds considerable potential in the field of beer production, offering novel perspectives on resource reuse (Ortiz et al., 2019; Pasquet et al., 2024). This shift not only enhances brand value but also provides competitive advantages and mitigates the risk of future regulatory changes (Julkovski et al., 2023).

The production of beer is a process that requires four fundamental ingredients: malt, hops, yeast, and water. Depending on the specific recipe, other ingredients such as wheat, rye, or barley may also be incorporated (Pasquet et al., 2024). The production of beer involves a series of process steps, including mashing, boiling, fermentation, and filtration. These steps result in the generation of various by-products such as brewers' spent grain (BSG), brewers' spent yeast (BSY), brewers' spent hops (BSH), and brewery wastewater (BWW). The process entails the removal of solid materials through a series of separation and filtration steps (Cimini & Moresi, 2021; Pasquet et al., 2024). One of the biggest by-products of the brewing process is the spent grain (Sganzerla et al., 2021). Many breweries work with farmers who use it to feed their livestock (Ortiz et al., 2019). While this is already a good alternative to disposal, there is still greater potential for its utilization, such as recovery of bioactive compounds, valorization as human food, bioconversion, and more. For example, a variety of extraction technologies can be used to recover lipid, protein, carbohydrate, lignin, and related bioactive compounds. These can then be used in the food and biotechnology sectors (Pasquet et al., 2024). One other by-product is yeast, which can be recovered at the end of fermentation and reused for the next batch. However, it should be noted that the performance is slightly reduced (Pasquet et al., 2024).

Another circularity strategy is the use of stale bread instead of malted grains to make beer, which has shown positive results in terms of taste and similar physio-chemical properties. This could reduce brewers' consumption of malt and avoid food waste (Pasquet et al., 2024).

A different possible use of by-products is the production of biogas and electricity. Methane can be produced by fermenting the biomass. This methane can be used to generate electricity and heat. Those can either be used directly in the brewery or fed into the grid (Pasquet et al., 2024). Furthermore, a way to make the brewery's energy consumption more sustainable is to implement and use renewable energy such as solar or wind power (Cimini & Moresi, 2021). The main energy consumed in the brewing process is the thermal energy required for the heating and cooling steps during the process. The use of heat exchangers and the general minimization of heat losses, as well as the use of the methods mentioned above, can be useful in reducing energy requirements (Ortiz et al., 2019).

Brewing beer produces a lot of wastewater, which is often not reused and ends up in the environment. This wastewater could be put to good use in agriculture, as it has been shown to have a positive effect on plant growth by using the nutrients in the wastewater as fertilizer. This would reduce the amount of fresh water needed and reduce the amount of fertilizer needed to be used (Pasquet et al., 2024).

The production of glass and aluminum packaging is another resource-intensive process. By using reusable glass bottles and steel kegs, the energy, raw material, and overall carbon footprint can be reduced. However, compared to disposable bottles, they still produce more waste and use more water, even after multiple uses. To keep the carbon footprint as small as possible, it would be advantageous to reduce the weight of the packaging, reuse the bottles as often as possible and recycle them at the end of their life cycle, and produce new bottles from a high proportion of recycled material (Cimini & Moresi, 2021).

Circular Practices in the Brewing Industry

Methodology

To evaluate whether circular practices are already being implemented in the brewing sector, it is logical to examine practical examples of implementation. For the purpose of this paper, one company example was examined through an interview, and other examples with public information.

The interview was conducted with Feldschlösschen, a large brewery near Basel, Switzerland, founded in 1876 (Feldschlösschen, 2025a). To investigate the sustainable and circular practices implemented at Feldschlösschen, an interview was conducted. A qualitative interview approach was selected to emphasize openness, flexibility, and responsiveness to context. As it involves iterative steps to gain specific insights and allows for establishing a more personal connection, conducting the qualitative research as an interview was deemed appropriate (Busetto et al., 2020).

A qualitative interview is a communication process that results in text as data. Interviews are, therefore, one of the most commonly used data evaluation methods. They are not conducted to get the objective truth but to gain subjective insights and examples from the industry (Hollenberg & Kaup, 2023). This use case is based on an interview conducted with the Chief of Technology and Sustainability of Feldschlösschen. The interview was structured as an online expert interview to gather insights into Feldschlösschen's practices and was conducted end of 2024 (Hollenberg & Kaup, 2023).

