Production Planning and Control

https://doi.org/10.1080/09537287.2020.1834637.
Received 19 Mar 2018, Accepted 19 Sep 2020, Published online: 06 Nov 2020

Developing a framework for adopting environmental manufacturing practices: learning from breweries

Peter Ball [a]* and Jill MacBryde [b]

[a] *University of York Management School, York, YO10 5GD, UK*
[b] *Design Manufacture & Engineering Management, University of Strathclyde, Glasgow, G1 1XJ, UK*

* peter.ball@york.ac.uk, +44 1904 32 5302

There is a growing desire to reduce the environmental impact of manufacturing operations through implementing new practices. There is a reasonable literature on environmental practices and the benefits they can bring. However, the literature is weak in two respects: firstly, it is heavily reliant on practices of leading firms, secondly there is little focus on understanding the conditions that foster the adoption of such practices.

This paper addresses these shortfalls by presenting evidence of how any firm can start to improve their resource efficiency using new practices. Studying organisations with similar market conditions and production systems allows us to look at a breadth of firms in a single supply chain tier, with a range of environmental maturity. A grounded approach employing interviews, workshops and observation uncovers the conditions that help and hinder adoption of new ways of working. Specifically, the motivations for cost reduction through resource efficiency, aided by communities of practice but hindered by organisational barriers.

Combining this with learning from theory, this paper advances environmental practice in manufacturing through learning from the experiences of UK brewers. The work contributes to knowledge by framing how companies of all shapes and sizes within a sector (not just the leading companies) can advance by adopting practices and avoiding barriers.

Keywords: Environmental practices, eco-efficient operations, organisational barriers, breweries, sustainable manufacturing

1. Introduction

Many manufacturing firms want to employ more environmentally friendly, resource efficient ways of working. Whether it is a concern for the environment, social pressure or a response to rising costs and growing pressure on raw material availability there is increasing attention being paid to environmental performance within manufacturing.

The academic literature and publications by industry bodies point us to the benefits of environmental practices. Practices can include design, materials, packaging, distribution, reuse, recycling, waste reduction and regulatory compliance (Yacob et al., 2018) and can be split between value-adding and support for value adding (Pande & Adil, 2019). The benefits of pursuing ecological responsibility are well documented on cost (Kleindorfer et al., 2005), more efficient use of resource (Schmidheiny, 2000), delivery of higher value products and services (Oliveira Neto & Lucato, 2016) and in turn competitiveness (Bansal & Roth, 2000). Equally the "reduce, reuse and recycle" practices that companies deploy to achieve these benefits are well documented (e.g. Despeisse et al., 2012). Work by Hami et al. (2019) is typical of work on practices making clear links between environmental practices and environmental performance.

Whilst we know *what* companies should be doing, it is more challenging to uncover *how* they can go about it. There is advice on adopting more environmental practices with much of this knowledge is drawn from documenting practices in successful firms. Wiesner et al. (2018) asserted this has mostly focused on large organisations with little known about SMEs (Hami et al., 2019). Potentially there are similarities with lean studies where few manufacturers achieve the considerable improvements of the leading firms (Garza-Reyes et al., 2018). There is the need to operationalise how improvements are made and how practices are shared (Bellgran et al., 2019). Firms may be unclear how to progress their journey and create the right conditions to encourage wider environmental practices in the workplace. The "know what" is well covered in the literature. The "know how" of acquisition and deployment, especially for smaller resource challenged companies, is a practice and theory problem worthy of further investigation.

This research uses breweries as the focal sector to increase our understanding of how environmental practice adoption can be increased. Breweries, like all manufacturers, seek to minimise cost and not be knowingly wasteful. Brewing is energy intensive and generates potentially valuable wastes (Sturn et al, 2012). An average brewery will use 0.48kWh energy and 4.4l water (BBPA, 2014) for each litre of beer with larger breweries typically more efficient than smaller breweries due to batch economies, more opportunity for heat exchange, etc. With the carbon footprint distribution typically including 39% ingredients, 25% brewery and 26% packaging and transport (BEIR, 2012), the brewery operation could have significant opportunity for savings. These proportions are greatly affected by the growing practices of farmers. The type of packaging used can also have a significant impact (Amienyo & Azapagic, 2016).

Energy intensive processes and potentially valuable wastes (Sturm et al. 2012) provides motivation to address environmental impacts. Additionally, the brewery sector is expanding with around 1,350 breweries in the UK in 2013 rising to 1700 breweries in 2015 and then 2,270 in 2018 (Simmonds, 2019). Similar growth has been seen elsewhere, e.g. in the USA (Anon, 2015). Such a developing sector could provide insight into how practices are being adopted and what is hindering them.

Interestingly, breweries operate a standard process, albeit at varying scales, in a common supply chain tier and therefore amenable to comparison of similar production systems delivering to similar a customer base of retail and public houses ('pubs' or bars). Like manufacturers in general they acquire new knowledge from others and implement practices to be more efficient. Breweries, especially smaller ones, may demonstrate lean thinking but not use lean terminology. They are known to be highly collaborative.

