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RESEARCH ARTICLE

Food Waste Utilisation in Beer Production: Enablers and Barriers within the European Craft Beer Industry

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Abstract

Considering the anticipated global growth of the beer industry amid climate instability and resource depletion, this study explores the emerging "bio-circular" practice of utilising food waste in beer production. Although gaining traction in the craft beer sector, a notable gap exists in the literature regarding the broader business context in which it operates.

To address this gap, the study identifies key enablers and barriers at a firm level across eight structural categories (internal and external), based on a sample of 7 craft practitioners from 4 European countries (the UK, Germany, Italy, and Belgium).

The findings highlighted two main enablers: the external factor of cooperation and partnerships, and the internal factor of purpose-driven management. While a fast-paced, competitive market presented the most substantial barrier, it affected craft beer producers, rather than the practice itself. Overall, the research suggests that no significant barriers exist to implementing the practice among viable craft beer producers.

Keywords Circular Bio-Economy · European Breweries · Craft Beer · Food Waste Utilisation · Beer with Food Waste · Beer Made with Bread

1. Introduction

Beer is currently the most consumed alcoholic beverage worldwide, with global production and consumption increasing since the 1970s (Colen & Swinnen, 2016). As a continuously growing industry, the beer sector is also a significant consumer of resources.

Traditional beer brewing incorporates four main ingredients: cereal grains, yeast, hops, and water (Baiano, 2021). This article focuses on the grain component, which is a key base raw material by mass. In most cases, the grain used is barley. Although the environmental impact of barley is generally lower than the impact of water use, electricity consumption, and packaging in beer production (Ness, 2018), barley can contribute from 25-46% to the overall carbon environmental footprint of beer (Almeida et al., 2018) depending on the transport (if imported) and level of agrochemicals used in production.

On the other hand, Mordor Intelligence forecasts that the European barley market will grow by 4.73% between 2024 and 2029, with clear signs that breweries are driving demand. Such demand for barley could exacerbate competition, given that it is used across sectors (especially as animal feed) and ranks as the fourth most important cereal worldwide (Miralles et al., 2021).

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Possible solutions to mitigate the dependency on barley (or any other mass-produced grain) could be found in the very beginning of beer brewing. Currently, barley is well established in the modern beer industry as the main grain input. However, beer can be brewed from various starch-containing sources, such as cereals, vegetables, and fruit (Hornsey, 2003). Historically, brewing was closely linked to food, especially bread (Katz & Voigt, 1986). In the past decade, using food waste (mostly bread) in the production of beer returned as a "bio-circular" practice to increase the sustainability of the brewing process (Connolly, 2019), as food waste can replace around 25%, and practically up to 60% of fresh barley (McDonagh et al., 2024; Martin-Lobera et al., 2025).

Throughout this research, several types of food waste were identified as functional input materials for beer brewing - with bakery waste and bread being the most common, but also cookies, rice, naan bread, oats, potatoes, and French fries. The brewing process with the food waste component is presented in Figure 1, where some of the aforementioned food waste categories are incorporated into the initial mash, along with cereal grain (malt). The rest of the process remains the same. There is no need to install new equipment or upgrade facilities, which makes the practice technically easy to adopt in existing breweries. However, brewers do need to organise the logistics of supplying food waste, prepare it for brewing, and adjust the recipe (Brancoli et al., 2020).

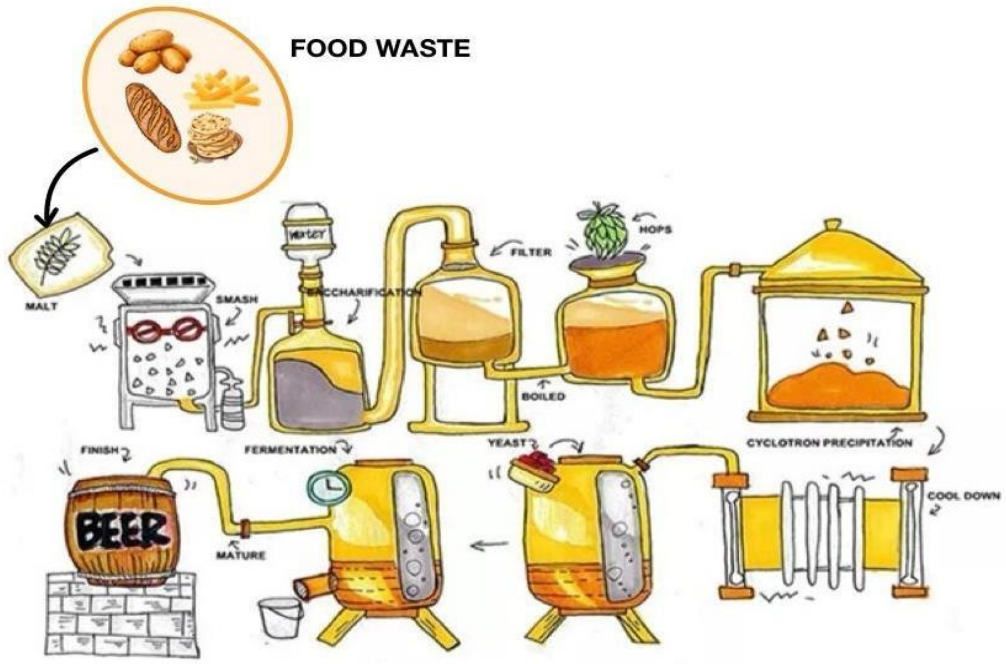

Figure 1. Schematic illustration of the beer production process with added food waste component (examples found via research) to the malt (Yanan, 2022)

Redirecting food waste to the brewing process has immediate environmental benefits. On the one hand, the sustainability of the brewing process increases. A study by McDonagh et al. (2024) found that using bread as input reduces microbreweries' annual global warming potential by 7.13% in carbon dioxide equivalent. Furthermore, reducing barley consumption decreases demand for barley cultivation, thereby lowering the associated use of land, water, fertilisers, and other inputs (Toast Brewing, 2024), as well as mitigating greenhouse gas emissions from landfilling or incinerating food waste (Ben Rejeb et al., 2022). It may also help address future environmental challenges as barley's environmental impact is predicted to intensify in the 2050 climate scenario, as increased production will be required to achieve the current yield due to an increase in

atmospheric CO2, higher temperatures, changes in rainfall patterns, and pest potentiality (Dijkman et al., 2017).

On the business side of opportunities, such practice could reduce procurement costs for fresh barley, diversify the input stream, and build supply chain resilience (especially regarding imported barley). It can also create local partnerships, as the short shelf life of food waste (Dymchenko et al., 2023) makes it most convenient to collaborate with nearby businesses.