Although Feldschlösschen has a sustainability report, reports are typically prepared to meet the requirements of specific stakeholders; therefore, obtaining more detailed information was essential (Amstutz, 2023). The interview was semi-structured, aiming to gain insights into personal perspectives, experiences, and opinions (Busetto et al., 2020). A semi-structured interview is based on an incomplete script. It includes prepared questions, but those are improvised during the interview (Myers & Newman, 2007). A semi-structured interview guide was prepared. The questions were collected, reviewed, refined, and organized to ensure a structured interview process.

The interview was transcribed using the Microsoft Teams transcription function, which can transcribe Swiss German. Subsequently, the transcription was reviewed and refined using ChatGPT to enhance its clarity. Filler words and redundant phrases were removed, the dialect was converted to High German, and linguistic errors were corrected to ensure the interview was comprehensible (Busetto et al., 2020). Furthermore, ChatGPT was used to code the interview and assist in identifying topics, categories, and concepts. Complete sentences were coded within specific subtopics related to circular brewing (Kuckartz & Rädiker, 2024).

Use Case of Feldschlösschen

The interview with the person responsible for sustainability at Feldschlösschen covers the brewery's implementation of circular practices, as well as the opportunities and challenges associated with the use of such practices. Hereby, Feldschlösschen has published sustainability reports since 2014 (Feldschlösschen, 2025b). However, according to the Chief of Technology and Sustainability at Feldschlösschen, the brewery has employed various methods and partnerships since 1975 and has progressively implemented more measures over the years. Their sustainability initiatives encompass multiple areas, though the focus of this chapter is on the implementation of circular measures. To identify these measures, statements from both the sustainability report and the interview are referenced and analyzed in the following.

Feldschlösschen utilizes several by-products of its production for various use cases. Brewer grains, for instance, are repurposed as high-quality raw materials in Switzerland, primarily as animal feed. In 2023, the brewery had 40,000 tons of brewer's grains as a by-product, of which 10,000 tons were used to replace imported animal feed, which is otherwise often transported from overseas (Amstutz, 2023). Ensuring that these materials are utilized without extensive supply chains is crucial for Feldschlösschen. They classify brewer's grains as high-quality products and sell them. Another by-product used by Feldschlösschen is yeast, which is used as animal feed or in the cosmetic industry. Feldschlösschen strives to position yeast as high as possible in the value chain. However, utilizing yeast for human consumption requires stricter hygiene and control mechanisms. Additionally, the alcohol produced as a by-product of non-alcoholic beer production is used to heat up the brewery, accounting for 35.3% of its required fuel energy (Amstutz, 2023).

In the interview, the production of biogas as a circular initiative, derived from wastewater fermentation, was highlighted. Biogas provides 37.2% of the brewery's required fuel energy and is used as heat energy (Amstutz, 2023). Approximately 1.2 million cubic meters of biogas are produced annually. However, the volume has been decreasing due to optimizations in wastewater production, which is preferable, as preventing by-products is more beneficial than reusing them.

Another circular measure is the utilization of waste heat. In the interview, it was explained that waste heat is used in collaboration with the Wärmeverbund Rheinfelden district heating system, which has supplied heat for commercial and residential applications throughout the city since 2014. Additionally, steam released during the wort boiling process is condensed via a turbine and reused. The condensed steam is employed in a heat exchanger to reheat the wort, with the process maintained by a mechanical vapor recompression. Furthermore, wort exiting the brewhouse at approximately 97 °C is cooled through a heat exchange process with cold brewing water. This brewing water is heated during the exchange and is reintegrated into the brewhouse process, effectively recycling thermal energy and reducing overall resource consumption.

The expert at Feldschlösschen emphasizes the importance of bottle recycling and reuse for achieving circularity. However, this process is constrained by bottle wear and tear and infrastructural challenges, such as the availability of reuse systems in gastronomy and supermarkets. Currently, 190 products of Feldschlösschen are sold in reusable packaging. For non-reusable packaging, the brewery uses plastic or aluminum. The plastic used is 100% recyclable, and the aluminum used is 66% (Amstutz, 2023). The Chief of Technology and Sustainability at Feldschlösschen underscores the necessity of political and legal frameworks to establish a comprehensive system for achieving circularity.

Overall, both environmental and economic opportunities in implementing circular brewery systems were identified in the interview. The circular projects implemented at Feldschlösschen do not generate revenues, but they are economically viable. In the interview, Feldschlösschen was considered a pioneer in sustainability issues, as it has implemented measures for many years and is gaining a competitive advantage through sustainable and circular practices. The projects positively influence the company's reputation, garnering substantial positive feedback from customers. The expert at Feldschlösschen advocates for stronger legal and governmental regulations to enhance circularity further in the brewery sector.