Hence for practice, research could give operations managers, including head brewers, guidance on how to advance the environmental agenda to reduce impact and cost. Key questions include

what motivates change, how are improvements identified, what practices are implemented, what barriers are faced and what outcomes are achieved.

Research on food and drink supply chains has been undertaken in diverse areas of life cycle analysis (LCA) (Hagelaar & van der Vorst, 2002), dynamic capabilities (Beske et al., 2014) and critical success factors (Grimm et al., 2014). In general there has been little on breweries. Despite the work on US breweries little research has been dedicated to UK brewers, especially microbreweries (Danson et al. 2015).

The researchers were keen to investigate firms operating in a similar environment. Studying the same sub-sector (Sureeyatanapas et al 2015), at the same supply chain tier and similar production systems (Rusinko, 2007) has the potential to uncover learning from a breadth of companies including those that may not conceptualise their activities in the environmental research language. This paper fills this gap by looking across a single tier of a supply chain (in this case the manufacture of beer) and looking at a cross section of "normal" firms who are actively wanting to adopt more environmental practices but are not necessarily leaders. Accordingly, the research question "How can environmental practice be adopted in manufacturing operations?" was posed.

The paper starts by first examining the literature on environmental practices in manufacturing to establish the limits of knowledge and to identify gaps. Second, the research method is presented and the empirical approach justified. Third, the findings from UK breweries in the areas of motivations, measurement, practices and barriers are presented and discussed. Fourth, the findings are combined with academic knowledge from several domains to formulate a framework. This framework could be used to help manufacturers to create the right environment to progress their journey to more environmental practice. It encompasses justification, approach, practices and community for advancing impact reduction in manufacturing operations. Finally, the limitations are discussed before considering the contribution to knowledge and practice.

2. Literature on enabling environmental progress

This overview section examines knowledge on environmental manufacturing practice. First, the operational motivation to change is examined. Next drivers and pressures on supply chains are uncovered. From here, lean and eco-efficiency are considered to establish what approaches are being used in support of the pressures for change followed by an examination of general practices. Finally, barriers that challenge environmental change are discussed before the gaps in knowledge of how to advance resource efficient environmental change are assembled.

2.1 Drivers to motivate change

Environmental impact reduction of operations is driven by input cost, waste cost, regulation, NGO activity and 'doing the right thing' (Bansal & Roth, 2000; Giunipero et al., 2014). Some act to mitigate against environmental impacts to build resilience (Leat & Revoredo-Giha, 2013). Giunipero et al. (2014) note there have been eras of focus on environmental sustainability from the 1960s compliance with regulation through to proactively seeking to gain value through strategic supply chain focus. There is now a clear distinction between less unsustainable and truly sustainable (Montabon et al., 2016).

In identifying the top drivers, Giunipero et al., (2012) cite management leadership and regulation as well as financial benefits, competitive advantage, certification and customer demand. Drivers can be divided into external regulation, values, uncertainty and market plus internal culture (including motivation and management commitment), process capability, strategy and resources (both capital and human) (Claro et al., 2013; Schrettle et al., 2014).

2.2 Supply chain pressure for change

There is the need for improved understanding of how firms behave environmentally to ascertain what factors induce environmental behaviour (Williamson et al., 2006) that in turn pressurises the

supply base to follow (Seuring & Müller, 2008). There has been significant focus on supply chains. Work has been carried out looking at buyer-supplier relationships (e.g. Schmidt & Schwegler, 2008), lean practices (Green et al., 2019), larger companies within a region (e.g. Hajmohammad et al., 2013), groups of companies in a supply network (e.g. Rusinko, 2007) and global supply chain sustainability (Yang et al., 2011).

There have been some studies looking at sectoral initiatives, for example the dairy industry (Glover et al., 2014), fashion (Macchion et al., 2018) and the rubber industry (Dubey et al., 2015). There is general agreement that there is scope to promote cleaner supply chain practices to small and medium-sized enterprises (Subramanian & Gunasekaran, 2015). Both Mollenkopf et al. (2010) and Pakdeechoho & Sukhotu, (2018) argue for collaboration to share knowledge and build capability by working across the supply chain. What work that has been done in this space has tended to focus on the activity of the bigger firm. Little work examines single, similar tiers of supply chains to look at behaviour across similar companies with similar processes (Rusinko, 2007).

2.3 Lean as an enabler for eco-efficiency

Lean is a potential enabler for environmental change in many manufacturing organisations. The process thinking fundamental to lean production can be extended to eco-efficiency improvement given that they both strive to reduce waste (Hartini & Ciptomulyono, 2015; Caldera et al., 2019) and seek value. Early work on practice bundles has been extended by Yang et al. (2011) who argue that lean is insufficient to improve environmental performance. Martínez-Jurado & Moyano-Fuentes (2014) see sustainability as the next extension of lean production with many citing better performance when lean and 'green' are combined (e.g. Hartini & Ciptomulyono, 2015).

