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Sustainability of craft beer produced in Wales

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Sustainability of craft beer produced in Wales

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Thesis submitted for the degree of Doctor of Philosophy

Title	Sustainability of craft beer produced in Wales
Supervisors	Dr Eifiona Thomas Lane School of Natural Science, Bangor University Dr David Styles School of Engineering, University of Limerick
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Executive Summary

Beer is a globally consumed commodity categorised as the fifth most popular drink. The brewing industry for many years has been dominated by a small number of businesses that own a majority of all global and regional beer brands. This has left customers will little choice in terms of brands and beer styles. Consumer demand is shifting to locally produced beer made by small and independent breweries and the number of these breweries has been steadily increasing. There are significant challenges facing small breweries to compete for market share in an industry dominated by the multinational beer brands. When consumers spend money on local businesses the benefits are transferred throughout the local economy. Meanwhile, there is debate over the environmental sustainability credentials of short, local value chains.

The first part of this study explores the definition of craft beer and the many factors that are associated with this term. As the multinational breweries recognise the growing popularity of beer made by small scale craft breweries, their focus has been on gaining market share within the craft sector by "craft washing" – producing beer presented as craft beer but not produced at a craft brewery or taking over existing craft breweries. There are several factors associated with the term “craft”, but more clarity is essential to assist consumers, retailers and policy makers to distinguish craft beer from the "crafty".

The second part of this work aims to understand the various ways small breweries benefit the local economy and community. Employment is a metric that is often used to measure the effects of businesses on local economies, but there are several other important factors that can be explored. In this study, seven small and independent brewery managers were interviewed to understand how they contribute to the local economy. Local employment is explored here together with the impact on food and drink tourism and how consumers are attracted to the unique experience of consuming beer and local food at a brewery. There are also contributions that are of great potential benefit but difficult to measure, such as the support of local charity and community ventures, and these intangible factors are also explored to collate a holistic understanding of socioeconomic contributions to the local, and in some cases rural economies

The third part of this work investigates the environmental footprint of small breweries by conducting life cycle assessments for breweries that participated in the second study. Previous studies of beer production at large multinational breweries have identified packaging as a major contributor to the environmental footprint of beer. In this study, surprising results identify downstream distribution – i.e. the transportation of beer from the brewery to retailer – as the hotspot, because small inefficient vans are used to deliver beer.

The life cycle assessment has provided a clear understanding of the environmental challenges facing small breweries, and in the fourth part of this work the focus was to explore ways to overcome these challenges. Three options were explored to reduce the environmental footprint of the breweries. Findings showed changing from single use glass bottle to either aluminium can or reusable glass bottle can have positive effect on environmental footprints, but changing from steel to polyethylene terephthalate kegs is a less environmentally friendly option. Further reductions are possible if mode of transport can be changed from van to lorry but to implement this change distribution loads must be increased – a possible solution could be collaboration to share distribution among local food and drink companies.

This study has addressed several gaps in academic literature whilst providing a grounded understanding of the brewing industry in Wales – a sector that has received little academic attention hitherto. It has also assisted small breweries to measure their environmental footprint and identified potential measures to improve sustainability that could be adopted by breweries and other food and drink businesses. Finally, this study provides new evidence to policy makers on how to facilitate carbon reductions in the food and drink sector.

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Wele rith fel ymyl rhod – o'n cwmpas
Campwaith dewin hynod
Hen linell bell nad yw'n bod
Hen derfyn nad yw'n darfod
Y Gorwel - Dewi Emrys.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

A	Acidification
ABI	Anheuser-Busch InBev
ABV	Alcohol by volume
AD	Anaerobic digestion
AUS	Australia
BBPA	British beer and pub association
BSG	Brewers spent grain
CHP	Combined heat and power
EBC	European brewers convention
EPD	Environmental product declaration
ESF	European social fund
EU	European Union
FE	Freshwater eutrophication
FRDP	Fossil resource depletion potential
GHG	Greenhouse gas
GWP	Global warming potential
HDPE	High density polyethylene
HMI	Human machine interface
HMRC	Her majesty's revenue and customs
IPA	India pale ale
KESS2	Knowledge economy skills scholarship 2
LCA	Life cycle assessment
ME	Marine eutrophication
NZ	New Zealand
PEF	Product environmental footprint
PET	Polyethylene terephthalate
PLC	Programable logic controller
POF	Photochemical ozone formation
PP	Poly propylene
SIBA	Society of independent brewers
SMOM	Social media opinion mining
TE	Terrestrial eutrophication
TTB	Alcohol and tobacco tax and trade bureau
UK	United Kingdom
USA	Unite States of America

Publications

Chapter 2 was published in Food Reviews International, April 2020

Title Crafty marketing: an evaluation of distinct criteria for "craft" beer

Authors D R Morgan, E Thomas Lane, D Styles

Chapter 4 was published in Sustainable Consumption and Production, November 2020

Title Thirsty work: assessing the environmental footprint of craft beer

Authors D R Morgan, D Styles, E Thomas Lane

Chapter 5 was published in Journal of Environmental Management, January 2022

Title Packaging choice and coordinated distribution logistics to reduce the environmental footprint of small-scale beer value chains

Authors D R Morgan, D Styles, E Thomas Lane

1. Introduction

1.1 Research rationale

For several years the brewing industry in the United Kingdom (UK) has been dominated by a small number of multinational corporations (Cabras & Higgins, 2016). Competition among the big organisations followed a continuous trend of mergers and acquisitions to achieve market dominance (Cabras & Higgins, 2016). This left consumers with little choice in terms of breweries and the type of beer available as most major breweries focused on making lager (Watts, 1991). Historically, ales would have been the typical beer made and consumed in the UK but as the industry shifted to mass production the popularity of lager grew from approximately 1% market share in 1960 to market leading by 1990 (Slade, 2009). A new trend emerged at the start of the millennium and the number of small scale independent breweries (namely "microbreweries") in the UK progressively increased to over 1800 in 2019 (V. Ellis et al., 2015; The Brewers of Europe, 2020). This phenomenon described as a craft beer revolution is believed to originate during the 1980's in the West coast of the United States of America (USA) (Carroll et al., 2000). The modern day revival of small scale craft breweries has been of significant interest to academic research in the USA (Fletchall, 2016; A. Murray et al., 2015; D. W. Murray et al., 2012), Italy (Esposti et al., 2017; Fastigi et al., 2015), Australia (Argent, 2018) and the UK (Cabras & Bamforth, 2016; Danson et al., 2015; Thurnell-Read, 2014). The growing trend of craft beer has also become a focus for the multinational breweries with general beer consumption in decline and the craft sector growing, big breweries are taking over independent breweries to gain a share of this niche market space (Davies, 2015; Farrell, 2015; Gatrell et al., 2018). The term "craft washing" has been used to describe beer made by the big breweries and sold as "craft" beer (Howard, 2017). This has prompted several discussions among breweries, academics, and industry association as to what constitutes a craft brewery (Brewers Association, 2018b; Frake, 2016; Gómez-Corona, Escalona-Buendía, et al., 2016; Watt et al., 2013).

The brewing industry faces several challenges in pursuit of environmental sustainability goals (Tokos et al., 2012). There is growing demand by consumers for food and drink production to impact less on the environment, to be grown organically and to be ethically sourced (Codron et al., 2006; Lodorfos et al., 2018). Recent studies have shown that consumers are willing to pay more for food and drink made with environmental and socially sustainable production methods (Bissinger et al., 2017; Didier et al., 2008; Lanfranchi et al., 2019; Tait et al., 2019). There are several factors to consider when assessing the sustainability of a businesses but the most commonly discussed is environmental sustainability (Vu et al., 2017). The production of raw ingredients (wheat, barley, hops, etc) is a big emitter of greenhouse gases (GHG) accounting for approximately 12% of the total emissions of beer (The Climate Conservancy, 2008). The cultivation of raw ingredients relies on nitrogen fertiliser and the inefficient use can lead to leaching in to ground water, rivers and oceans as well as driving climate change (Glass, 2003). The process of making beer is a major consumer of thermal energy, electricity and water (Olajire, 2020). However, beer production is not the foremost contributor to the overall carbon footprint of beer, packaging has been identified in several studies as the major hotspot (Amienyo et al., 2016; Cimini et al., 2016; Morgan, Styles, et al., 2020). Indeed, small breweries are faced with different set of challenges to the multinational mass producing breweries. The large breweries are able to achieve higher efficiencies because of the economies of scale involved- a large production output results in a lower unit cost, in energy and monetary terms (Sturm et al., 2013). Technological advances has enabled multinational breweries to automate the production processes leading to improved quality, reduced wastage and lower energy and water consumption (Morgan, Thomas Lane, et al., 2020). Although this kind of technology is often unaffordable to microbreweries there are many cost effective measures that microbreweries can employ to improve brewery efficiency such as insulating all pipes and vessels, installing variable speed drives to control motors and energy recovery from vapours (Sturm et al., 2013).

The global beer brands recognise the importance of global stakeholders, they have a carefully developed image and communicate their achievements of corporate social responsibilities through sustainability reports whereas the microbreweries are more influenced by the needs of local stakeholders (Quaak et al., 2007). Social sustainability and the creation of local employment is an aspect that microbreweries play an important role in as they offer good jobs that require training and upskilling in order to carry out the daily tasks (Cardoni et al., 2019). When these jobs are located in rural communities, they represent valuable opportunities for long term employment in regions of low employment (Argent, 2018). Microbreweries play an important role in the local economy as their business depend on local consumers and tourism (A. Murray et al., 2015; Ness, 2018). Food and drink tourism is a niche market space that not only attracts people to an area to sample the local food but to experience the local culture through the food and drink (Bruwer, 2003; Canovi et al., 2019; Duarte Alonso & Alexander, 2017; Getz et al., 2006; Jiménez-Beltrán et al., 2016; Kraftchick et al., 2014; Plummer et al., 2005; Sun et al., 2021). The use of place making in beer branding not only appeals to local consumers but can also attract tourists to experience the local beer and thus support wider tourism development across a region (Fletchall, 2016).

The food and drink industry is viewed as an important sector to the economy of Wales. In 2011, food and farming was added to the list of priority sectors, the nine priority sectors account for 45% of jobs in Wales (Welsh Government, 2018). The food and drinks action plan was published in 2014, it set out a goal of increasing the sales for the sector to £7 billion, a 30% growth (Welsh Government, 2014). The Welsh Government announced in January 2020 that the sales within the food and drink sector had exceeded the target by reaching £7.4 billion in sales (Welsh Government, 2020). Several food and drink clusters were launched in 2018 to assist in the development of the sector and accelerate the sales growth, the beer and cider special interest group form a subsector of the drinks cluster (Welsh Government, 2021a). In 2015, the Welsh Government enacted the Well-being of Future Generations Act placing legal duty on public bodies to safeguard the wellbeing of future generations (Well-Being of Future Generatin (Wales) Act, 2015). In this act "sustainable development" is defined as improving the economic, social, environmental and social wellbeing of Wales (Well-Being of Future Generatin (Wales) Act, 2015). A better understanding of sustainability of the brewing industry in Wales is needed not only from an environmental perspective, but also in terms of contribution to local economies.

1.2 Aims and objectives

The overall aim of this work is to understand the sustainability of small scale beer production in Wales by assessing the environmental footprint of breweries and other factors relating to the industry that impact the local economy and community.

The specific objectives of this research are:

1. To explore the definition of craft beer and the various criteria associated with this term (chapter 2)
2. To investigate the socioeconomic activity of small scale breweries in Wales (chapter 3)
3. To measure the environmental footprint of small scale breweries in Wales by developing a life cycle assessment tool (chapter 4)
4. To identify effective mitigation measures to reduce the environmental footprint of small scale breweries (chapter 5)
5. General recommendations to the brewing industry

1.3 Thesis synopsis

This thesis will follow a non-traditional work package structure with chapters two, three, four and five prepared for publication. Chapter 2 is an evaluation of the pertinent characteristics associated with the term craft beer. This chapter identifies the challenges faced by small scale breweries of competing with multinational organisations in marketing craft beer, before discussing how industry associations representing small scale breweries define craft beer. A shortlist of six criteria is developed by reviewing academic and grey literature, the viewpoints of several independent breweries in the UK and the criteria's proposed by industry associations. The shortlist includes creativity and innovation, brewery size, ownership, the use of high gravity dilution, the type of ingredients used and automation. This chapter concludes by proposing a novel short list of definitive criteria that can be objectively applied to discern genuine craft beer from generic beer marketed using the craft label.

This stage of the study transitions into data collection through face to face interviews with brewery owners. Chapter 3 discusses the nature of being a microbrewery in Wales by investigating the motivations behind establishing a brewery, how small local breweries contribute to place making, the importance of such small business in providing local jobs, how small breweries participate in food tourism and the benevolent work of small breweries in the local area. Seven microbreweries took part in this research, located in the north, mid and south Wales and coastal regions in north west and south west Wales.

Chapter 4 is a life cycle assessment of beer production and distribution across seven breweries using European Product Environmental footprint (PEF) methods (Fazio et al., 2018). This work measures the environmental footprint of the seven breweries and discusses the burdens associated with making beer at small scale. An MS Excel based tool was developed to measure the environmental footprint of beer produced by the participating breweries. This focuses on the entire life cycle of beer value chain stages, including cultivation of raw ingredients, upstream processing of raw ingredients, upstream distribution, brewery activities, packaging, downstream distribution and waste management. The impact categories considered in this study include fossil resource depletion potential, acidification, freshwater eutrophication, global warming potential, ionizing radiation, marine eutrophication, ozone depletion, photochemical ozone formation, terrestrial eutrophication and abiotic resource depletion potential. An expanded boundary approach was adopted to account for use of brewery by-products as animal feed in local farms. A sensitivity analysis focuses on the uncertainty of delivery distance and the recycle rate at the waste management stage of the life cycle.

Chapter 5 continues the work in Chapter 4 where mitigation measures are explored to reduce the environmental footprint of participating breweries. The findings from Chapter 4 identify the stages of the beer life cycle that account for the greatest proportion of the environmental footprint, primarily packaging and distribution, and Chapter 5 tests three mitigation options in order to reduce the overall impacts for each brewery (alternative packaging and distribution vehicles). A sensitivity analysis was conducted to understand the effects of increasing the amount of recycled material used in packaging material. This study has been undertaken to address several knowledge gaps that exist in current academic literature about sustainability of small scale breweries. There is also a practical element to this work that aims to help small scale breweries measure their environmental footprint and identify ways of reducing environmental burdens.

Chapter 6 is the final chapter and includes a general dissuasion of key findings from each chapter and explains how the aims and objectives in section 1.2 of this chapter have been met. There are several avenues for future research to pursue to build upon the body of knowledge in this domain and several recommendations for future research are put forward together with some recommendation directed at the brewing industry in Wales.

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2. Crafty Marketing: An Evaluation of Distinctive Criteria for "Craft" Beer

Abstract

There is increasing consumer demand for craft beer, and for clarification of its definition in the face of widespread (mis)marketing. In recent years many small scale and independent breweries have been purchased by large brewing organisations vying to get a share of the growing and profitable niche market in craft beer. This raises the question of whether the beer produced by such breweries can still be defined as "craft". Are there other factors that should be taken into consideration when defining genuine craft breweries? From the perspective of a consumer who seeks a craft product, little is known about how and where the beer is produced, and when labels are taken at face value there is a greater responsibility for retailers to distinguish between craft and mainstream beers. In this paper, we explore the conceptual and practical aspects of defining craft beer, with reference to definitions established by various national industry associations.

2.1 Introduction

2.1.1 Consumer perceptions of craft beer

Craft beer is often perceived by the consumer to originate from small and independent breweries that produce small batches of beer using the highest quality raw ingredients employing traditional brewing processes to produce an end product that is of superior quality in terms of distinctive taste and aroma (Gómez-Corona, Escalona-Buendía, et al., 2016; Kleaban et al., 2012). This is important given that the growth of the craft sector is down to consumer demand for a unique experience that may not be offered by beer produced by multinational organisations (Gatrell et al., 2018). Studies have shown that consumers apply a higher sense of value to an organisation that is seen to be "authentic" as opposed to "industrial" (Kovács et al., 2013). Consumers' ability to distinguish between a craft and non-craft beer is often limited to information displayed on the product label, and there are no clearly defined boundaries between mass-produced and craft beer. Market research by Mintel found that 44% of consumers would like a credible system of certifying craft beer (Mintel, 2017). As previously suggested, brewery size alone may not be a reliable indicator of craft beer, as there is a multitude of other factors that may differentiate craft beer from generic beer. In essence and generally speaking, a craft product is considered to be of superior quality, to be handmade and often produced in small quantities (Fillis, 2004). The crafts person is often trained on site by an experienced master crafts person with some time spent at college learning the academic principles (Gamble, 2001). Sennett states that "all craftsmanship is founded on skill developed to a high degree" and further notes that all forms of crafts are highly advanced skills developed over upward of ten thousand hours of experience, as an individual's skill develops their abilities become more "problem attuned" and able to make decisions on how to overcome more complex tasks – unlike the untrained individual who may struggle with basic tasks (Sennett, 2008). Rice (2016) discusses the "revolutionary" nature of craft beer that should be distinguished by the characteristics of "small" and "authentic", in contrast to "generic" industrialised brewing processes. The authors go on to highlight the coexistence of both "authentic" craft and the "inauthentic" crafty (Rice, 2016). It is also possible to find beer at the local supermarket that is branded as own brand and described to fit into the craft range.

The growing consumer demand for craft beer has not gone unnoticed by the leading global beer brands. Alcohol consumption in the UK has been steadily declining since 2004, and multinationals and established regional breweries are attempting to gain access into the growing craft sector by either releasing beers described as craft beer or acquiring already established breweries such as Meantime and Camden Town brewery (Davies, 2015; Farrell, 2015). The growing trend of multinational organisations taking over independent breweries in order to sell craft beer has been coined as "craft washing" in recent work (Howard, 2017; Wallace, 2019). The lack of clarity on the term craft beer has left this industry segment open for the large-scale breweries to produce new beer ranges that may be craft in name only, and that may not be produced using the traditional methods associated with a traditional craft brewery (Rice, 2016).

2.1.2 Existing definitions of "craft"

The Brewers Association in the United States (USA) has taken the approach of defining craft beer as being sourced from a craft brewery that is verified as such by successfully meeting a set of pre-defined criteria. The Brewers Association is a not-for-profit organisation that represents small and independent breweries in the USA (Brewers Association, 2019). Their definition of a craft brewery is based on three characteristics (Brewers Association, 2018b): (i) having an annual production up to 7,040,867 hl or 6 million beer barrels (US); (ii) no more than 25% of the business is owned by another "beverage alcohol industry member"; (iii) possessing a "TTB Brewers Notice" and produces beer as opposed to contracting this to a third party. Breweries that meet all three criteria can freely use the Brewers Association seal mark on their labels. To date, 4818 breweries in the USA use the seal to promote their beer, over 85% of members (Brewers Association, 2018c). The Society of Independent Brewers (SIBA) who represent brewers in Britain has also created a seal mark similar to the Brewers Association in the USA. To qualify for SIBA's seal, Brewers must meet two characteristics (SIBA, 2018): (i) compliance with SIBA's food safety and quality standard; (ii) the brewery is an independent brewery with no affiliation with another larger brewing organisation. Eight hundred and seventy breweries currently use this seal (SIBA, 2018). In contrast, 2378 breweries qualified for reduced duty, namely the small brewers relief, by having an annual production capacity under 60,000 hl in 2018 (Brewers of Europe, 2018). Thus, many small breweries are not covered by the main industry seal for small and independent brewers, and it is fair to say that the brewing industry is not as well represented as the USA. Meanwhile, the Italian government has recognised the importance of the Italian craft beer sector and has taken a proactive approach to protect the credibility of the craft market by passing a Law in July 2016 defining what can be classified and thus sold as craft beer. This Law stipulates craft beer should originate from a small brewery with an annual production of no more than 200,000 hl, that is operating independently of any other brewery, and must not subject the beer to pasteurisation or filtration (Centinaio, 2016). In this paper, we critically evaluate criteria proposed by various industry associations and others to define craft beer and select a relevant subset of these criteria that could be practically applied by consumers or industry organisations to accurately differentiate craft beers.

2.2 Methodology

The aim of this paper is to explore whether objective criteria can be applied to define the term “craft” beer by evaluating various characteristics proposed by industry associations, academic and grey literature and discussions and viewpoints of independent brewing organisations in the UK. We begin with the broader meaning of the term “craft”. What is a craft, how does one become a crafts person (and how long would this journey take)? We then critically evaluate craft definitions proposed by established industry associations in the USA and Britain. We conclude by proposing a short-list of criteria that could be objectively assessed to define craft beers.

2.2.1 The value chain of beer

Many factors influence consumer perceptions on what is a “craft” beer such as local embeddedness (Argent, 2018) sensory characteristics (Gómez-Corona, Escalona-Buendía, et al., 2016; Gómez-Corona, Lelievre-Desmas, et al., 2016) and aspects relating to place making (Fletchall, 2016). We do not address all of those factors in this paper but focus on more technical criteria that could be used to objectively define craft beer and underpin a verifiable label. To do this, it is first necessary to consider the life cycle of beer production. The beer value chain has been described in Figure 2.1 by dividing the stages of beer production into four steps. Firstly, cultivation of the raw ingredients includes all inputs (e.g. fertilisers), maintenance and harvesting operations prior to produce leaving the farm gate (Kok et al., 2018). This stage applies to any grown ingredients used in brewing, including hops, barley, and adjuncts such as wheat, rye, and oats among many others. The second stage covers the onward processing of the ingredients (Henderson et al., 1972). In the case of barley, this would involve allowing the barley to partially germinate followed by a period of time in a kiln to roast the malt, depending on the type of malted barley being made (The Maltsters Association of Great Britain, 2019). Following processing, ingredients would then be packaged and prepared for delivery to a brewery. Stage three of the value chain includes all activities at the brewery from goods arriving, through brewing processes, to the final products being packaged for delivery. The brewing process itself consists of three initial stages (Gillespie et al., 2010). Beginning with mashing where the barley and adjuncts are mixed with water and left to stand for approximately one hour in a vessel called mashtun. Next, the liquid is drained from the mashtun and additional hot liquor is poured over the content of the mashtun to ensure any remaining fermentable sugars are captured in a process called sparging. The liquid is transferred to a vessel traditionally known as the copper or boil kettle. During the boil, hops are included to add bitterness and aroma to the beer. The final stage of beer production starts with rapidly cooling the liquid from the kettle in preparation for fermentation where yeast is added. The beer will remain in a fermenter vessel – for ale, this could be for between 7 and 10 days but for lager, it can take a few weeks. Once fermented the beer is stored in vessels for maturation then placed in kegs, casks, bottles, or aluminium cans ready to be distributed. The final stage in the value chain covers distribution from the brewery to retailers. This is separated into two sectors known as on- and off-trade; the former represents pubs, clubs, and restaurants and the latter shops and supermarkets.

Growing, cultivating & harvesting raw ingredients 	Traditionally, barley has been the main source of fermentable sugar used to produce beer together with a number of adjunct such as wheat, oats and rye. They are included for qualities such as flavour, mouth feel and head retention. These are included in the early stage of brewing known as the mash. In the boiling stage of the brewing process the hops are added these add flavour and aroma (Kok et al., 2018).
Malting, drying & packaging 	For the purpose of this discussion the second stage of the value chain is from the farm gate, through the subsequent processing and packaging of major ingredients in preparation for use in the brewing process. Barley is processed by malting, which includes stimulating the barley to partially germinate before being heated in a kiln. The length of time in the kiln can result in a range of colour from light to dark beer. Other processes include drying of the hops, which is done to retain qualities such as colour, shatter, aroma, moisture content and alpha acidity (Henderson et al., 1972).
Brewing 	This involves milling the barley to brake open the husk, then mixing with other adjuncts depending on style and recipe in the mashtun which is soaked in water at 68 ˚C for a period upwards of 60 minutes. The mashtun is then drained of all liquid, and to ensure all fermentable sugars are extracted from the mashtun a process named sparging is employed, involving spraying hot water over the content of the mashtun. The extracted liquid is named wort and is transferred to a vessel named a kettle for rigorous boiling again for a period upwards of 60 minutes, with hops added at different intervals. Once complete the wort is transferred to a fermentation vessel where yeast is added. A fermentation can take upwards of 7 days depending on style of beer. Once fermented the beer is stored in a maturation vessel before it is packaged in to either keg, cask, bottle or can ready for distribution. Once matured, beer can be pasteurised or filtered, though this is not carried out at all breweries.
Distribution & retail 	Once packaged the beer is ready for distribution, beer sales are split in to two sectors, firstly on trade meaning pubs, clubs and restaurants who sell beer in cask, keg, bottle or can and the off trade such as food and drinks retailers like supermarkets selling only bottles and cans.

Figure 2.1. Beer value chain.

2.2.2 Criteria identification

First, a comprehensive list of possible defining criteria was created. Possible criteria were collated by firstly taking reference of industry association seals, as mentioned above, to establish criteria in current use (Brewers of Europe, 2018; SIBA, 2018). This was followed by an extensive literature search of peer-reviewed articles and grey literature using search words such as “craft”, “beer” and “brewing” (Bastian et al., 1999; Fillis, 2004; Gatrell et al., 2018; Gómez-Corona, Escalona-Buendía, et al., 2016; Howard, 2017; Rice, 2016; Wells, 2016). There has been some work in recent years on consumer perception (Gómez-Corona et al., 2017; Gómez-Corona, Lelievre-Desmas, et al., 2016), but we look to the industry and producers for their perspectives, including recent discussions in the brewing industry about independence and ownership disseminated on social media platforms such as Facebook, Twitter, and Instagram by many brewing organisations. Three social network sites have been selected to gain the viewpoints of breweries on the matter of multinational brewing organisation ownership of “independent” breweries: Facebook, Twitter, and Instagram accounts of 76 breweries were followed. The methodology used for tracking discussion was social media opinion mining (SMOM) a qualitative approach observing viewpoints expressed on social media posts. Previous studies have utilised Application Program Interface to follow social media discussions on topics of interest (Rahmani et al., 2014). This was considered unsuitable as the results would include public discussion. We observe the discussions, in this case, the reaction to the news that a London-based independent brewery had received an investment by a multinational brewing organisation in exchange for a share ownership in the business. The case study selected was a beer festival with a global attendance of over 70 breweries organised by the brewery in question. The approach taken in this case was to follow the accounts of the attending breweries.

2.3 Outcome

Following the comprehensive literature search, it was possible to identify a total of six specific factors that were highlighted as having a place in the overall discussion over craft and non-craft. Each criterion was categorised as either an excluding or indicative criteria. Excluding criteria reflect an activity or characteristic that is considered to preclude a beer from being defined as craft, whilst indicative criteria represent factors that have been accepted by the sector as relevant but could not be used to disprove or confirm any craft identity. The six criteria are summarised in Table 2.1.

Table 2.1. Shortlist of six criteria considered for craft definition.

Source	Criteria 1	Criteria 2
Industry Association	Size	Ownership
Brewing Industry	Ingredients	High Gravity Dilution
Observation	Automation	Creativity & Innovation

2.3.1 Brewery size

Perhaps the logical starting point in the definition of craft beer would be to consider the first defining criterion applied by the industry associations. Firstly, in order to avoid any confusion, it is important to distinguish between the term’s microbrewery and craft brewery. A microbrewery is defined by size alone, falling below a certain output threshold, and may fall within the definition of a craft brewery subject to other defining characteristics being met. According to the Brewers association in the USA, a microbrewery has an annual production of up to 17,600 hl (Brewers Association, 2018a) and according to their website, there are 4,247 microbreweries in the USA at present (Brewers Association, 2018d). As a defining criteria for a craft brewery, the Brewers Association has a maximum annual company production threshold of 7,040,866 hl. The Brewers of Europe classify microbreweries to be significantly smaller than the USA Brewers Association definition, with an annual production up to 1000 hl (Brewers of Europe, 2017). The brewing industry in the UK has no description of a microbrewery, but the UK Government allows tax benefits for smaller breweries in the form of a small breweries relief. This is a tiered system allowing a 50% tax reduction for the smallest producers of up to 5000 hl per year, with allocated benefits applied to larger breweries up to a maximum annual production of 60,000 hl. In recent years, many small scale and independent breweries have been purchased by multinational brewing organisations (Davies, 2015; Farrell, 2015; Furnari, 2011; Hancock, 2018).

The larger annual capacity threshold for craft breweries in the USA is likely to reflect the generally larger scale of brewing nationally compared with other countries. Specifying a maximum size for breweries producing craft beer may be somewhat arbitrary given that beer produced by large breweries could have many other qualities associated with craft beer. One example of this is the Scottish brewery BrewDog who reported total beer sales of 436,994 hl in their 2017 brand overview report (BrewDog, 2017). We will elaborate below the important characteristics of BrewDog beers that could define them as craft, despite the relatively large size of this brewer.

2.3.2 Process control and production methods

Process control via automation is playing an essential role in all aspects of plant operation at large-scale industrial food and drink production (Dahm et al., 1990). This technology enables autonomous production and monitoring of production plant but the outcome can erode human responsibilities, and traditional human tasks may be substituted by automated machinery. Human input may be confined to observation and monitoring of the process through a Human Machine Interface (HMI) or control room (Wu et al., 2016). Such modernisation of industrial production has seen many human tasks replaced by computerised control systems. This is not to say that automation does not have a place in a craft brewery. A modern bottling or canning plant, for example relies on automated control, and the advancing technology in terms of instrumentation can provide a brewer with better control of the brewing and fermentation processes, ensuring the quality of the final beer (Chakraborty et al., 2015). There are valid arguments for utilising such technology in small-scale production given the financial constraints faced by small producers with a limited workforce. This matter is explored further in terms of both the benefits of such technology and the potential conflicts with the concept of craft brewing.

The advantage of utilising automated technology is that allows for continuous monitoring of specific parameters, thus ensuring that output is of the highest food quality standards. Plant downtime can also be reduced as equipment can be taken offline or isolated as part of the control and monitoring – this feature prevents damage occurring to the equipment, for example pumps running dry and improves the overall economic efficiency (Livelli, 2012). Automation can also result in less produce being wasted, by taking simple mundane tasks away from human control and reducing human error. Water consumption is a factor that can be dramatically reduced by installing equipment that measures usage, enabling better management (Laughman, 2017).

However, a possible knock-on effect of employing such technology is the simplification of tasks and transfer of responsibilities away from humans, leading to the possible de-skilling of workers and ultimately reduction of staff numbers, though this is unlikely to be the case for a team at a small brewery. Traditional techniques and practices that are learnt and developed by experienced crafts people during a lifetime career could become redundant or unnecessary as tasks are taken over by automation in the overall brewing process at modern day breweries. The skills acquired by traditional brewers are of great importance for “occupational identity” (Thurnell-Read, 2014), and are needed for the formulation of new beers. There is a risk that specialist brewing skills may not be passed on to the next generation of craft brewers if reduced demand for these skills means that there is little scope for training. When used in combination with automation, the skills of a craftsperson may still be applied in the brewing process in a manner compatible with "craftsmanship". However, when data collected by monitoring devices are fed into a Programmable Logic Controller (PLC) processor that then controls tasks such as controlling valves, temperatures, levels within vessels and running pumps via pre-written software code, the role and specialist input of the craftsperson diminishes, potentially creating a valid exclusion criterion for craft beer.