Although utilising food waste in breweries theoretically offers environmental and economic benefits, it remains a niche practice primarily found in small-batch craft breweries. This study found the highest concentration of practitioners among craft brewers in Western Europe. Besides being confined to smaller companies in practice, academic research on utilising food waste in beer brewing remains limited and predominantly focused on technical aspects - such as recipe formulation, input proportions, process optimisation, etc. There is a lack of understanding regarding the broader business context, including practitioners' lived experiences, successes, and challenges in the implementation. To address this gap, the present article aims to provide insights from the experiences of seven European craft practitioners, analysed using mixed-methods research (semi-structured interviews and case studies) to identify firm-level barriers and enablers. To adopt the system-thinking lens, crucial for exploring circular practices (Iacovidou et al., 2021), the research examined both external and internal factors.

2. Literature Review

To ensure comprehensiveness, the literature review followed a systematic search process using major academic databases and targeted keywords related to utilising food waste in beer brewing and sustainable brewing. The search results were then distilled to studies relevant to the research topic. As the sample consisted of European craft brewers (further detailed in the Methodology), the review examined the broader context of the European beer market and its key challenges. Furthermore, as the distinction of craft brewing is central to this study, the main characteristics of craft brewing were also outlined. Finally, this section discusses the use of food waste in beer production within the broader framework of circularity principles and concludes by presenting literature coverage of the practice and the research goal.

2.1. European beer market

Through modernisation, beer brewing has become a globally significant industry (Rachwał et al., 2020). While China and the United States are currently the largest beer producers (BarthHaas, 2024), Europe, which was historically an important beer region, still plays a major role in current beer industry. In 2022, the European Union produced 34.3 billion litres of beer (Eurostat, 2023), closely following China's leading output of 35.5 billion litres. Additionally, Central Europe (namely the Czech Republic) holds the highest per capita beer consumption in the world (WHO, 2024).

However, to analyse the beer market, it is crucial to consider not only the size, but also its structure. The beer market is extensive and at the same time highly conglomerated, with half of the world's production being held by the 10 largest brewing groups (Basnet, 2022). For example, in the UK, the beer market is dominated by two foreign beer companies, American and Dutch, holding 40% of the market (Statistico, 2023). This homogenisation of the beer industry was strong after World War II, yet from the 1980s onward, amid the dominance of uniform mass-produced beer by large companies, craft[2] breweries gradually emerged (Cabras et al., 2016). The 2000s witnessed a global boom of craft producers, with the most significant growth in the USA (46%), closely followed by Europe (43%) (Callejo et al., 2019).

[2] Although there is no clear definition of the term "craft", as it is used variably in different regions, it generally refers to small independent local breweries that make more versatile beers compared to large breweries (Cabras, 2018)

Currently, Europe, despite being home to large beer companies (such as Heineken and Carlsberg), also has a fragmented market with numerous craft producers. In 2017, out of nearly 10,500 brewers in the EU, 75% were microbreweries and small and medium-sized breweries[3] (Baiano, 2021). As small breweries tend to be craft (Cabras et al., 2016), this market structure indicates the relevance and persistence of craft breweries in Europe.

2.2. The significance of craft

Europe's well-developed craft beer sector provides fertile ground for exploring alternative and sustainable practices within the brewing industry, as craft breweries tend to drive innovation. For instance, previous research has identified a strong correlation between the growth of the craft market and the variety of beers (Garavaglia & Swinnen, 2018).

Furthermore, two general principles of craft brewing - sustainability and locality - align with practices such as utilising food waste in beer production. Craft breweries stay local for numerous reasons - to have their local story, be authentic, and to work within their communities (Cipollaro et al., 2021), but it can also be a deliberate business strategy that helps shield brewers from intense competition faced at larger scales and enables partnerships with nearby businesses, which are helpful for utilising food waste with a short shelf life (Danson et al., 2015). Additionally, innovative sustainable practices combined with a local identity set them apart from big brands, a distinction that can help justify the higher prices of craft beers compared to mass-produced brands (Baiano, 2021).

Moreover, an enabling craft characteristic is a collaborative ethos that encourages knowledge sharing and the adoption of innovative practices. As Danson et al. (2015) note: "*The whole point of the product is not to have the 'best', thereby beating the competition, but instead to have a high level of diversity of flavoursome beers*."

2.3. Challenges of European brewers

Despite a mature market and long tradition, European brewers face significant challenges. The Economic Report of the British Beer and Pub Association (Frontier Economics, 2023) identifies rising costs and weakening consumer demand as key issues affecting UK brewers. The Brewers of Europe (2023) association emphasises that, following COVID-19 lockdowns, European brewers are facing geopolitical instability, inflation, government budget cuts, and increases in energy and raw material prices. Such circumstances led to manufacturing costs in 2023 rising by 20-25% compared to 2019 (The Brewers of Europe, 2023), with barley prices particularly affected. The global price of barley peaked at 109% in April 2022, after which it decreased, only to remain 40% above 2021 levels (IMF, 2023, as cited in FRED, 2024). Given the rising environmental challenges in barley production and demand from different sectors, it is highly unlikely that prices will return to pre-pandemic levels.

The most recent data further underscores these concerns: The Netherlands has its first decline in the number of breweries since 2010 (Centraal Bureau voor de Statistiek, 2025). The latest report by the British Beer & Pub Association and Zero Carbon Forum (2025) warns that climate risks, such as drought, extreme heat, and flooding, threaten domestic and international barley and hop production. The report suggests that in the future, crop yields may be diverted toward food security, rather than brewing.

[3] The categorisation of breweries depends on their annual beer production:
- microbreweries (less than 5,000 hL);
- small breweries (5,000 to 50,000 hL);
- medium-size breweries (50,000 to 200,000 hL);
- large breweries (200,000 to 1,000,000 hL);

and brewing groups (more than 1,000,000 hL), German Brewers Association (2006) cited in (Heyder & Theuvsen, 2008)

In light of these "developments", ensuring the future viability of the brewing sector will require exploring alternative resources to ease the pressure of traditional material procurement.

2.4. Circular opportunity found in food waste

Solutions to challenges facing the beer industry are increasingly found in a circular economy approach (Cimini & Moresi, 2021; Bonato et al., 2022). For breweries, this involves two key cycles:

- Technical: addressing packaging, energy, and transport;
- Biological: managing organic inputs and outputs (Cimini & Moresi, 2021).

Utilising food waste in beer production falls under the biological loop and illustrates the cascading principle - the transfer of materials from one industry, where their value is exhausted (e.g., unsold bread), to another, where they are transformed into higher-value products (e.g., beer). This principle underpins value creation as a detrimental process on which the circular economy relies (EMF, 2015).

Currently, most breweries apply the cascading principle by repurposing their by-products, including brewers' spent grain (BSG), which accounts for around 85% of total by-product weight (Veleva et al., 2024) and represents the majority of barley's carbon footprint (Almeida et al., 2018). In a study by Veleva et al. (2024) on small craft producers in the USA, 95% of the businesses in the sample have organised spent-grain management. The most common use is as animal feed (Bonato et al., 2022), but brewers are increasingly finding innovative ways to reuse BSG, such as using it as a substrate for mushroom cultivation, as ground mulch, or as an ingredient in bread, pizza dough, and even dog biscuits (Ness, 2018).