Checklists (Fercoq et al., 2016) and critical factors (Martínez-Jurado & Moyano-Fuentes, 2014) have been developed to support the integration of the two areas and Ball & Lunt (2020) detail a waste hierarchy tool (STRE3TCH) based on lean thinking to aid improvement. Such work on lean and eco-efficiency demonstrates advances but implicitly indicates a lack of standard tools. Perhaps because of this, Fercoq et al. (2016) challenge the availability of quality empirical evidence for the lean and eco-efficiency link despite the logical links and general acceptance of linking.

Claro et al. (2013) assert that leadership is key for implementing practices through the demonstration of social and environmental responsibilities. This leadership must be an organisational commitment to properly motivate those designing products and services (Pagell & Wu, 2009). It is likely that the skills learnt for lean achievements help with the skills for environmental achievements (Hajmohammad et al., 2013) and leaders can foster that translation. There are many issues for leaders. Firstly, the integration of separate staff groups, say, production and facilities (Melnyk et al., 2001) means working to common goals is challenging. Secondly, the breadth of skills required to address both lean and eco-efficiency is challenging for practitioners (Ng et al., 2015). Finally, redefining roles and responsibilities for such breadth (Kurdve et al., 2014) is difficult. So whilst the literature is strong on benefits, it is weaker on how to enable those benefits organisationally.

2.4 Adopting available environmental practices

Hami et al. (2015) define a sustainable manufacturing practice as "a firm's intra- and inter-organizational practices that integrate environmental, economic and social aspects into operational and business activities." Environmental practices are considered here in more detail as a way of doing something through technology (e.g. a more efficient machine), management (e.g. better scheduling of production) or people's routines (e.g. switching off a machine after use). This mirrors the categorisation from Sarkis (2001) of technology, management and people. Firms reduce environmental impact through the introduction of programmes to implement new practices (Hami et al. 2019), including changing technology (Kissock & Eger, 2008), better management of technology (Garetti & Taisch, 2012), and better management of wastes (Kleindorfer et al., 2005).

Tools can be a conduit for changing practice (Ehrenfeld, 2009) but Rusinko (2007) suggests that tool adoption lags specific practice adoption. The sharing of environment practices is another way that good practice is spread. Lopez Torres et al. (2019) use structured equation modelling to test the hypothesis that knowledge management contributes to mores sustainable operations. Conceptually they are ways of reaching a target level of performance (Davies & Kochhar, 2000) supported by repositories of practices (e.g. CO2PE! and EPA), academic literature and company websites. The focus on technology as the main resource consumer (Garetti & Taisch, 2012) is understandable but effective practices can also be expressed according to resource use (Despeisse et al., 2012).

Examples of eco-efficient practice are documented by life cycle stage by Despeisse et al. (2012) and for the supply chain by Subramanian & Gunasekaran (2015). They cover stages of production lifecycle, different types of resource types (energy, water, etc) and different approaches to reduction (removal, reuse, recycle, etc). The different ways of expressing practices enables others to access them more easily depending on whether they are trying to improve a piece of process technology or reduce the consumption of a specific resource. Whilst there is a wealth of practice and application outcome information available (Rusinko, 2007) there is less knowledge on how these practices are deployed (Despeisse et al., 2012).

In summary, the literature is strong on practices but generally weak on the conditions that foster the adoption of such practices. Whilst we know what companies should be doing, it is more challenging to uncover how they can go about it. More needs to be understood about what mechanisms foster the spread of practices and the language used for it. Environmental practices are seen by some as an extension of lean practices, however, this pre-supposes the existence of lean thinking and its associated language.

2.5 Barriers to adoption environmental practices

Yao et al (2019) take a mathematical modelling approach to explain why it is difficult for the Chinese government to achieve carbon reductions of SMEs through command and control, with the policy cost being high compared to the likely returns. Instead they advocate market-oriented mechanisms to encourage knowledge sharing among SMEs alongside subsidies that promote carbon reduction.

Process improvement approaches can identify improvement opportunities and practices can be adopted to achieve them, but barriers may exist to prevent them. A barrier hinders the achievement of improved efficiency (Jaffe & Stavins, 1994) and has technical, organisational and external forms. By understanding barriers, mitigating actions can help promote the implementation of better practice (Azevedo, 2012).

From an organisational learning perspective, barriers can relate to competence, culture or organisational structure (Gieskes et al., 2002). Barriers could be individual (Argyris, 1993) or team related (Tucker et al., 2007) and can relate to the overall vision, urgency to change and making change stick (Kotter, 1995). Operationally, when attempting change specific to environmental improvement, barriers arise due to the absence of awareness, metrics, business case, accountability, communication, motivation, responsibility or standards to name a few (Cherrafi et al., 2016; Giunipero et al., 2012; Kurdve et al., 2014; Murillo-Luna et al., 2011; Turesky & Connell, 2010).