Nevertheless, several challenges were acknowledged in the interview. Technical challenges include managing, for example, the wastewater plant, where it is difficult to cope with peak times when very large volumes of wastewater are suddenly produced. Additionally, low temperatures reduce the efficiency of the fermentation process. Realizing large-scale projects entails high costs, as they only pay off over extended periods. Therefore, it is crucial for stakeholders to adopt a long-term perspective and invest sustainably. The Chief of Technology and Sustainability at Feldschlösschen stresses that profitability is a prerequisite for enterprises to implement circular practices. The most significant challenge for Feldschlösschen will be addressing Scope 3 emissions, as substantial measures have already been implemented for Scope 1 and 2, and further progress will become increasingly difficult.

Other Examples of Circular Practices

While Feldschlösschen is a prominent example of circularity in the DACH region, other breweries have also adopted innovative strategies to integrate CE principles into their operations. Notable examples include HopfON, a startup in Munich, Germany; Kronenbourg, an established French brewery; and Heineken France, which has implemented a large-scale circular initiative through its Project Circle. Together, these cases illustrate how both emerging and established actors are addressing the brewing industry's environmental challenges through diverse and impactful circular approaches.

HopfON focuses on addressing the significant waste generated during hop harvesting. For every kilogram of usable hops, approximately 3.5 kg of residual biomass—comprising leaves, spines, and vines—are produced (Dazio, 2024). Typically discarded or posing challenges in disposal, this waste is repurposed by HopfON into sustainable building materials such as acoustic panels and thermal insulation. By converting waste into valuable products, HopfON reduces landfill contributions and decreases demand for conventional construction materials, minimizing its environmental footprint.

Furthermore, HopfON operates a closed-loop system that encourages customers to return used products for recycling into new materials. This approach ensures resource efficiency and demonstrates how breweries can extend their sustainability efforts beyond beer production to encompass their entire value chain (Dazio, 2024).

In contrast to HopfON's startup model, Kronenbourg, with a history dating back to 1664, exemplifies how large-scale breweries can integrate CE principles. Its strategies span by-product valorization, energy transition, sustainable packaging, and public engagement. Kronenbourg has implemented effective strategies for managing by-products from its brewing process. For instance, in 2022, the company repurposed 76,000 tons of BSG as animal feed, supporting local farmers and reducing waste-related emissions (Kronenbourg, 2023). Additionally, 9000 tons of spent yeast were redirected to the French food industry, particularly for bakery applications, illustrating how industrial by-products can be integrated into broader supply chains to enhance resource efficiency (Kronenbourg, 2023).

Kronenbourg has also invested significantly in reducing its carbon footprint, showcasing its commitment to sustainability. A €9 million investment transformed the logistics fleet at its Obernai brewery to fully electric vehicles, thereby improving energy efficiency (Usine Nouvelle, 2023). Additionally, renewable energy and heat recovery systems have been integrated into its operations, further reinforcing the company's dedication to sustainable energy use. While these initiatives align more closely with sustainability than circularity, both approaches share the common goal of reducing environmental impact and promoting resource efficiency.

The company also actively engages the public through initiatives such as the "Recycler c'est gagner" campaign, which promotes recycling awareness during events and festivals. Moreover, its long-term sustainability program, "Ensemble vers un impact zéro," aims for zero carbon emissions, zero water waste, and zero packaging waste. While these goals primarily emphasize sustainability, they complement CE principles by addressing systemic environmental challenges and fostering responsible resource use (Kronenbourg, 2025).

In addition to the initiatives undertaken by breweries such as Kronenbourg and innovative startups like HopfON, Heineken France stands out as another key player in the brewing industry's transition toward circularity and carbon reduction. In partnership with the European LIFE Programme, Heineken France has developed an ambitious CE initiative known as Project Circle. The LIFE Programme, launched by the European Climate, Infrastructure and Environment Executive Agency (CINEA), supports public and private initiatives in the fields of environment and climate action. With a budget of €5.4 billion, it operates through four sub-programs, including Circular Economy and Quality of Life, and aims to foster innovation across the European Union (European Commission, 2025).

Project Circle exemplifies the integration of upcycling and renewable energy production within brewery operations. It focuses primarily on the revalorization of BSG, which constitutes around 20% of the output of beer production and accounts for approximately 85% of total co-products generated by the brewery (Heineken France, n.d.). Through a long-standing partnership with the Duynie Group, Heineken has implemented an innovative mechanical process that is entirely solvent- and chemical-free for separating the proteins and fibers contained in the spent grain. This upcycling approach transforms what was previously treated as waste into high-value inputs for other sectors.