Even though there is creativity in utilising spent grain, experimenting with inputs and, even more specifically, food waste as an input is far less common, despite evidence suggesting that brewing or ethanol production are among the most effective uses of food waste (Brancoli et al., 2020). Given that one-third of all food produced globally is wasted (UNEP, 2024), and bread is among the most discarded items by mass (Scherhaufer et al., 2018), there is a clear opportunity for breweries to adopt food waste as a sustainable raw material.

2.5. Research gap and goal

Rising circularity within the brewing sector is reflected in the academic literature, yet research regarding food waste utilisation in beer production is limited compared to other circular practices.

While some studies focus on firm-level circular/sustainability transitions (Cimini & Moresi, 2021; Lemaire, 2020; Albert, 2021; Ball & Macbryde, 2022; Veleva et al., 2024; Ness, 2018) and circular business models (Nitkiewicz & Pachura, 2022; Julkovski et al., 2022), most research focuses on a specific circular practice. The most commonly studied practice is the use of brewers' spent grain (BSG) (Bonato et al., 2022; Ortiz et al., 2019; Kerby & Vriesekoop, 2017), which is a logical focus given its ubiquity in breweries. In contrast, the use of alternative input sources is a relatively novel practice, primarily observed among sustainable craft breweries, and is much less documented in literature.

Recent research that aligns more closely with the research topic explores the connection between the brewing and food sectors from the perspectives of utilising BSG in the food industry (Rachwał et al., 2020) and in the production of bread (Vriesekoop et al., 2021). On the other side, researchers examined best practices for food waste utilisation, including in breweries (Brancoli et al., 2020), and more specifically, technical aspects of using bread in brewing (Dymchenko et al., 2023; Martin-Lobera et al., 2022; Martin-Lobera et al., 2025; Dall'Acua et al., 2025).

However, no academic research was found that explored the utilisation of food waste in beer production from a business value chain perspective. Given Eisenreich et al.'s (2022) assertion that circular economy practices influence all value chain activities, this research seeks to address that gap by investigating the key enablers and barriers to food waste utilisation in beer production across internal and external company segments.

3. Methodology

A mixed-methods research design was employed to ensure a comprehensive understanding of the practice and to capture real-time examples. The study began with secondary online research on the broader beer industry to identify all businesses[4] that use food waste in beer production. This review revealed that craft producers were the main practitioners of food waste utilisation in beer production. Although some big brands collaborated with the organisation Toast Ale (Beeson, 2023) to produce limited-edition beers made from food waste, no major brewery was found to have established a consistent product line based on this practice.

Regarding the geographical coverage of the sample, two regions with the most prominent and long-lasting craft sector, North America and Europe (Callejo et al., 2019), were initially included. The sample comprised 28 businesses, as shown in Table 1. However, only four North American businesses were found to practise and market food waste utilisation in production, and none of them responded to the interview inquiry. This led to the continuation of the research with a sole focus on the European area.

Table 1. Initial sample and response results

Region	Contacted	Replies	Interview
US and Canada	4	0	0
EU	12	4	2
UK	12	5	3

The core data for the article were obtained through semi-structured interviews, which were identified as the most appropriate method to capture real-world practices, lessons learned, and practical insights. Five interviews were conducted with three UK and two EU organisations (Germany and Italy). The response rate of 17.8% was satisfactory, given the research's requirement to obtain interviews with management (e.g., founders/owners/managers), as questions focused on the business value chain. The interviewed organisations differed in location, size, range, and experience with food waste utilisation, as shown in Table 2, so the data came from diverse craft producers, giving a better representation of the sector.

Table 2. Company profiles of interviewed organisations

Company	Role of an interviewee	Location	Size	Range	Employees	Founded in	Period of utilising food
Biova project	Co-founder and president	Torino, Italy	Micro business	Regional-national	6	2019	2019-present
Crumbs brewing	Co-founder	Reigate, UK	Micro brewery	National	3	2017	2017-present
Jaw Brew	Founder	Glasgow, UK	Micro brewery	Local	3	2014	2016-2022
Knärzje	Founder	Frankfurt am Main, Germany	Medium sized company	Regional	3	2019	2019-present
UnBarred	Marketing and operations manager	Brighton, UK	Micro brewery	National	15 (8+7 taproom personnel)	2014	2022-present

[3] Some businesses were breweries, while others were organisations that did contract or cuckoo brewing, meaning they don't own brewing facilities but they rent or cooperate with existing breweries (Cabras, 2018). Hence, entities in the paper are referred to as businesses or organisations rather than solely breweries.

Among the 24 contacted breweries found in the secondary research, two organisations came across as particularly relevant for the practice: Toast Ale (UK), one of the leading advocates of the practice, and Brussels Beer Project (Belgium), as the creator of the first commercial bread beer in Europe in 2015 – Babylon (BBP, 2023). Although interviews with these companies could not be conducted due to limited availability, their data was found valuable for the research, so they were included in the study through case analyses. Data were collected from publicly available sources, including sustainability reports, academic publications, news articles, and published interviews.

In the end, data triangulation was conducted to ensure validity and reliability (Yin, 2018). Interview and case study data were analysed using NVivo software, with data coded and assigned to categories. Coding was deductive and inductive (Hennink et al., 2020). Deductive coding followed Cantú, Aguiñaga, and Scheel's (2021) framework on internal and external barriers and enablers for circular economy initiatives, adapted to food waste utilisation practice (e.g., the infrastructure category was excluded, as beer production using food waste does not require additional infrastructure).

Two parallel sets of codes were established: external/internal categories (adopted from Cantú et al., 2021) and enablers/barriers, with references double-coded as a category and an enabler/barrier.

Categories: External

a) User's behaviour
b) Regulations
c) Economy and market competition
    - *Large beer market*
    - *Craft beer market*
d) Supply chain and logistics
    - *Partnership and collaborations*
    - *Logistics*

Internal

e) Finance
f) Knowledge
g) Organisation and management
    - *Organisational resources*
    - *Management*
    - *Localisation*
h) Product and materials characteristics

Inductive codes (in italics) were added to the code sets when significant topics were mentioned repeatedly in interviews and case studies. These were incorporated as subcategories to facilitate a structured analysis. For example, within the external category of Economy and market competition, interviewees distinguished between the craft beer market and the large beer companies market. Further exploration of the data and results will be presented in the coming section.

4. Results

The practice of utilising food waste in beer production (hereinafter referred to as "the practice") was explored within the European craft sector, where secondary research identified that the majority of practitioners were from the UK, with around 15 UK companies, compared to 3-4 in EU countries such as Belgium and Germany.