2.3.3 High gravity dilution

As discussed in the beer value chain, high gravity dilution is undertaken by some breweries after the fermentation stage. By measuring the original gravity from a sample of wort taken before the yeast is added and then measuring the beer when fermentation has finished it is possible to calculate the alcohol by volume (ABV) of the beer (Ferguson, 2016). Beer styles such as Belgian tripel, imperial stout, and barley wine are all examples of high gravity beer with alcohol content ranging from around 8 – 11% ABV or higher (Ferguson, 2016; Poelmans et al., 2019). With high gravity dilution, the higher alcohol content can be diluted with deoxygenised water, resulting in an increased volume of the final beer at 11.5° Plato. It has been found that increasing the fermentation temperature to 18° C can enable a high gravity wort of 22° Plato to ferment within the same time as a wort of 15° Plato. Diluting down a 22° Plato wort can increase brewing capacity by 91%, whilst diluting down a 15° P wort can increase brewing capacity by 30%, compared with aiming for a wort of 11.5° P (Lima et al., 2011).

This procedure clearly has numerous economic and potential environmental benefits for industrial brewing, including reduced capital costs, energy, and water inputs per litre of beer produced. However, this process does have some disadvantages including a reported decrease in "brew house material efficiency", a reduction in hop utilisation and has a negative effect on the head retention (Cooper et al., 1998). This process has previously been discussed among craft brewers as one that could not be associated with craft brewing, given their focus is on exploring new flavours (Watt et al., 2013). For this assessment, high gravity brewing is included as an exclusion criterion however it must be noted that at present not all beer labels contain details on the original specific gravity.

2.3.4 Independent ownership

The steady growth and subsequent industrialisation of large-scale brewing have resulted in a small number of multinational organisations retaining a large proportion of the beer sales market (Elzinga et al., 2015; Fastigi et al., 2015; Wells, 2016). Over the past decade, multinational breweries have taken aggressive measures to gain an advantage over their competitors to achieve a greater proportion of the market share. The most high profile example was the acquisition of SAB Miller by

AB Inbev in a deal said to be worth £79 bn making this the third largest merger in corporate history leading to ABI being the largest brewing company in the world (Daneshkhu, 2016; Nurin, 2016). A growing trend within the craft sector has appeared where independent breweries are taken over by multinational organisations. Meantime brewery was taken over by SAB Miller in 2015 and later that year Camden Town Brewery was purchased by AB Inbev (Davies, 2015; Farrell, 2015).

Recent studies led by Gomez-Corona categorised the beer industry as two sectors: craft and industrial (Gómez-Corona et al., 2017; Gómez-Corona, Escalona-Buendía, et al., 2016). It could be interpreted that based on this description beer not produced using industrial production methods would necessarily be craft beer and vice versa. Further consideration suggests that accurate classification of craft beer is more nuanced than this. For example, a brewery employing small-scale manual production processes cannot be defined as craft if under the ownership of a multinational organisation according to other existing criteria. Share ownership is acceptable in the USA up to 25% for craft definition (Brewers Association, 2018b) but the Assured Independent campaign in the Britain stipulates total independence as a qualifying requirement (SIBA, 2018). The flexible approach of the Brewers Association allows a craft brewery to seek investment if retaining majority share and maintaining control of the business. This stance can allow a business to expand and access new markets. Here, we adopt the stance taken by the Brewers Association, and propose retaining a minimum 75% ownership of the business; a value below this would act as an excluding criteria (Brewers Association, 2018b).

2.3.5 Ingredients

The creation of unique flavours has been a key selling point of craft brewing (Bastian et al., 1999). As previously discussed by Bogdan et al. (2017) non-malted grains such as barley, corn, rice, wheat, oats, and rye are known as solid or mash vessel adjuncts. The liquid or kettle adjuncts varieties include malt extract popular among home brewers and sugar syrups derived from sugar cane and sugar beet (Bogdan et al., 2017). A variety of beer styles can help differentiate breweries but also demonstrates an in depth understanding of various styles and brewing techniques required to produce, e.g. sour beer or barrel-aged beers. The use of high-quality raw ingredients is expected to be an essential characteristic of craft beer and is often discussed as central to the ethos of many craft breweries (Kleaban et al., 2012). This point is often highlighted with breweries detailing the specific ingredients on the packaging and sometimes openly sharing the recipes for their beers. For example BrewDog has published the “DIY Dog” – a collection of all beer recipes from the entire BrewDog range for home brewing replication (Watt et al., 2018). In addition to providing the home brewer with an opportunity to reproduce recipes, this also has an additional advantage of showing complete transparency with the ingredients used. There has been some speculation over the type and quality of raw ingredients used in beer produced by multinational breweries, with barley being substituted with other lower-cost fermentable ingredients such as rice and maize (Poreda et al., 2014). The basis for this is reported to be to produce a beer that is lighter in colour and supposedly flavour (Stika, 2017). However, there is also significant suspicion that such substitutions may be more financially motivated rather than driven by quality and flavour objectives (Watt et al., 2013). For example, sucrose-based syrups are used to produce a higher gravity wort at lower cost than barley malts, often as the preliminary step to high gravity dilution as previously discussed with the aim to increase the capacity of the brewhouse rather than to improve flavour (Bogdan et al., 2017). In contrast, craft brewers may advertise their ingredients to promote a beer, and this practise is often seen when breweries collaborate to produce a one-off beer (Brewdog, 2019; Omnipollo, 2018). The style of beer and ingredients is often announced on social media platforms as a low-cost but powerful method to promote their product. A Twitter post from a Danish brewery named Mikkeller shared what they claim to be the first collaboration with a brewery from Bhutan using an unusual ingredient combination including pineapples and Himalayan pink salt. This can be seen as an example of a modern day brewery responding to the growing demand by the consumer for transparency and the desire to know more about where the food comes from, and that it is produce safely and sustainably (Beulens et al., 2005; Wognum et al., 2011).

2.3.6 Creativity and innovation

One factor that is not so regularly discussed when defining craft beers is the diversity of choice on offer to consumers. The evolution of big brewing has resulted in mass production of a limited number of brands, potentially leaving the consumer with a few choices of beer. The majority of beer produced by the big organisations is lager with a few ale or stout options. These are heavily marketed to the consumer in television advertisements and online, with some brands going a step further by associating beer with events, sports, or pastimes (Vinjamuri, 2019). The BBPA reported that Lager is the most popular beer in the UK making up 74% of the total beer sales in 2016 (British beer and pub association, 2017). On the other hand, in terms of independent or small-scale brewing, there is an endless list of beer styles that is on offer to the consumer (Gatrell et al., 2018). Craft breweries have the agility to make one off, experimental or seasonal beer and later decide if a new beer should be added to a core range based on consumer feedback. This is an important characteristic of many craft breweries. However, it is the choice of the individual brewery as to whether they produce an ever changing range of beer by experimenting with different styles and ingredients or simply focus on a core range and do it well. This is considered to be a reliable metric to establish whether a brewery is craft or not as it is an important indicator that could be readily used to inform consumers about the craft nature of a brewery.

The following table includes the characteristics found to be associated with craft beer together with a short description. Some characteristics have previously been identified as essential factors and are thus considered to be exclusion criteria. If a single exclusion criteria is found for a particular beer or brewery where it is brewed, the craft identity is negated.

2.4 Discussion

This assessment has taken the approach of reviewing the current literature and viewpoint of prominent brewers within the UK brewing industry that has been outspoken about the topic of craft beer and established industry associations to define craft beers. This exercise has highlighted that the term “craft beer” is far more complex and difficult to accurately define than previously postulated by consumers, industry stakeholders, and academics (Gómez-Corona et al., 2017). From this, a conclusion is made on a subset of the relevant criteria that can be used to define craft beers from the full list in Table 2.2 and these criteria are evaluated below. The proposed shortlisted criteria could be used by industry associations to verify a brewery’s compliance, e.g. in order to qualify for the use of a “craft” seal mark. Proposed criteria could also be employed by the retail industry, particularly supermarkets, to allocate shelf spacing for a “genuine craft beer range” or even to edit out craft “imposters” from their assortment (e.g. to demonstrate commitment to provenance and sustainability). Some characteristics have previously been identified as essential factors and could be used in this case as exclusion criteria. If a characteristic from Table 2.3 is appointed as exclusion criteria it could be viewed the beer and brewery in question fall outside the definition and therefore the craft identity would be negated. The UK has been revaluating its relationship with the EU and an important point to consider is that the UK is the foremost importer of beer from elsewhere within the EU (Brewers of Europe, 2017). Figure 2.2 shows a process diagram to assist in the determination of whether a beer can be categorised as craft or not. This exercise is designed to exclude beer that is non craft by answering three questions.

Table 2.2. Craft beer characteristics – Full list.

Characteristics	**Description**
1. Size	A maximum annual production of no more than 200,000 hl
2. Automation	The overall process governed by human control with automation supporting the human decision.
3. High Gravity Dilution	Producing wort with a higher gravity then diluting the alcohol content
4. Ownership	The brewery must retain 75% ownership of the business
5. Ingredients	The use of adjuncts for the purpose of enhancing the overall flavour and experience not substituting ingredients to reduce the cost of production
6. Creativity and Innovation	A range of core and seasonal beer, a variety of various e.g. Sour beer or barrel ageing

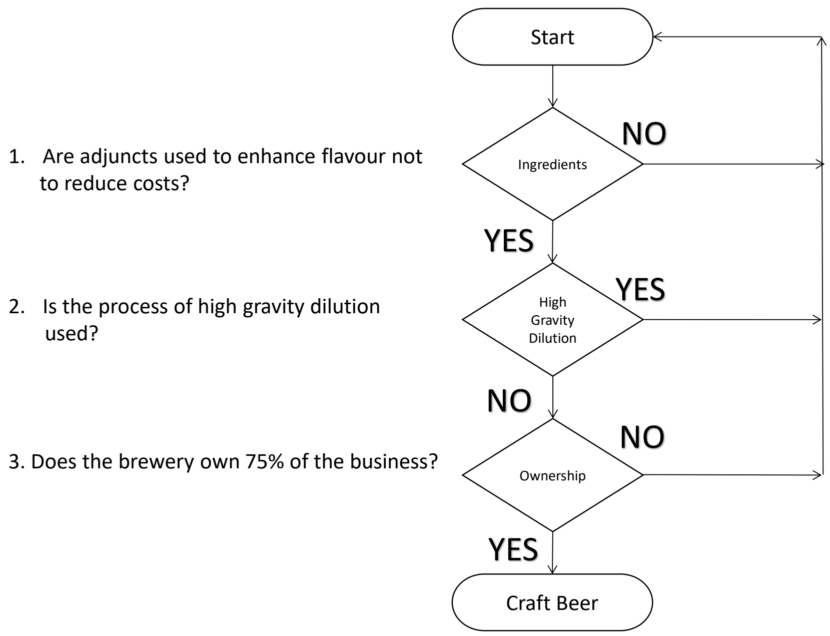

Figure 2.2. Flow diagram to assess craft beer based on pertinent criteria proposed in this study.

Table 2.3. Conclusions on the criteria pertaining to the definition of craft beer.

Characteristic	Description	Appropriateness	Concluding comment
1. Size	A maximum annual production no more than 200,000 hl	Indicative Criteria	Size criteria should be removed as an excluding criteria and observed as an indicative criteria
2. Automation	The overall process is governed by human control with automation	Indicative Criteria	Impractical. Could be used as a defining criterion but would require brewery inspections, and boundaries of automation and human control fuzzy
3. High Gravity Dilution	Producing wort with a higher specific gravity than the final beer, and diluting down to produce the final product	Excluding Criteria	This is a useful exclusion criterion that indicates decision making driven by cost rather than flavour beer
4. Ownership	The brewery must retain 75% ownership of the business.	Excluding Criteria	A useful metric and simple to gather evidence
5. Ingredients	Adjuncts are selected for the purpose of enhancing, not simply to reduce cost of production	Exclusion Criteria	An important criterion that is central to the craft brewing ethos
6. Creativity and innovation	The brewery produces a diverse and evolving range of core and seasonal beers, including a variety of beer styles (e.g., sour beer or barrel aged beer)	Indicative Criteria	A useful criterion to indicate craft brewing

2.4.1 Production size

The annual production of a brewery has been included by industry associations. It is a factor that will undoubtedly provoke disagreement. After reviewing the literature, this criterion we propose that there is no evidence to support any specific threshold, and therefore conclude that this criterion should be withdrawn entirely to place emphasis on other important defining criteria.

2.4.2 Automation

The hands-on process of brewing is an intrinsic aspect of craft beer that attracts consumers (Rice, 2016). As for other artisan products, there is a need to define this desirable quality. Producing beer using a fully automated control system, as one would expect to see at a modern brewery, means that the craft person is somewhat disconnected from the produce he or she creates. It would be foolish for a brewery to decide not to utilise modern instrumentation for the benefit of efficiency, to reduce wastage, and maintain quality. A modern facility can still be viewed as craft brewery providing that human decision making is the overall controlling factor throughout the brewing process. As with many small businesses often employing a limited workforce, the use of technology can be essential for the smooth running. One observed example of this had a single person running the business. This brewer was not in a position to employ any workers but instead used instrumentation to monitor the fermentation process remotely, allowing the business owner to spend more time at home with family and enabling a healthier work-life balance. This factor is a valued way of informing the consumer how the beer is produced but this is not considered suitable as a excluding criteria.

2.4.3 High gravity dilution

This process has potential financial benefits for mass production but this is a polar opposite focuses of craft brewing and this has been discussed as having an effect on qualities such as head retention (Stewart, 2007). Given that members from the craft beer industry have also expressed a negative view of this process we propose this should be used as an exclusion criteria (Watt et al., 2013). It is the breweries decision what information to print on the label and original specific gravity is not always shown. For this to be a possible criteria a certification scheme would need to verify this regulated by a governing body.

2.4.4 Ownership

It is very important to take into consideration the ownership when questioning whether a brewery is craft or not. The negative views held by independent breweries have been discussed earlier in regards to accepting investment from multinational brewing organisation and the inflexible attitude towards any collaboration with a recipient of such investment. Whilst investment from a third party being either a larger brewery or investment company can enable a business to grow and potentially access new markets there is also a sense of suspicion by consumers surrounding outright ownership given that the investors' ability to influence production and accounting amongst other things, this might have an effect on the quality of the final product (Frake, 2016). It is wise to set an ownership limit for the craft brewery to continue operations as normal but equally important to enable growth through investment there for it would be wise to adopt the stance taken by the Brewers Association with a 25% ceiling on investment.

2.4.5 Ingredients

The central point that should have no compromise is the quality of the raw ingredients going into a craft beer because taste, provenance, and authenticity are key characteristics attributed to craft beer by consumers (Gómez-Corona, Lelievre-Desmas, et al., 2016). The use of high-quality raw ingredients and the use of adjuncts to enhance the overall beer experience and not to reduce costs should be viewed as a core criterion. This point is set to safeguard the quality and maintain a distinction from mainstream mass-produced beer. Sugar syrup is an example of an adjunct used primarily to enhance alcohol yield rather than deliver distinct flavour, and as such, when used as a primary adjunct, can be readily identified as an exclusion criterion for craft definition. There may be some ambiguity over other low-cost adjuncts such as maize and rice, but the onus rests on the brewer to demonstrate that such ingredients contribute to a distinctive flavour. Some brewers already share specific information on their websites, but this key information would be more appropriately shared at the point of sale, with packaging appealing to both the proactive retailers and consumers. It is also important to understand the view of brewers who feel that sharing such information could affect their competitive advantage and to navigate this matter it may be necessary for a certification body to take control of this and to confidentially check compliance on all matters and to provide a system as simple as a tick box to show the successful achievement of all criteria.

2.4.6 Creativity and innovation

This could be used as a defining criterion and as previously discussed the craft producers have the ability to experiment and make new beers as limited release before incorporating to a core range. This also could be a requirement for meeting the craft definition if it was adopted by an industry association and complying with this could simply require the creation of new beers annually. This ensures that the skills of the crafts person are continually developed and encouraged to express themselves with new ingredients.

2.4.7 Limitations of the study

It must be noted that some criteria do have limitations surrounding the availability of information regarding specific activities has been difficult to obtain from a desktop analysis. The subject of ownership is often publicly reported in newspaper articles and social media platforms when a company is acquired, and this has been found to be the simplest criteria to verify. The original specific gravity is sometimes shared, this is quite simple information to include on packaging but without this voluntarily being available high gravity dilution is difficult to clarify. This is another reason for a governing body to take responsibility over a certification scheme. Although it has no overall effect on the definition, it is believed that indicative criteria should be available to the consumers to understand how the beer is made in order to facilitate an informed decision.

2.5 Conclusion

This chapter has addressed objective number 1 of the aims and objectives outlined in Chapter 1 section 1.2.

To ensure quality and maintain credibility it stands to reason that a craft beer can only come from a genuine craft brewery. However, there are no universally accepted definitions of what a craft beer or craft brewery is. In this paper, we critically explore existing definitions and propose a set of universally applicable criteria to rigorously distinguish craft beer. It might be easier to define what craft beer isn’t rather than what it is, as it is such a contentious subject. Any attempt to define craft beer such as our will inevitably provoke debate and come under some scrutiny. Craft beer is certainly not mass produced, and it is difficult to associate craft beer with multinational brewing and the organisations who produce mainstream beer. Craft beer is perceived as “honest” and uncompromising in terms of flavour but may be either traditional or modern. Craft beer is made using traditional brewing processes and uses the best quality raw ingredients with adjuncts included to enhance the flavour and experience not to reduce cost.

2.6 Recommendation

It is recommended that to safeguard the true quality and identity of craft beer, an independent and autonomous industry board or organisation is required to check individual compliance with a set of objective criteria, such as those proposed in this paper. Broad acceptance of criteria for “craft” definition by the sector would require intensive stakeholder consultation by the prospective validating organisation, with a clear mandate to ensure that criteria remain meaningful and verifiable. Whilst greater transparency of ingredients and brewing processes is required, ideally, though labelling, this must be balanced with the need to maintain a degree of confidentiality around proprietary processes. An opt-in labelling scheme could be based on voluntary sharing of such information, which in itself may be a useful indication of craft credentials.

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3. Brewing up a small and sustainable business

Abstract

Small breweries play a crucial role in local economies by providing local jobs, support local ventures and collaborate with other business to attract consumers to their local area for food tourism. As consumers are shopping locally in search of shorter supply chains and food traceability there has been a growing interest in locally produced food and drink. With several lessons to learn from as Wales and the United Kingdom recovers from a global pandemic and the disruptions caused by geopolitical matters there is a strong argument to buy locally and avoid complex supply chains. This chapter explores the motivations behind establishing small breweries, the importance of the local area to brand identity and place making. In rural areas these businesses are an important provider of jobs that can upskill the local workers and offer job prospects for young people in the form of apprenticeships. Over one hundred small scale breweries exist in Wales and the breweries that participated in this work represent a diverse nature of craft beer with a variety of case studies from rural and urban locations, traditional real ale producers to the modern and experimental.

3.1 Introduction

The revival of the brewing industry over the past two decades and the shift towards neoloclaism has returned what was once a widely consumed mass processed and generic produce into a variety of beer styles produced at small scale microbreweries serving the local area (Flack, 1997). The emerging popularity of farmers market is in part down to consumers ability to purchase fresh food with the shortest supply chain and considered to be superior in quality to supermarket produce (Wolf et al., 2005). Food festivals have also emerged as a popular platform for many local producers to showcase their produce to a wide audience from within the local area hosting the event and to visiting tourists (Lee et al., 2011). These events demonstrate the emerging trend of neolocalism.

Neolocalism is a term that has often been used in academic literature to discuss the role small local breweries play in creating a sense of place, celebrating the unique aspects of the local area through branding, collaborate with other businesses in the interest of improving local area and for the social capital amongst businesses and community (Argent, 2018; Flack, 1997; Fletchall, 2016). Holtkamp (2016) highlights the importance of understanding the extent a business engages with neolocalism and proposes an assessment tool based on a breweries branding, environmental performance and community engagement (Holtkamp et al., 2016). The advances in technology has resulted in shifting the trend of people consuming locally produced goods to have access to alternative products made on an industrial scale and sourced from overseas weakening or in some cases eliminating "place based ties" (Schnell, 2013).

The craft brewing industry is considered to be the foremost example of consumers moving away from the big beer brands in search of produce with local connections (Taylor et al., 2020). Schnell and Reese (2014) discuss place making and the unique opportunity of connecting with the "place" at local breweries (Schnell et al., 2014). Company name, logos and product names are all effective ways of connecting the brewery with the local area (Holtkamp et al., 2016). A study of place making in New England, USA found breweries showcasing the local wilderness, ways humans enjoy the great outdoors and nautical history in company identity, concluding that large multinational brands have nationally recognised motif where as regional and microbreweries focus on a local themes (Debies-Carl, 2019).

Food tourism plays an important role in local economies by showcasing the unique produce available in the local area, contributing local economic and cultural development (Cavicchi, 2013; Plummer et al., 2005). As an offshoot of food tourism the food festivals provide an opportunity for consumer to meet with producers, sample the produce and learn about how the food is made (Y. G. Kim et al., 2010). It is also opportunity for some producers who may not have direct contact with the consumer because of supply chains to put a face to the company, offer samples and gain feedback (Plummer et al., 2005). Ale trails are another phenomenon that has evolved as a facet of beer tourism that allows consumers to follow a planned route visiting breweries and pubs to sample the locally produced beers (Slocum, 2016). There are several unique examples of beer trails that have been organised around local activities for example City trails that lead consumers along a tram route, arranged in parallel with hiking paths or by visiting pubs along a river (Feeney, 2017). In north Wales there is an annual beer festival named Cwrw ar y cledrau (Rail Ail) that showcase real ale from breweries across Britain organised by Rheilffordd Ffestiniog ac Eryri (Welsh Highland railway) giving attendees the opportunity to travel by a historic steam train visiting the many local pubs along the railway route (Rheilffyrdd Ffestiniog ac Eryri, 2021). A study of a Canadian ail trail conducted by Plummer (2005) finds advertisement through word of mouth to be the most effective way to reach customers and those attending the ale trail plan on visiting local restaurant and pub as well as the breweries, showing that such events can draw in customers and benefit other businesses within the local economy (Plummer et al., 2005). To develop craft beer tourism Alonso (2017) discussed the need for all stakeholders to create a "craft brewing culture" built on knowledge sharing and education, strengthening ties across the beer value chain and gaining critical feedback to continue raising standards (Alonso et al., 2017).

3.1.2 Craft Innovation

An extensive study of innovation from the perspective of micro and small craft breweries located in Italy, Spain and the United Kingdom conducted by Alonso (2017) concludes that there are several ways breweries define innovation but the common view point include the creation of new recipes, the use of social media as a marketing tool and combining gastronomy with a craft beer experience (Duarte Alonso, Bressan, et al., 2017). Cabras (2015) discusses the growth of two globally recognised beer brands that identifying investment in innovative technology to reduce the energy consumption and a commitment to environmental responsibility as one strategy and the capitalising on geographical provenance linking the brand to the local area as another common strategy (Cabras & Bamforth, 2016).

There are several ways to define how consumers are attracted to experience the unique food and drinks on offer at a particular destination. Ellis (2018) states the most common terms are culinary tourism, gastronomic tourism and food tourism (A. Ellis et al., 2018; Horng et al., 2012; Sánchez-Cañizares et al., 2012). The global wine industry attract consumer interest worldwide and exemplifies both popularity of food and drink tourism and the positive effect this has on local economies (Carlsen, 2004; Ferreira et al., 2017; Hall et al., 2019; Simeon et al., 2011). As a subset of the food industry the small scale breweries also attract consumers to visit an area and experience the local produce for beer tourism (Alonso et al., 2017). Ellis (2018) concludes that culture is a core concept for food tourism the motivations behind the experience include history, origin, place and the spoken language of the location (A. Ellis et al., 2018). There are several opportunities for consumers to sample locally produced beer the most common being at a pub or restaurant but beer tourism represents other experiences such as ale trails, beer festivals, tasing events and brewery tap rooms (Duarte Alonso & Alexander, 2017; Plummer et al., 2005). There could be environmental benefits for consumers visiting brewery tap rooms by avoiding the distribution of beer from brewery to retailer, a major environmental hotspot for small scale breweries (Morgan, Styles, et al., 2020).

3.2 Methodology

The seven breweries researched in this work are located across Wales in both urban and rural location with varying population. In some cases, they are established in relatively large towns whereas others have chosen to establish a business in a more remote location that could be described as rural but this term is used in an arbitrary way with no specific assumptions for the localised population (Bosworth, 2012). The face to face interviews undertaken was an opportunity to collect two sets of data, first the information about the brewery and socioeconomic activity and secondly data to be used for conducting an environmental footprint assessment (Chapter 4 & 5). The interviews would start with a short discussion lasting ten to fifteen minutes following an unstructured interview guide with discussion of an informal nature (Denscombe, 1998). The conversation would cover topics relating to how the company was started and the motivations behind establishing the brewery, the attitude towards environmental responsibilities and the relationship with other enterprises in the local area (The interview guide is included in Appendix 1).

3.2.1 Study area for project

The main goal for the PhD project was to attract as many small scale breweries as possible from across Wales. The study was supported by the Welsh Government food and drink division and funded by the KESS 2 scholarship. At the beginning of the project in 2017 a search of all breweries in Wales led to the conclusion that no single database was complete and it was therefore necessary to combine all data bases from independent and government websites such as Visit Wales, Drinks Wales and Business Wales before further searches on social media platforms and beer rating websites to account for the entire population of breweries (Business Wales, 2021a; Drinks Wales, 2021; Visit Wales, 2021). This list included multinational, regional, and small scale breweries (See Appendix 2 for list of breweries in Wales). The database was organised based on geographical location and divided into counties and publicly available data was sourced from the company website such as postcode, contact email or mobile number and name of brewery owner. Knowledge transfer plays a key part in the establishment and progressions of a small business internally and through external business networks (Massaro et al., 2019; Muskat et al., 2017). This becomes more pertinent when the transfer of knowledge relate to the daily tasks performed at a craft business where the knowledge is embedded in the creation of the product and the ability to recreate the same product relies on all parties understanding the processes and procedures involved (Cardoni et al., 2019). In a study of six microbreweries considered to be entrepreneurial family business, Mc Grath et al (2018) discusses the benefits of working as a family included familiarity with unique ingredients, understanding of distribution systems and gaining expert advice from an extended network of friends the knowledge transfer in this case was possible because the businesses capitalised on an existing network to overcome challenges or to address knowledge gaps (McGrath et al., 2018).

A probability sampling technique is based on an assumption that a sample area can represent a cross section of the wider population (Karami, 2011). In this case the sampling approach is a non-probability because it is not possible to tell if the data represents the entire population (Denscombe, 1998). Unlike stratified sampling where each member of the population has an equal chance of being chosen a short list consisting of only small and independent breweries was collated (Bryman et al., 2007). The regional and multinational breweries were eliminated from the study to form a shortlist of small and independent breweries this action of selecting the subset of breweries is defined as quota sampling (Denscombe, 1998; Karami, 2011). Self-selection or volunteer bias can result in a sample area that does not give an accurate description of the wider population (Heckman, 2010). In this study the breweries were informed of the nature of the research and invited to take part. This action could result in a bias depending on the case studies individual agenda towards sustainability. The final short list consisting of 72 craft breweries. Figure 3.1 shows the locations of the short list of breweries in Wales that were invited to participate in this study.

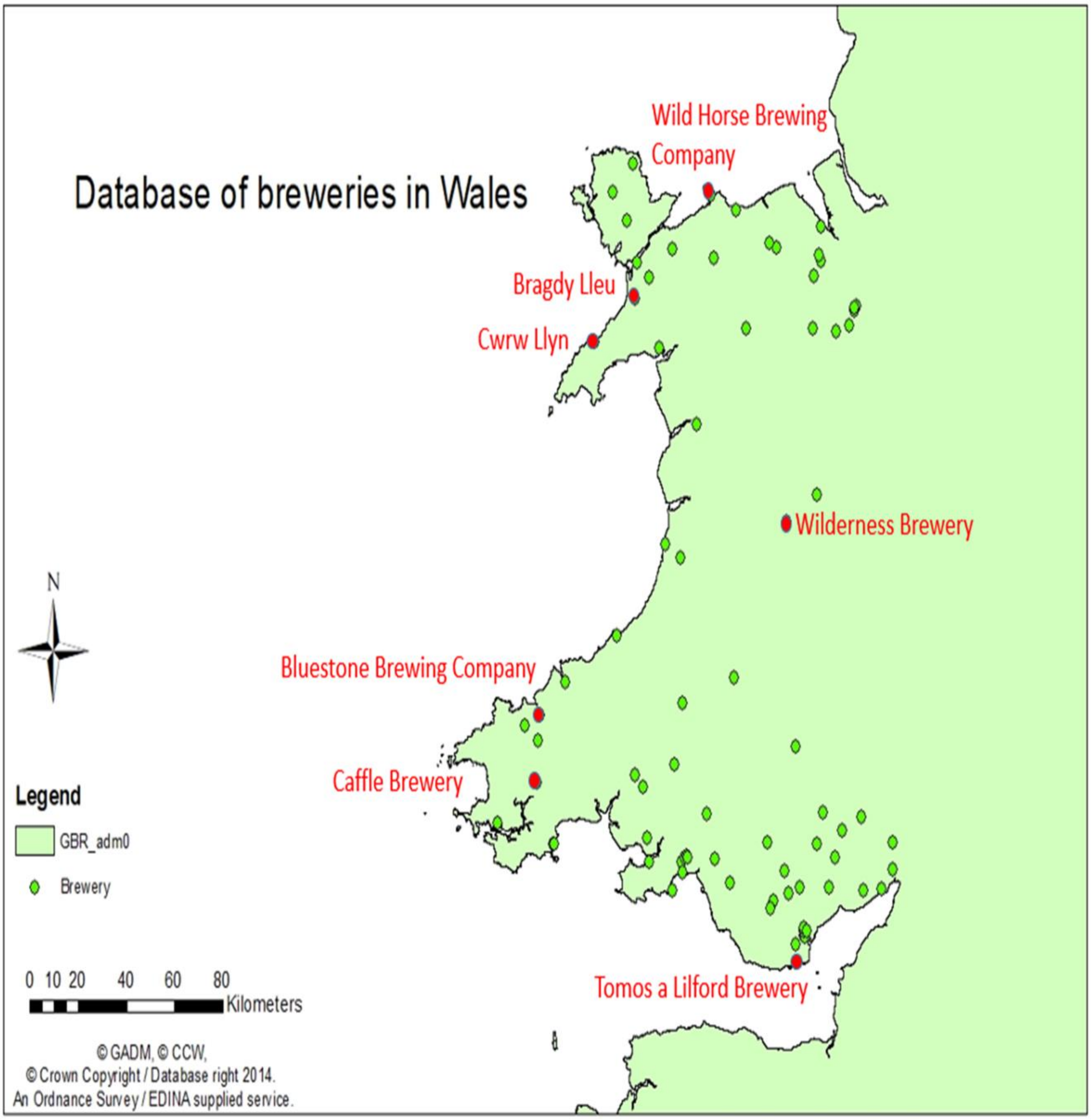

Figure 3.1. Map of Wales showing the locations of small scale breweries with green dot, red dot shows the location of the seven case study breweries. Regional or multinational breweries are not included in this figure.