Literature on barriers covers organisational versus individual (Sorrell et al., 2000), supply chain (Rahman et al., 2020), technologies (Klassen, 2000), energy efficiency (Johansson & Thollander, 2018) and strategic approach (Macchion et al., 2018). Methodologically, for single company case research is common (e.g. Miller et al., 2010) and for multiple companies surveyed (e.g. Zhu & Sarkis, 2004) or open access data (e.g. King & Lenox, 2001) is common. By understanding barriers, mitigating actions can help promote the implementation of better practice. Despite this, research of multiple companies, especially for general environmental improvement barriers, in the same industrial sector or supply chain tier is lacking. Assuming barriers are generic across sectors could miss opportunities to better understand how to support particular sectors and why differences could arise.

2.6 Gaps in knowledge on environmental practices in manufacturing

The literature overview identified a number of gaps. Firstly, whilst there is research on 'what' practices are being deployed, this has not been matched with 'how' they are adopted; tools and organisational setups have yet to become common knowledge and practice. Whilst there are many published classification models for what types of environmental practices exist ("know what"), there is little specific to how environmental practices are adopted ("know how"). There is less research on how barriers can be overcome and no sector specific research.

The literature overview highlighted new practice adoption, telling us what can be achieved (e.g. Pagell & Wu, 2009) and the impact on supply chains (e.g. Giuinipero et al., 2014; Pagell & Wu, 2009). This aids learning but potentially misses out on the wider motivations of industry and what helps and hinders the advance of sustainable practices in most manufacturers. Weisner et al. (2017) call for a holistic model of how firms, including SMEs, manage change towards sustainability and criticise existing academic models as being generalized from models developed within large organizational contexts.

There is also use of survey or public data in the existing literature (e.g. Hajmohammad et al., 2013; Rothenberg et al., 2001) and this can inform macro level understanding or lower level tiers (Meinlschmidt et al., 2018) but misses out motivations, challenges and adoption readiness at an operational level, especially from companies that want to progress but may not have significant track record of progression.

Diffusion frameworks exist for supply chains between buyer and supplier but there is an absence of such frameworks for industry sectors. Additionally, there is an absence of a universally accepted 'production system' for environmental practices in the same way there is for, say, lean. Combining new knowledge of how improvements are made in operations with the existing work on what practices to adopt would generate new knowledge for how "normal" firms might journey towards sustainability.

The gaps in the literature led the researchers to want to understand the journey of "normal firms" towards more sustainable manufacturing. The over-arching research question "How can environmental practice be adopted in manufacturing operations?"

3. Research design to understand adoption

The research draws empirically from UK beer producers. In seeking to understand how breweries have adopted environmental practices, the unit of analysis was the company production site and included supply chain interactions but not an examination of other supply chain actors. The research focused on operations at the same supply chain tier of a supply network and excluded retail (onsite 'brewery tap', pubs, bars), hotels or shops (physical or online). Given the earlier absence of literature to frame the problem, it is necessary to empirically examine practice to build new knowledge.

A grounded approach based around process thinking offers an opportunity to capture why and how environmental actions are undertaken and use this to structure a rich picture of a sector. Included in the research were those with a motivation to improve their environmental performance and open to research data collection. No filtering on level of maturity of environmental progress was attempted, hence this work captures companies at any stage of their environmental work, not just those recognised to be leaders. Large, medium, small and micro brewers contributed to the research with a self-selecting and population bias towards smaller brewers. It should be noted that each brewery site of a large company may consider themselves to have the behaviour and constraints of a medium-sized company given they operate largely independently of the parent company. Lists of breweries (between 60-100 per event) were collated from public information of all breweries within the vicinity of each planned event. An estimated one-hour travel time to each venue was the focus of the list collation. The main form of contact was by emailing all breweries (or filling out website contact forms) (by the authors) within reach of the workshop locations (Glasgow, Huddersfield, Oxford). Where telephone numbers were available, each brewery was then contacted by telephone by a telesales company to encourage attendance. Additionally, brewery

membership and other support organisations broadcast the research project and events regionally and nationally. Of those that registered for the events approximately a quarter of would not appear at the event. No fee was charged for attendance, only presenters were eligible for travel cost reimbursement.

Two methods of data collection were used. First, eight one-to-one face-to-face interviews took place with breweries (nine people in total), typically at their production site. Interviewees had the role of head brewer, production manager or sustainability lead. As is common for all but very large companies, there was typically only one person evident with a sustainability or environmental remit or ambition. Interviews were guided by themes from the literature, namely: **why** are they motivated to change and what are the drivers for change (internal and external, including the supply chain)? **how** are they starting on their sustainability journey, do they have a process they are following, what sustainable practices are they adopting and what are the factors that are helping and hindering progress? Finally, **what** were the benefits? If needed, prompts were given on resources (e.g. energy and water) and on process (e.g. switching off and process control). The question order and response was interviewee led with unanswered questions prompted at the end. Written notes were made against template data collection sheets formed from the literature themes. This gave insights to the brewers' motivations and benefits as well as practices deployed and barriers encountered.