The collected data, as presented in Table 3, revealed two distinct business approaches to the practice:

- In addition to the existing brewing activities - The Brussels Beer Project, UnBarred, and Jaw Brew focused primarily on beer production with a variety of beers beyond those made with food waste.
- A core business idea - Toast Ale, Knärzje, Biova, and Crumbs Brewing focused on saving food and made beers only with food waste, mainly by cuckoo brewing.

Table 3. Characteristics of food waste utilisation of businesses in the sample

Business	Brewing approach	Type of food waste	Percentage of mash	Annual quantity of used food waste in production
Biova project (Italy)	Cuckoo brewing	bread, broken pasta and broken rice	30%	10.5 tons of surplus bread
Brussels Beer project BBP (Belgium)	Brewery	bread, speculoos, beetroots & pear, apples	20%	10 tons of bread per year
Crumbs Brewing (UK)	Cuckoo brewing	bread, naan, coffee grounds	Up to 25%	56,600 loaves saved to date
Jaw Brew (UK)	Previously a brewery, now a pub	bread and morning rolls	40% (low alcohol beer)	-
Knärzje (Germany)	Cuckoo brewing	bread	25%	surpassed 10 tons
Toast Ale (UK)	Brewery, cuckoo brewing, franchising and licensing	bread, oats, crumpets, rice hulls	25%	3.8 million slices to date (end of 2024)
UnBarred (UK)	Brewery	leftover husks from chocolate and coffee	-	-

Furthermore, as also shown in Table 3, two approaches to the utilisation of food waste were recognised:

- As a 20-40% replacement of barley in malt. In most cases, the food waste used was bakery waste, as well as cookies, naan bread, fruits, pasta, and rice.
- Wasted materials such as coffee and chocolate husks are added to the mash in smaller quantities (a few %) that contribute to the taste but don't replace barley. In the data set, the only example is UnBarred. Even though it doesn't reduce the use of fresh barley, it still constitutes a circular practice as it utilises food waste.

Regarding the types of food waste, the availability of local supply is crucial. Businesses in the sample demonstrated connections to local suppliers; for instance, in Italy, pasta was an input. The type of food waste also determined how much barley could be replaced: bread was the most commonly used, and the medium share it replaced was 25%, with the highest amount at 40%.

Companies in the sample tracked their food waste utilisation using various metrics (tons, loaves, slices). Comparing their efforts - such as Toast Ale saving 3,8 million slices in nine years (Toast Brewing, 2024) - to the equivalent of 25 million slices of bread wasted daily in UK homes (WRAP, 2023), the limited impact of such initiatives is evident. Addressing food waste at scale requires prioritising prevention, as outlined in the food waste hierarchy (EEA, 2020). However, in the second step of the hierarchy - recovery and reuse stage, beer and alcohol production with food waste, **if scaled up,** can provide a valuable pathway.

4.1. Enablers and barriers

The results compiled in Figure 2 show each category as both an enabler and a barrier. The categories most significant to the practice have the largest sections and the greatest difference between enablers and barriers.

For example, the most prominent barrier is an external category of Economy and competitive market, and the most prominent enablers are the external category of Supply chain and the internal category of Organisation and management.

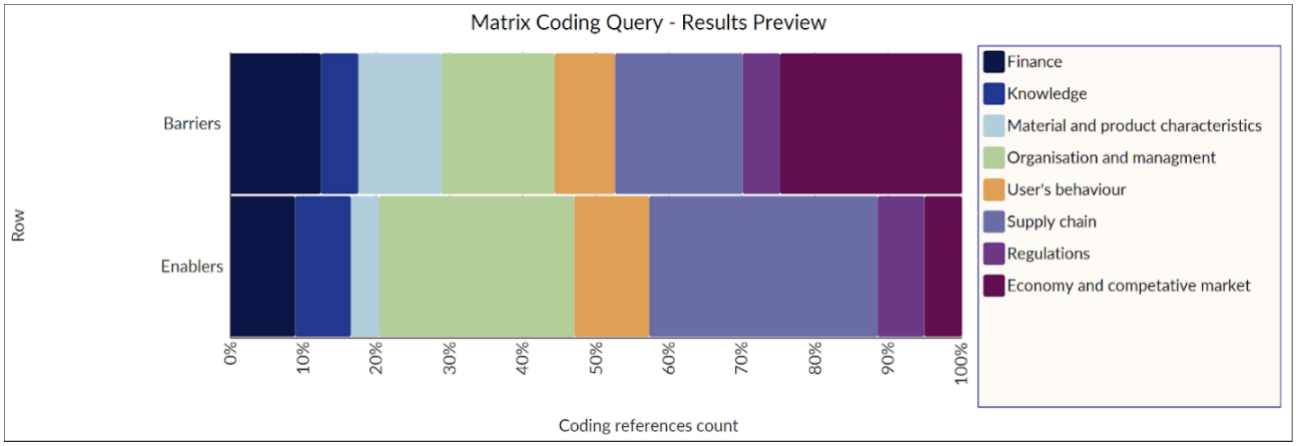

Figure 2. Distribution of coded references across "Enabler" and "Barriers" classification