3.2.2 Case studies

Breweries were contacted by email to inform them of the KESS 2 project giving a short description of the work and the researchers interest. The approach taken to contact the breweries was to work through the list by county with the intention of arranging interviews by region for efficiency and to keep travel to a minimum. After contacting 72 breweries, seven agreed to take part in the study and a secondary message was sent to all other breweries. The breweries are spread across Wales, three in the north, one in mid Wales, two are located in the Pembrokeshire area and one in south Wales. The interviews were conducted over a 16 month period from September 2018 to January 2020 and organised around the availability of the breweries. The logos and examples of beers produced by the case studies have been included for visual reference in the Appendix 3 and 4. Case study discussion and interviewee response to questions have been anonymised. According to Her Majesty's Revenue and Customs (HMRC) a small business is one that employs less than 50 people and has a turnover below 10 M Euros furthermore a micro business employs up to 10 people with a turnover up to 2 M Euros (HM Revenue & Customs, 2019). The UK is home to approximately 2200 breweries and 1897 of these qualify for the government scheme to support small breweries namely the small brewers relief (The Brewers of Europe, 2020).

3.2.2.1 Case study 1

The brewery is located on an industrial estate in mid Wales. The front entrance to the industrial unit leads to a room used for testing beer quality, office space and an informal brewery shop. A doorway from office leads to the production area, a space that is both brewery and barrel storage room. The business was established in 2017 with the intention of producing a range of farmhouse style beer with mixed fermentation. The beers are described as being "sour or slightly funky" in taste. The founder decided to move away from a city life where he worked as a head brewer to the Welsh borders with the intention of establish his own brewery. The price of renting a commercial space was an important factor when deciding on establishing the brewery in mid Wales. At present the founder is the only employee but there are plans to install a new bottling machine and the expansion could result in employing an assistant. From the extensive search of breweries in Wales this is the only example known to exclusively brew sour beer and to have a barrel ageing program. The founder explained how recreating the same beer is very difficult with barrel ageing and mixed fermentation. The supply of barrels is continually changing, and the introduction of wild yeast and foraged fruits can yield different results. There is a constantly changing product range, but the style of beer is often based on Saison, Grisette, Pilsner and pale ale recipes.

Having worked in several other breweries the founder decided to follow his interest in barrel ageing and mixed fermentation beer. He explained the risk involved with this style of brewing, the beer will spend several months in a barrel before its ready for packaging, there is always a possibility the beer might not turn out as expected and could end up being poured down the drain. As a head brewer he didn't feel it was right taking this kind of risk in someone else's brewery. By moving to mid Wales, he was able to keep the costs down, something that was particularly important when approximately a quarter of the beer goes into the barrel ageing program. The barrels are imported by a local business and previously used to store whiskey, sherry, or wine. Cleanliness is the most important aspect of any brewery and a thorough cleaning cycle is done before a beer is brewed to remove any bacteria that could spoil the beer (Ferguson, 2016). The biggest cause of contamination for beer is lactic acid bacteria yet this is a typical ingredient used to make sour beer (Bokulich et al., 2015). The company values are listed on the company website, these include "equality, transparency and the environment". The brewery has a policy of being open and transparent, for every beer produced it is possible download brewing data sheets from the website. These include information on raw ingredients, the type of yeast, process data in each stage of brewing and analytical information for calculating alcohol content. The founder purchases energy from a green energy supplier and use only recycled and recyclable packaging material. The brewery has a batch capacity of around 800 L and on average produce one batch every two weeks.

3.2.2.2 Case study 2

The company was founded in 2013 and is described as an "eco-friendly family run brewery" and employ six members of staff. The brewery occupies several outbuildings on a working farm located in Pembrokeshire area of south Wales. The buildings consists of an office space, tap room, bottle shop (open from Monday to Saturday) and brewery with a batch capacity of 10 beer barrels (1636 L) producing a variety of core and seasonal beer made in the style of traditional real ale with some products suitable for gluten free or vegan diets. The brewery produced over 100,000 litres of beer in 2019. Casks are filled on site, but the bottling is done under contract by another brewery. This involves transporting the beer to Staffordshire, a 558 km round trip. The interviewee explained as a company they strive to improve their environmental footprint and recognised the environmental implications of packaging offsite. In 2018, the brewery received financial backing from the Coastal Community's Fund to install a bottling plant on site (Business Wales, 2021b). Other environmental initiatives include using the by product from the brewing process namely brewers spent grains (BSG) as animal feed. The advantage of having a brewery on a working farm means there is no further transportation required. The wastewater from the brewery is filtered through a read bed system and some electricity is produced on site with photovoltaic panels fitted to the brewery roof. The tap room serves beer, non-alcoholic drinks, and snacks. It is a cosy space with some room to sit inside and seating spaces in the farmyard. Local community groups such as gardening club regularly meet at the brewery and the local cycling group occasionally stop for refreshments. The brewery started an initiative by involving the local community to grow small hop plants at home. When the hops are ready to harvest, they are returned to the brewery, the hop cones are picked and added to the beer made on the same day. Every participant is given a box of beer and in 2020 the profit from this collaboration was donated to the Watershead Foundation (Welsh Country, 2020).

3.2.2.3 Case study 3

This business was established in 2013 as a venture between a group of friends with a common interest in beer and brewing. The brewery is based in the north Wales county of Gwynedd. The brewery has a batch capacity of 1000 L with two fermentation vessels. Originally 14 directors were involved in establishing the business, but several have resigned with only five members remaining. The brewery is deeply connected to local area with many of the directors in full time employment and working locally. The members work on a volunteer basis with all profit used to expand the business. The business does not employ a full time member of staff at present, the brewing and all other work is carried out in the evenings and weekends. The workload is delegated among the directors including brewing and local beer deliveries. At the start of the business, several founding members attended Brew lab training course in Sunderland to improve their understanding of the brewing process. The original brewing equipment had a batch capacity of 245 L and was purchased from a brewery located in Dolgellau. The same equipment was used by three other breweries in the north Wales area before its arrival at case study 3 brewery. In 2009 it was purchased second hand from a brewery in Yorkshire by a brewery based in Llanrwst then in 2010 sold to a brewery in Nefyn on the Llŷn Peninsula who later sold it to the brewery in Dolgellau in 2012. The business owner explained how the original equipment was heated by a gas burner and for their needs they installed a heating element converting it from gas to electricity. After its use at this brewery in 2016 the equipment was sold to a brewery in the nearby town of Bethesda. The industrial unit that houses the brewery has reached its capacity with no more space for new equipment. Because of the lack of space there is no on site bar, but the brewery does operate a mobile bar for events. There are plans to expand into a new facility enabling an increase in brewing capacity and a new visitor centre and tap room. The move will be an opportunity for the company to fulfil several environmental objectives including the installation of solar panels for electricity generation, purchasing a hybrid van for local deliveries and a battery operated forklift truck. The director is eager to improve the prospects for the next generation in the area. He explained how a big part of his motivation to set up a local business was to provide jobs and skills to young people in the area. The core range of beer consists of four traditional real ale beers named after characters from the Welsh folk tales of “Y Mabinogi”.

3.2.2.4 Case study 4

The brewery is located on an industrial estate in south Wales and was originally established by three friends brought together by a mutual interest in brewing. During the time of the interview one director was employed full time as the head brewer taking care of the day to day running of the business while the other members had full time jobs but doing un paid work at the brewery on their days off. In response to being asked why they started the business the interviewee said, “we are passionate about making beer and the way it can bring people together to enjoy an occasion”. When asked about the number of beer recipes produced at the brewery the interviewee listed 13 different beers mainly pale ale and India pale ale styles. “We are interested in historic beer ingredients our rosemary beer is quite popular, other beer recipes have included bog myrtle, yarrow, hay”. This is an ancient style of beer known as Gruit using botanicals instead of hops (Verberg, 2018). In 2018 the brewery received recognition for their Rosemary beer in the Indy best award for botanical beers (Independant, 2018). The brewery originally had a mashtun capacity of 700 litres and two kettles both 350 litres and brewing once or twice a week. The equipment was purchased second hand and repurposed for its use at the brewery. It may sound strange to have two kettles, but it gave some flexibility with production volumes. The company uses a contract bottling service that has a minimum 600 litre requirement meaning both kettles would be used to make beer allocated for bottling. There is also some flexibility to make different beers at the same time by using the same base malt and splitting the wort in to two kettles. This has some similarity to a process known as Parti-Gyle where the first wort is extracted to make strong beer and the grains would be reused to make a second batch of weaker beer (Craft Beer and Brewing, 2016). In the winter months when there is less demand a single kettle can be used to fill up to 8 firkin casks with a capacity of 40.9 litres. Recently there have been several changes to the business investing in new equipment, increasing the batch capacity to 1300 litres, the website has been updated and new beers added to the range packaged in 0.44 L can or 5 litre mini kegs. The building layout consists of brewery, cold store, tap room and brewery shop. There is a musical theme at the bar area with several instruments placed around the room with a relaxed attitude for people to pick an instrument and play. During the summer months there is a weekly gathering with local food producers selling food outside the brewery.

3.2.2.5 Case study 5

The brewery is established in the Pembrokeshire area by a husband and wife in 2013 after several years of running a successful outdoor adventure business. The brewery has a batch capacity of 654 litres, three fermentation vessels and a recent increase in demand has led to the investing in two new conditioning vessels. The interviewee explained that she manages the office work and her husband the takes care of the brewery. The owners have taken several measured to reduce the environmental footprint of the brewery. The interviewee explained “We don’t use any single use plastic packaging for our products”. The spent grain from the brewery is either given to local farms or used to feed their animals. Wastewater is treated through a read bed system and the used hops are composted. The brewery has developed a regular local demand with a beer made exclusively for a local pub.

Deliveries are all within a 48 km (30 m) radius with most deliveries in the Carmarthen, Tenby and Saundersfoot area. It was explained during the interview that the company have a strong local demand that is enough to run their business. This was a good lifestyle balance and the owners had no interest to expand out of their local area choosing to focus on maintain the relationships within the local economy. There is a core range of five beers available all year with a selection of seasonal brews some using locally foraged ingredients such as nettles and seaweed. The brewery web shop has a list of recipes for customers to follow and pair with their beer. One recipe is for dog biscuits made with spent grains; the brewery will give these to customers if they can collect direct from the brewery shop.

3.2.2.6 Case study 6

This brewery is based in the county of Gwynedd in north Wales. It was established in 2015 by husband and wife who were inspired after visiting several craft breweries across Canada and north America. The building is a converted industrial unit almost full to capacity with brewery equipment. Consisting of purpose built mashtun and kettle with a batch capacity of 1600 litres and four fermentation vessels. There is a grain silo and conveyor system to transfer grains in to the mashtun and several vessels arranged around the periphery of the unit with a canning machine located in the middle of the floor space. The cold storeroom is used to store beer and a stairway leads above this room to an office space. It was clear from the site visit that the brewery has almost exceeded the available space at the current site. There is a bar and shop space built next to the cold room for customers to collect beer purchased on the website, during the summer months the bar is open for a few hours on Saturday afternoons. This brewery produces a wide variety of beer styles influenced by the UK, USA and Europe including porters, stouts, pale ales, India pale ales and lagers that vary in strength between 3.8% to 10% alcohol by volume. There is a small number of core beers and several one off brews are released throughout the year. The product labels are all uniquely designed often with subtle referencing to the local area or popular activities in north Wales like cycling or climbing. The brewery has produced several beers in collaborated with other breweries for example a beer was made with another north Wales brewery to celebrate the company's 5th birthday. They also took part in the "All together" project a worldwide collaboration organised by New York brewery Other Half to support the hospitality industry following the disruption and lengthy lockdowns caused by the corona virus. Any brewery in the world could participate in this venture by downloading labels and promotional graphics then brew a beer using a base recipe created by Other Half brewing company. Each brewery was encouraged to add their own individual twist to the beer. Participants were asked to donated some proceeds to help their local hospitality industry (Other Half Brewery, 2020). Case study 6 brewery decided to use the proceeds to replace the beer sold to their customers following the Covid 19 national lockdowns replacing over 2180 pints.

The brewery employs several members of staff to carry out brewing duties, office work, and beer deliveries. During the first few weeks of the Covid 19 pandemic the brewery started to operate a home delivery service initially within the Llandudno area but later expanded to cover Anglesey, parts of the Llŷn peninsular and Chester. The brewery operates a mobile bar that is used during the summer months to attend festivals and food slams throughout the north Wales area. The young age of the brewery, several varieties of beer styles on offer and collaborations with other breweries portrays an image that fits in with the modern day craft brewery.

3.2.2.7 Case study 7

The business was established as a joint venture in 2011 between twelve friends who thought it would be fun to set up a brewery together. The interviewee explained how an advert for second hand, 245 litres brewing equipment appeared on the notice board at the local pub. The group decided to invest in the equipment and started to make the first few batches in a converted cow shed before moving to an industrial unit. The group members had a diverse professional background, but only one member had prior brewing experience. The interviewee explained that local breweries were quite helpful during the early days of the business, several nearby breweries were visited to gain a better understanding of brewing beer at a commercial scale. After rapid growth and strong demand for locally produce beer new brewing equipment was installed capable of making 815 L of beer at a time. The increase in capacity was still not enough to meet the demand and in 2015 a new brewery was built. The building comprises of visitor centre with bar area, a glass partition separates the brewery from public area allowing people to safely watch the beer being made. A stairway in the entrance are leads to an office space and grain store above the bar. The design layout of the grain store has a hopper positioned above the mashtun for simple and efficient transfer of ingredients. The brewery received £64,400 funding from the coastal communities' fund for the new brewing equipment and a new delivery van.

The directors recognised a clear demand in the area for locally produced beer and to cope with this they would a full time employee to running the business. One director was appointed as the brewery manager and employed on a full time basis. The other directors are very much involved with the day to day running of the business often helping at the brewery and running the mobile bar at many of the local food and drink festivals. The company employ several staff across the business work in the office, brewery assistants, beer deliveries and a manager running the onsite bar. At present there are seven core range beers, six real ale style and one lager. The brewery is located in a rural area that has a strong Welsh population and attracts many tourists during the summer months. A key objective outlined when the business was established was to create beer with a strong Welsh connection.

3.3 Discussion

3.3.1 Provenance, placemaking and embeddedness

This research finds several examples of placemaking with the breweries connecting the business or beers they produce with places, prominent landmarks or even folk law legends. This is done in several ways through company or beer names, beer labels or the company logos. It is a common strategy for the case studies to connect their brewery with the local area appealing to the local consumers or visiting tourists (Fletchall, 2016). Cwrw Llŷn have used this repeatedly by naming the business after the Llŷn peninsula in north Wales, their logo is the outline of the land that reaches out into the Irish sea. Their beer names include Porth Neigwl a local tourist hotspot and surf location. They also have beers named after folk law tales that relate to the area such as Seithenyn or Brenin Enlli (Cwrw Llyn, 2020). Another brewery with a similar example is Bragdy Lleu in Dyffryn Nantlle. The brewery and beer names are based on the medieval Welsh folk tales of "Y Mabinogi" and the images on beer labels depict each character (Bragdy Lleu, 2020). Wild horse brewery have made some connections with the local area but these are very subtle. The company occasionally release one off brews with cryptic label themes, for example a beer released named 872 with a label image of a mountain; those who spend time in the north Wales mountains will know the elevation of Moel Siabod mountain is 872 m. The beer brewed to celebrate their 5th year in business was named 554 based on the elevation of Moel Famau mountain. The labels are often shared on their social media accounts before the beer is launched but the names of the mountains are never mentioned resulting in followers trying to guess name of the mountain. Similarly, Bluestone brewing's name has no geographical connection but the theme for this brewery is the stone that has been excavated in the Preseli area and used to construct local buildings. The stones were also transported 400 km to form the circular stone formation at Stonehenge. The range of beer all follow a stone theme with either rock or stone in the beer name, examples include Stone Cold India pale ale and Rockhopper pale bitter. Tomos a Lilford brewery have named some of their bee after local areas such as Vale Pale after the Vale of Glamorgan, Nash Point after a nearby coastal headland and Southerndown Gold after a local beach (Tomos a Lilford, 2021).

Caffle Brewery and Cwrw Llŷn have a strong local demand and community support for their produce something that is difficult to achieve within a highly competitive market (Danson et al., 2015). Both breweries are located in rural areas popular with tourists during the summer months. Cwrw Llŷn appeal to the local community through their use of Welsh language and linking the business to the geographical area with logos and beer names creating a sense of local ownership by the consumers.

Businesses in rural areas have a finite customer base and recognise the importance of service and value adding activity to retain customers (Bosworth, 2012). Both breweries produce a rural product and go further by using locally sourced ingredients or reaffirming the local connection branding the produce with a story that connects the product to the place. Argent (2017) concludes that the local embeddedness of small scale breweries in rural Australia is manifested from a desire to strengthen local development, produce beer using locally sourced ingredients and to "foster mutualistic functional relationships with other local businesses" (Argent, 2018). The definition of social capital by Portes (1998) is "the ability to secure benefits through membership in networks and other social structures" (Portes, 1998). This so called bonding element of social capital where strong links exist among actors that creates a sense of cohesion in the pursuit of a mutually beneficial goal that can also transfer innovation through social networks (Adler et al., 2002; Aldecua et al., 2017).

3.3.2 Start up and motivation

Bosworth (2012) discusses the nature of running a small business in rural communities with a researcher – practitioner study of a small family run business and identifying the motivations of adopting the rural lifestyle to focus on family life (Bosworth, 2012). Habbershon (2003) discusses the primary role of a business leader is to create profit and to gain a competitive advantage over other organisation whereas the interests of family run businesses are to create wealth for the current and future generations of the family (Habbershon et al., 2003).

Several breweries were started as family venture, Caffle brewery and Wild Horse brewing were both started by husband and wife; Tomos a Lilford was originally started by two brothers and a friend; Bluestone brewing company was established as farther and daughter venture and the members of Cwrw Llŷn include a farther and son. Findings by Bau et al (2019) indicate family run rural businesses grow more than non-family firms, they have better local knowledge, are more locally embedded and take advantage of local networks and resources (Baù et al., 2019).

3.3.3 Local employment

The roles within a small brewery are not limited to just making beer there are several other tasks that must be managed to keep the business functioning such as branding, marketing, sales, logistics and book keeping to name a few (Gatrell et al., 2018; Holden, 2011; Kristandl et al., 2018; Mathias et al., 2018; Rojas-Cuevas et al., 2020). These are often the responsibility of the founders though some are outsourced when specialist skills are required like legal services, website development, engineering and advertisement (Sako, 2006). As breweries grow the workload increases resulting in the need for additional staff and in rural setting where jobs are less abundant a brewery can be an important provider of jobs that require specialist skills. For Bragdy Lleu one of the main reasons for starting the company was to create local jobs. Wilderness Brewery was also hoping that the installation of new equipment would result in taking on a new employee. Three of the seven case study breweries employ people on a full time and seasonally basis. Bluestone brewery, Cwrw Llŷn and Wild Horse brewing are the largest breweries in this study producing over 100,000 litres a year and employ several people for office work, deliveries and brewery activity. The Welsh drinks cluster beer and cider group and Food skills Wales have arranged a brewing curriculum for breweries in Wales the program is delivered by Brew Lab and is intended to deliver training sessions across Wales (Brewlab, 2020).

3.3.4 Food tourism

This research has found several examples of how breweries participate or contribute to beer and food tourism. The most common way to do this among the case studies was to welcome their customers to the brewery for tours or on weekends when taprooms were open. According to Bluestone brewery website there are regular events hosted at the brewery with live music and food. The farm yard in front of the brewery and office building is transformed in to stage and dance floor area with a capacity of 450 people (Blustone Brewing co, 2021). During the summer months Wild Horse brewing and Tomos a Lilford operate brewery taprooms. Tomos a Lilford have an event named street food Saturday, with local food producers invited to set up stall outside and sell food to the brewery customers. Wild Horse brewing have a similar event that happens during spring and summer months. The roller shutter door is opened at the front of the building and customers are welcomed to sit on long tables inside the brewery. A purpose built bar serves beer and snacks, local food producers are also invited to park directly outside the brewery. Cwrw Llŷn host an annual event next to their new brewery, a temporary stage is built for local bands to playing live music and local producers are invited to sell food. This is a common phenomenon, many craft breweries host food and drink events for example Cloudwater in Manchester, a brewery with international recognition for their high quality beer host a “Friend & Family & Beer” event (Cloudwater Brewing company, 2019). Another example is the end of summer yard party organised and hosted at the Five Points brewing company in London providing music and street food for customers (The Five points brewing company, 2019).

Food festivals can be an opportunity for small businesses to connect with a large number of consumers and to network with other businesses (Hjalager et al., 2018). The majority of the case study breweries regularly attend food festivals, food slams and seasonal events such as Christmas markets. Cwrw Llŷn are often seen running their bar named “Y dafarn deithiol” (mobile tavern) at the annual Caernarfon festival, Bragdy Lleu have attended Christmas market at a local garden centre and Wild Horse brewing have been operating their mobile bar at several north Wales food slams. The Royal Welsh Agricultural show hosts a food and drink exhibition that attracts retailers from across Wales. During the PhD project the researcher attended the show in 2018 and 2019 and observed only a small number of breweries in attendance. Case study 2 was seen at the event in 2018, this was the only case study observed at the event.

3.3.5 Benevolent work in the local community

Wilderness Brewery support several charities that include Hope Not Hate, Mermaid, Brewgooder, the Trussell Trust, Plan International and Refuge. The nature of operating a small business means there is a limited amount of funds available to invest in worthwhile causes. The director of one case study brewery explained that if there is money available at the end of the year they will donate some to good causes. In July 2019 Wild Horse brewing took part in a collaboration with three other breweries; Brick Brewery from London, Hawkshed Brewery from the Lake District and Fallen Brewing from Stirling to complete the three peaks challenge by climbing Ben Nevis, Scafel Pike and Snowdon within twenty four hours. The venture also included the creation of three signature beers with Brick

Brewery and Wild Horse Brewing making an East Coast IPA with the label image of mount Snowdon. A charitable donation was made to the Ogwen Valley Mountain rescue team by pledging 50 pence for every can or pint sold and £5 for every keg sold at the Wild Horse brewery and Brick brewery tap rooms. Bluestone Brewing donate and support several good causes locally and overseas fundraising for the Welsh air ambulance and DPJ foundation a charity that support mental health of workers in the agricultural industry in Pembrokeshire. The brewery is also a collection centre for bikes and clothes for charities in Africa and Syria and after a visiting Ethiopia the founder used the breweries public platform to start an initiative to supply binoculars and bird books for guides in lake Ziway, Ethiopia. Several interviewees explained how they felt a sense of obligation to support charity work. Case study 1 discussed they are keen to make charitable donations but have to see how much money is available at the end of the year stating "as a small business we do what we can, we buy carbon credits to reduce our footprint" In contrast Adnams is a regional brewery based in Suffolk, England and is a nationally recognised beer brand. The company established the Adnams community trust issuing grants between £100 and £2500 to good causes within a 25 mile distance of Southwold (Adnams Southwold, 2021).

Several measures to reduce brewery environmental footprint were also discussed during the interviews. Cwrw Llŷn have experienced a rapid growth since the company was started in 2011, the brewery has the largest annual production out of all case studies. When the business moved to the new site it was possible to install purpose built brewing equipment and to use simple but effective measures to reduce energy consumption such as using incoming water to cool wort. This transfers heat from wort to the cooling water, the water is then stored in tanks ready to be used to make the next batch of beer. Bluestone brewing investment in photovoltaic panels enables them to produce some energy on site. Caffle brewery and Bluestone brewery have both installed read bed systems to process wastewater.

3.4 Conclusion

This chapter has addressed objective number 2 of the aims and objectives outlined in Chapter 1 section 1.2.

The purpose of this chapter was to gain a fuller understanding of how the participating case studies contribute to the economic and social value of the local community. The following conclusions have some similarities to results in previous studies (Bastian et al., 1999; V. Ellis et al., 2015; Fletchall, 2016; Gatrell et al., 2018; Hall et al., 2019).

Breweries have demonstrated several variations of connecting their company or produce with the local area and in some cases the provenance is considered so valuable that the entire company branding relates back to the area (Appendix 3 shows logos from several breweries in Wales). As new breweries enter the market the need to connect the brand to the local area is still considered to be important, but differentiation is also necessary therefore companies connect to the area in more creative and imaginative ways even gamifying product releases as discussed in case study 6. A recurring method of company and product branding using folk law and local history was also a theme found in this work. These can be unique ways for breweries to appeal to the local consumers and intrigue visitors as discussed in case study three and seven, a phenomena also found in previous studies (Bastian et al., 1999; V. Ellis et al., 2015; Fletchall, 2016; Gatrell et al., 2018).

The case studies can be divided in to two categories based on annual production volume: below 30,000 litres and above 100,000 litres. It was not possible to ascertain a corelation between annual production volume and the need to start recruiting additional staff. However, for case study three and seven the breweries were founded by several people able to provide unpaid work for the business. Case study 7 has been developing over a ten year period with directors originally working as volunteers but quickly recognising the need for full time staff. One director was appointed as the brewery manager, the company has progressively developed in terms of brewing capacity and the business employs several members of staff. Case study 3 is a similar example but at a different stage of company growth with several directors in full time employment and running the brewery outside. The company has been established for eight years producing less than 30,000 litres but in a planning stage for expansion. The two companies are of a similar age and several factors could explain the difference in production volume, but a notable difference is the appointment of a director as a full time employee. This could explain the vast difference in production output. The breweries in a position to employ staff contribute to local employment, upskilling local people into several roles not only brewing but good jobs transferable to other industries.

Food and drink tourism plays an important role in rural communities and local economies in developing the ability for businesses to network with other producers and to connect with consumer (Hall, 2005). This work has seen several examples where breweries participate in some form of food tourism the most common example were festivals, food slams, local produce market and events planned on site at the breweries with local food vendors also attending. Local food festivals and seasonal fairs were seen as good opportunities to meet with consumers trial new products and test market response. There have been several examples of breweries contributing to social or environmental initiatives, but the small breweries have a limited amount of money to support worthwhile causes. Several breweries have demonstrated the willingness to help worthwhile local causes and donate money when funds are available.

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4. Thirsty work: Assessing the environmental footprint of craft beer

Abstract

This study assessed the environmental footprint of craft micro-breweries in Wales using attributional life cycle assessment with an expanded boundary to account for the use of co-products as animal feed on local farms. Seven breweries took part in this study, each with unique characteristics, inter alia, annual beer production volumes, batch capacity, beer to water ratio and packaging formats. Value chain stages included barley and hop cultivation, upstream processing, upstream distribution of brewing ingredients, brewery production, packaging, downstream distribution of beers and waste management. Contrary to previous studies of mass-produced beer where packaging has been found to be the hotspot driving the largest share of environmental burdens, this study found downstream distribution to be the unexpected hotspot owing to inefficient use of light commercial vehicles for regional distribution of the beer. Packaging burdens for micro-breweries were modest owing to the majority of beer being distributed in re-usable casks and kegs rather than bottles. But where bottles were used, contract bottling increased transport requirements and footprints. Carbon footprints ranged from 760 to 1900 g CO_2 eq. per L beer, whilst for fossil resource depletion ranged from 12 to 30 MJ per L. Normalised scores were highest for fossil resource depletion, global warming potential, acidification, terrestrial eutrophication, freshwater eutrophication, marine eutrophication and photochemical ozone formation. Distribution and packaging present opportunities to reduce the environmental footprint of craft beers that require further investigation.

4.1 Introduction

The average consumption of alcohol in the UK is 9.7 L per capita (OECD Health Data, 2020). In 2018 over 4.2 billion L of beer was produced placing the UK as the third largest beer-producing country in Europe with over 1900 small scale breweries having an annual production capacity up to 60,000 hectolitres (HL) in operation (Brewers of Europe, 2019). On a global scale this commodity is said to be the “ fifth most consumed beverage” behind “tea, carbonates, milk and coffee” (Olajire, 2020).

Several academic studies have been carried out to assess the environmental footprint of beer production, and mainly focused on large scale multinational brewing organisations (Cimini et al., 2016; Koroneos et al., 2005; Sipperly et al., 2014). Some brands have published environmental product declarations (EPD), a transparent method of sharing environmental performance (Reggiori, 2011c, 2011a, 2011b, 2011d). Less research appears to have been focused on the small scale brewing sector, a facet of the industry that has distinct characteristics and is growing, but faces different challenges compared to the large scale producers (Amienyo et al., 2016; Cordella et al., 2008). The five stages of a product life cycle can be defined as raw material acquisition, production, distribution, consumer use, disposal and recycling (Cimini et al., 2018), translating into cultivation, upstream processing, upstream transportation, brewery activity, downstream transportation and brewing and packaging waste for beer value chains (Morgan et al., 2020).

The beer brewing process combines a variety of ingredients depending on the style of beer being produced but the four most popular cultivated grains are barley, wheat, oats and rye (Amienyo et al., 2016). Work published by Rajaniemi (2011) found rye to have the highest greenhouse gas (GHG) emissions of 870 g CO2 eq. per kg, compared with 570–590 g CO2 eq. for wheat, barley and oats (Rajaniemi et al., 2011). These grains can have a further use after beer production, and "spent grains" are viewed as valuable co products (Kerby et al., 2017). A study by Hortenhuber (2011) of greenhouse gas emissions from cultivating protein-rich feedstuffs found that soybean meal has the highest emissions with one kg of dry matter equivalent to 3278 g CO2 eq., largely caused by indirect emissions from land use change. Excluding indirect land use change emissions resulted in a soybean meal footprint of 613 g CO2 eq. per kg dry matter, leaving distillers dried grains with solubles to become the highest emitter of greenhouse gases with 1191 g CO2 eq. per kg of dry matter (Hörtenhuber et al., 2011). The brewing stage itself relies on a large amount of thermal energy and consumes between 4 – 7 L of water per 1 L of beer (Olajire, 2020; Scheller et al., 2008). The bill of materials for a commercial brewery will include not only brewing ingredients but products necessary for maintaining and cleaning the facility (Cordella et al., 2008). However the brewing stage has been found to be a relatively minor contributor to the overall carbon footprint of beer and this study aims to explore if this is the case for small scale beer producers that do not have the economies (efficiencies) of scale of the mass-producing multinational breweries (Amienyo et al., 2016; Cimini et al., 2016).