Second, three half day workshops took place regionally at breweries to collect data on practices and barriers for 5-10 invited brewers in a group setting. Overall 20 breweries attended these events with a total of 26 brewery staff attending. Each event had an additional three non-brewery presenters and up to five other attendees (consultants and industry support employees). Stimulated by three to four resource efficiency presentations (host brewery, guest brewery, one or two industry support organisations) the brewers were then divided into groups to identify successes and challenges. Facilitated by the paper authors, the groups discussed the issues for their businesses that included their motivations, their challenges, their approaches, their practices and their outcomes. This enabled prompted discussions around issues and allowed observations on the level of willingness to share and the acceptability of adopting practices from other companies. The groups recorded their inputs on post-it notes and placed these on flip charts within their groups. As the discussions progressed they reorganised their post-its to cluster similar points. The post-it note flip chart outputs from each group were photographed for later tabulation and coding.

Collaboration and communities were not part of the planned data collection but were frequently evidenced in the interviews and workshops. Given a small overlap between interviewees and workshop attendees, a total of 33 brewery employees from 26 breweries contributed to the research. The sample included companies of various sizes, some were large, some SME and some micro (less than 10 employees). There were more small and micro companies than large which is consistent with the profile of the sector.

The data collected was initially (open) coded and clustered according to brewer motivations and benefits as well as practices deployed and barriers encountered. The codes were developed from interview notes and the documented outputs from groups at each workshop. As clusters were formed the codes were refined (axial). Metric and practice data were structured with a process mindset according to resource flow (e.g. energy, grain) and practices (e.g. reuse, minimisation) by process stage (e.g. fermentation, filling). In the findings section, the clusters are represented by the table headings and the refined codes are represented by the table contents, for example a metric cluster would be "Cost reduction" and associated code would be "Defray upgrades". Although brewers varied in their way of describing production (e.g. by resource flow or by process stage), none struggled to understand the alternate description. The language of the brewers aligned to general operations management process thinking. With hindsight, this approach was vindicated as whilst the approaches and improvements were cited, they were rarely expressed in the language of lean or sustainability, hence structured questionnaires could have used inappropriate language. The coded and clustered data (for example, the barriers to environmental improvement) were compared with literature.

4. Findings from UK brewers

In this section we present the findings from the data collection exercise with the brewing companies. The authors took a grounded approach, asking them to talk about their sustainable manufacturing journey. Key prompts were around the drivers, the practices, the enablers and the barriers. There were instances of universal adoption given the common process steps (e.g. use of heat exchangers to reduce power consumption), common materials (spent materials going to farms or anaerobic digestion), sector benchmarking (metrics on water use per litre of beer produced) and shared values. The shared values were evident from interviews and workshops where brewers spoke of social purpose of the enterprise, heritage of the product and cooperation with one another. The common process used by all brewers, the common interfaces with up and down stream supply chain, shared passion for customers enjoying their product, etc. fostered the conditions for sharing and cooperation that could be important learning for other sectors.

4.1 Benefits and their measurement.

Companies provided the benefits they realised (Table 1). The table contents here and later represent the clusters (e.g. Output) and revised codes (e.g. value from wastes). It is difficult to separate the desire to improve environmental performance with the desire to reduce costs. There were some instances of activities that would produce little or no cost benefit. For example, water use reduction where the water is abstracted rather than purchased from town supply. Whilst the benefits are drawn from brewers, the focus is not specific or unique to breweries as a sector with manufacturing.

Table 1. Benefits of environmental focus

Input & external	**Process**	**Output & impact**
Purchase cost	Operations cost	Value from wastes
Resilience to scarcity	Defray upgrades	Disposal cost
Lower footprint	Lower footprint	Brand presence
Opens doors to collaboration		Brand leadership
		Market share growth

In the main, activities sought reduce use of resource to deliver cost and impact reduction. Those that were motivated to reduce environmental impact (rather than as a consequence of cost reduction) exposed themselves to a wider range of opportunities. For example, reusing cleaning chemicals until exhaustion was triggered by the motivation to reduce environmental impact and implemented because it reduced cost. Resilience was cited several times either because of market availability (e.g. foreseen scarcity of American hops) or infrastructure (e.g. ability to draw more water from town supply or abstraction). Benefits of environmental agendas to engage employees or gain consumer (not necessarily immediate customer) recognition were cited although no quantitative evidence presented. This latter point aligns with the strong values and purpose that many of these businesses articulated. Overall, it is suggested that the businesses wanted to "do the right thing" and reduce cost with less emphasis on market advantage and no mention of market pull. This suggests a contrast with other sectors in which external factors are commonly cited as the strongest drivers for environmental action.