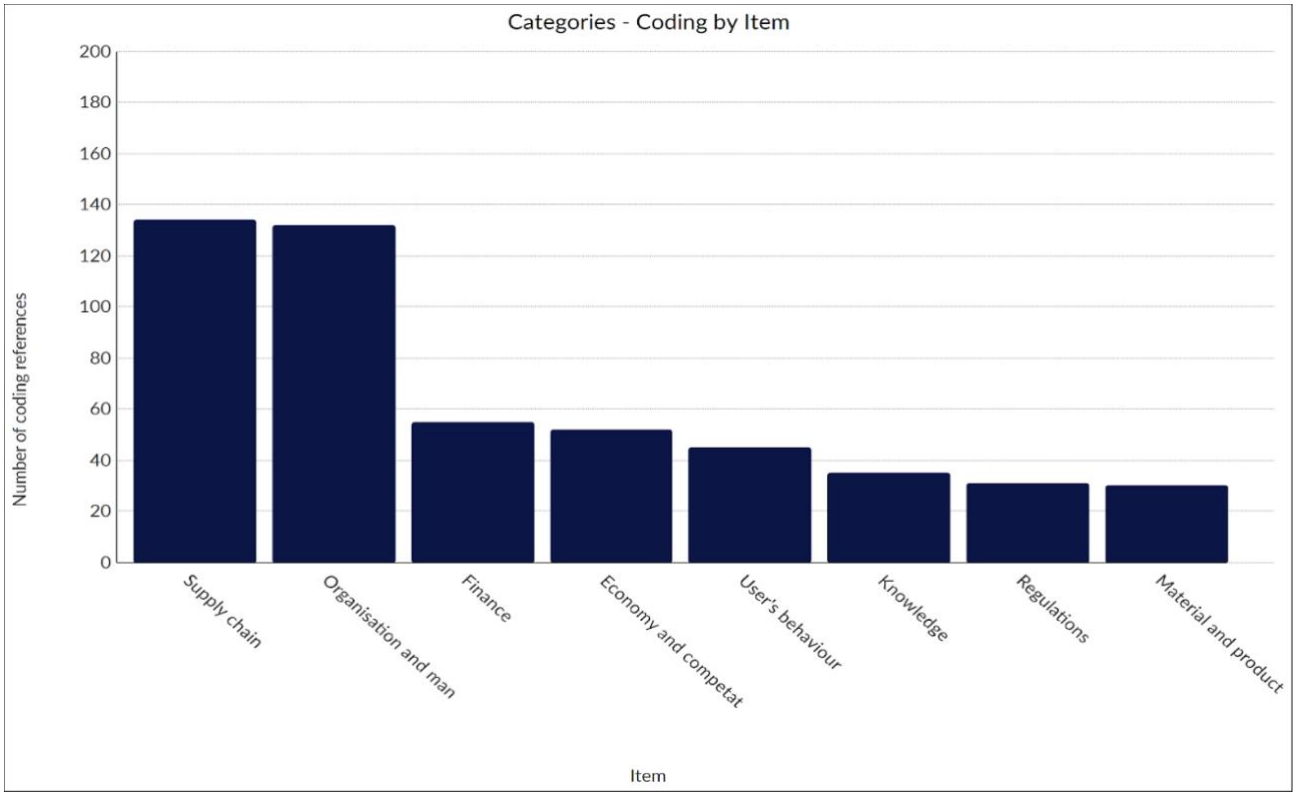

Figure 3. Frequency of coding references by category

The presence of each category in the data set is contrasted in Figure 3, which shows that the main enablers were discussed substantially more than the others.

The next section provides deeper insight into the results by exploring each category and its subcategories, and, where possible, comparing them to the literature. Categories were highly interlinked and mutually influential; therefore, the most prominent connections will also be presented.

4.2. External categories

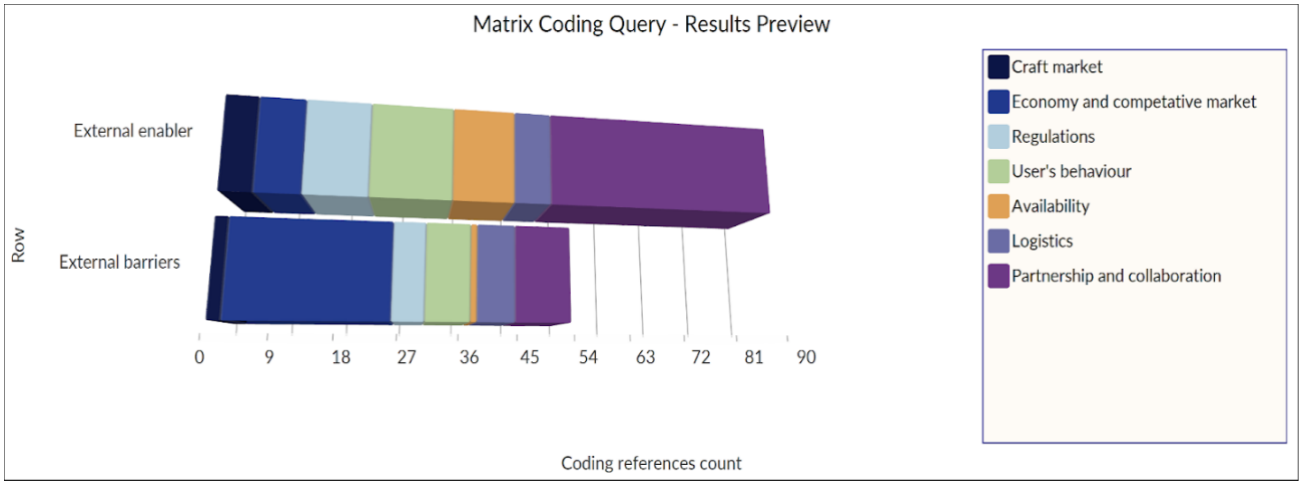

Figure 4. Comparison of coding references for each external category based on enabler and barriers section

4.2.1 Economy and competitive market The economy and competitive market segment incorporates market structure and competition, which influence the organisation's position and success (Cantú et al., 2021).

Data showed a distinction between the large beer market and the craft beer market**,** so they were explored individually.

The large beer market was emphasised as the **most limiting factor**. As the sample ranged from microbreweries to small and medium companies, the market dominated by big companies (Basnet, 2022), negatively affected their market opportunities and growth potential.

German brewery Knärzje emphasised the problem of competition with big brands, given their lower prices and major market share, especially in restaurants and bars, where craft brewers could potentially charge higher prices. Furthermore, the Italian organisation Biova highlighted the tactics of major companies of marketing "craft-looking" beers, which further intensified competition.

Conversely, *the craft beer market* is characterised by a community- and cooperation- based style versus a competitive style of functioning (Danson et al., 2015). Toast Ale's *Rev-ALE-ution* website, which promotes other craft brands, illustrates how craft brewers tend to welcome competition (Connolly, 2019). Such a cooperative environment has especially positive effects on building and sharing knowledge about a novel practice. This is why the Craft market in Figure 4 is separated from the overall Economy category, so its enabling effect can be recognized.

4.2.2 Regulations Regulations refer to government policies and legislation, as well as third-sector structures (certification and awards), that could influence the practice. In this study, regulations did not present a substantial barrier or enabler.

Even though some regulatory barriers could be overcome, they still impacted businesses. As the Italian organisation Biova mentioned, "*by the Italian law, the food surplus needs to be bought, not donated, to be used for business purposes*" which affected their finances. The German Purity Law ensures beer quality but restricts

recipe changes (Szolnoki et al., 2021), forcing German company Knärzje, which uses surplus bread, to navigate extra bureaucracy to label its product as beer:

"Old laws that are inhibiting innovations" (Knärzje)

Still, it is not just the existing legislation seen as negative, but also the lack of new and effective regulations that could push sustainable practices (Rizos et al., 2016). Even though the supranational level of European legislation is quite ambitious for circular practices, the regional and local levels are still in development (Bianchi et al., 2023). The Biova project noted the need for enabling legislation, citing the example of French laws on food waste and the ban on supermarkets destroying food waste (Mourad, 2016).

On the other hand, the potential benefits were seen in prizes and certifications that were not just external verifiers of the organisation's claims (Boiral and Gendron, 2011), but also a platform for cooperation and possible support. For example, Knärzje had help from the BioLand Association with the bureaucratic problems posed by the above-mentioned Purity law.

4.2.3 Supply chain

The supply chain category has two subcategories:

a) Partnerships and collaborations

Partnerships and collaborations are seen as the biggest enablers of the practice (Figure 4).

The benefit of partnership increases as cooperation with supplier(s) surpasses solely transactional value. The best example was given by the Knärzje company, which extended its partnership with the supplier to mentorship and investment. It benefited both sides, as suppliers had the output for the "*huge amount of bakery waste*" (Knärzje), relieving the pressure for waste management and promoting their business as innovative and sustainable.