Previous studies found cultivation and packaging as being significant environmental hot spots (Koroneos et al., 2005; Talve, 2001). A more recent study on packaging showed that reusable stainless steel kegs generated smaller environmental burdens than glass bottles (Cordella et al., 2008). Cimini (2016) also found kegs to have smaller carbon footprints in a study that compared five packaging scenarios, with 330 ml glass bottles sold in a multi pack having the largest carbon footprint (Cimini et al., 2016). In a comparative study of two beer styles, lager and ale, packaging was also highlighted to be responsible for a high share of life cycle energy demand, whilst lager had a higher carbon footprint due to the electricity requirements for cooling during fermentation and maturation (De Marco et al., 2016). Glass packaging has been found to create large burdens in many studies, though if bottles can be reused instead of recycled or disposed of, the environmental impact is reduced (Heller, 2017; Mata et al., 1999).

As a by-product of the brewing process, insoluble raw ingredients in the form of brewers spent grains can account for approximately 85% of all solid input and are a rich source of protein and fibre (Mussatto et al., 2006). There are several options for making use of this resource, including use as animal feed with or without drying to preserve shelf life (Mussatto et al., 2006). There is also a compelling argument to utilise this relatively cheap and abundantly available by-product for human consumption because of its nutritional value and availability in large quantities through the year (Lynch et al., 2016). When dried and milled in to a fine powder this can be added to flour to make bread (Waters et al., 2012), cookies (Öztürk et al., 2002) and bread sticks (Ktenioudaki et al., 2012). Anaerobic digestion is another option for making use of brewers spent grains (Leinonen et al., 2018). Onsite anaerobic digestion is a viable option for large scale breweries given their high throughput of by-products the economies of scale of the required infrastructure (Agler et al., 2010). The geographical location of the brewery can affect the way spent grains are used. Rural breweries can easily donate spent grains to local farms, but this option is more difficult for urban breweries where composting or anaerobic digestion are often preferred treatment options (Kerby et al., 2017). Brewery waste water can also be processed via anaerobic digestion to reduce organic matter content and produce biogas (Alvarado-Lassman et al., 2008). Studies on the distillation of spirits such as whiskey have shown that spent grain from distilling, namely draff, could be used for biofuel production or to replace animal feeds such as rapeseed or soybean meal. The results show replacing soybean meal has the most positive mitigating effect on the net greenhouse gas emission balance (Leinonen et al., 2018). A novel approach to mitigate climate change in the production of gin by using peas as a source of starch was shown to reduce the environmental footprint of gin compared to conventional distilling using wheat as grist (Lienhardt et al., 2019)

This study presents new data on how small breweries source their ingredients, manage their onsite processes, package and distribute their beer and deal with co-product and waste streams in order to calculate novel environmental footprints for micro-brewed beer.

4.2 Materials and methods

4.2.1 Case study group

The case study group of breweries that participated in this study represent a diverse cross section of the brewing industry in Wales and span across the entire country. The annual production volume ranges from 13,000 L to over 190,000 L and the styles of beer produced vary with some breweries producing a core range of traditional real ales, through beers influenced by European and US beer styles, to some examples of barrel aged beer. A small number of breweries produce lager, a style of beer that takes longer to ferment at a lower temperature, and has previously been found to have a higher carbon footprint than ale (De Marco et al., 2016). It is also important to note that the alcohol content of beers produced across these case study breweries varies between 3.6 and 10% ABV.

4.2.2 Goal and Scope

The goal of this study is to evaluate the environmental impact of craft beer production, in particular at small scale in microbreweries, by developing a life cycle assessment (LCA) calculation tool for small and independent breweries in Wales. It is intended that results can be used by brewery managers to identify environmental hotspots in their processes and associated mitigation measures to make their processes more sustainable. Footprint information could also be displayed on product labels, following third party validation, to assist consumers in selecting more environmentally sustainable products.

The functional unit for this study has been defined as the production of 1 litre of beer, packaged according to individual brewery specifications and delivered to the retailer. Given the diverse nature of craft beer distribution (e.g. direct sale from casks in local pubs versus international retail in bottles or cans), a cradle-to- grave scope was considered to include diverse packaging and distribution options within and across breweries.

4.2.3 System Boundaries

The value chain of beer has been divided in to seven stages beginning with cultivation of barley, wheat, oats, rye and hops, processing to include malting for barley, wheat, oats and rye and drying of hops, upstream distribution from farm gate to processing plant and onward to brewery, brewing, downstream distribution from brewery to retailer and finally treatment of waste products (Figure 4.1) (Morgan et al., 2020). The filling of cans and bottles in some cases is done under contract at another site away from the brewery. Although this happens after the beer has matured this is accounted for in the upstream distribution as the full bottles in most cases are returned to the brewery and the transportation is done by using the same vehicle as with transportation of raw ingredients. It is also important to segregate the results for downstream distribution where the vehicles used by the breweries are much smaller. This study takes a cradle to grave approach and includes the entire life cycle of beer and its packaging. However, in the absence of data from retailers on storage and refrigeration, this step was not accounted for. Many breweries donate their spent brewing grains to local farms and to account for this an expanded boundary is applied.

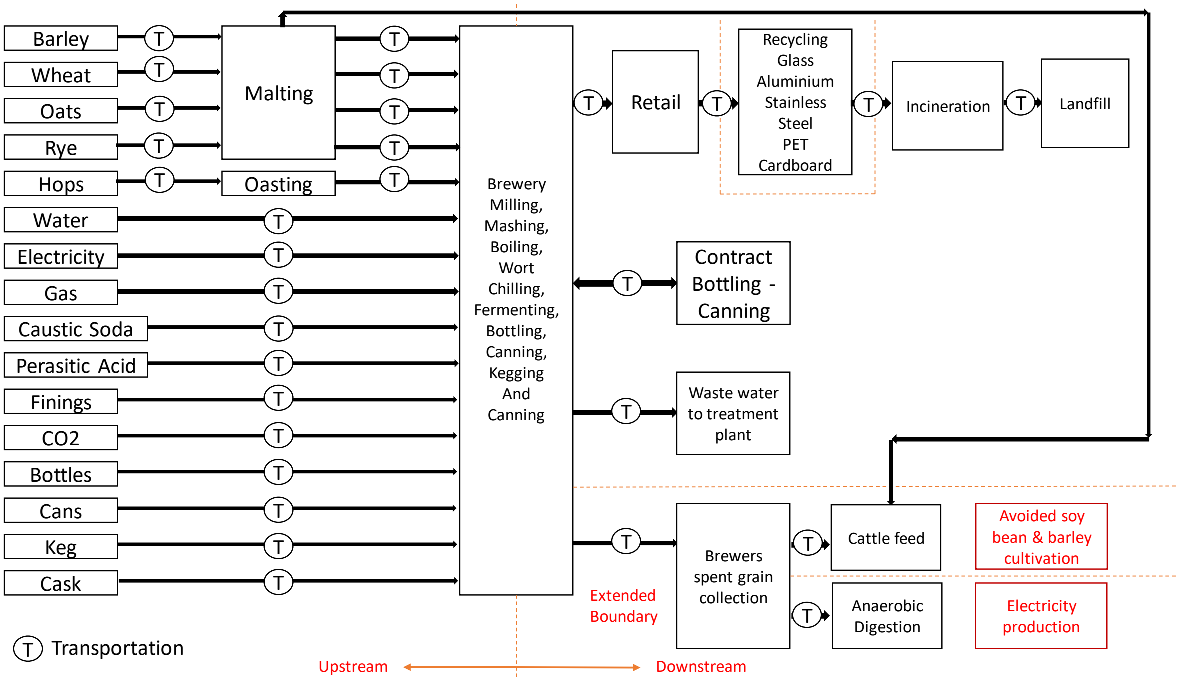


Figure 4.1. Life cycle stages of beer production with system boundaries to encompass all main processes from production of raw ingredients to final waste treatment, including downstream delivery to retailers. Key steps include cultivating raw ingredients, malting or drying of ingredients, onsite brewing, downstream distribution, waste treatment and system credits if spent grain is used as cattle feed or anaerobic digestion.

4.2.4 Life cycle inventory compilation

Activity data were largely collected via face to face interviews with managers of Welsh breweries, with some data for off-site activities sourced from industry associations and suppliers (British hop association, 2020; Charles Fareham, 2020; Crown, 2020; MAGB, 2011; Rawlings, 2018a, 2018b; Welsh Government, 2019). Given the iterative nature of the LCA process for beer calculator development, interviews were followed up by specific queries. 72 breweries were contacted and a total of seven breweries participated in this study representing 10% of all identified small scale breweries. Primary data were also collected from a packaging hire company to understand the nature of keg and cask distribution and reuse (Kegstar, 2019). This information was essential to establish how frequently these types of packaging are reused, and their life span, in order to relate production and end- of-life burdens to the reference flow of one batch of beer.

Table 4.1. Batch average inventory reference flow inputs and outputs for each brewery, anonymously referred to as breweries A - G.

	Unit	In/Out	BrewA	BrewB	BrewC	BrewD	BrewE	BrewF	BrewG
Cultivation									
Combined grains	kg	Out	215	94	152	321	217	392	391
Hops	kg	Out	4	1.5	2	6	22	9	11
Processing									
Malting									
Water	L	In	5792	2529	4113	8617	5856	10572	10537
Gas	MJ	In	446	195	317	664	451	815	812
Electricity	kWh	In	24	10	17	36	25	45	45
Grains	kg	In	215	93.9	152	320	217	392	391
Malting	kg	Out	165	72.3	117	246	167	302	301
Hops									
Oil for Hop drying	MJ	In	1.4	0.5	0.6	2.1	7.9	3.1	3.8
Combined Upstream Transport									
16-32t truck	t-km	In	222	150	129	255	430	510	244
Freight ship	t-km	In	42.9		6.3	38.8	6.5	33.9	86
Brewery activity									
Water	L	In	4380	2345	2886	7349	2714	10000	6520
Electricity	kWh	In	425	24	203	261	404	750	
Gas	MJ	In		83					749
Diesel	L	In				22			
Finings									
Caustic soda	kg	In	1	1	1	1	1	1	1
Peracetic acid	L	In	1	1	1	1	1	1	1
Co_2 Gas	kg	In						23.9	
N_2 Gas	kg	In							
Beer	L	Out	834	469	607	1470	905	1990	1271
Packaging									
Aluminium can	kg	In							3.2
Glass bottle	kg	In	55	75	116	78	325	300	103
HDPE cask	kg	In		0.79	1.7	5.9	1.6		
PET keg	kg	In							1.9
Stainless steel keg	kg	In	0.5		.05			0.3	2.5
Stainless steel cask	kg	In	0.6	0.4				2.7	
Cardboard packaging	kg	In	2.6	2.6	4	2.7	11	10	7
Downstream distribution									
Delivery van	t-km	In	156	180	143	652	222	375	876
Waste									
Water	m3	In	3.3	1.7	2.1	5.4	1.7	7.4	4.8
System credits									
Avoided soybean meal	kg	In	-32	-18	-29	-62	-42	-78	-75
Avoided barley grain	kg	In	-29	-17	-27	-57	-39	-72	-69
Avoided electricity	kg	In							

Table 4.2. Characterisation table for volume of ingredients per litre, transportation data and packaging preference.

	Unit	**BrewA**	**BrewB**	**BrewC**	**BrewD**	**BrewE**	**BrewF**	**BrewG**
Annual production	L	13336	25800	26695	154339	19000	191000	142400
Brewery Energy	MJ/L	1.8	0.4	1.2	1.2	1.6	1.3	3.3
Malts/L Beer	kg/L	0.19	0.15	0.19	0.16	0.18	0.15	0.23
Hops/L Beer	kg/L	0.005	0.2	0.03	0.003	0.02	0.04	0.009
Hop/malts	%	2%	2%	1%	2%	10%	2%	2%
Batch average transport by lorry	t-km	222	150	129	255	430	510	244
Batch average transport by ship	t-km	42	0	6.3	38	6.5	39	86
Batch average downstream delivery distance	t-km	156	180	143	653	222	375	876
Percentage of beer In keg/cask	%	87	73	68	91	40	74	80
Percentage of beer In bottle/can	%	13	27	32	9	60	26	20
Offsite packaging	Y/N	No	Yes	No	Yes	Yes	Yes	No
Land transportation of hops by country	km	(EU)1685		(USA)4768		(AU/NZ)568		
Transportation of hops by ship	km	(EU)44		(USA)7041		(AU/NZ)25,041		

4.2.4.1 Cultivation

Cultivation inputs for beer production fall under two main categories, malting ingredients and hops (Koroneos et al., 2005; Moir, 2000). The malting ingredients or grist include all variants of malting barley, wheat oats and rye. Hops are used in much smaller quantities compared to grist but can incur significant transport activity given the distances some hops travel (Table 4.2).

4.2.4.2 Malting ingredients

Demand for barley comes from the brewing industry for its starch content and from the livestock production industry for its protein and fibre content (Akdenyz et al., 2006; Frégeau-Reid et al., 2001). It is reported that approximately 1.9 M tonnes of malting barley was grown in 2019 in the UK with over 25% of this being used by the UK brewing industry, but it is the distilleries that consume most of the domestic grown barley (MAGB, 2019).

4.2.4.3 Hops

Hops (Humulus Lupulus L) grow naturally in the northern hemisphere between the 35th and 55th parallel and spanning from Japan, Serbia, Europe and North America (Delyser et al., 1994). There are few data on the environmental burdens of hop cultivation. A previous study found that agricultural inputs to hop cultivation gave rise to 9.85 kg of CO2 per kg of hops (Foster et al., 2006), whilst a more recent study found that hops contributed less than 1% to the overall greenhouse gas emissions from the New Belgium brewery (Ali et al., 2010). In this study the cultivation of hops is quantified based on Ecoinvent data, in which the global warming potential is 0.08 kg CO2 eq. per kg of hops (Wernet et al., 2016).

4.2.4.4 Upstream processing

The next stage of the value chain covers the processing of the raw ingredients via two main processes: malting for the grains and drying for hops.

4.2.4.5 Malting

The ingredients used by the breweries arrive having undertaken some level of processing. In the case of brewer's grains these can require malting, which alters both the absolute dry matter mass and moisture content. To account for this, we assume that 1.3 tonne of barley is required to produce one tonne of malt where moisture content originally at 14% is reduced to 4% (MAGB, 2011), ensuring a consistent mass flow of ingredients from upstream cultivation and into downstream transport to the brewery. These data are similar to those published for Danish maltsters, where 1.2 t of barley are needed to produce 1 t of malt (Kløverpris et al., 2009). The grains arrive at the malting plant with a moisture content of approximately 14% (Boys, 2011), where they are screened to remove foreign matter. At this point small kernels are also removed but stored as they can later be used as animal feed (Swanston et al., 2012). The steeping stage lasts 2 - 3 days and involves hydrating the kernels over time to increase the water content (Bairds Malts, 2020). The grain is then removed from the ”steep tanks” to start the germination process and left for several days allowing proteins to be broken down in to amino acids and releasing starch (Crisp Maltings, 2020b). The process of malting was not found within the available LCA data sets. Therefore, data on energy and water consumed during the malting process were obtained from maltsters association of Great Britain (MAGB, 2011). The total water required for processing one tonne of malt is 3.5 m^3 and the electricity and gas consumption are 150 kWh and 750 kWh respectively. From Table 4.2 it is evident that the input of malts per litre of beer ranges from 0.15 to 0.23 across the case study breweries. The ratio of malts to beer for the multinational brewery Birra Peroni Srl was reported to be 0.11 kg per L of beer. Lower consumption for the large brewery could reflect higher brewery efficiency or the use of processes such as high gravity dilution (Cimini et al., 2018; Lima et al., 2011). The final product is a malted kernel with a moisture content of 4% (MAGB, 2011). The small kernels and culms are combined as co products and used for animal feed – this amounts to 4% of the finished malts. There are several malting suppliers in the UK and many brewers will purchase from multiple suppliers depending on price and availability. Transportation from supplier to brewery is based on 30 tonne curtain sided lorry.

4.2.4.6 Hop processing

To preserve the hops and retain the essential qualities, whole cones are dried in a kiln taking moisture content from between 65 - 80% down to 8 - 10% (Carter et al., 2020). This is likely to be the most energy intensive stage of production after cultivation. No specific process could be found in Ecoinvent for hop drying, but fuel oil use per kilo of dried hops is estimated at 0.412 L/kg (Hauser et al., 2019). The Ecoinvent process used in this case was "heat production, light fuel oil, at industrial furnace 1MW" to produce 4.9 kWh of heat corresponding to 0.412 L fuel input. A cross check with direct fuel CO_2 conversion factors (DEFRA, 2019) indicated that Ecoinvent global warming potential (GWP) values were less than 15% higher than direct emission values, accounting for machinery burdens etc. Hop pellets are produced by milling the hop cones in to a powder then compressing the matter in to pellets to facilitate handling and addition to wort (Moir, 2000). Although no data could be found regarding electricity consumption for hop milling, a default value was used based on milling malted barley, with 1 kg requiring 0.0065 kWh (Kløverpris et al., 2009).

4.2.4.7 Upstream Transportation

4.2.4.7.1 Distribution of malting ingredients

Several malting companies operate malting plants in England and Scotland (MAGB, 2020). The upstream distribution comprises of two stages, referred to here as leg one and leg two. Leg one is from farm to malting company the distance from farm to maltster was based on figures provided by Crisp Maltings who state that the "majority of their requirements [are cultivated] within a 100 km radius of each plant" (Crisp Maltings, 2020a). Whilst leg two is from malting company to brewery. This stage of distribution depends on the location of the brewery relative to the location of malt supplier(s). The participating breweries were asked to list all suppliers and the number of deliveries received in the calendar year. The average distance from each supplier is multiplied with the total weight of goods received from that supplier per delivery, repeated for every delivery in a year, to calculate aggregate t-km malt transport per annum. This figure is then divided by the number of batches brewed and then with the average batch volume. All inputs and outputs for up- stream distribution are added up and multiplied by transport burdens for a freight lorry, 16 - 32 metric ton, EURO4 (Wernet et al., 2016).

4.2.4.7.2 Distribution of Hops

Table 4.2 shows that for five breweries hop input amounts to approximately 2% of the weight of total brewing ingredients. Yet hops are the ingredients that have been transported the furthest and to account for this the brewers were asked to specify where their hops came from. To streamline the data three categories for hops were created referring to the general location they were cultivated: USA, EU and AUS/NZ. Table 4.2 shows the estimated transport distance for lorry and container ship.

4.2.4.7.3 Distribution of packaging and cleaning substances

Many breweries use contract packaging for bottles and cans, to avoid the labour requirements of packaging large quantities of beer by hand, reflecting the fact that bottling machinery can be a large investment for a small business, and also ensuring quality standards and extended shelf life via pasteurisation undertaken by the bottling contractors (Nyamunda et al., 2018). Table 4.2 indicates which breweries use contract bottling, and which breweries undertake this process on site. If breweries package beer on site, the distance from packaging supplier is applied to transport calculations.

4.2.4.8 Brewery Operations

4.2.4.8.1 Milling

Malted barley requires milling before it can be used for brewing. The barley grain structure is comprised of three parts, the germ, endosperm that contains the necessary brewing starch and grain covering comprising several protective layers (Mussatto et al., 2006). No specific data were collected on milling, but this will be accounted for within the total electricity usage. Taking reference data provided by Kloverpris et al (2009), the electricity required to mill 10 tonne of barley is approximately 65 kWh (Kløverpris et al., 2009). In the case of one brewery taking part in this study with an average grist input of 246 kg per batch, the electricity demand for milling with such equipment is estimated at just 1.6 kWh (a minor share of total brewery electricity consumption)(Kløverpris et al., 2009).

4.2.4.8.2 Mashing

Whilst extraction rates can vary between different varieties of grist approximately 80% of the dry matter is extracted during the mashing stage (Owuama et al., 1987). An expanded boundary approach has been adopted to include the use of co-products as cattle feed on neighbouring farms, the main fate of spent grains in the rural microbreweries studied (Kerby et al., 2017).

4.2.4.8.3 Boiling

Wort must be boiled for a minimum of 60 minutes and is the most energy intensive stage of producing beer (Willaert et al., 2004). There appears to be no clear correlation between a change in energy consumption as brewery size increases. Brewery A has an energy consumption of 1.8 MJ per L of beer and for brewery F 1.3 MJ per L whereas brewery G has the highest energy consumption of 3.3 MJ per L (Table 4.2). This is higher than the thermal energy reported to be consumed by Birra Peroni Srl between 0.64 and 0.78 MJ per L of beer (Cimini et al., 2018). An electric element fitted directly in the kettle was found to be the most popular method of boiling wort. Two of the participating breweries used a steam generator and only one brewery use a gas burner. In one case a diesel generator was required to provide 3-phase supply for the steam generator. Ecoinvent data for diesel generator (19 - 75 kW capacity) operation was used to represent the latter example. The generator used by the brewery was of the Genset brand, model no MG50 SS-P 50kva or 40 kWh. To be certain of the suitability of the data set it was considered prudent to cross check with figures published by DEFRA for diesel consumption. The technical data sheet for the generator stated that operating at 75% capacity consumes 8 L/hr diesel, and according to DEFRA 1 L of diesel is equivalent to 2.6 kg CO_2 eq. (DEFRA, 2019). The hourly emission of 20.8 kg CO_2 eq. is within 15% of the Ecoinvent data (18 kg CO_2 eq. per hour) used in this study. Ecoinvent data were used because they include all other impact categories.

4.2.4.8.4 Wort Chilling

After boiling, wort is chilled to the correct temperature for the yeast to be added. The chilling of wort provides a low-cost option for energy recovery, and to do this cold water is used to cool wort through a counter flow heat exchanger. The heated water that exits the device can be stored in the hot liquor tank to be used in the next batch (Leiper et al., 2006).

2.4.8.5 Fermenting and conditioning

Beer is stored in the fermentation vessel for between 7 and 10 days (Sipperly et al., 2014). It is then transferred to a vessel for conditioning at constant temperature, requiring the use of refrigeration.

4.2.4.8.6 Equipment cleaning

A large share of total water used by the brewery will be for the cleaning in place (CIP) process to clean equipment after producing each batch (Pettigrew et al., 2015). Caustic is firstly used to remove any residue left from the brewing process followed by parasitic acid to sterilise the equipment (Canut et al., 2008; Chen et al., 2012). The cleaning solutions used are modelled on a ratio of 10 - 20 g: 1 L caustic soda to water and 10 - 20 ml parasitic acid per litre of water. The production of Acids and Alkaline cleaning agents used in the CIP process is accounted for in the brewery activities stage, whilst wastewater that is sent to drain is accounted for in the waste management stage of the LCA.

4.2.4.9 Packaging

The breweries use a variety of different methods of packaging depending on where the beer is sold. For the on-trade sector beer is packaged into various Kegs and Casks. In this study three different materials are used. Firstly, Polyethylene Terephthalate (PET) kegs are used by the breweries as a single-use option for beer sales were returning the keg is not an option. These comprise 100% recycled polypropylene (PP) base and carry handle and the PET component is made of 100% virgin material. Stainless steel kegs and casks are treated differently to single use packaging as these have a life expectancy of 30 years (Thielmann, 2020). A national hire company provided figures on the average cycling rate of kegs and casks, used for plastic and stainless steel containers in this study (Kegstar, 2019). Based on an annual reuse rate of 4 times, lifetime uses are estimated at 120 cycles for stainless steel. The mass of the used stainless steel kegs is divided by the lifetime cycle rate. The same approach is applied to high density polyethylene (HDPE) casks, although the life expectancy is 7 years with a lifetime cycle rate of 21. Aluminium cans comprise of two components, the main body of the can and the end cap. The two parts are secured together after filling by compressing the two parts into a double seam. Bottles similarly have a metal crown cap that is secured on to the bottle after filling. Cans are used in 330 ml or 440 ml and bottles in 330 ml, 500 ml and sometimes 660 ml formats (Crown, 2020; Rawlings, 2018a, 2018b). Bottle weights were taken from supplier data sheets. Cardboard is used as secondary packaging for cans and bottles and a random sample of cardboard box was taken from a brewery to weigh the mass of secondary packaging for glass bottles. After use, PET kegs, cans and glass bottles can be disposed of or recycled.

4.2.4.10 Downstream Transport

This section covers the distribution from brewery to retailer. In most cases the studied micro-breweries deliver locally and have a set route that is repeated on a weekly basis. Distributors are often used by the brewery when the beer needs to be delivered outside of the normal (local) delivery area. The same company was named during the interviews as they have a national coverage. There is some uncertainty surrounding the true distance a beer might travel but for each courier service an estimated 200 km was applied. In all cases breweries and distributers use vans of similar size, represented by the Ecoinvent process “market for transport, freight, and light commercial vehicle”.

4.2.4.11 Waste

There is a high demand for water at breweries not only to produce beer but for cleaning and the consumption. Water use has been used to benchmark brewery efficiency (Fillaudeau et al., 2006). With technological progression on water management the volume of waste water produced per L of beer is considered to be between 3 and 10 L (Kanagachandran et al., 2006). Olajire (2012) discusses several factors that can affect the level of water consumption and how this is governed by the efficiency of the plant and equipment (Olajire, 2020). The increased level of organic matter in brewery waste water means it falls within the category of “high strength waste” based on its chemical oxygen demand (Kanagachandran et al., 2006). The levels of organic matter makes the waste water particularly suitable for treatment with anaerobic digestion (Alvarado-Lassman et al., 2008). Although two of the participating breweries have reed bed systems for their wastewater none have any mechanical means of waste treatment on site therefore the process market for wastewater average was used for all cases (Wernet et al., 2016).

4.2.4.12 System Credits & Co Products

Spent grain co-products from the brewing process can be used as animal feed. All breweries stated that they donate spent grains to local farms and to account for this an expanded boundary approach has been adopted. Based on digestible energy and crude protein nutritional value to cattle (Feedipedia, 2020), 1 kg of spent grain can replace 0.47 kg of barley and 0.51 kg of soy bean. The volume of raw ingredients after carbohydrates have been removed during the mash has been based on the EBC approximate extraction rate of 70%.

4.2.5 Impact assessment

Table 4.3 shows the life cycle impact assessment methods based on 13 impact categories recommended by the European Product Environmental Footprint (Fazio et al., 2018). Open LCA v.1.10.2 was used to calculate the environmental footprints of relevant processes extracted from the Ecoinvent v.3.5 database (Wernet et al., 2016). Processes were then aggregated according to life cycle inventories (Table 4.1) in MS Excel to generate final footprint results.

Table 4.3. Life cycle impact assessment methods used in this work.

Impact Category	Indicator	Unit	LCIA Method
Climate change	IPCC 2013 GWP 100a	kg CO_2 eq.	Baseline model of 100 years of the IPCC
Ozone depletion	ILCD 2011 Midpoint	kg CFC-11	Steady-state ODPs 1999 as in WMO assessment
Human toxicity, Cancer	ILCD 2011 Midpoint	CTUh	USEtox model (Rosenbaum et al, 2008)
Human toxicity, cancer effects	ILCD 2011 Midpoint	CTUh	USEtox model (Rosenbaum non-et al, 2008)
Ionizing radiation	ILCD 2011 Midpoint	kg U235 eq.	Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al, 2000)
Photochemical ozone formation	ILCD 2011 Midpoint	kg NMVOC	LOTOS-EUROS model (Van Zelm et al, 2008) as implemented in ReCiPe
Acidification	ILCD 2011 Midpoint	mol H+ eq.	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)
Eutrophication terrestrial	ILCD 2011 Midpoint	mol N eq	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)
Eutrophication freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P e ILCD 2011 Midpoint	EUTREND model (Struijs et al, 2009b) as implemented in ReCiPe
Eutrophication Marine	ILCD 2011 Midpoint	kg N eq.	EUTREND model (Struijs et al, 2009b) as implemented in ReCiPe
Ecotoxicity freshwater	Comparative Toxic Unit ILCD 2011 midpoint	CTUeq.	USEtox model (Rosenbaum et al., 2008)
Abiotic depletion	CML-IA baseline	kg Sb eq.	(Guinée et al., 2002) and van Oers et al. 2002
Abiotic depletion	CML-IA baseline	MJ	(Guinée et al., 2002) and (fossil fuels) van Oers et al. 2002

4.3 Results and discussion

Environmental burdens per L of beer varied considerably across the different micro-breweries (Table 4.4), reflecting different scales, batch capacity, packaging preferences and downstream distribution distances. Global warming potential ranged from 760 g CO_2 eq. per L (Brewery A) to 1900 g CO_2 eq. per L of beer (Brewery G). In a study by Amienyo (2016) comparing beer in a variety of packaging options GWP results range from 575 g to 842 g CO_2 eq. per L for beer distributed in 0.44 L aluminium cans and 0.33 L glass bottles, respectively (Amienyo et al., 2016). An assessment of the multinational brewing brand Peroni reported footprints of 567, 665, 692 and 248 g CO_2 eq. per L of beer distributed in 0.66 L and 0.33 L glass bottles, 0.33 L aluminium can and 30 L reusable stainless steel keg, respectively (Cimini et al., 2016). Meanwhile, we find Fossil resource depletion potential (FRDP) burdens to range from 12 MJ per L of beer in the lowest case up to 30 MJ per L (Table 4.4). This is wider the range reported by Amienyo (2016), who calculated FRDP burdens ranging from 10.3 to 17.5 MJ per L (Amienyo et al., 2016), reflecting the large transport and distribution burdens found for the small scale breweries considered here (Figure 4.3).

Table 4.4. Environmental burdens for the functional unit of 1 L of beer across seven breweries (A-G) and 13 impact categories.

Impact Category	Unit	BrewA	BrewB	BrewC	BrewD	BrewE	BrewF	BrewG
Abiotic depletion	g Sb eq.	0.0024	0.0059	0.0041	0.0051	0.0039	0.0033	0.0067
Fossil resource	MJ	12	21	17	20	20	14	30
Acidification	molc H+ eq.	0.0067	0.0095	0.0087	0.0087	0.010	0.0072	0.013
Freshwater ecotoxicity	CTU eq.	1.6	0.95	1.2	0.88	1.8	1.4	2.5
Freshwater Eutrophication	g P eq.	0.24	0.42	0.36	0.37	0.34	0.30	0.52
Global warming potential	g CO_2 eq.	760	1300	1000	1200	1200	870	1900
Human toxicity cancer effects	CTUh	1.7x10-7	1.2x10-7	3.9x10-8	1.4x10-7	7.2x10-7	1.6x10-7	3.0x10-7
Human toxicity non cancer	CTUh	4.8x10-7	4.1x10-7	2.5x10-7	4.5x10-7	1.6x10-6	4.5x10-7	8.4x10-7
Ionizing radiation	Bq U235 eq.	190	160	190	170	220	180	360
Marine Eutrophication	g N eq.	3.2	3.5	3.4	3.5	3.5	2.7	5.1
Ozone depletion	g CFC 11 eq.	0.00013	0.00037	0.00026	0.00031	0.00023	0.00020	0.00035
Photochemical ozone formation	g NMVOC eq.	3.7	6.6	5.0	6.4	6.1	4.2	9.8
Terrestrial eutrophication	molc N eq.	0.020	0.027	0.024	0.027	0.027	0.020	0.040

Normalised scores (Figure 4.2) indicate comparatively large contributions to FRDP from beer production and consumption. This is followed by global warming potential, marine eutrophication, terrestrial eutrophication, photochemical ozone formation, freshwater eutrophication and acidification. Figure 4.3 shows how the stages of the beer value chain contribute to each of the six highest categories.