For metrics used to assess the benefits (see Table 2) common responses were noted. Again, the table shows the clusters and revised codes. Brewers gave similar operations metrics that covered input, process and output. One cited biodiversity. Little visual management was observed or spoken about. There were differences in the granularity of metrics. Whilst some only measure water consumption at site level for reporting for industry benchmark metrics, others measured in detail, even to the amount of water used by each hose. The measurement was not always a reflection of the process or cost control. For example, a brewer who has a landlord/tenant relationship may not monitor their water use closely as their water costs are built into facility rental cost whereas a brewer who is constrained by local water access may monitor more closely for capacity reasons.

Material reduction (e.g. grain) was not explicitly mentioned as an environmental, resource efficiency metric despite practices that will have reduced material use such as double brewing and centrifuging.

Table 2. Metric category and typical metrics

Input	**Process**	**Output**	**General**
Energy use Water consumption site	Water consumption within process Energy	Production Carbon content Waste output	Biodiversity

4.2 Practices deployed

Data collected on the operations is presented using a process mindset of input, process and output. This was sufficiently generic to cope with the different mindsets encountered of viewing the operation as a sequence of process steps or as a flow of raw materials to product and wastes (See Table 3). Numerous practices were offered and many were common. Some were mentioned by a small number of businesses as they relied on both scale and available space, e.g. anaerobic digestion to convert wastes into energy. For the purposes of this paper, the detail of each practice is of passing interest so only a summary is shown in the table; it is the types of practice (prevent, reduce, reuse, etc) and the focus across the lifecycle stages that is important. Again, most of the practices are not unique to breweries or food and drink and could be applicable to manufacturers from any sector.

The brewers referred to key inputs of materials, water, energy and packaging. Such groups are common in the environmental practice literature. Raw materials were grouped together except for water which was both a raw material and a general utility. Other practices related to people. Whilst many interviewees were exposed to both suppliers and customers, many of the practices are technological and relate to their own operation, i.e. they relate to how they could change their own processes to be more resource efficient. In small breweries, there is line of sight from raw material store to finished goods and waste collection. This inevitably influences individuals' understanding of the lifecycle of the raw materials. Outside of production, all brewers sought to gain value from solid wastes either through exchange with farmers or energy generators. It was only the larger brewers that spoke of influencing the upstream and downstream supply chain on carbon or cost or both.

The findings presented in Tables 1, 2 and 3 use common headings of input, process and output. This demonstrates alignment between practices, metrics and benefits. For example, the practice of reducing water use (Table 3) will be picked up by input metric of site water consumption (Table 2) and realised through the benefit of lower footprint and lower purchase cost (Table 1). For example, the practice of reducing use (of energy) (Table 3) will be picked up by process metric of energy (Table 2) and realised through the benefit of lower operations cost and lower footprint (Table 1).

Overall, the changes were generally described as part of ongoing resource efficiency focus. Few brewers used lean manufacturing language or cited the use of lean tools or explicit process improvement approaches. Despite not citing the explicit use of tools and language that surrounds philosophies such as lean, the outcomes were the same and there is potential to explain approaches with lean concepts or environmental improvement methods. The absence of the lean language is a valuable outcome of this work as it could inspire mechanisms for environmental practice dissemination and adoption within manufacturing generally.

Table 3. Summary process view of improvements to production operations by resource type

Type	Input	Process	Output
Materials and consumables	Regional sourcing Develop suppliers (farms) Reuse (others' waste bread)	Standard Operating Procedures (SOPs) Measure Stop loss (scrap, waste) Reduce use (double brew) Reuse (yeast, cleaners)	Segregate to maintain value Reuse (farms, foodstuffs, Anaerobic digestion (AD))
Water	Reduce by using available resource (rainwater) Smooth utility demand	Measure Stop leaks Reduce use Reuse	Prevent (Filter/settle before discharge)
Energy	Renewable energy Reuse others' wastes (AD) Reduce by using available resource (e.g. outside air)	Prevent use (insulate) Stop use (switch off) Reduce use (set points, minimise brew cycle, efficiency equipment)	Reuse (Heat exchange)
Packaging, storage and transport	Reduce Use recycled Use biodegradable	Reduce (energy efficiency)	Reduce (light weighting, consolidation, vehicle efficiency)
People		Sharing knowledge Training / develop skills Foster behaviour change Process improvement culture Promote circular thinking	Certification for market advantage Customer awareness Promote landfill diversion

4.3 Barriers to progress

In asking for practices that reduced environmental burdens, the brewers were also asked what was preventing their adoption. These were termed barriers and were clustered into similar groups (Table 4). The similar groups of finance (short and long term), people (desire and ability to change), organisation (benefit or ability of the company to impact on change), process and tools (how to impact on the way the business runs) are mapped to key references to barriers from the fields of change management, lean, environment and energy. The groups in table 4 draw on Rahman et al.'s (2020) categories of barriers of finance, knowledge, organisation and technology as well as Ball & Lunt's (2019) people, process and tools.