This category is crucial for companies that are cuckoo or contract brewing. It means they are reliant on other breweries, but also flexible to expand their network and form new partnerships - championing this approach is Toast Ale with 87 partners worldwide (Toast Brewing, 2024).

However, for successful cooperation, a proper partnership is crucial (Bressanelli et al., 2022). For the interviewees, challenges occurred when the new partners, mainly when scaling up, didn't share the same values.

"It is very good when people are on the same side, but it is very challenging to create a bigger network if they don't see the importance and benefit of cooperation ...Some bakers …don't want to make their business more complex… they don't like to advertise the fact that they have waste..." (Crumbs)

This was recognised in the latest Ellen MacArthur report (2025) as one of the main pitfalls of scaling circular economy principles, which typically rely heavily on partnerships.

An essential element of these collaborations concerns the *availability of suitable partners and food waste suppliers*. In the sample, brewers generally expressed a positive outlook, given the wide range of potential food waste sources (Figure 4). However, a lack of awareness among potential partners remains a barrier, as many businesses generating food waste do not yet recognise it as a resource for other industries. This issue aligns with broader gaps in awareness of circular economy opportunities within the media and business communities, as noted by Unbarred Brewery.

Additionally, the issue can be instability among partners if they close or move, especially when brewers are localised and have fewer options. This issue was demonstrated in the dataset: first, when the brewery closed and second, when the supplier closed. In both cases, the practice completely stopped, and no new partnerships were made on either side.

Besides businesses, additional stakeholders included universities that conducted life-cycle assessments and measured the breweries' carbon footprint. This support is particularly valuable, as companies can benefit from such data but often lack the resources to assess and monitor their sustainability levels.

b) Logistics

This subcategory within the supply chain emerged as a challenge, becoming increasingly complex as operations scale up:

"practicality and the logistics of using by-products from another business is more the barrier rather than anything else…if it's local it's easy "(UnBarred)

The importance of shared values and goals is important for this barrier, as the Biova project mentioned:

"It's not too complicated, but it's something you really have to work on … it's also the reason why a lot of breweries did one single experiment and then gave up …And if you don't have a very strong commitment, you don't do it."

However, the logistical problems depend on the case, and for some companies, such as Jaw Brew, it didn't present a problem, because *"bakers had a distribution network that went past our front door."*

An example from Crumbs Brewery illustrates the possibilities of improving logistics:

"we encourage him (supplier) to when he delivers fresh, he also collects back any unsold bread that his customers have"

By utilising their bread waste, suppliers improved their logistics for collecting more food waste, underscoring the importance and impact of the partnership in extending the circular approach.

4.2.4 Users' behaviour Users' behaviour towards beer made from food waste was overall positive. From one point of view, it made the beer stand out as Crumb's interviewee mentioned: "*know that you just want to get a reaction from the customers, the worst thing you can be is boring*." It distinguishes this type of beer from others, an especially important advantage in the highly diverse craft beer market.

The food waste ingredient proved to be a good initial catch, and some customers were drawn to sustainability. However, for long-term loyalty, interviewees emphasized quality as an undisputed requirement. Certifications and prizes serve as proof of quality, especially because craft beer lovers tend to be less loyal and more inclined to explore different beers (Connolly, 2019).

Interviewees said only a small number of customers were hesitant about the beer because of its use of food waste, contrasting earlier findings of negative perceptions of reused products (Govindan & Hasanagic, 2018). Broader research into consumer attitudes could confirm whether this positive reception holds, potentially encouraging other breweries to innovate with food waste.

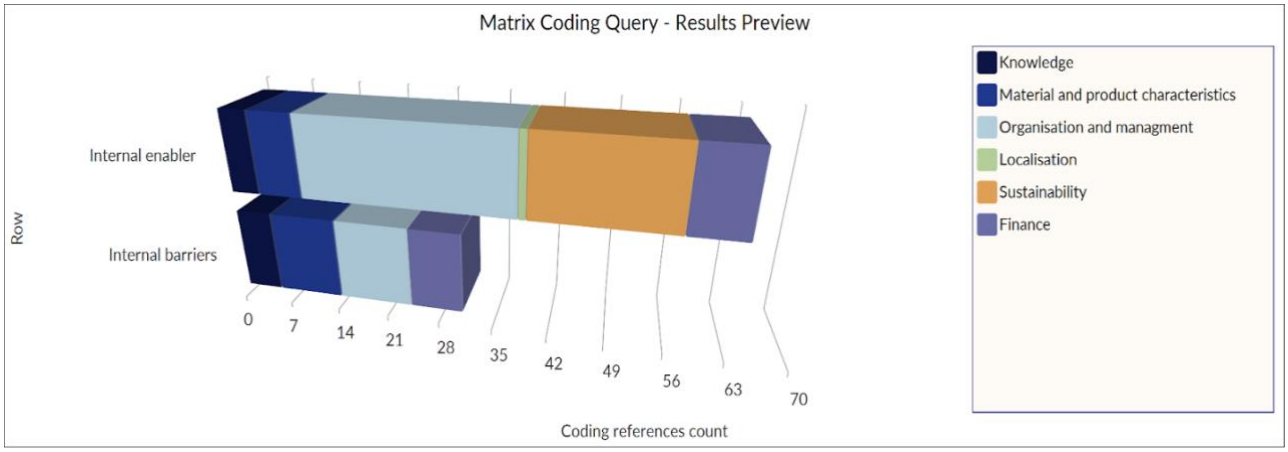

Figure 5. Comparison of coding references for each internal category based on enabler and barriers section

4.3. Internal categories

4.3.1 Knowledge Knowledge is a very important factor in introducing and implementing novel practices, as companies often lack the knowledge and expertise for implementation (Rizos et al., 2016). However, Figure 5 illustrates that this category had a comparable effect as both a barrier and an enabler, since the collaborative and sharing ethos of the craft sector helps offset knowledge gaps. Examples are Toast Ale and Jaw Brew publicly publishing their recipes, as well as interviewees collaborating and sharing their knowledge on the local level.

Likewise, the transfer of knowledge is beneficial to decrease the trial period for the development of beer, which can take up to "*a few months to develop the Hardtack beer because we had nothing to base it on*." (Jaw Brew*)*.

Currently, it is hard to determine how widely the practice is spread and how brewers are aware of it, but it is safe to say the knowledge is spreading with each brewery. From the dataset, the most active promotion agent is Toast Ale, reaching 15 million people on social media, collaborating with 87 breweries worldwide, and working with 85,000 home brewers in 2023 (Toast Brewing, 2024).