On one side of the process, proteins are refined to retain their properties and improve yield, resulting in a final product concentrated to over 70%, suitable for multiple applications in the agri-food industry. On the other, the fibers are dried and combusted in a dedicated biomass boiler to produce renewable steam energy. This steam not only powers a significant portion of the brewery's energy needs but also supports the internal drying processes for both the fibers and proteins, forming a closed-loop energy system.

A notable advantage of the Circle system lies in the internal revalorization of BSG within the brewery itself. Previously, Heineken sold its spent grain to external buyers, and distribution was carried out via truck transportation, thereby contributing to the brewery's carbon footprint. With Project Circle, not only is the material still revalorized, but it is also done locally, eliminating the need for external transport. This localization significantly enhances the circular nature of the process while reducing associated CO_2 emissions, demonstrating how circularity and carbon efficiency can be mutually reinforcing when integrated into site-level operations.

According to Heineken France, the implementation of Project Circle at its Mons-en-Barœul site has led to an annual saving of approximately 20,000 tons of CO_2 equivalent, factoring in both the site's emissions and the avoided emissions from reduced transportation (Heineken France, n.d.). With its proven impact, Heineken aims to extend the Circle system to six breweries across France by 2027, reflecting a scalable and replicable model of circular innovation within the industry.

In addition to examples from Europe, recent research highlights the growing adoption of CE principles among craft breweries in southern Brazil. According to Julkovski et al., these breweries are increasingly integrating both biological and technical resource loops into their operations, demonstrating how small- and medium-sized enterprises (SMEs) can contribute meaningfully to sustainable transitions in the brewing industry (Julkovski et al., 2024). Among the most common strategies observed is the revalorization of brewing by-products, including malt residues, yeast, and trub, which are often repurposed as animal feed, compost, or incorporated into food products such as bread and cookies. Furthermore, industry initiatives such as those led by the Brewers Association are encouraging microbreweries to adopt practices that reduce water and energy consumption, thereby supporting a sustainable transition. The rise of certifications such as B Corp is also encouraging breweries to rethink their governance and environmental impact, like New Belgium Brewing, a pioneer in renewable energy and responsible packaging management.

Water reuse and closed-loop water systems also feature prominently, with some breweries investing in effluent treatment and water-saving technologies to reduce freshwater consumption—a critical concern in water-intensive processes like beer production. In terms of energy, several breweries have adopted solar panels and low-consumption equipment, contributing to carbon footprint reduction and increased energy self-sufficiency. Additionally, efforts to reuse or recycle packaging, such as glass bottles and biodegradable materials, show alignment with technical cycle strategies, even though challenges remain in scaling such practices.

Notably, innovation plays a central role in these transitions. Breweries identified in the study often pair circular strategies with product and process innovations, including the use of vegan inputs and partnerships with local cooperatives for waste collection and sorting. While some breweries have adopted a more reactive approach, others actively pursue systemic and proactive circular models, positioning themselves as local leaders in sustainability. Overall, the Brazilian craft brewing sector illustrates how CE principles can be successfully localized and adapted, even within smaller-scale, resource-limited contexts (Julkovski et al., 2024).

It is evident that, also in the DACH region, an increasing number of brewing companies are implementing circular measures within their operations. Extensive research has identified numerous examples of such implementations, with breweries integrating circularity in diverse ways. For instance, Bitburger repurposes brewer's grains as animal feed (Bitburger Braugruppe, 2025), while Gruibinger Bier (2025) and Orca Brau incorporate surplus bread from bakeries as an ingredient in their beer (Karmann, 2021). Additionally, Schweiger Bräu utilizes its wastewater for heat and electricity generation (Domke, 2022). Numerous other cases demonstrate the adoption of at least one circular principle within brewing companies.