Three fields of literature are used to gather the barriers. Firstly, given the frequent reference to lean by the environmental literature, the lean thinking literature is used, in particular Turesky & Connell (2010) and Hicks & Matthews (2010). Secondly, given the focus of this work is on environmental practices, the environmental literature on barriers is examined including Caldera et al. (2019), Cherrafi et al. (2017), Giunipero et al. (2012) and Sorrell et al. (2000). Finally, energy efficiency literature is drawn from given the incidence of papers on barriers (Johansson & Thollander, 2018; Lunt et al. 2014; May et al, 2016), that energy is a major consideration of manufacturers (Dieste et al., 2020) and that breweries are energy intensive operations. It is perhaps unsurprising that most of the barriers listed appear in the environmental and energy literature given that these fields have built the more general fields.

Table 4. Barriers experienced by brewers in starting or progressing environmental reduction activities

Barriers	**Barrier cited**	**Discipline**		
Finance		**Lean**	**Green**	**Energy**
Access to capital	Capital investment significant decision Changing legacy capital will take time Payback time Grant availability		x	x
Cash flow	Availability & prioritisation of cash to invest Size & scale of small brewers' limits options Short-term needs undermine long term		x	x
People				
Change culture	Ability to adapt to change		x	
Resources	Lack of available people Multitasking hinders specialism Skills	x	x	x
Training	Time to acquire knowledge Access to (central) knowledge base	x	x	x
Knowledge	Knowledge to approach reduction Awareness of practices Ability to share practices	x	x	x
Risk	Fear of getting it wrong Confidence to invest Pessimism of leaders	x	x	x
Organisation				
Inertia	Lack of urgency of staff to progress Reluctance to change existing practice Water seen as cheap resource	x	x	x
Ownership	Gipsy or cuckoo brewer Building tenant not owner	x		x
Priority	Lack of regulatory pressure Saving energy not core to business No control on project selection Pressure on cost from customers No environmental pull from customers			x
Principal-agent	Landlord provides "free" water to tenant		x	x
Process & tools				
Split incentive	Waste separation not beneficial to brewer Beneficiary in sharing with competitor		x	x
Selection	Ability to plan to smooth flow Low process speed Low impact -vs- low cost Limited process innovation witnessed		x	x
Information	Ability to measure challenging Lack of metering to understand use		x	x
Opportunity	Waste volume limited for valorisation Water abstracted not town Savings achieved so new advances harder			

Interestingly, the aforementioned authors cite many other barriers such as lack of vision, lack of management support, poor communication, poor project selection, values and not removing obstacles to vision. These barriers were not apparent. This could be due to many small companies in the sample which would be less likely to face challenges with communication and a failure to

appreciate the company core values. Barriers such as Sorrell et al.'s heterogeneity did not arise as brewers rarely cited their differences beyond their recipes.

Financial barriers were noted by many. Given most have steady production, the need to replace equipment is infrequent so upgrade to higher resource efficiency plant is infrequent. Further, the small size of many brewers and associated lower cash flow meant that spend was directed to low-cost and short-term payback projects. Brewers reported that much can be achieved without significant spend through changes in operating practices but recognised that there were limits with their current installed capacity.

Organisational barriers captured the wider issues, some of which can relate to larger organisations, e.g. environmental improvement project proposals compete with other proposals in a structured selection process. Many organisational barriers relate to the lack of incentives for action or the inability to act, e.g. the lack of customer pull, the long-term rental of premises or the short-term use of another company's brewing equipment (gipsy brewing).

Many technical change process barriers related to the lack of perceived or actual benefit available. For example, some companies were too small to gain volume benefits from separating wastes or their building lease included water supply. Additionally, brewers seeking to provide a high-quality product at low cost had less incentive to reduce impact.

5. Making sense of the journey towards sustainable manufacturing

In this section the authors pull together the data gathered from the sector to sense make the journey towards sustainable manufacturing and build a route map that may help other firms (from any sector) to adopt more sustainable practices. We recognise that a few of the practices and technologies talked about in the context of brewing will not be applicable in other sectors, who will have their own priorities. But the aim is to build a framework that can then be added to by researchers looking at other settings. There is some element of intellectual arbitrage in the development of the framework, i.e. using information from one discipline and applying it to another. The authors are taking what they learnt from the brewers in terms of the journey and then overlaying this with good practice change management from the business literature. So whilst the focus of this paper is environmental practices and sustainable manufacturing, the authors are borrowing from other disciplines to bring new insights that may help manufacturing firms wishing to embrace change and more sustainable manufacturing operations. The sub-sections that follow draw out the overall themes arising from the data collected to propose a framework and suggest future work.

5.1 Motivation for change

Pressures (drivers) from external actors did not feature significantly in the data capture. This contrasts with other sectors where change may arise from communities (Beamon, 2008), the supply chain (Pagell & Wu, 2009), consumers (Claro et al., 2013) or the need to comply with legislation (Williamson et al., 2006; Giunipero et al., 2014). Indeed, in Seuring & Müller's (2008) framework, the triggers were external and few pressures were internally generated. Some brewers spoke of the marketing benefits improvements but this appeared more as an offering, rather than a response, to the market. Environmental compliance was rarely cited and when it was it related to effluent handling without burdensome language. In Danson et al.'s (2015) work on UK microbreweries provenance as a market differentiator was cited but not sustainability or environmental credentials. This therefore relates back to the earlier literature by Williamson et al. (2006) which questioned whether regulation was negative or positive.