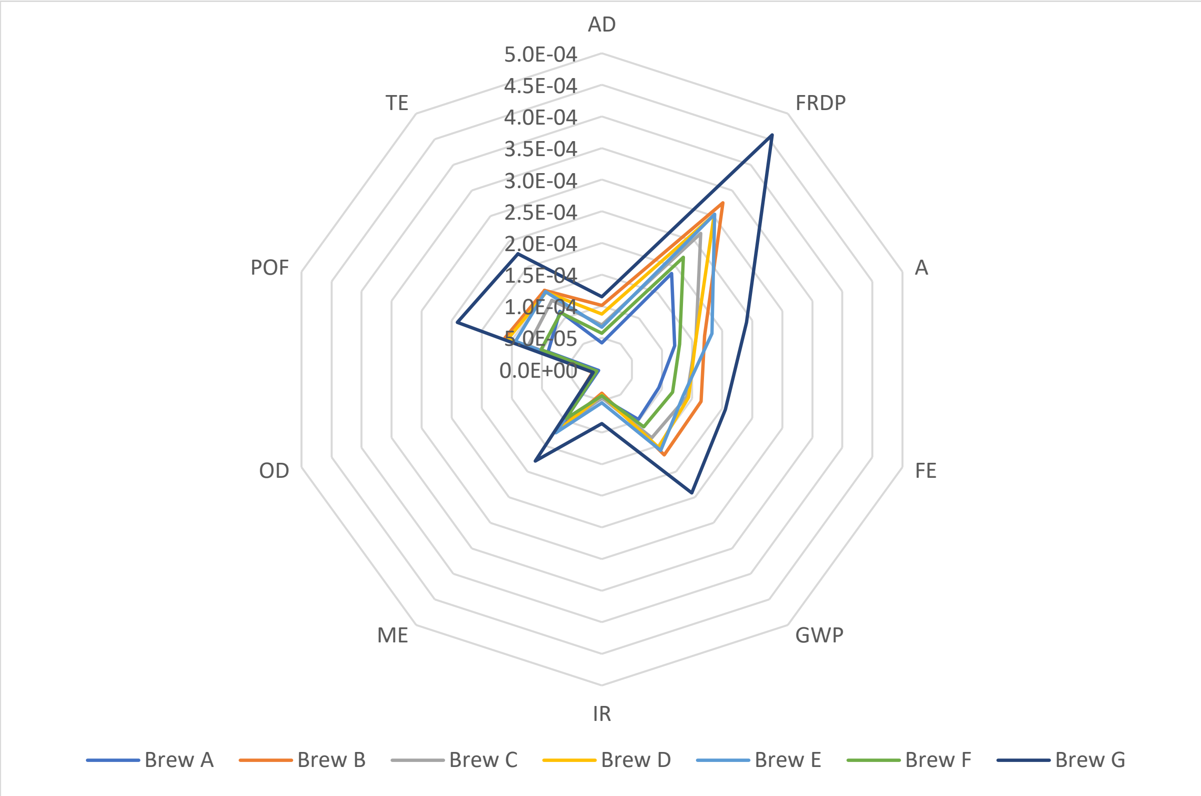
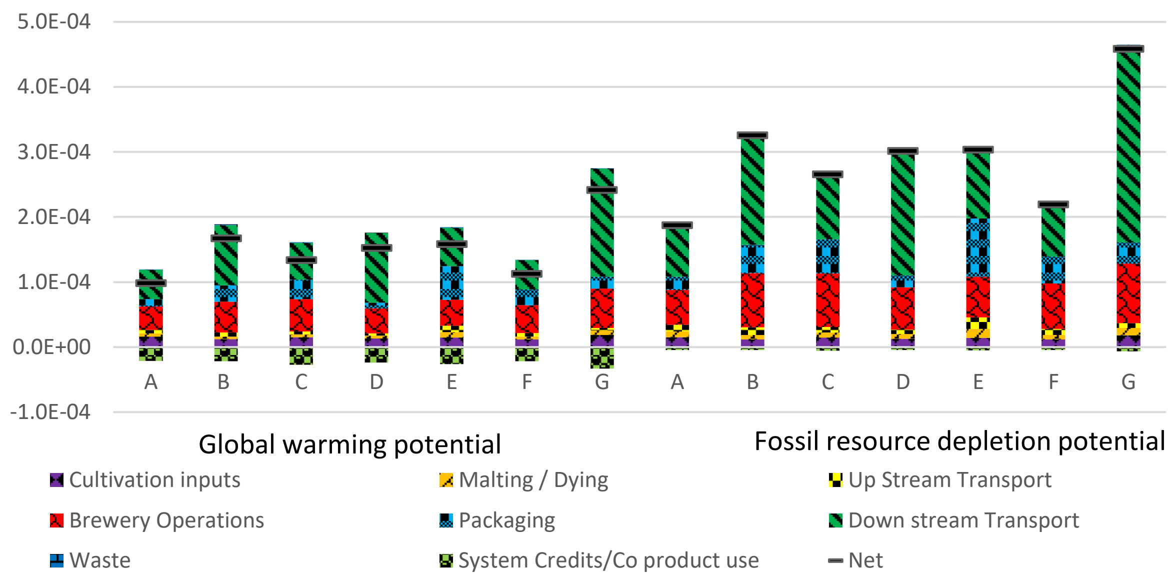
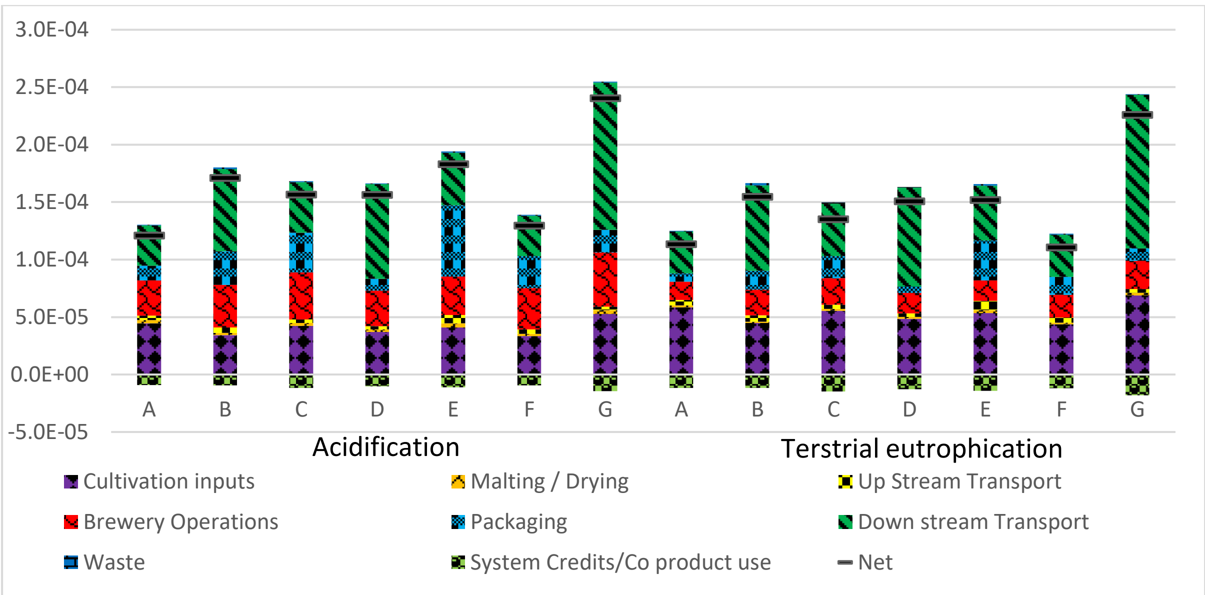


Figure 4.2. Radar plots of normalised scores for 1 L of beer produced by seven breweries across ten impact categories. Clockwise from top abiotic depletion, fossil resource depletion, acidification, freshwater eutrophication, global warming potential, ionising radiation, marine eutrophication, ozone depletion, photochemical ozone formation and terrestrial eutrophication. Following PEF recommendations the human toxicity impact categories are not included (Sala et al., 2018).


5.0E-04
4.0E-04
3.0E-04
2.0E-04
1.0E-04
0.0E+00
-1.0E-04
A B C D E F G A B C D E F G
Global warming potential
Fossil resource depletion potential
Cultivation inputs
Malting / Dying
Up Stream Transport
Brewery Operations
Packaging
Down stream Transport
Waste
System Credits/Co product use
Net


3.0E-04
2.5E-04
2.0E-04
1.5E-04
1.0E-04
5.0E-05
0.0E+00
-5.0E-05
A B C D E F G A B C D E F G
Acidification
Terstrial eutrophication
Cultivation inputs
Malting / Drying
Up Stream Transport
Brewery Operations
Packaging
Down stream Transport
Waste
System Credits/Co product use
Net

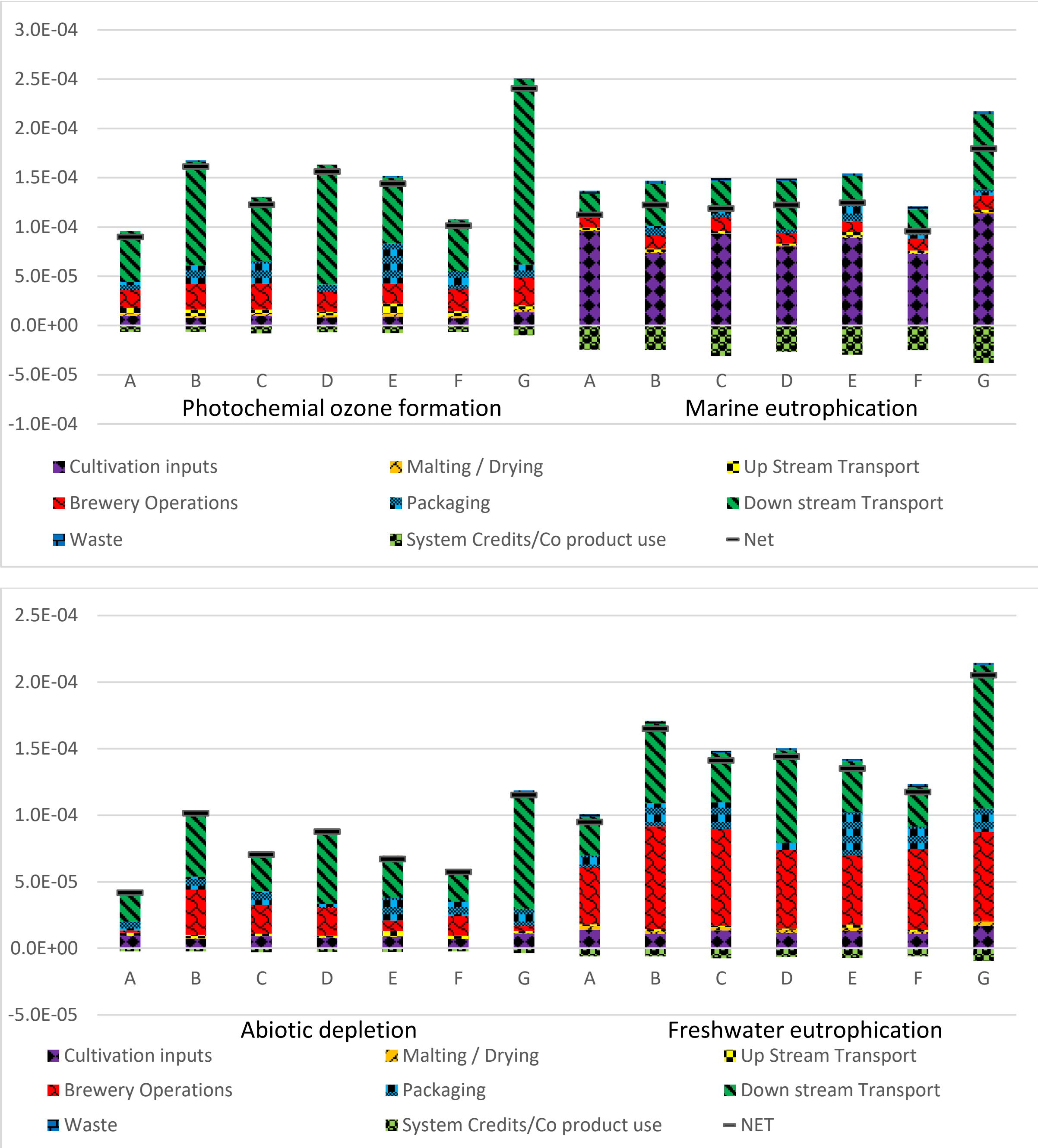


Figure 4.3. Contribution analyses for normalised scores (dimensionless) for global warming potential (GWP) and fossil resource depletion (FRDP), acidification (A) and terrestrial eutrophication (TE) and photochemical ozone formation (POF) and marine eutrophication (ME) abiotic depletion (AD) and freshwater eutrophication (FE) for all participating breweries with different stages of value chain including system credits.

4.3.1 Upstream activity

Table 4.5 shows average results across the seven case studies in terms of percentage contributions to overall burdens for each impact category across all stages of the beer life cycle. In a previous study, cultivation was the second highest contributor to GWP (Cimini et al., 2016). This study work finds cultivation to make a comparatively small contribution to GWP, but a large contribution to marine eutrophication, contributing on average 58% across all case studies. Although not the foremost contributor to acidification and terrestrial eutrophication burdens, cultivation none the less makes substantial average contributions of 24% and 34%, respectively, to these impact categories across all case study breweries (Figure 4.3; Table 4.5). The malting and drying stage makes a small contribution to the overall footprint results across all impact categories. The largest FRDP burden for this stage of the life cycle, 0.91 MJ per L, was recorded at brewery E which produces the second smallest annual volume of all case studies. The mass of hops used by this brewery amounts to 10% of the combined malts compared, to no more than 2% in other cases (Table 4.2). Primary data indicates high oil consumption for hop drying (WOLF Anlagen-Technik GmbH & Co. KG, 2020).

4.3.2 Brewery activity and packaging

Previous studies have found that the onsite beer production process is not the foremost contributor to overall beer footprints (Amienyo et al., 2016; Cimini et al., 2016). On average this stage accounts for 26% of beer GWP burdens and 25% of beer FRDP burdens (Table 4.5). Brewery G has the largest GWP burden for the brewery activity stage of the life cycle, at 470 g CO_2 eq. per L beer (Figure 4.3). The impact category most affected is freshwater eutrophication, with brewery activity responsible for an average 43% of this impact category. Contributions to marine eutrophication, terrestrial eutrophication and acidification are smaller, averaging 8%, 13% and 21% respectively across all breweries.

Interestingly the brewery with the highest annual production is brewery F, with a production volume above 100,000 L per year, and beer from that brewery has the second smallest footprint across all impact categories. This brewery packages 26% of the beer brewed into glass bottles equal to the average across all case studies (Table 4.2). Six out of seven breweries packaged between 68% and 91% of produced beer in reusable kegs or casks, and in most cases the impact for the packaging stage is quite low. As seen with the study conducted by Cimini (2016), beer packaged in to kegs results in a lower GWP than using glass bottles or aluminium cans (Cimini et al., 2016). Brewery E however packaged 40% of beer into casks and 60% into single use bottles, resulting in large contributions to FRDP and GWP (Figure 4.3). This is the only brewery studied where the packaging stage contributes more to both GWP and FRDP than brewery operations.

4.3.3 Downstream activity

The waste stage of the life cycle was generally found to make small contributions to the selected impact categories shown in Figure 4.3. Cimini (2016), in a study that focused on a globally recognised brand of lager, also found waste management to be the smallest contributing stage to overall GWP results (Cimini et al., 2016). In all case studies, waste was the smallest contributor to GWP, FRDP and acidification. Six out of seven case studies showed very small waste stage contributions to terrestrial eutrophication, and two out of seven showed small waste contributions to freshwater eutrophication, but for abiotic depletion the malting and drying stage showed the smallest contribution.

Downstream distribution appears to be a critical stage in the beer life cycle and on average across all case studies is the largest single contributor to the results of GWP, FRDP, acidification, abiotic depletion, terrestrial eutrophication and photochemical ozone formation impact categories (Figure 4.3; Table 4.5). This stage of the life cycle has not been identified as a hot spot for GWP in the case of multinational brands of beer (Cimini et al., 2016; Koroneos et al., 2005). Although not the primary contributing stage for marine eutrophication and freshwater eutrophication, downstream distribution was found to be the second most important stage for these two impact categories.

By comparing the normalised results, it is clear that the impact category that is most influenced by use of co-products for animal feed, via avoidance of soybean meal and barley cultivation, is marine eutrophication (Figure 4.3). Brewery G had the largest animal feed credits per litre of beer, at -1.1 g N eq. for marine eutrophication and -260 g CO_2 eq. for GWP. The smallest credit for marine eutrophication was for brewery A (-7 g N eq. per L) and the smallest GWP credits were for breweries F, B and A (all -170 g CO_2 eq. per L).

Table 4.5. Average result for each life cycle stage of the beer value chain, the impact categories include abiotic depletion (AD), fossil resource depletion (FRD), acidification (A), freshwater eutrophication (FE), global warming potential (GWP), marine eutrophication (ME), photochemical ozone formation (POF) and terrestrial eutrophication (TE).

	ARDP	FRDP	A	FE	GWP	ME	POF	TE
Cultivation Inputs	12%	5%	24%	9%	8%	58%	6%	34%
Malting	1%	3%	1%	2%	2%	1%	2%	1%
Up Stream Transport	3%	4%	2%	1%	3%	2%	4%	3%
Brewery Operations	18%	25%	21%	43%	26%	8%	16%	12%
Packaging	13%	15%	16%	12%	14%	6%	13%	10%
Down Stream Transport	51%	51%	34%	34%	45%	23%	58%	39%
Waste	1%	1%	1%	1%	1%	2%	1%	1%

4.3.4 Sensitivity analysis

The downstream distribution stage of the beer value chain was found to be a significant contributor to the environmental footprint of beer produced by micro-breweries. This was due to all breweries using the light commercial vehicles to distribute the beer from brewery to retailer. The participating breweries were asked to provide the total mileage for 2019 and the usual weekly delivery route. There may be some uncertainty surrounding these distances as seasonal change in demand is a factor that can alter the distances and frequency for making deliveries. A sensitivity analysis was conducted to assess the effects of uncertainty by adjusting the distances and vehicle type for courier and brewery delivery (Table 4.6).

Changing transport mode from van to lorry can reduce GWP results by 45% on average, with the greatest reduction of 62% for brewery D (Table 4.6). The average reduction for FRDP was similar, at 42%, and for brewery G FRDP footprints reduced from 30 to 12 MJ per L beer. However, these reductions would only be achieved if these larger lorries could be filled to typical capacities assumed in Ecoinvent (Wernet et al., 2016). This would require less frequent distribution and/or collaboration with other local businesses (e.g. food wholesalers) that distribute products over a similar area (Bi et al., 2020).

Increasing transportation distance by 20% increases the GWP footprint between 8 and 10%. This effects brewery G the most, increasing beer footprints to 2100 g CO_2 eq. 34 MJ per L for GWP and FRDP, respectively (Table 4.6). Reducing the transport distance by 20% reduces GWP by between 5 and 15%, reducing brewery D footprints down to 1000 g CO_2 eq. 17 MJ per L beer for GWP and FRDP, respectively (Table 4.6).

Increasing the volume of waste sent to landfill and incineration by 30% resulted in no significant effect on GWP but increased abiotic resource depletion potential by between 35 and 129%, with brewery B seeing the highest increase from the default value to 0.00011 g sb eq. Increasing the recycle rate by 20% reduced the volume of waste to landfill to 5% and incineration to 10%, reducing abiotic depletion footprints by between 21 and 52%, down to 0.00003g sb eq. per L for Brewery G.

Table 4.6. Results for sensitivity analyses on downstream distribution against baseline results for GWP and FRDP from commercial van deliveries. Delivery distances were increased by 20% and decreased by 20%, and the type of vehicle used was changed from delivery vans to 7.5 - 16t lorries (assuming average load factors). GWP and abiotic resource depletion potential (ARDP) results are also shown for default assumptions of 65% recycling, with a reduced recycle rate of 5% and an increased rate of 85%.

Process	Unit	BrewA	BrewB	BrewC	BrewD	BrewE	BrewF	BrewG
GWP results for van (default distance)	**g CO_2 eq.**	**760**	**1300**	**1000**	**1200**	**1200**	**870**	**1900**
FRDP results for van (default distance)	**MJ**	**12**	**21**	**17**	**20**	**20**	**14**	**30**
Transport with lorry and default distance								
GWP	g CO_2 eq.	450 (-41%)	660 (-49%)	650 (-35%)	450 (-62%)	820 (-32%)	560 (-35%)	730 (-61%)
FRDP	MJ	7.4 (-39%)	11 (-46%)	11 (-35%)	8.4 (-58%)	14 (-30%)	9.5 (-32%)	12 (-60%)
Transport with van and distance increased by +20%								
GWP	g CO_2 eq.	830 (+9%)	1400 (+8%)	1100 (+10)	1300 (+8%)	1300 (+8%)	940 (+8%)	2100 (+10%)
FRDP	MJ	13 (+9%)	23 (+11%)	19 (+9%)	22 (+10%)	21 (+5%)	15 (+7%)	34 (+13%)
Transport with van and distance decreased by -20%								
GWP	g CO_2 eq.	690 (-9%)	1200 (-8%)	950 (-5%)	1000 (-17%)	1100 (-8%)	800 (-8%)	1600 (-15%)
FRDP	MJ	11 (-8%)	19 (-10%)	16 (-8%)	17 (-15%)	18 (-10%)	13 (-7%)	26 (-13%)
Default recycle rate of 65% with 10% waste to landfill and 25% waste to incineration								
GWP	g CO_2 eq.	760	1300	1000	1200	1200	870	1900
ARDP	g sb eq.	0.000014	0.000048	0.000024	0.000013	0.000033	0.000021	0.000063
5% recycle rate with 40% waste to land fill and 55% waste to incineration								
GWP	g CO_2 eq.	760 (-)	1300 (-)	1000 (-)	1200 (-)	1200 (-)	870 (-)	1900 (-)
ARDP	g sb eq.	0.000019 (+35%)	0.00011 (+129%)	0.000044 (+83%)	0.000019 (+46%)	0.000071 (+115%)	0.000037 (+76%)	0.00013 (+106%)
85% recycle rate with 5% waste to landfill and 10% waste to incineration								
GWP	g CO_2 eq.	760 (-)	1300 (-)	1000 (-)	1200 (-)	1200 (-)	870 (-)	1900 (-)
ARDP	g sb eq.	0.000011 (-21%)	0.000025 (-47%)	0.000015 (-37%)	0.000011 (-15%)	0.000016 (-51%)	0.000014 (-33%)	0.00003 (-52%)

4.4 Conclusion

This chapter has addressed objective number 3 of the aims and objectives outlined in Chapter 1 section 1.2.

The novel footprints for micro-brewed beer presented in this study show that small scale brewing has its own set of environmental hotspots and challenges distinct from larger brewing organisations that have been foot-printed in the past. In particular, downstream distribution is a significant hotspot for the overall footprints of micro-brewed beer, especially for GWP (carbon footprints) and FRDP, owing to use of small commercial vans rather than larger trucks. Use of larger vehicles could be a highly effective mitigation option for this hotspot, but would require larger volumes to be transported, potentially only achievable via collaboration with other local businesses. These results again highlight that "food miles" alone are not necessarily a useful indicator of environmental impact – mode of transport is critical. For one brewery, a particularly large input of hops resulted in a significant contribution to the FRDP footprint owing to very high oil consumption for hop drying, highlighting the potential for efficiency improvements in some upstream processes.

Cultivation is another stage of the beer life cycle that consistently contributes to several impact categories, most notably acidification, terrestrial eutrophication and marine eutrophication. Brewery operations are a major hotspot for freshwater eutrophication and contribute significantly to GWP, freshwater eutrophication, abiotic depletion, terrestrial eutrophication and photochemical ozone formation. It is unclear whether micro-breweries are less efficient than larger scale breweries in terms of onsite energy consumption per litre of beer. Overall, these micro-breweries had lower contributions from packaging compared with larger breweries studied in previous studies because of a higher dependence on reusable kegs and casks for localised distribution. All the micro- breweries studied sent co-products to neighbouring farms to feed animals, leading to environmental credits via soybean and barley displacement, most notably offsetting marine eutrophication burdens. Waste management and upstream distribution of ingredients to the breweries are the two stages of the life cycle that consistently contributed the least to all impact categories, despite hops being sourced from across the world.

Based on this novel analysis of micro-brewed beer, we recommend further investigation of the following promising mitigation options: coordinating distribution with other local businesses, moving from contract- to inhouse- bottling, exploring potential to operate a reusable glass bottle scheme, substitution of glass bottles with aluminium cans.

4.5 References

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5. Packaging choice and coordinated distribution logistics to reduce the environmental footprint of small-scale beer value chains

Abstract

This study assesses the extent to which packaging and distribution impacts can be mitigated as environmental hotspots in the life cycle of micro-brewed beer. We conduct life cycle assessment (LCA) of seven breweries and compare their existing packaging and distribution practises with three mitigation options; use of aluminium cans or reusable glass bottles instead of single use glass bottles or use of polyethylene terephthalate (PET) kegs instead of steel kegs. Findings show that all participating breweries can achieve reductions across multiple impact categories if single use glass bottles are changed to aluminium cans or reusable glass, and further reductions are possible if mode of transport is changed from small delivery vans to lorries for distribution to retailers. The use of PET keg as an alternative to reusable steel keg is a less environmentally sustainable option when beer is delivered short distances, but some savings are possible in long distance scenarios using vans. Carbon footprints per litre beer range from 727 to 1336 g CO_2 eq. across the case study breweries, with reductions of 6-27% or 3-27% by changing to aluminium can or reusable glass bottle, respectively, when beer is delivered by van. The optimal combination of reusable glass bottle delivered by lorry reduces carbon footprints by between 45-55% but will require significant investment and coordination across the wider food and drink sector to implement. Identifying the best packaging material requires a holistic approach that considers interactions and burdens across packaging manufacturing, distribution, use and end-of-life stages.

5.1 Introduction

The Circular Economy has become established as an alternative, more sustainable model to aspire to, compared with the wasteful traditional approach taken in the manufacturing of goods involving a linear path of continuous extraction of finite raw materials and disposal to landfill or incineration following first use (Korhonen et al., 2018). Packaging plays a crucial role in protecting food and drink, extending the shelf life and ensuring food safety standards can be maintained from the post production stage through to consumption (Verghese et al., 2012). The negative effects of food packaging arise at the post-consumer stage. High consumption of fast moving consumer goods leads to unsustainable burdens from large volumes of waste packaging (Niero et al., 2017). In order to close the loop, there is a need for economic progression away from this reliance on finite natural resources (Kirchherr et al., 2017). Indeed, the effects of adopting a circular economic model are not confined to environmental metrics but also affect economic, technical and social domains (Iacovidou et al., 2017).

The most common packaging formats for beer are stainless steel kegs or casks, high density polyethylene casks, glass bottles, aluminium cans and polyethylene terephthalate (PET) kegs (Lorencová et al., 2019; Olajire, 2020). Several life cycle assessment (LCA) studies of beer production have identified packaging as the main hotspot and single use glass bottles incur larger environmental burdens than other packaging options (Amienyo et al., 2016; Cimini et al., 2016; Koroneos et al., 2005). The global warming potential (GWP) of beer packaged in glass bottles at a large scale multinational brewery was found to be 740 g CO_2 eq. per litre, 7% higher than for beer in aluminium cans and 196% higher than beer in a 30 L stainless steel keg (Cimini et al., 2016). Indeed numerous LCA studies have focused on packaging materials for food and drink (Amienyo et al., 2013; Ferrara et al., 2021; Hallström et al., 2018; Nessi et al., 2012; Von Falkenstein et al., 2010). A recent study of alternative wine packaging found single use glass bottle to have the highest GWP burden followed by PET, reusable glass, aseptic container (multilayer polymer-coated paperboards) and bag in box (Ferrara et al., 2020; Robertson, 2021). Kouloumpis (2020) found single use glass bottles to have higher GWP burdens than PET bottles because of impacts associated with production and transportation (Kouloumpis et al., 2020).

Contrary to previous LCA studies of large-scale drinks supply chains, a recent LCA study of beer produced in microbreweries with different packaging preferences, conducted by Morgan et al. (2020), found downstream distribution (rather than packaging) to be the main hotspot for many breweries and environmental impacts – because of reliance on small delivery vehicles with high emissions intensities per tonne-km of transport. Sensitivity analysis showed that an average 45% reduction in GWP could be achieved by changing mode of transport from light commercial vehicles to lorry (Morgan, Styles, et al., 2020). There is growing interest among modern day consumers to “buy local” from small scale producers, and phenomena such farm-to-fork or paddock-to-plate driven by the perceived benefits of quality, traceability and sustainability (Selvey et al., 2013; Verger et al., 2018). This drive to shorten supply chains is no less relevant following geopolitical matters like Brexit and recovery from a global pandemic (Hendry et al., 2019; Hobbs, 2020). There is an urgent need to better understand the implications of supply chain downscaling in terms of interactions across production efficiency, packaging choice, distribution logistics and packaging end-of-life.

The beer sales market consists of two segments referred to as on-trade and off-trade. The former consists of venues such as pubs, clubs and restaurants, whilst the latter includes shops and supermarkets (Tomlinson et al., 2014). On-trade consumption has fallen 37% since 2000, and in 2018 the on-/off-trade drinking split was 46%/54% respectively (Brewers of Europe, 2019; British beer and pub association, 2017;). Beer for the on-trade sector is largely sold in keg and cask whilst bottled and canned beer can be for either the on- or off-trade (Morgan, Styles, et al., 2020). The advantage of keg or cask is the ability to distribute a larger volume of beer in a single container, and a useful life of up to 30 years for a stainless steel keg makes this a lower impact packaging option compared to single use packaging such as aluminium can or single use glass bottle (Cimini et al., 2016; European Commission, 2018). An emerging alternative to the reusable keg is the single direction polyethylene terephthalate (PET) keg championed by manufacturers as a sustainable alternative that doesn't require a return journey back to the brewery, though little mention is made of transport for waste collection or recycling (Dolium, 2021; Keykeg, 2020). A thorough literature search found no academic peer review LCA studies have been conducted on PET kegs, but environmental product declarations (EPD) by the Carlsberg group have presented results for a 20 L modular PET keg with GWP results ranging between 502 to 562 g CO_2 eq. per 1 L of packaged beer (Reggiori, 2011c, 2011d, 2011a, 2011b). Pertinent to the off-trade, the use of aluminium cans by small and independent breweries in Britain has shown significant growth as an alternative to glass bottles, and is expected to continue in popularity (SIBA, 2020). A study of suitable packaging options for a Czech style lager concluded that aluminium can was the best option as a single-use packaging in terms of beer preservation, out-performing glass and PET bottles in tests of colour stability, beer foam stability and sensory analysis (Lorencová et al., 2019).