Discussion

As demonstrated by the practical examples, the brewing industry has already implemented many circularity practices identified in the literature research. Feldschlösschen, in particular, has incorporated numerous circular measures identified in the literature review within the company. Most methods for implementing circularity in the brewing industry are used in some way at Feldschlösschen. The company can be regarded as a pioneer, having implemented several measures over many years and made long-term investments. However, it is important to note that both the interview and the sustainability report are subjective and likely aim to enhance Feldschlösschen's reputation. Statements should be critically assessed, and areas for improvement must be identified. Feldschlösschen is focusing on all aspects: reputation, economic benefits, and sustainability. The company's overall strategy does not seem to focus on becoming a circular business but rather on maintaining profitability. In the interview, it is highlighted that some measures are implemented for reputational benefits. Long-term investments also have to impact future revenue streams. There is still room for improvement in terms of circularity. While many measures are already implemented, the expert at Feldschlösschen acknowledged potential advancements, particularly concerning Scope 3 emissions and in increasing the utilization of by-products, wastewater, and waste heat. Some methods discussed in the literature, such as using methane for electricity and heat generation or collaborating with stakeholders to repurpose materials like stale bread instead of malted grains, have not been implemented (Pasquet et al., 2024), but sometimes new other innovative principles are used.

Examples from HopfON, Kronenbourg, and Heineken France highlight the brewing industry's overall potential to effectively integrate CE principles. HopfON illustrates innovative, small-scale approaches, such as repurposing hop waste and establishing closed-loop systems (HopfON, 2025). In contrast, Kronenbourg demonstrates how large, established breweries can combine industrial innovation, community collaboration, and public engagement to reduce their environmental impact (Kronenbourg, 2025). Similarly, Heineken France exemplifies how circularity can be embedded within large-scale operations through technological innovation, local revalorization of by-products, and renewable energy integration, all of which contribute significantly to emissions reduction and circular resource use (Heineken France, n.d.).

While the brewing industry has made notable progress in integrating CE principles, there are still several untapped opportunities. For example, advanced valorization of brewery by-products by recovering various compounds such as lipids, proteins, carbohydrates, lignin, and related bioactive compounds and their further reuse in the food and biotechnology sectors (Pasquet et al., 2024). In addition to by-product utilization, breweries can explore alternative raw materials to reduce their environmental footprint, like the use of food waste, such as stale bread, as an alternative to malted barley (Pasquet et al., 2024), an approach that has already been implemented by some of the companies discussed earlier. Another key factor in the brewing industry's transition to circularity is related to energy consumption. While breweries have increasingly adopted biogas and solar energy, broader integration of renewable technologies could further reduce dependence on fossil fuels (Pasquet et al., 2024) & (Cimini & Moresi, 2021). In addition, reducing the energy required by using innovative methods, such as heat exchangers and generally minimizing heat losses, would be beneficial to reduce the energy required (Ortiz et al., 2019). Furthermore, breweries consume significant amounts of water, yet current efforts to recycle wastewater remain limited. Moving to a circular approach, where all wastewater is treated and reused, could significantly reduce water consumption (Pasquet et al., 2024). Another key area for circularity improvement in the brewing sector is the improvement of reusable packaging through maximum reuse, as well as packaging weight reduction and logistics innovations (Cimini & Moresi, 2021). Addressing these opportunities could further improve sustainability, reduce waste, and create new revenue streams for breweries.

However, there are several potential challenges to the application of circular strategies. While several studies have indicated the potential use of brewery waste products, the majority of these studies have been conducted at the laboratory scale, and there is a lack of cost-benefit or market analysis and industrial trials (Cimini & Moresi, 2021). A further factor that must be considered is the consumer acceptance of the solutions proposed, which plays a crucial role in determining their overall acceptance (Duong & Saphores, 2015). In addition to the challenges mentioned, there are technical issues to be addressed. For instance, the high moisture content of the by-products gives rise to microbiological risks and requires additional processing steps, such as drying. This challenges the economic feasibility (Cimini & Moresi, 2021). A study by Ortiz et al. (2019) demonstrated that not all solutions are appropriate for small breweries, as they are neither energetically nor economically profitable. Therefore, it can be concluded that there is no universal solution applicable to all breweries, since the selection of an appropriate solution is contingent upon factors including the size of the brewery in question and its economic background (Pasquet et al., 2024).

One other key reason why companies are reluctant to transition toward circular business models (CBMs) is the lack of a strong legal framework that encourages or mandates circular practices. Currently, there are no binding regulations or sufficient incentives that push businesses to reduce their environmental impact or adopt circularity (Assmann et al., 2023). Without such external pressure, most companies continue operating within linear models, as they are already optimized for cost efficiency and short-term profitability.