4.3.2 Organisation and management This segment was adapted from the original work (Cantú et al., 2021) into three subcategories:

a) Lack of *organisational resources (time and/or labour)* presents a barrier in the sample, as interviewees were mainly smaller businesses with few workers (an average of three). The use of food waste increases labour requirements, and the recipe development can be time-consuming, thereby raising overall expenses. Companies that are cuckoo brewing incur additional costs due to a longer rental period, the need for extra labour, or the need for existing employees to multitask.

b) Subcategory of *management* involves management capabilities and overall company culture towards sustainability and circular practices (Rizos et al., 2016). Contrary to claims that circular transitions are primarily financially driven (Masi et al., 2018), this study found that a strong commitment to sustainability motivates innovation and integration into viable business models. **Strong commitment to sustainability showed as the second main enabler of the practice**, highlighted in Figure 5:

"positive, sustainable message at the heart of the business" (Crumbs)

These findings align with those of Veleva et al. (2024), who identified environmental stewardship as the top driver for SME craft brewers in the USA, followed by cost savings. Similarly, Purwandani and Michaud (2021) reported that internal motivations are the most significant drivers for SMEs' adoption of sustainable practices, alongside the opportunity to improve public image.

c) *Localisation* is the special subcategory extracted because of its prevalence in the data set as a craft managerial strategy to differentiate, be authentic, and competitive in the market.

It is closely linked to the above-mentioned management category - by being localised, breweries are connected to their communities - as well as their supply chain stakeholders - farmers, suppliers, customers, employees, and heavily dependent on their reputation, which can really push them into sustainability practices to create positive change (Veleva et al., 2024).

However, a localised approach could pose a threat due to limited local development, potentially jeopardising businesses during crises and market fluctuations. This is seen in the example of Jaw Brew:

"we became more local and we were only really brewing to supply our own pub and other very local events ...after lockdown and increase in the cost of energy, we found that it was no longer viable" (Jaw Brew)

4.3.3 Product and materials characteristics The wide variety of food waste types available as inputs, and the associated opportunity for experimentation, act as enablers of the practice. When combined with the craft beer industry's localised approach, this encourages the use of nearby resources, supporting local food waste utilisation - a critical factor given the fast spoilage of food waste.

Research on the technical aspects of incorporating food waste into beer production supports its viability. Studies by Martin-Lobera et al. (2022, 2025) and Dall'Acqua et al. (2025) generally report positive outcomes, producing beers of comparable quality and showing no significant differences in most physico-chemical parameters or in sensory evaluations compared to conventional beer.

Furthermore, the characteristics of the beer depend on the type of food waste and the recipe used. Data show that bread and bakery waste are the most commonly used, typically replacing 15–50% of the malt, mainly up to 25-30% because:

"Beyond 25%, the mash gets very difficult to deal with because it gets very sticky and also your mash becomes less efficient." (Crumbs brewing)

However, some brewers have already developed methods to use more than 25% food waste, and several organisations such as Toast Ale (Jones, 2018) and Crumbs are exploring ways to maximise this proportion.

Additional technical barriers concern preparing food waste to a specific moisture level for the mash. Different breweries have their approaches to stabilise, shred, preserve, and prepare food waste - from freezing, drying with distinctive methods, and shredding with machines (increasing their energy usage). Another technical requirement is time - brewers could take several months to develop the final product, which impacts the finance segment. As mentioned before, the remedy is knowledge sharing, with a substantial body of knowledge present among the practitioners interviewed.

Finally, the reuse of food waste can require stringent hygiene measures. Characteristics of the brewing process (controlled and sterile) present an internal enabler, as they relieve the pressure of hygiene regulations that can cause complications for other reuse options.

4.3.4 Finance The financial impact of food waste utilisation on business performance appears to be relatively limited. Generally, there is no large investment, e.g., in technology, and the increase in labour and processing costs (freezing/drying) is balanced out by the lower cost of the resource (barley replacement). In most cases analysed, businesses got food waste for free or paid a nominal fee, so that the cost balance meant the price of beers made with food waste didn't differ from the price of those made solely with barley.

Most organisations saw no immediate financial gains from the practice, but integrating this practice with circular business models and building local stories enhances competitiveness and long-term financial stability, especially when scaling up (as in the Biova project). Overall, financial risks are low, and input diversification provides stable pricing compared to barley's market fluctuations.

5. Discussion

During the coding process in NVivo, connections between categories were continuously present. For example, in the interview with Biova, a statement was coded into multiple categories:

"(We pay) one euro cent per kilo. This is compulsory because it's the only way to make it legal." (Biova)

This sentence was coded under both Finance and Regulations, demonstrating the mutual influence between the two categories. Using clustering based on coding similarity, all connections were visualized in Figure 6, illustrating how all segments are interconnected and mutually influential.

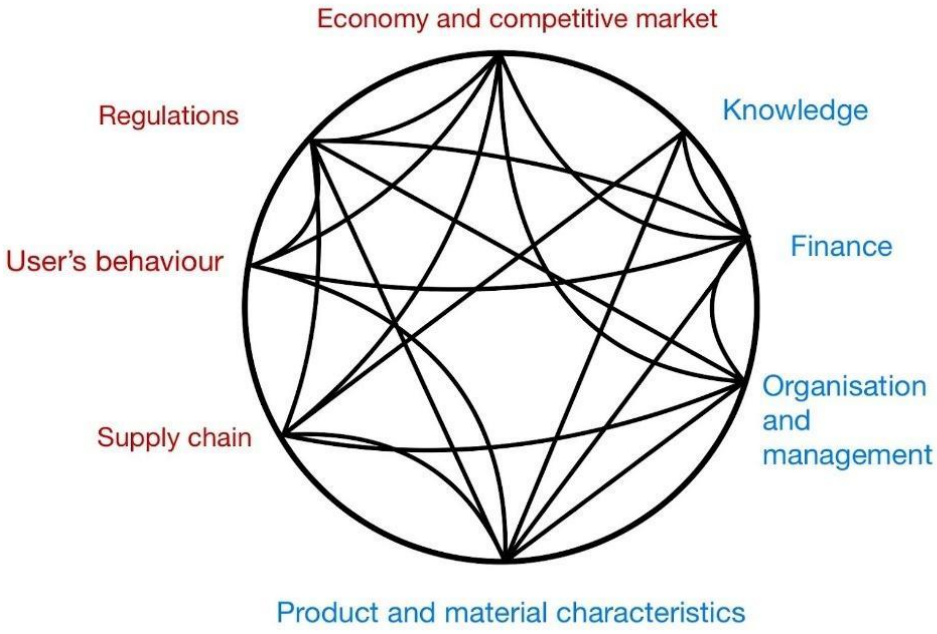

Figure 6. Direct interconnections of categories - blue internal categories, red external categories

Furthermore, each category appeared in both the enablers and barriers sections due to the complexity within each category and the varying company contexts. However, some categories leaned more toward being enablers or barriers.