There is significant value to be gained from a circular business model by shifting the focus away from primary raw material use towards reuse or recycling (Zink et al., 2017), requiring product design with disassembly and reuse at the concept stage (Rathore et al., 2011). Revaluating the reverse logistics pathways for waste glass collection could improve the supply of cullet ultimately increasing the recycle content in glass packaging (Testa et al., 2017). As demand for plastic packaging increases the entire model needs revaluating to phase out petrochemical plastics and move towards developing a bio based value chain for plastic (Lamberti et al., 2020). The EU has an average recycle rate for container glass of 73%, and whilst recycling rates are improving, the UK figure is 68% (FEVE, 2015). Several LCA studies conclude that glass packaging GWP footprint could be reduced by changing to a glass reuse system (Landi et al., 2019; Stefanini et al., 2021; Tua et al., 2020).

This work focuses on the unique challenges faced by small scale beer production to reduce packaging and distribution hotspots. Recent LCA evaluation has highlighted, somewhat counter-intuitively, that dependence on small vans to conduct local deliveries represents a major environmental hotspot for micro-brewed beer. For the first time, using a rich real-life dataset from multiple micro-breweries, we explore the interaction between packaging and distribution burdens in the context of environmental footprints for short drinks supply chains. Our work assesses the mitigation potential of reusable bottles, aluminium cans and PET kegs across seven breweries, each with a different approach to packaging and distribution, to explore context specificities when determining more sustainable and circular packaging and distribution options. The outcome from this work is expected to give new insight into the challenges and opportunities of implementing sustainable packaging and distribution across shorter supply chains.

5.2 Methodology

5.2.1 Goal and scope definition

The overall objective of this study is to evaluate the influence of different packaging and distribution options on the environmental footprint of beer produced by seven small-scale breweries, often referred to as "micro-breweries". In table 5.1 the annual production for the breweries range from 13,336 L to 191,000 L. The target audience is small-scale food and drinks manufacturers, sustainability analysts and policy makers wishing to identify more sustainable (circular) packaging and distribution options. Each of the seven case studies have unique characteristics in terms of raw materials, packaging preference and delivery distance. Here we attempt to identify the best packaging option to reduce the environmental footprint by focusing on two key stages of the beer life cycle, production of packaging material and transportation. The default packaging for each brewery is compared against three alternative packaging options applied to equivalent formats. In option one, all beer distributed in single use small packaging (single use glass bottle or aluminium can of various sizes) is instead packaged in 0.44 L aluminium cans. In option two, all beer distributed in single use small packaging is packaged into reusable bottles that undergo 30 bottle collection, washing and (re)use cycles. In option three, all beer distributed in reusable kegs or casks is instead packaged in single-use PET keg, representing an increasingly popular packaging and distribution option for small-scale breweries owing to simplified linear logistics (Tsallagov, 2021). The functional unit is defined as one litre of packaged beer at the point of retail to the consumer. The objective here is to identify the best packaging and distribution option(s) to reduce the overall environmental footprint of beer for each of the seven case study micro-breweries.

The life cycle impact assessment is carried out according to the guidance provided by the European Product Environmental Footprint (PEF) method (Fazio et al., 2018), excluding more methodologically uncertain toxicity and water scarcity impacts. Thus, 10 impact categories were analysed: GWP, fossil resource depletion potential (FRDP), acidification potential, freshwater eutrophication potential, ironizing radiation potential, marine eutrophication potential, ozone depletion potential, photochemical ozone formation potential, terrestrial eutrophication potential and abiotic resource depletion potential. Of these, additional emphasis was placed on three impact categories with high normalised scores (Figure 5.3): GWP, FRDP and acidification potential. Open LCA v.1.10.2 is used for some calculations taken from Ecoinvent v 3.5 data base (Wernet et al., 2016). Data are collated in MS Excel to generate the final footprint results. The complete list of default findings for all case studies are shown in Table 5.2. In order to compare impact categories, the results have been normalised based on global per capita factors (Fazio et al., 2018).

5.2.2 Single packaging material footprint

The case studies have quotas of beer allocated to packaging options based on the personal preference for each brewery. Table 5.1 shows the unique combinations of reusable keg and cask and single use small packaging like bottles and cans across the breweries. To understand how each packaging material influences brewery footprints in isolation, a generic case study was created based on brewery G, with all beer distributed in single packaging options across scenarios.

Table 5.1. Packaging quotas for batch average beer production and weekly distribution distance.

Packaging option	Unit	Volume	BrewA	BrewB	BrewC	BrewD	BrewE	BrewF	BrewG
Single use glass	L	0.33	83						156
Single use glass	L	0.5		125	194	130	543	500	
Aluminium can	L	0.44							94
Stainless steel cask	L	40.9	292	172				1333	
HDPE cask	L	40.9	172	172	394	1340	362		
Stainless steel keg	L	50	250						
Stainless steel keg	L	30			18			104	962
PET keg	L	30							85
Offsite Packaging	Y/N		No	Yes	No	Yes	Yes	Yes	No
Beer sold in keg /cask	%		87	73	68	91	40	74	80
Beer sold in bottle/can	%		13	27	32	9	60	26	20
Annual production	L		13336	25800	26695	154339	19000	191000	142400
Water to beer	L		5.3	5	4.8	5	3	5	5.1
Weekly delivery	km		155	343	184	383	161	130	522

Table 5.2. Default results of environmental burdens for the functional unit of 1 L of beer

Impact Category	Unit	BrewA	BrewB	BrewC	BrewD	BrewE	BrewF	BrewG
Abiotic resource depletion potential	g Sb eq.	0.0023	0.0049	0.0032	0.0036	0.0033	0.0029	0.0045
Fossil resource depletion potential	MJ.	11.64	17.47	14.18	14.04	17.64	12.56	21.64
Acidification	molc H+ eq.	0.0065	0.0082	0.0076	0.0066	0.01	0.0066	0.01
Freshwater ecotoxicity	CTUeq.	1.6	0.79	1.1	0.7	1.8	1.3	2.3
Freshwater eutrophication	g P eq.	0.23	0.37	0.32	0.29	0.31	0.28	0.41
Global warming potential	g CO_2 eq.	727	1056	837	815	1102	766	1336
Human toxicity cancer effects	CTUh	1.7x10-7	1.2x10-7	3.6x10-8	1.4x10-7	7.2x10-7	1.6x10-7	3.0x10-7
Human toxicity non cancer	CTUh	4.8x10-7	3.9x10-7	2.3x10-7	4.2x10-7	1.6x10-6	4.4x10-7	7.9x10-7
Ionizing radiation	Bq U235 eq.	190	132	167	136	204	163	309
Marine eutrophication	g N eq.	3.1	3.1	3	2.8	3.3	2.5	4.2
Ozone depletion	g CFC 11 eq.	0.00012	0.00032	0.00021	0.00023	0.0002	0.0002	0.00023
Photochemical ozone formation	g NMVOC eq.	3.5	5.1	3.7	4.2	5.2	3.5	6.6
Terrestrial eutrophication	molc N eq.	0.02	0.022	0.02	0.02	0.024	0.018	0.03

5.2.3 System boundaries

An attributional LCA is implemented in this study (Finkbeiner et al., 2006). Cultivation, processing, upstream distribution, brewing, packaging, downstream distribution, and waste management are included in the scope of the analysis (Figure 5.1). An expanded boundary approach is applied to account for by-products from brewery processing used as cattle feed, with "credits" from avoided barley and soy meal production (Morgan, Styles, et al., 2020).

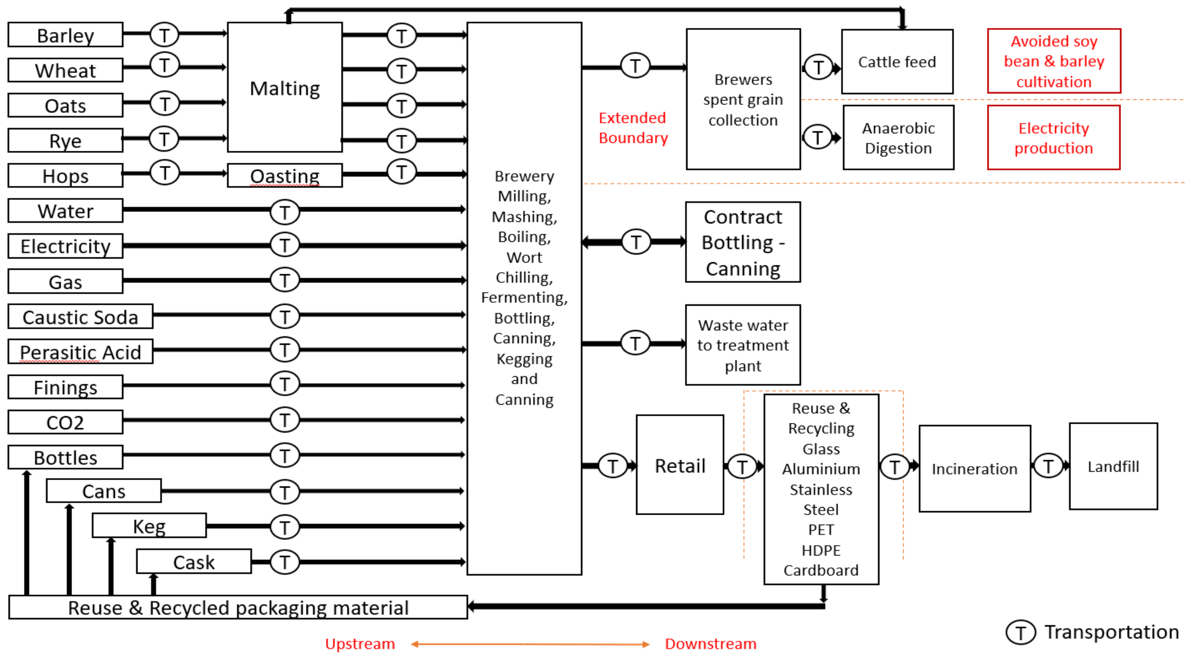


Figure 5.1. Scope of product life cycle included in this study with system boundary consisting of production of raw ingredients, processing, upstream transportation, brewery production, downstream distribution and waste with an extended boundary to account for substitution of barley and soy meal by brewers spent grain and malting by-products used as animal feed (Morgan, Styles, et al., 2020).

5.2.4 Ingredients and production

The primary ingredients used across all case study breweries are shown is Table 4.1 (Chapter 4), the volume of combined grains refers to a mixture of wheat, oats and rye but barley is the primary ingredient. Average batch volume varies between 469 and 1990 L for participating breweries Water is used in beer production and to clean the equipment, sometimes in large quantities (Edmonds, 2016). A brewery with relatively good efficiency can achieve a ratio ranging between 4 and 7 litres of water per litre of beer (Olajire, 2020). The participating breweries consumption is between 3 and 5.3 of water per litre of beer (Table 5.1).

5.2.5 Packaging

All participating breweries have differing packaging profiles, involving different packaging materials, container capacities and the volume of beer allocated to each packaging type. Table 5.1 shows a summary of batch average packaging profiles for each participating brewery with between 9% and 32% of beer packaged into single use packaging, apart from brewery E where 60% of beer is packaged in single use glass bottles.

5.2.6 Transport

Transport activities arise primarily in to two stages, upstream transport of ingredients and packaging to the brewery and downstream distribution of beer from the brewery to the retailer. In previous work, upstream transport made little contribution to the overall results regardless of long transport distances, and the critical point was identified as downstream distribution because of the use of light commercial vehicles to distribute beer to customers (Morgan, Styles, et al., 2020). Table 5.3 shows transport activity factors for beer across different packaging options for each brewery, expressed as kg-km per litre of beer.

Table 5.3. Transport activity factors for distribution of packaged beer from each of the case study breweries, with default results representing current packaging preferences for comparison with alternative options. Option 1 represents all beer packaged in single use glass bottles replaced with 0.44 L aluminium cans. Option 2 represents all beer packaged in single use glass bottles replaced with reusable glass bottles. Option 3 represents all beer packaged in reusable kegs and casks replaced with 30 L single use polyethylene terephthalate kegs.

		{Single packaging transport factors}									
Packaging	**Unit**	**All Can**	**All Bottle**	**All PET**	**BrewA**	**BrewB**	**BrewC**	**BrewD**	**BrewE**	**BrewF**	**BrewG**
Bottle	kg-km/L				12	85	47	27	135	53	51
Can	kg-km/L										20
Stainless steel keg	kg-km/L				75		5			14	323
Stainless steel cask	kg-km/L				87	94				65	
HDPE cask	kg-km/L					78	74	218	40		
PET keg	kg-km/L										11
Total (default)	kg-km/L				174	257	126	245	175	132	405
Aluminium can	kg-km/L	268			8	55	30	18	87	34	53
Stainless steel keg	kg-km/L				75		5			14	323
Stainless steel cask	kg-km/L				87	94				65	
HDPE cask	kg-km/L					78	74	218	40		
PET keg	kg-km/L										11
Total Option 1	kg-km/L	268			170	227	109	236	127	113	387
Reusable bottle	kg-km/L		432		13	92	51	29	146	57	85
Stainless steel keg	kg-km/L				75		5			14	323
Stainless steel cask	kg-km/L				87	94				65	
HDPE cask	kg-km/L					78	74	218	40		
PET keg	kg-km/L										11
Total Option 2	kg-km/L		432		175	264	130	247	186	136	419
Bottle	kg-km/L				12	85	47	27	135	53	51
Can	kg-km/L										20
PET keg	kg-km/L			269	134	130	65	181	33	56	216
Total Option 3	kg-km/L			269	146	215	112	208	168	109	287

Packaging and distribution: single use bottle 0.3 kg, reusable bottle 0.365 kg, aluminium can 0.015 kg, 50 L stainless steel keg 12.3 kg, 30 L stainless steel keg 9.5 kg, stainless steel cask 10.1 kg, HDPE cask 5.05 kg & 30 L PET keg 1.07 kg.

5.2.7 Option one: replacing single use bottle with aluminium can

This option involves directly exchanging the volume of beer each brewery packages in glass bottles to aluminium cans to understand how the lighter material affects packaging and distribution burdens. The capacity of aluminium cans varies, as it does for bottles, but for this scenario a 0.44 L can is used to represent the most popular size option among breweries (Wavegrip, 2019). This means that regardless of a brewery's preference for 0.33 L or 0.5 L glass bottle, the scenario focuses on a single can size.

5.2.8 Option two: Taking single use glass bottles and replacing them with reusable bottles

The value chain stages that are affected from this change are packaging, upstream distribution, downstream distribution and end-of-life. A reusable bottle scheme requires the bottle to be thicker and more robust, resulting in the 0.33 L bottle being 30% heavier and the 500 ml bottle 22% heavier than the lighter single use version (Vetropack, 2021). A reuse rate of 30 cycles is assumed based on PEF recommendations, and the total weight of glass bottles used is divided by the reuse rate (European Commission, 2018). It is assumed that post-consumer stage for distribution of single use and reusable glass would be similar on the basis that both packaging options are processed domestically and not exported. There is no change to the downstream distribution delivery distances but transporting heavier bottles does increase kg-km transport factors (Table 5.3). Primary and secondary data were used to account for the bottle washing process based on machinery with a capacity of 60,000 bottles per hour consuming 0.010 kWh of electricity, 0.44 L of water, 0.008 kg of caustic and 0.088 MJ of natural gas, per litre of beer packaged (IC Filling Systems, 2021; Jade Trading, 2021; Ponstein et al., 2019).

5.2.9 Option three: replacing conventional kegs and casks with single use PET alternative

Similar, to the aluminium can scenario, the volume of beer packaged into reusable kegs and casks according to each brewery's packaging and distribution strategy is replicated with a single use one way PET keg. The participating breweries have individual preferences for using kegs and casks, and in order to understand the effects of using PET on the environmental footprint, beer that would be packaged in to the reusable kegs and casks is modelled with the 30 L size PET keg options (Keykeg, 2020). The purpose of this exercise is to understand how the reduction in weight affects both up and downstream distribution when using the lighter PET keg, and to compare the manufacturing and end-of-life burdens of different volumes of different packaging materials. The majority of reusable keg and cask are owned by the breweries and are made of stainless steel or high density polyethylene (HDPE) in a constant cycle of filling, distribution, dispensing at the place of retail, empty containers collected by the brewery, cleaning and then reuse. The PET keg is promoted as a more sustainable option because of its light weight construction, it does not require a return journey to the brewery and is recyclable (Keykeg, 2021). The majority of the UK post-consumer plastics are exported often to countries with low environmental standards raising some uncertainties around the true fate of used PET kegs (Bishop et al., 2020; Wrap, 2019).

5.3 Results

The default environmental footprint per 1 L of beer varies greatly amongst all case studies (Table 5.2), reflecting different scales, batch capacity, packaging preferences and downstream distribution distances. The carbon footprint results range from 727 g CO_2 eq. per L (Brewery A) to 1336 g CO_2 eq. per L of beer (Brewery G), with a median value of 837 g CO_2 eq. per L for brewery C. Brewery E has the largest GWP burden for packaging, at 406 g CO_2 eq. per L owing to the heavy reliance on glass bottles. Brewery G has the largest GWP burden for combined packaging and distribution, at 893 g CO_2 eq. per L, owing to a long average transport distance of 522 km.

5.3.1 Switching packaging options across micro breweries

Changing single use small packaging to either aluminium can or reusable glass bottle is effective in reducing GWP burdens. The packaging material that resulted in the biggest reduction for each brewery is shown in Figure 5.2. Reusable glass bottle is the best option for breweries A, C and E whilst aluminium can is the best option for breweries B, D, F and G. Brewery E shows the biggest beer footprint reduction of 27% from changing to reusable glass bottle (1102 g CO_2 eq. down to 803 g CO_2 eq. per L beer) and a reduction of 27% from switching to aluminium can (1102 g CO_2 eq. down to 807 g CO_2 eq. per L beer). The mean average reductions (across all breweries) for each relevant stage of the beer life cycle for aluminium cans vs single use bottles are: 15% for upstream transport, 45% for packaging production, 11% for downstream transport, and 30% for waste management (Table 5.4). Aluminium cans reduced the average overall beer footprint by 14% (across all breweries). The small increase in weight of reusable glass bottle results in an average 4% increase (across all breweries) to upstream transport burdens and an average 3% increase (across all breweries) to downstream transport burdens. However, switching to reusable bottle achieves a 68% reduction in packaging production burden, and a 40% reduction in waste management burden, resulting in an overall beer footprint reduction of 13% (Table 5.4). Overall, changing from stainless steel to PET keg increases beer footprints by an average 14% (across all breweries), and up to 29% for Brewery D (815 kg CO_2 eq. up to 1050 kg CO_2 eq. per L beer) (Table 5.4). Brewery G was the only case study to show a small (2%) reduction in beer footprint from using PET keg, owing to having the longest downstream distribution distance of 522 km (Table 5.1).

FRDP burdens are reduced when packaging material is changed to aluminium can or reusable glass bottle across all breweries. Aluminium can is the best option for reducing FRDP burdens for breweries B, D, E, F and G, whilst breweries A and C see bigger reductions in FRDP burdens from switching to reusable glass bottles. Changing default packaging to aluminium can results in an average reduction (across all breweries) of 15% to upstream distribution, 41% to packaging, 11% to downstream distribution, 57% to waste management, and an overall average reduction (across all breweries) of 12% in beer footprints. As for GWP, reusable glass bottles result in an average 4 & 3% increase (across all breweries) of upstream and downstream FRDP burdens respectively, but packaging and waste management burdens are reduced on average by 64% and 64%, respectively, resulting in an average overall beer footprint reduction of 11% across all breweries (Table 5.4). Brewery E sees the biggest reduction in beer FRDP footprints of 24% for aluminium cans, reducing the burden from 17.65 MJ down to 13.48 MJ per L beer. Brewery E also sees the biggest FRDP reduction, of 23% for glass bottle, from 17.65MJ down to 13.55MJ per L beer. The PET keg option increases FRDP footprints across all case studies by an average of 21%, increasing the footprint for Brewery D from 14.04 MJ up to 19.66MJ per L beer.

Acidification burdens are reduced when single use glass packaging is changed to aluminium can or reusable glass bottle. The aluminium can was best option for reducing acidification burdens for breweries B, D and G whilst the reusable bottle system was best for breweries A, C, E and F. With aluminium can we find average reductions (across all breweries) of 14% for upstream distribution, 57% for packaging, 11% for downstream distribution, 37% for waste stage and an overall average reduction of 15% (Table 5.4). Reusable glass bottles incur an average 4 & 3% increase (across all breweries) to up and downstream distribution respectively, but reductions of 78% for packaging, 46% for waste management and overall average reduction of 15% across all breweries (Table 5.4). Brewery E sees the biggest overall reduction in beer footprint of 29% with a switch to aluminium cans, with acidification footprints reducing from 0.00952 molc H+ eq. to 0.00679 molc H+ eq per L beer. Brewery E see the biggest reduction in beer footprint of 31% for reusable glass bottle, with footprint reducing from 0.00952 molc H+ eq. to 0.00657 molc H+ eq. per L beer. Switching from steel to PET kegs resulted in an average acidification increase (across all breweries) of 6%, with brewery D showing the biggest change of 14% to increase beer footprint from 0.0066 molc H+ eq. to 0.0076 molc H+ eq. Brewery G is the only case study to show a (4%) reduction in beer footprint following a shift to PET keg, from 0.0103 molc H+ eq. to 0.0099 molc H+ eq. per L beer.

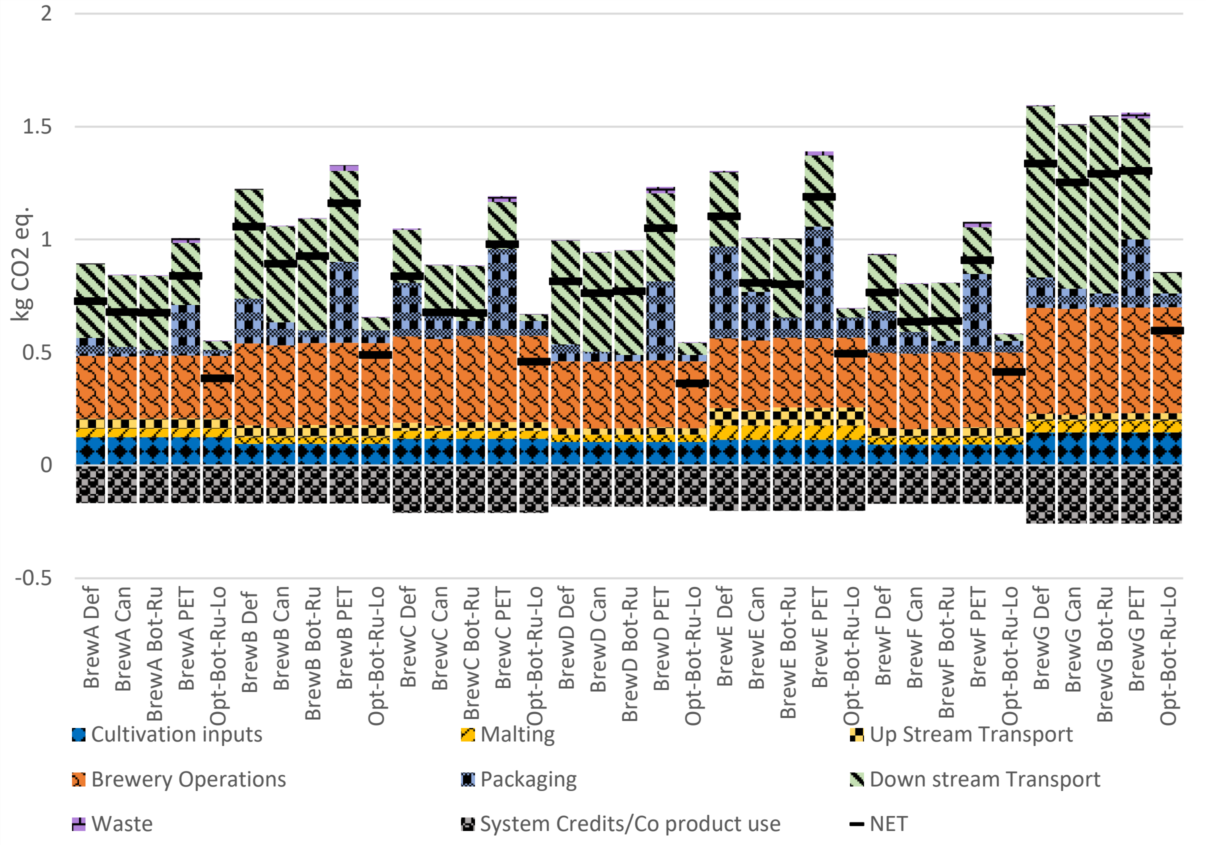
Switching to reusable bottles is the best option to reduce freshwater eutrophication, abiotic resource depletion potential and ionizing radiation burdens, whereas switching to aluminium can is the best option to reduce marine eutrophication, ozone depletion, photochemical ozone formation and terrestrial eutrophication burdens.

Table 5.4. Mean average change across all breweries for each relevant stage for the beer life cycle including global warming potential, fossil resource depletion potential and acidification.

Global warming potential	Can	Bot	PET
Cultivation inputs			
Malting			
Up Stream Transport	-15%	4%	
Brewery Operations			
Packaging	-45%	-68%	
Down stream Transport	-11%	3%	
Waste	-30%	-40%	
System Credits/Co product use			
Total	-14%	-13%	14%

Fossil resource depletion potential	Can	Bot	PET
Cultivation inputs			
Malting			
Up Stream Transport	-15%	4%	
Brewery Operations			
Packaging	-41%	-64%	
Down stream Transport	-11%	3%	
Waste	-57%	-64%	
System Credits/Co product use			
Total	-12%	-11%	21%

Acidification	Can	Bot	PET
Cultivation inputs			
Malting			
Up Stream Transport	-14%	4%	
Brewery Operations			
Packaging	-57%	-78%	
Down stream Transport	-11%	3%	
Waste	-37%	-46%	
System Credits/Co product use			
Total	-15%	-15%	6%



2
1.5
1
0.5
0
-0.5
kg CO2 eq.
BrewA Def
BrewA Can
BrewA Bot-Ru
BrewA PET
Opt-Bot-Ru-Lo
BrewB Def
BrewB Can
BrewB Bot-Ru
BrewB PET
Opt-Bot-Ru-Lo
BrewC Def
BrewC Can
BrewC Bot-Ru
BrewC PET
Opt-Bot-Ru-Lo
BrewD Def
BrewD Can
BrewD Bot-Ru
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BrewG Def
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BrewG Bot-Ru
BrewG PET
Opt-Bot-Ru-Lo
Cultivation inputs
Malting
Up Stream Transport
Brewery Operations
Packaging
Down stream Transport
Waste
System Credits/Co product use
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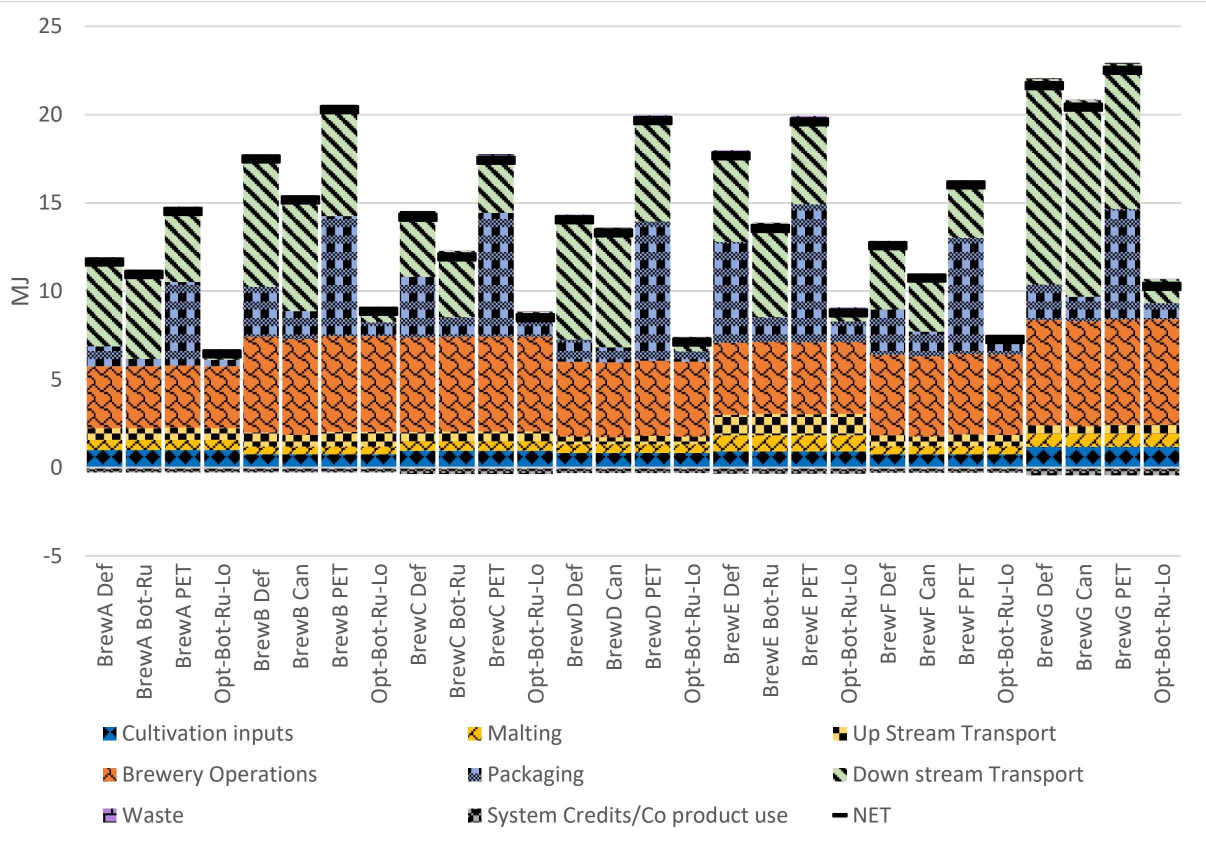