Another significant barrier is the perception gap among managers. While CBMs offer benefits such as cost savings through resource efficiency, increased supply chain resilience, and improved market differentiation, these advantages are often poorly understood or undervalued by decision-makers. Companies may also fear the risk of cannibalization, where longer-lasting products reduce sales volume, impacting profitability in traditional models (Assmann et al., 2023). Furthermore, the financial and operational costs of transitioning are high. Implementing a CBM requires substantial upfront investments, new technologies, and a restructuring of supply chains. The complexity of this shift, combined with uncertainties in taxation policies, customer acceptance, and supply chain adaptation, makes companies hesitant (Assmann et al., 2023). Even if regulation were introduced, companies would still need a clear roadmap, financial support, and collaboration with supply chain partners to make the transition feasible. However, as seen in the Swiss referendum on February 9, 2025 (Tombez, 2025), both businesses and the public remain cautious about committing to CE policies, further delaying widespread adoption (Assmann et al., 2023). Without stronger political will, regulatory support, and awareness-building, CBM adoption will likely continue to progress slowly. As the industry partly transitions from linear to circular models, challenges such as economic feasibility, regulatory barriers, and consumer acceptance must be addressed.

Another important aspect of this is artificial intelligence (AI), which plays a fundamental role in enabling the transition toward a CE by optimizing resource use, enhancing decision-making, and transforming business models. AI-powered tools such as machine learning, deep learning, and predictive analytics help optimize material flows, improve waste management, and support sustainable supply chains (Madanaguli et al., 2024). AI enhances CBMs through four key capabilities: integrated intelligence, for example, by using real-time data analysis for decision-making, process automation, for example, by reducing waste through predictive maintenance, AI infrastructure and platforms, for example, by supporting circular supply chains, and ecosystem orchestration by facilitating collaboration among stakeholders (Madanaguli et al., 2024).

Additionally, AI facilitates CE by supporting system optimization, redesigning business models, and fostering ecosystem innovation (Tutore et al., 2024). Using the ReSOLVE framework (Regenerate, Share, Optimize, Loop, Virtualize, and Exchange), AI enables companies to design circular strategies that extend product life cycles, enhance resource efficiency, and develop digital solutions to replace physical products (Tutore et al., 2024). By leveraging AI, businesses can transition from linear to circular models more efficiently, reducing environmental impact while maintaining profitability. However, successful adoption requires investments in AI infrastructure and regulatory support to overcome current implementation challenges (Madanaguli et al., 2024; Tutore et al., 2024).

Nonetheless, adopting circular practices will be essential for achieving sustainability goals and ensuring the long-term viability of beer production. While the brewing industry has already integrated many circular practices identified in the literature, there remains significant room for improvement. A full transition to a CBM, rather than simply incorporating circular elements, will be key to maximizing sustainability impact. Whether through the adoption of advanced technologies such as AI or the implementation of robust legal frameworks, there is immense potential to transform our current economic models. By leveraging these innovations and regulatory measures, industries can accelerate the shift toward a truly CE, fostering both environmental and economic resilience.

Conclusion and Outlook

At the outset of this chapter, skepticism regarding the brewing industry's compatibility with the principles of a CE was prevalent. A more detailed analysis revealed significant potential for circularity within this sector. However, it should be noted that only some breweries were analyzed in detail, which limits the results of this paper.

The industry heavily relies on numerous components essential for beer production, many of which are discarded despite retaining considerable value. This observation underscores a substantial opportunity for the sector to position itself as a pioneer in the revalorization of by-products. By revalorizing by-products such as BSG and BSY for animal feed, bioenergy, and food production, the brewing industry is implementing circular practices. Innovative approaches include wastewater recycling for agriculture, methane production for energy, and sustainable packaging solutions such as reusable bottles and kegs. These practices align with theoretical principles of the CE, such as the 9-R strategies (e.g., reuse, recycle, and repurpose), and emphasize minimizing waste, optimizing resource use, and regenerating natural ecosystems.

This model of circularity goes far beyond traditional views by promoting a systematic transformation of production processes. It emphasizes waste reduction and resource optimization while fostering sustainable economic growth. The findings highlight that circular innovation has the potential to enhance competitiveness and stimulate development within the brewing sector. While the brewing industry has made considerable progress in adopting CE principles, significant untapped opportunities remain. Challenges such as scalability, financial barriers, and regulatory constraints highlight that it requires further alignment and development to fully realize the potential of circular practices.

Furthermore, the CE extends beyond environmental commitments, offering practical solutions to pressing climate and economic challenges. By revalorizing underutilized resources and rethinking industrial processes, this model significantly reduces emissions while providing viable solutions to contemporary economic issues. The insights emphasize the necessity of promoting CE principles across various sectors, including brewing, to unlock their potential for achieving a sustainable and resilient future.

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