The strongest enabler observed was the organisation's strong commitment to "doing the right thing", aligning their passion for brewing with the sustainability practices of food waste utilisation:

"a beer that has a benefit for society." (Knärzje)

Management driven by sustainability, and aware of circular possibilities, had the motivation to change the traditional functioning models:

"to show that it's possible to think of a company in a different way ... being circular, not linear, and to demonstrate that you can have a business that is sustainable..." (Biova project)

As Rizos et al. (2016) note, when the business mindset shifts to circularity, barriers from a linear perspective become opportunities in a circular one. Companies embracing this change become knowledge creators and industry influencers (Cantú et al., 2021). Examples in the dataset illustrate this, from Crumbs brewing influencing its supplier's waste collection to Toast Ale's broader industry and social impact.

However, Nitkiewicz and Pachura (2022) argue that the company's individual goals are minuscule compared to the challenges posed by external factors. They emphasise the role of partnerships and networks in overcoming limitations, which in the dataset is the second-strongest enabler. **Stable partnerships, when based on shared values, reaped the most success**. However, this means that the availability of the appropriate partner is a barrier to a crucial enabler.

Arguably, the combination of two main enablers within the craft industry could help overcome lower-level barriers such as a lack of knowledge or logistical challenges. Main outcomes of the research (Figure 7) show that the majority of the categories were neutral or had similar enabler/barrier effects depending on the context. A valuable direction for future research could be the exploration of categories such as Finance, Material and Product characteristics, User behaviour, Knowledge, Logistics and Regulation to determine their impact on a more positive or negative outcome. In the sample, some categories showed potential to become stronger enablers. For example, Regulation could create a push if legislation determines greater food reuse or a ban on food waste destruction, as well as User behaviour and Knowledge with higher awareness and popularisation of the practice.

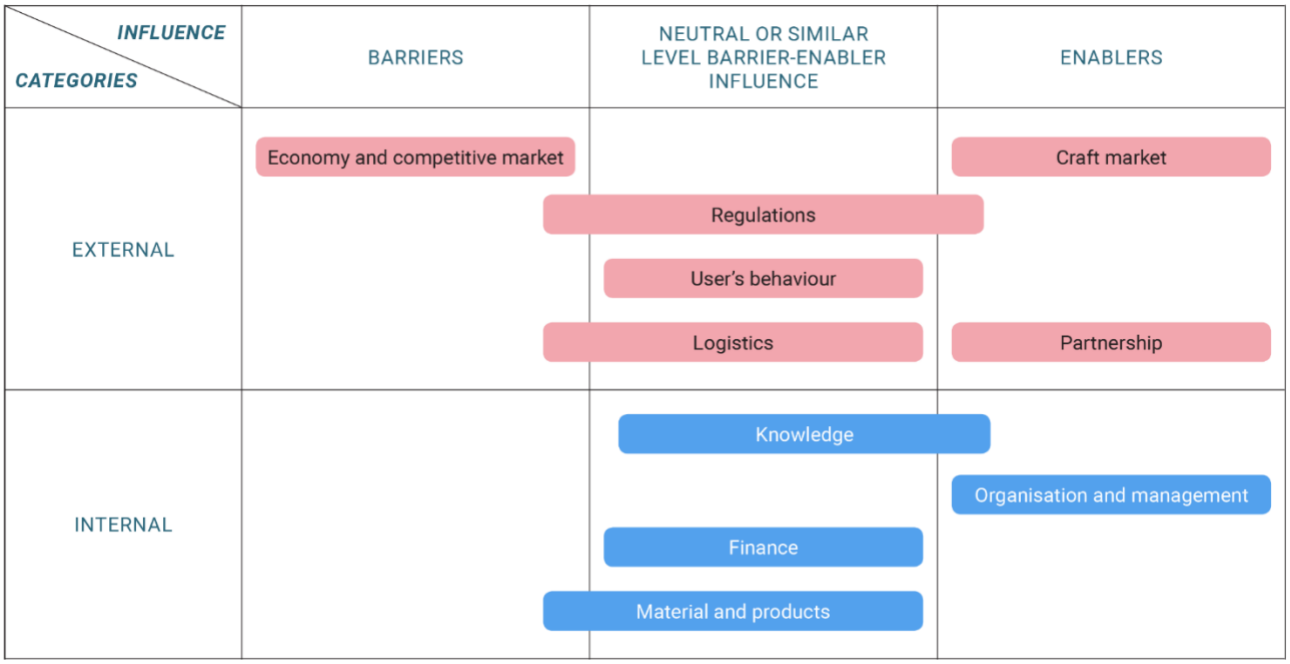

Figure 7. Table summarizing the conclusion of the results showcasing the general tendency of the external (red) and internal (blue) categories for positive (enabler), negative (barrier) or neutral effect

Furthermore, defined enablers reflected the craft beer industry's transparent, sharing, and cooperative ethos, which presented itself as a fertile ground for the development of circular practices. Craft's inclination to form local partnerships aligns with the practice, given the rapid spoilage of food (Dymchenko et al., 2023). An additional important enabler is that the practice can be incorporated into the existing breweries, with no need for new equipment or technology.

However, the prevailing external barrier is the Economy and competitive market category, reflecting a deeply rooted linear system (Dervojeda et al., 2014) in which these companies work. It is a barrier to the development of craft and smaller beer producers, which is then reflected in the results. Large beer brands appeared less inclined to adopt this practice, possibly due to their reliance on standardised, large-scale production (Cabras, 2018).

Nevertheless, as resource and economic instability persist and reshape the expanding beer market, this practice, currently limited to the craft sector, could gain traction in the broader industry. A potential solution lies in the success of pioneers in the study's sample, whose commitment to sustainability, innovative circular business models, and emphasis on non-monetary benefits have enabled them to overcome existing challenges.

6. Conclusion

The goal of the study was to shed light on the business environment for utilising food waste in beer production and to support its growth by increasing awareness of key implementation factors at the firm level.

An examination of leading practitioners in the European craft beer sector revealed that the most significant enablers were sustainability-oriented management combined with effective cooperation and partnership. The craft sector, reliant on cooperation and a local approach (Baiano, 2021), proved fertile ground for the development of this practice. Data indicate that such an enabling combination can mitigate low-level barriers, such as a lack of knowledge, logistical challenges, and inhibiting or neglecting regulations. However, the prevailing external barrier was the Economy and competitive market category, which reflected the challenge posed by the conglomerated beer market to craft brands, not particularly the practice itself.

Further research is needed to explore several aspects highlighted in this study, including the success of the practice across different scales (e.g., craft vs. large-scale breweries, local/national/international level), consumer perception, potential regulatory implications, and the material opportunities of different food waste types. Addressing these gaps could enhance the existing knowledge base and support informed decision-making.

Finally, the research findings suggest that, in a viable beer company with access to suitable food waste suppliers, the practice of utilising food waste in beer production does not face significant barriers. Potential challenges can generally be overcome through sustainability-oriented and/or purpose-driven management, and a knowledge-sharing and collaborative business environment.

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Declarations

Competing Interest The author declares that there are no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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