25
20
15
10
5
0
-5
MJ
BrewA Def
BrewA Bot-Ru
BrewA PET
Opt-Bot-Ru-Lo
BrewB Def
BrewB Can
BrewB PET
Opt-Bot-Ru-Lo
BrewC Def
BrewC Bot-Ru
BrewC PET
Opt-Bot-Ru-Lo
BrewD Def
BrewD Can
BrewD PET
Opt-Bot-Ru-Lo
BrewE Def
BrewE Bot-Ru
BrewE PET
Opt-Bot-Ru-Lo
BrewF Def
BrewF Can
BrewF PET
Opt-Bot-Ru-Lo
BrewG Def
BrewG Can
BrewG PET
Opt-Bot-Ru-Lo
Cultivation inputs
Malting
Up Stream Transport
Brewery Operations
Packaging
Down stream Transport
Waste
System Credits/Co product use
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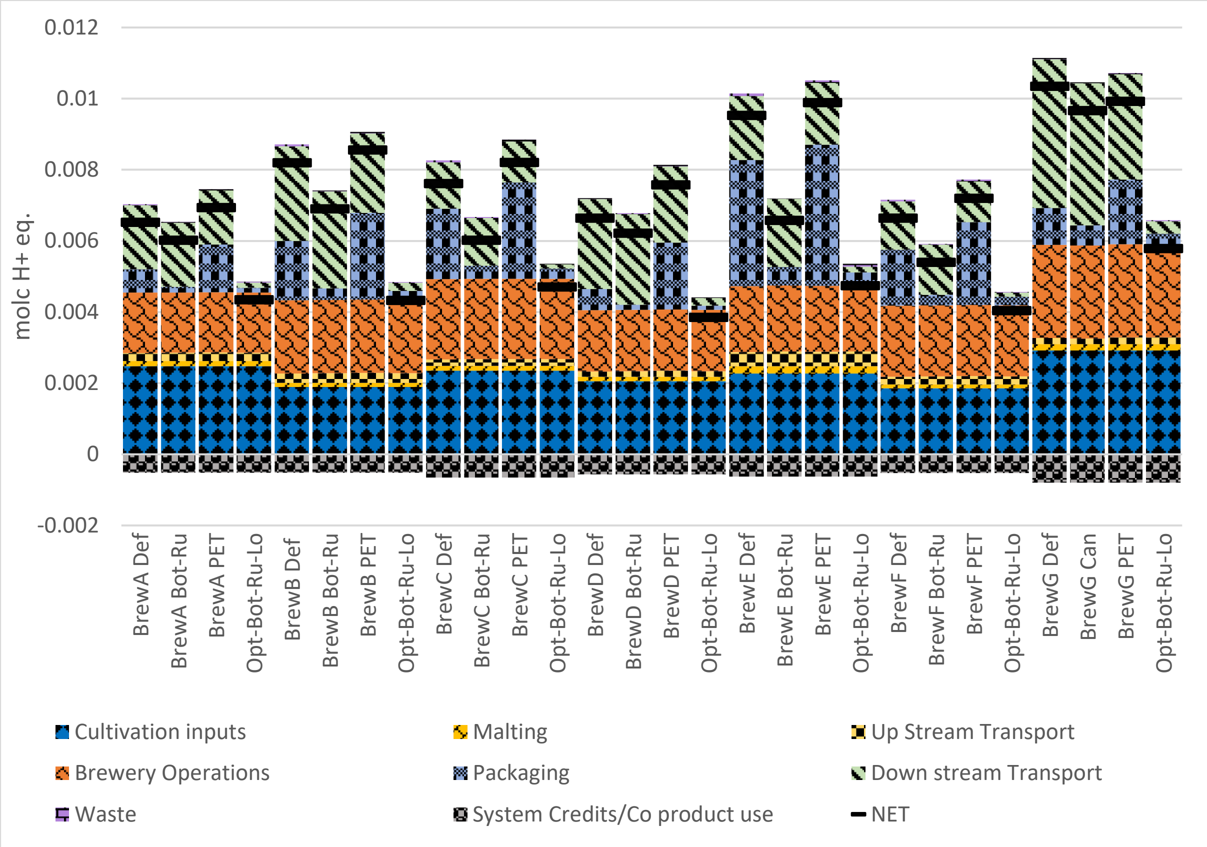
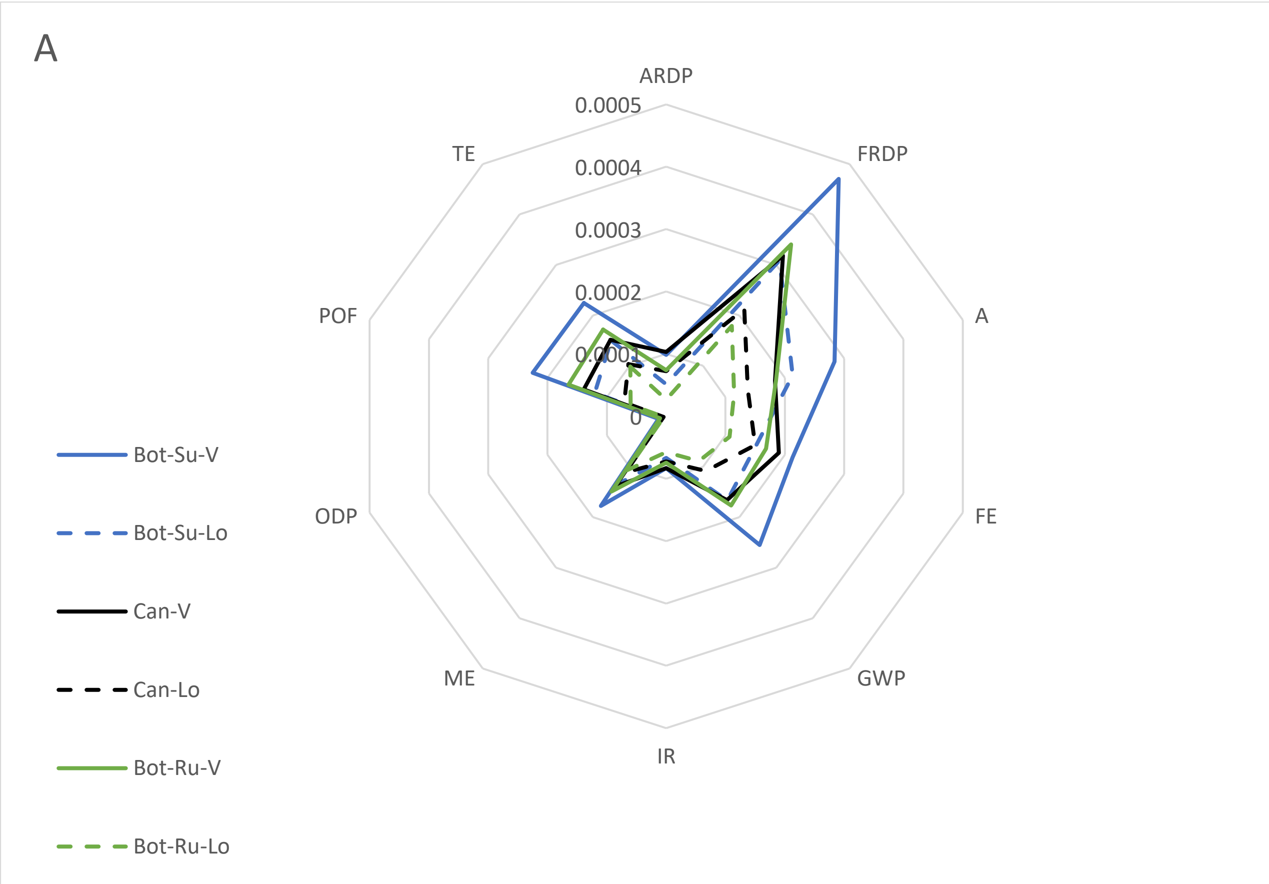


Figure 5.2. GWP, FRDP and Acidification footprints for beer produced across seven case study breweries. Results show default values (Def), best performing single use packaging for each brewery showing either reusable glass (Bot-Ru) or aluminium can (Can), reusable keg and cask changed to PET keg (PET) and optimised method combining reusable bottle with a shift from van to 7 – 16 tonne lorry for distribution (Opt-Bot-Ru-Lo).

5.3.2 Comparative performance of combined packaging and distribution options

Distribution from brewery to retailer has been identified as a particular hotspot for micro-brewed beer because it is typically carried out using small vehicles that are inefficient at transporting cargo (Morgan, Styles, et al., 2020). Figure 5.3 A shows generic footprints with all beer in a single packaging material, for transport with van or lorry over 522 km (adapted from Brewery G data). Single use bottle delivered with van (Bot-Su-Van) results in the largest burdens across all impact categories, with the highest normalised scores for FRDP, GWP, photochemical ozone formation and terrestrial eutrophication (Appendix 5). Scores for aluminium can delivered by van (Can-Van) and reusable glass bottle delivered by van (Bot-Ru-Van) are very similar. Both options have lower scores (smaller burdens) compared to single use bottle, with the biggest differences for FRDP and acidification (Figure 5.3 A). When the mode of transport is changed to lorry, the footprints for all packaging options are reduced (Figure 5.2), and the comparative performance of reusable glass bottle (Bot-Ru-Lorry) improves the most to achieve lowest normalised scores across all impact categories (Figure 5.3 A).

Figure 5.3 B shows that PET keg delivered with van (PET-Keg-Van) has the highest normalised scores for FRDP and freshwater eutrophication, whilst stainless steel keg delivered with van (SS-Keg-Van) has the highest scores for abiotic depletion potential, acidification, GWP, marine eutrophication, ozone depletion potential, photochemical ozone formation and terrestrial eutrophication. When mode of transport is changed to lorry, the footprints for all packaging options are reduced, HDPE cask and stainless steel keg and cask show biggest improvements to normalised scores across all impact categories (Figure 5.3 B).



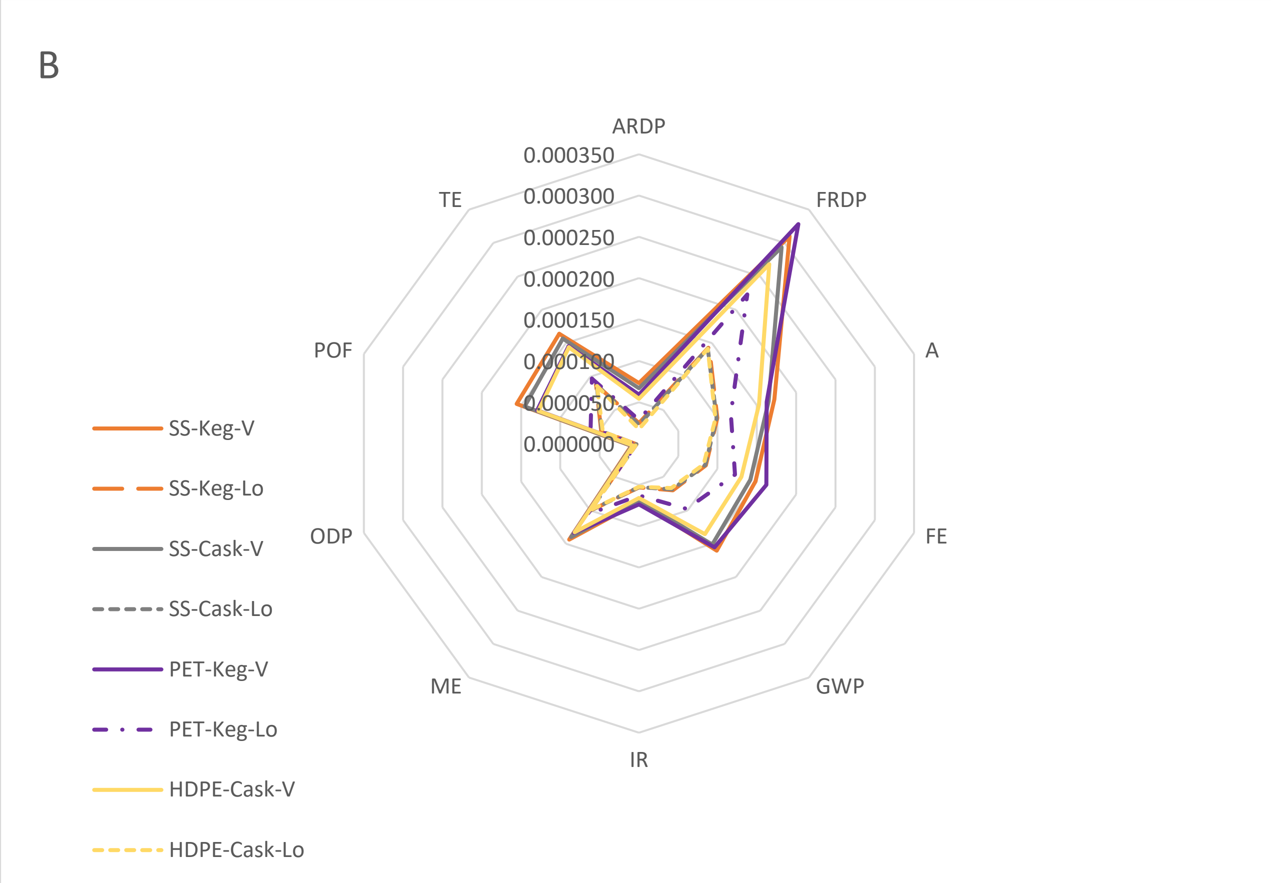
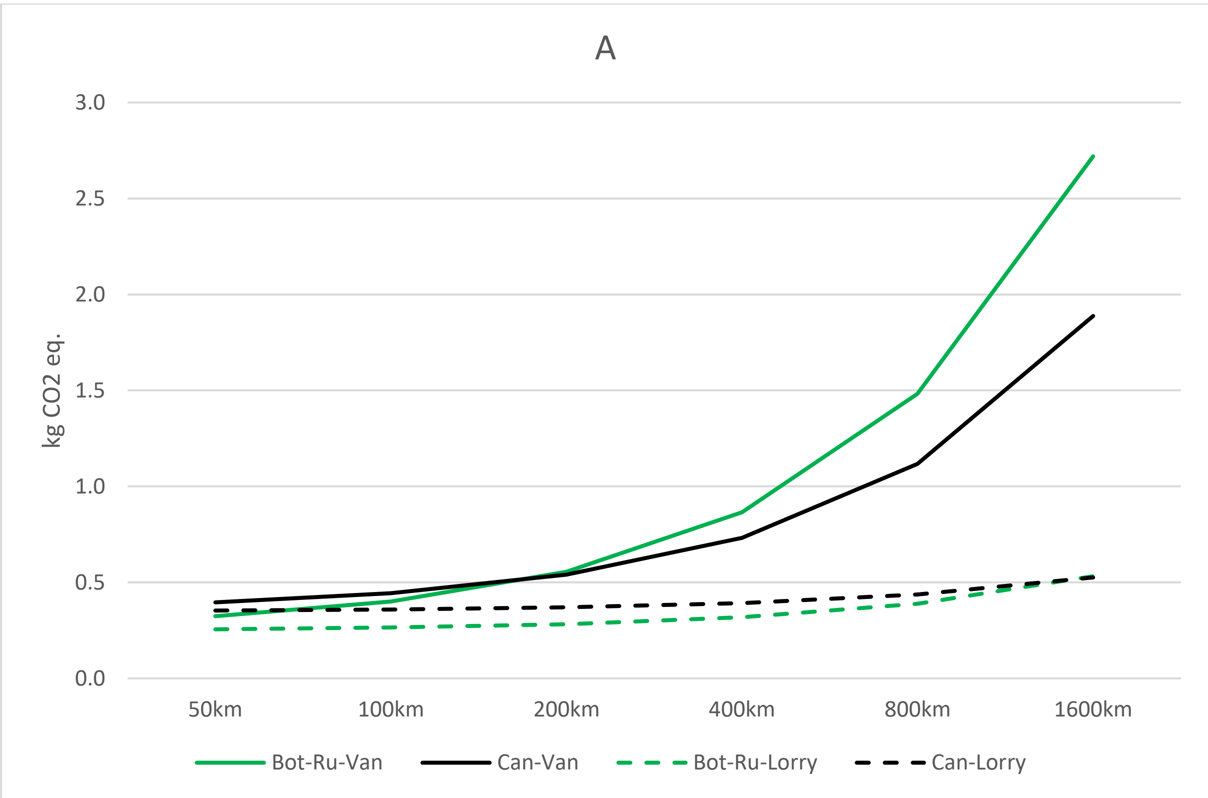


Figure 5.3. Part A shows a radar plot of normalised scores across ten impact categories for single use glass bottle and delivery with van (Bot-Su-Van), single use glass bottle delivered with lorry (Bot-Su-Lorry), aluminium can delivered with van (Can-Van), aluminium can delivered with lorry (Can-Lorry), reusable glass bottle delivered with van (Bot-Ru-Van) and reusable glass bottle delivered with lorry (Bot-Ru-Lorry). Part B shows normalised scores for stainless steel keg delivered with van (SS-Keg-Van) stainless steel keg delivered with lorry (SS-Keg-Lorry), stainless steel cask delivered with van (SS-Cask-Van), stainless steel cask delivered with lorry (SS-Cask-Lorry), PET keg delivered with van (PET-Keg-Van), PET keg delivered with lorry (PET-Keg-Lorry), HDPE cask delivered with van (HDPE-Cask-Van) and HDPE cask delivered with lorry (HDPE-Cask-Lorry). The impact categories include Abiotic resource depletion potential (ARDP), Fossil resource depletion potential (FRDP), Acidification potential (AP), Freshwater eutrophication potential (FEP), Global warming potential (GWP), Ionizing radiation (IR), Marine eutrophication potential (MEP), Ozone depletion potential (ODP), Photochemical ozone formation potential (POFP) and Terrestrial eutrophication potential (TEP).

5.3.3 Lowest burden packaging choice across distribution options

In Figure 4 the combined GWP burden of packaging and distribution stages are taken from the generic single packaging footprints. The solid lines in Figure 5.4 A show aluminium can delivered by van and reusable bottle delivered by van, showing that reusable bottles have a lower GWP burden up to approximately 200 km, but that aluminium cans have a lower burden at greater distances. Aluminium cans have a larger packaging production burden than bottles, but heavier weight of glass bottles compared with aluminium cans increases distribution burdens. If mode of transport is changed to lorry, reusable bottles retain an environmental advantage over aluminium cans up to 1600 km distribution distance (Figure 5.4 A).

Figure 5.4 B compares the combined production and distribution burden of stainless steel keg and PET keg. The GWP burden for stainless steel kegs remains below that of PET kegs up to approximately 400 km distribution distance with vans. Stainless steel kegs have a lower packaging production footprint across 120 use cycles compared to single use PET containers but are heavier and therefore incur greater transport burdens (Appendix 5: stainless steel kegs weigh 316 g/L of beer whilst PET kegs weigh 36 g/L of beer). If mode of transport is changed to lorry, stainless steel kegs maintain an environmental advantage well beyond 1600 km (Figure 5.4 B).



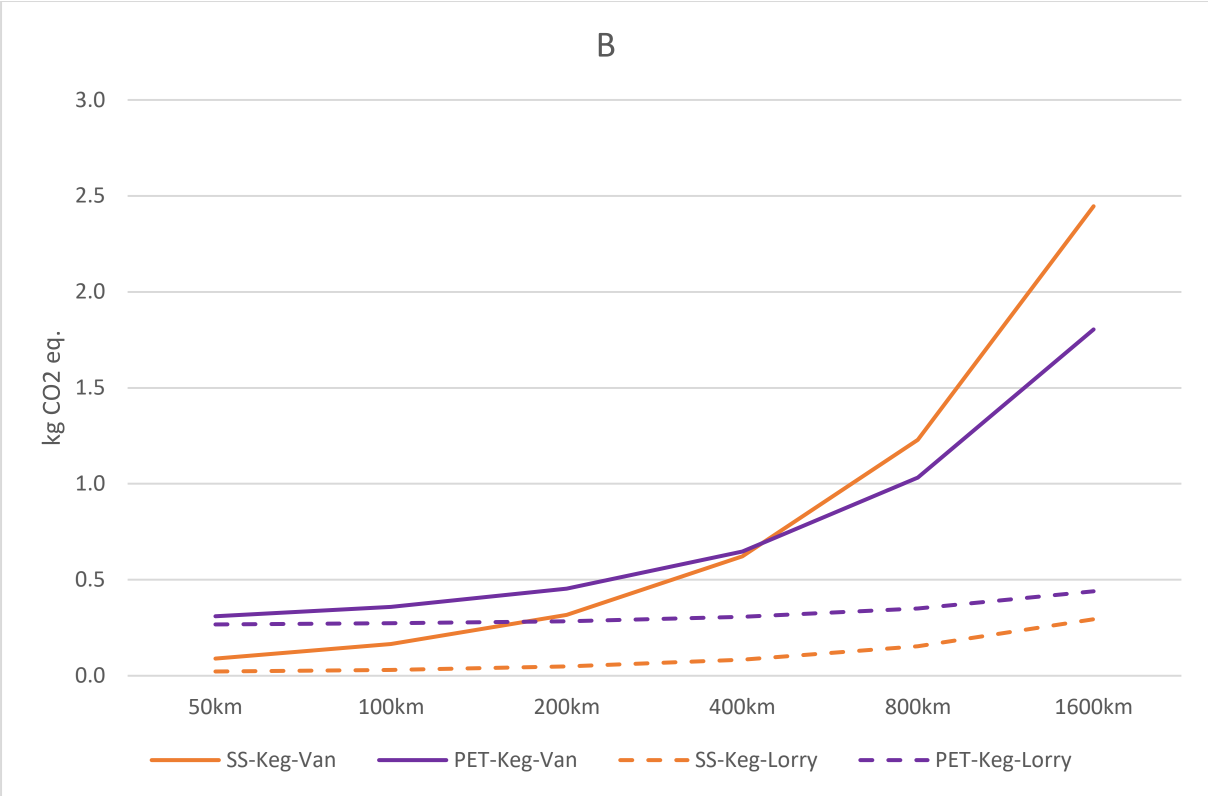


Figure 5.4. Chart A shows the combined GWP results for packaging and distribution for reusable bottle delivered by van (Bot-Ru-Van) and aluminium can delivered by van (Can-Van). The dotted lines show reusable bottle delivered by lorry (Bot-Ru-Lorry) and aluminium can delivered by lorry (Can-Lorry). In Chart B combined GWP results for packaging and distribution for stainless steel keg delivered by van (SS-Keg-Van) and PET keg delivered by van (PET-Keg-Van). The dotted lines show stainless steel keg delivered by lorry (SS-Keg-Lorry) and PET keg delivered by lorry (PET-Keg-Lorry).

5.3.4 Sensitivity analysis

In order to understand uncertainties, a sensitivity analysis was carried out focusing on the recycled content of packaging material. Table 5.5 shows generic single-packaging beer footprints alongside the mixed packaging portfolio beer footprints from the seven case study breweries, for GWP and abiotic resource depletion potential. The single packaging material footprint is a generic footprint with all beer packaged into can, reusable bottle or PET keg. Three sensitivity analysis were carried out, including having aluminium produced with 80% recycled material, glass bottle made with 69% recycled cullet using Ecoinvent 3.5 process for (DE) packaging glass, and PET made with 100% recycled material using Ecoinvent 3.5 process for (CH) bottle grade recycled PET (Wernet et al., 2016). The percentage change discussed in sensitivity analysis is benchmarked against default findings not the results in mitigation options.

Aluminium can with 80% recycled material reduces generic beer GWP footprint by 13%, to 737 kg CO_2 eq. and the case study brewery footprints by between 8% (BrewA, D & G) and 33% (BrewE). The abiotic resource depletion potential footprint of generic beer (100% aluminium can baseline) is reduced by 15%, to 0.0044 g Sb eq., with BrewG showing the largest reduction in beer footprints for the case study breweries, a 3% reduction – reflecting small share of aluminium cans in the breweries.

Reusable glass bottle with 69% recycled material reduces generic beer GWP footprint by 1%, to 1004 g CO_2 eq. and case study footprints between 4 (BrewG) and 29% (BrewE). Abiotic resource depletion potential result for generic beer footprint shows 0.3% change, case study breweries footprints are reduced between 3% (BrewD) and 18% (BrewE).

PET keg made with 100% recycled material reduces generic beer GWP footprint by 14%, to 655 g CO_2 eq., and case study brewery G footprint is reduced by 6% to 1254 g CO_2 eq. Abiotic resource depletion potential footprint for generic beer is reduced by 19%, to 0.0022 g Sb eq., with a maximum reduction of 18% seen for Brewery G.

Table 5.5. Sensitivity analysis for GWP and ARDP results associated with increasing share of recycled materials across different packaging options. Generic beer footprints relate to all beer being packaged in a single format. Percentage changes in results relate back to default results for each brewery, which are based on brewery-specific packaging mixes.

		{Single packaging material footprint}									
Process	**Unit**	**All Can**	**All Bottle**	**All PET**	**BrewA**	**BrewB**	**BrewC**	**BrewD**	**BrewE**	**BrewF**	**BrewG**
Default GWP	g CO_2 eq.	850	1014	765	727	1057	837	815	1102	766	1336
Default ARDP	g Sb eq.	0.0052	0.0052	0.0027	0.0023	0.0049	0.0032	0.0036	0.0033	0.0029	0.0045
Scenario one											
440 ml can, 80% recycled aluminium											
GWP	g CO_2 eq.	737			667	863	641	753	739	607	1230
		(-13%)			(-8%)	(-18%)	(-23%)	(-8%)	(-33%)	(-21%)	(-8%)
ARDP	g Sb eq.	0.0044			0.0023	0.0048	0.0033	0.0036	0.0034	0.0029	0.0044
		(-15%)			(+1%)	(-1%)	(+2%)	(-0.3%)	(+4%)	(+1%)	(-3%)
Scenario two											
Reusable bottle, 69% recycled cullet											
GWP	g CO_2 eq.		1004		674	917	662	768	780	630	1289
			(-1%)		(-7%)	(-13%)	(-21%)	(-6%)	(-29%)	(-18%)	(-4%)
ARDP	g Sb eq.		0.0039		0.0022	0.0046	0.0028	0.0035	0.0027	0.0026	0.0043
			(-0.3%)		(-4%)	(-6%)	(-13%)	(-3%)	(-18%)	(-10%)	(-4%)
Scenario three											
PET keg, 100% recycled PET											
GWP	g CO_2 eq.			655	769	1082	906	853	1145	830	1254
				(-14%)	(+6%)	(+2%)	(+8%)	(+5%)	(+4%)	(+8%)	(-6%)
ARDP	g Sb eq.			0.0022	0.0020	0.0046	0.0032	0.0035	0.0033	0.0027	0.0037
				(-19%)	(-11%)	(-6%)		(-3%)		(-7%)	(-18%)

Rounding may show the same results when percentage difference are small

5.4 Discussion

5.4.1 Short-term packaging options for mitigation

Packaging and distribution are two critical stages of the beer life cycle. When changes are made to the packaging stage these can affect distribution because of packaging weight. When beer has a short delivery distance the critical factor to consider is the burden associated with producing the packaging. As delivery distance increases the burden of distributing the beer increases and will eventually exceed the burden for manufacturing the packaging. At this point the mass of the packaging option becomes the critical factor. Single use glass bottle was the most popular option among case studies and the environmental footprint of beer can be significantly reduced if breweries are willing to change packaging material. All case studies demonstrated reductions in overall global warming potential, fossil resource depletion, acidification, terrestrial eutrophication, photochemical ozone formation and marine eutrophication burdens per L of beer when aluminium cans or reusable glass bottles replace single use glass bottles. Neither mitigation option was an outright best solution across all impact categories because of the variations in delivery distance and volume of beer allocated to single use packaging in each case study. The only packaging mitigation option immediately available to small breweries in the UK is the aluminium can, as there is no established bottle return scheme in place in the UK (Błażejewski et al., 2021; Butler et al., 2005; Mühle et al., 2010).

Recently, distribution was identified as an unexpected environmental hotspot for beer produced by micro-breweries (Morgan, Styles, et al., 2020). The logic of replacing heavy reusable kegs and casks with lighter, single-use PET kegs focuses on reducing transport loads, and may reduce handling costs (Keykeg, 2021). However, the burden of producing single use PET keg increases the footprint beyond the savings achieved from distribution. Switching to larger delivery vehicles would mean that distribution burden savings from PET kegs become trivial. The results show that changing from reusable keg and cask to single use PET keg increases burdens for six out of seven of the case studies. In some circumstances switching to PET keg can reduce carbon footprint, notably with van delivery beyond 400 km (Figure 5.4 B). The convenience of PET Keg is appealing and can reduce footprints when long distance delivery is needed, but findings also show reusable steel kegs have a lower footprint when beer is distributed by lorry, up to the 1600 km maximum distance modelled here (Figure 5.4 B). Whilst some LCA studies have focused on PET bottles (Cappiello et al., 2021; Cottafava et al., 2021; Ferrara et al., 2021; Nessi et al., 2012; Stefanini et al., 2021), no previous studies could be found assessing the environmental footprint of PET kegs. The advantage of PET has been marketed as a “one way” container aimed at producers who send beer further than their normal delivery area with no need to collect (Keykeg, 2021). Waste polyethylene from the UK is exported to countries like China, Indonesia, Malaysia and Vietnam for recycling, associated with significant littering of the environment (Bishop et al., 2020), raising questions around current marketing of PET kegs as a sustainable option with lower transport burdens owing to “no return trip” (Dolium, 2021; Keykeg, 2021). New advances in keg tracking technology will allow hire companies to know the location of their kegs at every stage of the beer life cycle, enhancing the security and sustainability of reusable kegs (Smart container company, 2021). Reusable steel kegs have a life expectancy of up to 30 years and represent a more circular packaging option, especially when combined with more efficient (lorry) transport (Thielmann, 2020).

5.4.2 Bottle return schemes

This study has shown that a reusable glass bottle system is an effective way of reducing the environmental footprint of beer compared to the current model of single use glass and recycling, and that reusable glass bottles are the best option on a local basis. Similar assessments for mineral water (Tua et al., 2020) and milk (Błażejewski et al., 2021) also considered a reuse rate of 30 cycles to show reusable glass bottle to be the best option. A reusable glass bottle scheme would require a new pathway for collection, cleaning and distribution and the success of this kind of system would rely on industry or government financial support and coordination (Cottafava et al., 2021). Since 2019, the UK government has been reviewing a deposit return scheme for packaging designed to incentivise consumers to return empty packaging for reuse (DEFRA, 2019). Deposit return schemes are already in place in several European countries operated through reverse vending machines that repay consumers for returned packaging (Oke et al., 2020; Oltermann, 2018). An interesting example of collaboration among businesses to manage packaging waste was of the Soju producers in South Korea. Soju is one of the most consumed alcoholic drinks in South Korea (S. Y. Kim et al., 2021). Several prominent producers agreed to standardise the colour and size of bottle used in order to streamline collection, handling, and redistribution. The agreement among all Soju producers is not enforced by law and in 2019 a new brand was launched in a different bottle causing logistical difficulties as the bottles were not of the standardised shape and colour, resulting in criticism from other members of the scheme having to sort the bottles when received back from the consumer (Dong-hwan, 2019). Such a system is an efficient way of inventory pooling that can reduce cost and improve logistic performance, but the lack of government regulation leaves the system vulnerable (Ko et al., 2012; Moon-kyu, 2019). Collaboration among Welsh micro-breweries (and/or other drinks manufacturers) could facilitate an efficient bottle reuse scheme.

5.4.3 Mode of distribution

In the context of global supply chains, “last mile delivery” is often regarded as the shortest leg of the journey (Arroyo et al., 2020; Bergmann et al., 2020). The majority of case studies source some raw ingredients from overseas, but the “last mile” in the value chain incurs a significant burden owing to the weight of beer (mostly water) and packaging, and the inefficient mode of transport used by micro breweries for product distribution (Morgan et al., 2020). There is a potentially significant reduction to footprints if breweries are able to change the mode of transport from van to lorry. This is an effective measure to significantly reduce the overall environmental footprint of beer, but implementing it would require dramatic increases in the size of delivery batches to realise the potential savings – which only accrue when lorries operate at high payloads (Galos et al., 2015; Hazen, 2014). Lessons of how small businesses work together may be learnt from other divisions of the food sector in Wales, such as mixed food boxes, by drawing in collaboration from different local producers to coordinate local deliveries (Moragues-Faus et al., 2020). Collaboration among local producers already arises in several regions of Wales, and these networks are believed to have strengthened as a direct result of the Covid-19 pandemic (Prosser et al., 2021). There has been a revival in the UK of small dairy companies providing home delivery services popular with environmentally conscious consumers able to shop locally in order to avoid the complex supply chains established for the supermarkets (Hayes, 2018). A similar trend has occurred as small breweries adapted to Covid 19 restrictions by providing home delivery services to customers, showing that a direct home delivery and collection system is feasible (Wild Horse Brewing co, 2021). However, no studies could be found of businesses actively sharing delivery loads to reduce the environmental footprint of distribution. This must be a priority to reduce a hotspot for increasingly popular local and artesian food and drink products often perceived to have a smaller environmental footprint because of factors such as shorter supply chains (Smith et al., 2008).

5.4.4 Limitations

Some assumptions were made on delivery distance when beer was distributed by courier. Most case studies ship a small fraction of beer by courier outside of normal delivery routes and in all cases a 200 km distance is applied to courier delivered beer. In most cases, courier was used for shipping beer packaged in glass bottle or aluminium can, apart from Brewery A who use currier to deliver hired steel keg and cask. There are also some limitations on data used for raw ingredients. The cultivation of barley is based on an Ecoinvent process for French barley as no process existed for UK barley (Wernet et al., 2016), though yields and inputs are similar. It was not possible to get specific data on the consumption of energy, water and electricity for malting and estimates are based on data sourced from maltsters association of Great Britain website (MAGB, 2011). The results also relied on transport burdens expressed per t-km from Ecoinvent (Wernet et al., 2016), which in turn embed assumptions regarding average load factors and return distances.

5.5 Conclusion

This chapter has addressed objective number 4 of the aims and objectives outlined in Chapter 1 section 1.2.

This study has shown that micro-breweries face particular challenges in terms of efficient and sustainable packaging and distribution. Solutions require an individual approach to determine appropriate measures that can reduce environmental footprints, demonstrated here based on packaging weight and distribution distances. Results from this study may be applicable to larger scales of brewing, but also to other small-scale food and drink producers facing similar challenges in terms of packaging and distribution.

Changing from single use bottle to aluminium can is an effective measure to reduce environmental footprints across the study breweries, confirming that the findings of previous studies also apply to small scale beer value chains (Amienyo et al., 2016; Cimini et al., 2016). This is believed to be the most convenient option for the breweries, but some traditional consumers may prefer glass to aluminium can. The advantages of reusable glass bottles over single use are widely known (Ferrara et al., 2020; Ponstein et al., 2019; Solano et al., 2021; Tua et al., 2020). Here it is also found to be a viable mitigation option for small scale breweries distributing beer on a local basis. The success of such a system would require new post-consumer pathways to be created to process reusable bottles, and the greatest savings involve combining this with more efficient transport mode. A (standardised) reusable bottle system could be expanded to other food and drink producers, but would probably require government support in the form of financial assistance, coordination and regulation to instigate. New insight provided here has shown single use PET kegs incur a greater environmental cost than steel kegs, unless beer is transported long distance by inefficient delivery vans. Plastic end-of-life is also associated with considerable environmental impact via littering that is not captured in current LCA methodology, so that reusable steel kegs are likely to be a superior environmental option overall.

Small business networks in Wales could present an opportunity to consolidate freight into larger loads and justify the use of larger transport vehicles (lorries) to distribute produce. The considerable coordination required could be achieved through informal agreements across businesses, and/or could be led by third party distributors. Further research could focus on cross-sectoral models to achieve optimised logistics, and the impact of emerging technologies such as keg tracking and delivery vehicle electrification to better understand long-term prospects of environmental mitigation from packaging and distribution.

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6. Discussion

This chapter will summarise the key findings as outlined in the research aims in Chapter 1.

6.1 Key findings

This study was conducted to gain a better understanding of the sustainability of small scale breweries in Wales by conducting face to face interviews to establish socioeconomic contributions and life cycle assessment to measure environmental footprint. Overall, this study was successful in accomplishing the aims and objectives outlined in Chapter 1. The term craft beer has generated considerable interest in academic work, and from industry associations. There has been some debate about the term among the brewery population over several years, in part relating to the significant challenges faced by small scale independent breweries to compete with multinational organisations for market share. The multinational breweries have recognised the significant growth in the craft sector and have attempted to gain market share by producing beer labelled as “craft”, or by purchasing existing craft breweries. A clear definition is essential to assist consumers when purchasing craft beer and there is a responsibility on retailers to ensure the validity of beers on display in the craft beer range. Chapter 2 explored several criteria often associated with the term craft beer. A comprehensive literature search identified six factors that could be used to distinguish craft from non-craft beer. Some currently proposed factors were considered to be arbitrary and ineffective in distinguishing a craft brewery, for example based on size in terms of annual production. It was concluded that focusing on production processes, such as the use of high gravity dilution, provided more robust differentiation. Criteria were identified as either excluding criteria or indicative criteria. Excluding criteria represent factors or activities incompatible with the term “craft brewery”, whilst indicative criteria represent factors that have been regularly discussed by the industry as being dominant factors associated with craft production and identity but could be difficult to apply in a manner that definitely confirms craft identity. The short list of excluding criteria includes, ownership of more than 25% share of the brewery by another business, use of high gravity dilution, inclusion of raw ingredients to reduce costs rather than to enhance flavour and experience. An important outcome for this chapter identifies annual production or brewery size as an unreliable metric because no viable rational could be found to support the exclusion of a craft brewery based on its size. This finding challenges common perceptions. The exploration of the various definitions of craft breweries assisted in brewery engagement with subsequent research.

The focus of Chapter 3 was on socioeconomic impact of small scale breweries in Wales and how they form a vital part of the local economy. The data collection for Chapter 3, 4 and 5 was undertaken through a single interview with brewery managers, in some cases followed up with questions asked via email or phone. The research showed that small breweries play an important role in employing local people, offering good job prospects with opportunities to up-skill staff. The ability to provide future jobs to local youth was a central objective of one case study brewery manager, and several other brewery managers mentioned future job opportunities as their businesses expanded. Annual production could be interpreted as a proxy for employment opportunities, with findings showing breweries with an annual production output in excess of 100,000 L of beer able to employ several members of staff. However, due to the limited number of case studies it was not possible to gain an accurate correlation between brewery production volumes and job creation. There were several examples of breweries established as family ventures such as father and son or father and daughter but the most common was a husband and wife business. Although there are some financial constraints for small breweries to make charitable donations it is evident that when funds are available there is a clear support for charitable work. Many breweries support multiple charitable groups in their local area and nationwide charities. There have been several cases of using the public profile of the brewery to promote charitable fundraising campaigns and to raise awareness.

There is a recurring theme among the participating breweries to connect the business and its produce to the local area (Holtkamp et al., 2016). This is a more common theme for small businesses that recognise the value in local economies (Wells, 2016). In some cases, the breweries have recognised the value of the local economy and the need to create a strong connection by instilling the local theme in all aspects of branding company logos and product labels. This finding aligns with Taylor (2020) where brewers capitalise on place making and appealing to consumers in search of produce with "place and brand attachment" (Taylor et al., 2020). Murray (2015) and Taylor (2019) have both explored brand loyalty and the consumer's willingness to pay for local produce (A. Murray et al., 2015; Taylor et al., 2019). When a story is communicated in Welsh it appeals to the local community, but it also stands out to visiting tourism as small independent local breweries support the concept of place-making, in turn supporting food and drink tourism (Fletchall, 2016). Beer tourism is a phenomenon that has been widely discussed in academic work (Csapó et al., 2016; Rogerson et al., 2019; Schroeder, 2020). In this study the breweries regularly participate in some form of food and drink tourism, and the most common approach is to organise events at the brewery. This is an efficient and cost effective form of food and drink tourism as the main expense for the brewery is to employ bar staff. There is also an element of collaboration with other businesses when companies are invited to provide food for the attendees. Indeed, collaboration is considered to be very important to the success of not only small breweries, but small businesses in general (Alonso et al., 2018; De Martino et al., 2018). Local business clusters have many positive effects on rural economies (Martinidis et al., 2021). The results from the LCA study in Chapter 4 showed a substantial impact attributed to downstream distribution. The nature of operating a small business in a rural environment can have a multiplier effect on jobs in local supply chains (Benedek et al., 2020). The delivery of beer generates high environmental impact (as identified in subsequent chapters), but on the other hand will create significant economic activity and local or regional employment opportunities.

In Chapter 4, the environmental footprint of beer produced by seven breweries was measured by conducting an attributional life cycle assessment. This study was unique as it assessed several beer footprints across a range of small scale breweries in Wales previous studies have been focused on a single case study brewery (Cimini et al., 2016; De Marco et al., 2016; Koroneos et al., 2005; Talve, 2001). Findings show that small breweries are faced with different challenges to larger breweries. A particularly surprising result was the impact associated with downstream distribution because of light commercial vehicles being used to deliver beer from the brewery to the retailer. This impact global warming potential and fossil resource depletion potential in particular, and highlights that the use of food miles as an environmental indicator can be misleading – the *mode* of transport must be considered. A study of Australian wine consumed in the UK showed viticulture and transportation as the main hotspots across majority of impact categories considered (Amienyo et al., 2014). The raw ingredients used for brewing often require distribution on a global scale and this is particularly true for hops as many popular hop varieties are sourced from the USA, New Zealand, and Australia. The impact of distribution had a minimal effect on the overall footprints owing to relatively small quantities and efficient modes of transport, but the processing of hops was found to be a particular burden because of the oil used in the hop drying process – mostly impacting fossil resource depletion potential. Previous work identifies packaging as an environmental hotspot for beer, with glass bottles responsible for the biggest burdens (Amienyo et al., 2016; Cimini et al., 2016). Increasing the recycled content of glass wine bottle by 10% can reduce overall GWP results by 2% (Amienyo et al., 2014). In this study, packaging was found to contribute less to overall burdens than in previous studies because in most cases reusable kegs and casks were the preferred methods of packaging. However, one participating brewery chose to package most of their beer in single use glass bottles. This was a valued input as it showed that single use packaging can have a considerable impact on the environmental footprint of beer produced in small scale breweries, as found in previous studies for larger breweries (Amienyo et al., 2016; Cimini et al., 2016). This study shows that by choosing to sell most of the beer on trade, small scale breweries allocate more beer to reusable keg and cask resulting in packaging footprint contributing significantly less to the overall footprint. This finding was included in a publication contributing to a better understanding of the challenges faced by small breweries (Morgan, Styles, et al., 2020). Cultivation of brewing ingredients did not have a major effect on global warming potential but accounted for a large proportion of acidification, terrestrial eutrophication, and marine eutrophication burdens. All breweries participating in this research donate their spent grains to local farms as animal feed. This can generate significant environmental credits through the avoidance of barley and soy cultivation for cattle feed. In contrast, large breweries have the finances to invest in on-site anaerobic digestion plants to generate bioheat and bioelectricity that can be used by the brewery (Andrews et al., 2011). Interesting, the low-tech approach of small breweries actually results in better environmental outcomes because the spent grains can be used to avoid cultivation of high-protein animal feed, including soy beans associated with land use change in Latin America (Leinonen et al., 2018).

The work in Chapter 5 develops the findings in Chapter 4 and explores potential mitigation options to reduce the environmental footprint and improve the sustainability of participating breweries. Mitigation options include changing single use glass bottles to aluminium cans or to reusable bottles. Changing reusable kegs and casks for single use (lighter) polyethylene terephthalate keg was also explored as a potential mitigation option but results show this to be a less environmentally-friendly option. The four stages of the beer life cycle affected by mitigation options were (i) upstream and (ii) downstream distribution, (iii) packaging production, and (iv) waste management. Findings showed that reductions were possible if aluminium cans replaced single use glass bottles. A reusable glass bottle scheme could also reduce the environmental footprint of beer. When the mode of transport to deliver beer from the brewery to retailer is changed from light commercial vehicle to lorry, large additional reductions are possible. There is an interaction between packaging and distribution and changes to packaging can affect distribution footprint because of packaging weight. When vans are used for localised deliveries the packaging material with the lowest manufacturing impact should take precedence but as delivery distance increases so does the impact of distribution. There is then a point at which packaging weight becomes dominant over packaging manufacturing burden. The best option for all breweries is reusable glass bottle delivered by lorry. The polyethylene terephthalate keg was not a viable option to reduce environmental footprints. Apart from one brewery, this option increased the environmental footprint of delivered beer.

6.2 Limitations of the study

Over 70 small and independent breweries in Wales were contacted at the start of this project and the goal was to attract the majority of the population to participate in the study. However, the final number of seven case studies, although low, did not limit the impact of the study. Participating breweries were very open and willing to share all the necessary data to conduct this research, resulting in an in-depth analysis of each brewery. The brewery environmental footprints do not include the burdens of brewing yeast because no data could be found for this ingredient. There were also some uncertainties in the downstream distribution and waste management stages of the brewery assessments. Most breweries use a courier service to deliver beer outside of their regular delivery area. The true distance that beer travels by courier is difficult to quantify so a 200 km distance was applied to any beer delivered in this way. There was also some uncertainty in the assessment of waste management and how much waste is recycled. Changing the rates of recycling, landfill and incineration in Chapter 4 sensitivity analysis had a minimal effect on GWP but in some cases a significant change in abiotic resource depletion potential.

6.3 Recommendations for future work

Whilst this research has addressed numerous knowledge gaps surrounding the environmental footprint and the socio-economic activity of small scale beer production, there are still several areas that would benefit from future research. Some priority research tasks are recommended below.

- The MS Excel tool used to conduct the life cycle assessment in Chapter 3 could be developed further for industry use as an interactive software tool. This could eventually enable breweries to continuously monitor their environmental footprint.
- A feasibility study of collaboration among local food and drink producers to establish a coordinated deliveries system. This could be assessed in several regions across Wales to establish a national food and drink network, and could have a positive effect on the environmental footprint of small businesses whilst promoting collaboration in local economies to reduce delivery costs for small businesses.
- A study of alternative transport modes such as electric vehicles as a replacement to light commercial vehicles would continue the work from Chapter 5.
- Barley is cultivated in some areas of south Wales, but harvested barley must be transported to England for malting. A feasibility study of establishing a small malting facility in Wales could be conducted, alongside an investigation into the environmental implications of domestic malt production, and engagement with the brewing industry to establish the demand for Welsh malted barley.

6.4 Implications for the brewing industry in Wales

There are several opportunities for small breweries and the wider brewing sector to become more sustainable. In some cases, significant environmental footprint reductions are possible, but these can only be achieved through commitment by the breweries, collaboration within the brewing sector and government backing. The introduction of a deposit return scheme may be an opportunity to incentivise consumers to return empty food and drink packaging to improve recycling rates (Welsh Government, 2021b). A reusable bottle scheme in Wales could be effective in reducing the environmental footprint of breweries longer-term, but this would require some changes to the existing supply chain and government intervention. This would improve the existing waste management structure by elevating packaging end-of-life management from recycling to reuse, a progressive step forward towards a circular economic model. Business clusters do exist in several regions of Wales and have been formally created as government backed initiatives (top-down) or developed organically by local businesses (bottom-up). Reductions to environmental footprint are possible if breweries and other local businesses can work together to improve the efficiency of distributing produce from brewery or food production facilities to retailers or final consumers. This could be achieved by combing delivery loads across businesses and sectors. It may be possible to achieve through an informal agreement but will require highly coordinated planning – potentially engaging third party delivery companies with access to distribution logistic expertise in the design. The objective of such a venture should be to support a shift from use of small vans to more efficient lorries to conduct deliveries. Meanwhile, the environmental footprint of all breweries could be reduced quickly if breweries are willing to change packaging material from single use glass bottle to aluminium can in the short term.

In 2014 the Welsh Government published “Towards Sustainable Growth: An action plan for the food and drink industry 2014 – 2020”, which outlined 48 actions that were necessary to achieve sustainable growth within the food and drink industry (Welsh Government, 2014). The outcomes from this research study have identified 9 of the 48 actions listed in the report as priorities for Welsh food and drink industry. The development of essential skills, collaboration between the industry and academia and promotion of the Welsh language are included in action 4, 9 and 11 respectively. However, as a recommendation to the industry, collaboration among food and drink producers is a viable option to reduce distribution burdens. Effective implementation of action 23 to develop food distribution could also address the measures outlined in action 44 to develop Wales as a destination that has environmentally responsible businesses and action 46 “to promote Wales as a low carbon food production country” (Welsh Government, 2014). The work in Chapter 4 and 5 has aligned with action 47 assist the brewers to measure their footprint and put forward actions that could reduce their footprint. The findings in Chapter 3 contribute towards a better understanding of corporate social responsibility as outlined in action 48.

6.5 Conclusion

This study has taken a novel approach to understanding the sustainability of small scale breweries. The findings in this thesis have identified several opportunities for small breweries to reduce environmental burdens and made several recommendations that can be implemented by individual breweries, by local businesses to coordinate deliveries, and a transformational change in packaging reuse – away from single use glass bottles. These changes, if adopted, could make significant reductions to the environmental footprint of the brewing sector in Wales. This study has also provided new insight into the socioeconomic activity of small breweries in Wales. Connecting brewery branding with the local area or a prominent landmark is a theme that several breweries use to promote the business, and in turn the local area (Fletchall, 2016). The ability to attend a brewery and consume the beer at its source is a unique food tourism experience. This study has found several examples of breweries opening their facilities to the public and working with local food producers to provide a gastronomic experience of local food and drink. It also shows how small breweries are an important linkage between food tourism and place making (Stoilova, 2020). Attracting beer tourists to attend a brewery taproom or to follow an ale trail can also have positive effect on other businesses within the local hospitality industry. This is vitally important to rural economies that rely on tourism (A. Murray et al., 2015).

The work presented in this thesis has contributed to a better understanding of how small scale breweries and other food and drink producers can work together to reduce carbon emissions and achieving a circular economy. The novel approach taken here has revealed some unexpected results and provided a better understanding of the environmental burdens associated with small scale beer production and proposed a number of options to mitigate these burdens. Small breweries play an important role in local and rural economies and this study shows the impact can affect employment, tourism, and the wider hospitality industry. This research work was carried out to help small scale breweries to become more sustainable and to highlight the environmental and socioeconomic advantages of locally produced beer compared to the beer made by the multinational breweries. The findings have addressed several knowledge gaps in the academic literature and can be used by the industry, policy makers and consumers to support and encourage sustainable development within local supply chains and shorten the linkages within food and drink value chains.

6.6 References

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Appendix 1: Brewery Interview Guide

Background information

How did the brewery business start?

How many people were involved at the start and how many do you employ today?

What was your understanding of the brewing process at the start?

What type of beer do you produce?

Do you have a bar or shop at the brewery?

Do you participate in any food and drink festivals or events?

Do you support any charities?

Brewery environmental questionnaire

How many batches of beer did you make in 2019?

How much malted barley did you use in 2019? (This should include all types of malted barley)

How much Wheat did you use in 2019?

How much Oats did you use in 2019?

How much Rye did you use in 2019?

Please include any other ingredients and amounts used in 2019?

How much water did you use in 2019?

How much Electricity did you use in 2019?

How much Gas did you use in 2019?

How much beer did you produce in 2019?

What is the average boil time?

How much CO_2 did you use in 2019? (Please include cylinder size)

How much Nitrogen did you use in 2019? (Please include cylinder size)

How much hops did you use in 2019? US kg, EU kg, AU/NZ kg, UK kg

How much Caustic did you use in 2019?

How much Parasitic Acid did you use in 2019?

Please list the amount of finings used in 2019?

What happens to the spent grains after brewing?

Packaging

How much beer was packaged in to 50 L SS Keg in 2019? (This should include rental kegs)

How much beer was packaged in to 30 L SS Keg in 2019? (This should include rental kegs)

How much beer was packaged in to 40.9 L Cask in 2019? (This should include rental Casks)

How much beer was packaged in to 20 L Cask in 2019? (This should include rental Casks)

How much beer was packaged in to 10 L PET keg in 2019?

How much beer was packaged in to 20 L PET keg in 2019?

How much beer was packaged in to 30 L PET keg in 2019?

How much beer was packaged in to 330 ml glass bottle in 2019?

How much beer was packaged in to 500 ml glass bottle in 2019?

How much beer was packaged in to 660 ml glass bottle in 2019?

How much beer was packaged in to 330 ml cans in 2019?

How much beer was packaged in to 440 ml cans in 2019?

How much packaging cardboard did you use in 2019?

How much polyethylene wrap did you use in 2019?

How many pallets did you use in 2019?

Distribution

What was your total mileage including collections and deliveries for 2019?

How many deliveries of cleaning ingredients did you receive in 2019?

How many deliveries of empty bottles and cans did you receive in 2019?

Where are the bottles and cans delivered from?

Please list your suppliers and the number of deliveries received in 2019?

Appendix 2: List of Breweries

Brewery Name	Location	Brewery Name	Location
Anglsey Brewhouse	Llangefni	Druid Brewery*	Penysarn
Anglesey Brewing Co	Valley	Bragdy Cybi	Holyhead
Bragdy Mona	Gaerwen	Purple Moose	Porthmadog
Cwrw Ogwen	Bethesda	Cwrw Llyn	Nefyn
Cwrw Cader	Dolgellau	Bragdy Nant	Llanrwst
Bragdy Lleu	Penygroes	Snowdonia Park	Waunfawr
The Old Market Hall	Caernarfon	Conwy Brewery	Llysfaen
Geipel	Gellioedd	Snowdon Craft Beer	Llandudno
Wild Horse Brewery	Llandudno	Facer’s brewery	Flint
Hafod Breweing Co	Mold	Polly’s	Mold
Cwrw Ial	Llanarmon yn Ial	Buzzard Brewery*	Denbigh
Dovecote	Denbigh	Heavy Industry	Henllan
Llangollen Brewery	Llangollen	Big Hand Brewing Co	Wrexham
Wrecsam Lager	Wrexham	Magic Dragon Brewing	Wrexham
Mc Givern Ales	Wrexham	Erddig Brewery*	Wrexham
Axiom Brewery*	Wrexham	Sandstone Brewery	Wrexham
Brecon Brewery	Bridgend	Montys Brewery	Hendomen
Heart of Wales Brewery	Llanwrtyd Wells	Llangorse Brewery*	Brecon
Lythic*	Llangorse	Wilderness Brewery	Newtown
Mantle Brewery	Cardigan	Gwynant Brewery*	Aberystwyth
Oast House Brewery*	Aberystwyth	Penlon Brewery*	New Quay
Cardigan Brewery	Cardigan	Evans Evans	Llandeilo
The Felinfoel Brewery	Llanelli	Hand Made Beer Co*	Capel Dewi
Jacobi Brewery	Llanwrda	Left Bank Brewery	Llangorse
Coles Brewery	Llanddarog	Bluestone Brewing Co	Cilgwyn
Little Dragon Brewery*	Hilford Haven	Seren Brewing Co*	Clynderwen
Tenby Brewing Co	Tenby	Gwaun Valley Brewery	Pontfaen
Caffle Brewery	Narberth	Tenby Harbour Brewery	Tenby
Boss Brewing	Swansea	Gower Brewing	Swansea
Tomos Watkin	Swansea	Mumbles Brewery	Swansea
Bryncelyn Brewery	Ystalyfera	The Pilot Brewery	Mumbles
Free Time Brewing co	Swansea	Beer Riff	Swansea
Borough Brewery	Port Talbot	Cerddin Brewery	Maesteg
Bragdy Twt Lol	Pontypridd	Glamorgan Brewing Co	Pontyclun
Grey Trees Brewery	Aberdare	Otley Brewing*	Pontypridd
Hop Craft Brewery	Pont y Clun	Waen Brewery*	Llanidloes
VOG Brewery	Barry	Tomos a Lilford	Cowbridge
Bullmastiff Brewery	Cardiff	Brains	Cardiff
Crafty Devil Brewing	Cardiff	Pipes Brewery	Cardiff
Zerodegrees	Cardiff	Lines Brew Co	Usk
Tudor Brewery	Abertillery	Rhymney Brewery	Pontypool
Brew Monster	Caerphilly	Tiny Rebel Brewing	Newport
Baa Brewing*	Chepstow	Castles Brewery*	Caldicot
Kingstone Brewery	Chepstow	Untapped Brewing co	Raglan
Mad Dog Brewery	Penperlleni	AB-Inbev	Magor

Extended List of breweries found after research had been completed

Brewery Name	Location	Brewery Name	Location
9 Lives brewing	Swansea	Arcadian Brewing Co	Cardiff
Anglo-Oregon Brewing*	Newport	Axton Brewery*	Holywell
Bang-On Brewery	Bridgend	Black Cloak Brewing	Colwyn Bay
Bragdy'r Bwthyn*	Bae Cemaes	Cwm Rhondda Ales ltd	Treorchy
Cold Black Label	Bridgend	Dog's Window Brewery	Bridgend
Fairy Glen Brewery ltd	Maesteg	Lucky 7 Beer Co	Hay-on-Wye
Mabby Brewing Co	Pontypridd	Myrddins Brewery & Distillery	Barmouth
Neath Ales*	Port Talbot	Twin Taff	Merthyr Tydfil
Top Rope Brewing	Queensferry	Victoria Inn Brewhouse	Haverfordwest
Well Drawn Brewing Co	Caerphili		

* Represents breweries that have been dissolved or closed

Appendix 3: Company logos of the seven participating breweries.

(Wilderness Brewery, 2021)

(Caffle Brewery, 2021)

(Blustone Brewing co, 2021)

(Wild Horse Brewing co, 2020)

(Tomos a Lilford, 2021)

(Cwrw Llyn, 2020)

(Bragdy Lleu, 2020)

Appendix 4: Examples of beers produced by case study breweries

Appendix 5: Footprint generated from BrewG with all beer in one packaging option and delivered 522 km

	ARDP	FRDP	A	FE	GWP	IR	ME	ODP	POF	TE
Default	7.78E-05	0.000331	0.000186	0.00016	0.000172	7.31E-05	0.000147	9.88E-06	0.000162	0.00017
Bot-Su-V	9.84E-05	0.00047	0.000284	0.000213	0.000255	8.34E-05	0.000178	1.32E-05	0.000225	0.000224
Bot-Su-Lo	5.13E-05	0.000309	0.000213	0.000152	0.000167	6.65E-05	0.000136	6.98E-06	0.00012	0.00015
Can-V	0.000103	0.000318	0.000184	0.00019	0.000166	8.33E-05	0.000139	8.17E-06	0.000139	0.000152
Can-Lo	7.24E-05	0.000213	0.000138	0.00015	0.000109	7.23E-05	0.000111	4.13E-06	7.07E-05	0.000103
Bot-Ru-V	7.36E-05	0.000341	0.000185	0.000168	0.000177	7.42E-05	0.000149	1E-05	0.000165	0.000172
Bot-Ru-Lo	2.66E-05	0.000179	0.000114	0.000107	8.86E-05	5.73E-05	0.000107	3.85E-06	6.01E-05	9.82E-05
	ARDP	FRDP	A	FE	GWP	IR	ME	ODP	POF	TE
SS-Keg-V	7.3E-05	0.00031	0.000172	0.000148	0.00016	7.04E-05	0.000144	9.64E-06	0.000156	0.000164
SS-Keg-Lo	2.46E-05	0.000144	9.97E-05	8.51E-05	6.99E-05	5.31E-05	0.000101	3.28E-06	4.82E-05	8.8E-05
SS-Cask-V	6.7E-05	0.000294	0.000165	0.000142	0.000151	6.88E-05	0.00014	9.01E-06	0.000145	0.000157
SS-Cask-Lo	2.27E-05	0.000142	9.88E-05	8.43E-05	6.84E-05	5.29E-05	0.0001	3.2E-06	4.72E-05	8.72E-05
PET-Keg-V	5.93E-05	0.000328	0.000163	0.000162	0.000155	7.37E-05	0.000134	7.7E-06	0.000129	0.000145
PET-Keg-Lo	2.86E-05	0.000223	0.000117	0.000122	9.8E-05	6.27E-05	0.000106	3.67E-06	6.14E-05	9.7E-05
HDPE-Cask-V	5.43E-05	0.000268	0.000153	0.00013	0.000136	6.58E-05	0.000133	7.9E-06	0.000128	0.000144
HDPE-Cask-Lo	1.74E-05	0.000142	9.74E-05	8.23E-05	6.65E-05	5.26E-05	9.94E-05	3.05E-06	4.6E-05	8.6E-05
HDPE Cask	5.43E-05	0.000268	0.000153	0.00013	0.000136	6.58E-05	0.000133	7.9E-06	0.000128	0.000144
HDPE Cask-Lor	1.74E-05	0.000142	9.74E-05	8.23E-05	6.65E-05	5.26E-05	9.94E-05	3.05E-06	4.6E-05	8.6E-05

g / L of packaging material

	g/L
SS Keg	316
SS Cask	247
HDPE Cask	124
PET Keg	35
Can	34
Single use bottle	590
Reusable bottle	660

Appendix 6: Participant consent form

PRIFYSGOL
BANGOR
UNIVERSITY

Title: An investigation into the Sustainability of Craft Breweries in Wales.

Purpose and Background.

Dyfed Morgan is a student at Bangor University and is conducting a research project into the brewing industry in Wales. You have been asked to participate in the research as your understanding of the industry and your experience of running a brewery will provide valuable data for the research.

The objective of this research is to gain a better understanding of sustainability of the craft brewing industry in Wales. The questions will focus on matters relating to onsite processes at your brewery and the use of raw ingredients. An aspect that is of significant interest is your view on the craft beer sector.

Procedures

If you agree to participate in this research the data will be collected through an interview that is expected to last 1 to 1.5 hours.

Risk

The research is not anticipated to collect any commercially sensitive information. Should you feel uncomfortable with answering any of the questions you may stop your participation.

Researcher Name: Dyfed Morgan.

Participants Name: ……………………………………

Company: ……………………………………

The researcher Dyfed Morgan has explained the nature of the research and its objectives.

I understand that I have the right to withdraw from this research at any time.

Signature of Participant: ……………………………………

Date: ……………………………………