The language of resilience was used with concerns expressed about input of resources either now or in the future. The former mainly related to sourcing water at volume due to physical limitations of the utility infrastructure rather than a regional shortage. The latter related to hops given the rise in more heavily hopped beer globally expected to exceed predicted growth outputs in the medium term leading to cost and potential access uncertainties. Within the beer lifecycle the

largest carbon footprints occur in agriculture and brewing (Anon, 2012). The language of carbon footprint was seldom used. The larger brewers did have upstream supply chain activity and all brewers demonstrated a focus on the internal efficiency, especially energy. In line with Montabon et al. (2016), the activities took a resource-based view and focused on becoming less unsustainable. One larger brewer that, like other brewers, sourced grain from UK, used Life Cycle Analysis (LCA) to identify packaging rather than agriculture as the biggest carbon impact and therefore the potential for the largest savings.

Most advances cited appeared to be driven internally from a combination of 'doing the right thing' (in contrast to Claro et al.'s (2013) perspective of sustainability being beyond moral or legal requirements) as a consequence of the strong leadership values (Jabbour et al., 2017) and opportunities for cost reduction. Purposefulness, particularly in one business, was emphasised. Indirectly this aligns with Williamson et al.'s (2006) work on SMEs that shows business performance (as well as regulation) as behavioural drivers. Whilst improvements in environmental performance can be retrospectively justified after cost reduction activities have been completed, the language in which improvements were offered suggested the opportunities had been discovered from taking an environmental perspective. A few changes offered did not save cost but most did. It is judged that brewers take a resource efficiency perspective on change; they seek opportunities to reduce resource use which in turn reduce environmental impact and reduce cost. Many of the changes volunteered would not be obvious results of lean, production efficiency thinking.

The reasons for instigating change towards lower environmental impact of operations were varied and predominantly driven from within. Justification (the drivers) for change centred on the aforementioned values, impacts, resource efficiency (avoiding wastes), resilience and brand. Therefore, motivation is used to form the first part of the framework that will be presented later.

5.2 Barriers to change

The insights obtained on barriers indicates where work is required to foster progress in environmental advance. The insights are supported by literature (especially Sorrell et al., 2000) and are biased towards the challenges in smaller organisations.

Few of the brewers were environmental leaders (using Wiesner et al. (2018) definition of leaders have having recognition compared to other firms) but they had a desire to improve their environmental performance with some early in their journey. This could explain why many barriers identified were related to people (Sturm et al., 2012), their sense of urgency to change and their ability to undertake change. The need to acquire and manage knowledge is discussed extensively by Schrettle et al. (2014) as an enabler for sustainability progress. Small companies face greater challenges than large firms in pursuing environmental challenges (Murillo-Luna et al., 2011); having time for individuals to develop specialist knowledge when acquiring that knowledge could result in lower capacity in the business. This reinforces Ng et al.'s (2015) point that the potential for practitioners is being overwhelmed by breadth of skill requirement.

Financial barriers were considered significant, in part due to the small size and therefore stability and cash availability. Cost in general is a known inhibitor (Gopal & Thakkar, 2016; Seuring & Müller, 2008) but here the challenge is related to scale. The technology utilised in brewing is not undergoing significant change, the capital is long lasting and significant capacity changes are infrequent. Such legacy capital means that technology-driven resource efficiency improvements will be slow across the sector. Retrofit improvements such as insulation were cited over replacement.

Organisationally, multi-tasking across diverse activities from purchasing, production and sales hampers the acquisition and use of knowledge. How to extend production efficiency thinking to resource efficiency and environmental stewardship generally for busy, generalist brewers is new to the literature and calls for new ways of thinking on management imperatives. The 'lack of priority' barrier has been identified before (Lunt et al., 2014) but is not common in literature yet it was notable in this research. It was observed for several brewers that they were not incentivised to change where there was no cost benefit to themselves. Control of inputs or separation of outputs

could benefit others but only indirectly affect the brewer. It is only behavioural change of infrastructure actors (e.g. landlord, utility or municipality) that would motivate the brewer to change. This suggests resource cost or resource value is not significant in the relationship between these other parties and brewers, especially smaller ones. A specific barrier given was the lack of external pressure to change from a regulatory angle supporting the findings of Giunipero et al. (2014) and Williamson et al. (2006) that the absence of regulation is a barrier to environmental advance. Process and tools type barriers were cited but they were rarely the first to be volunteered. Many of these types of barriers existed, e.g. how to obtain and analyse data, but were potentially masked by the emphasis on people and their willingness to trust the application of advances made by others.

Overall the implications of barriers suggest that progress can be enabled by people development whilst recognising small firms are challenged by their own financial position and brewery infrastructure. These findings are compatible with Cherrafi et al. (2017) who identified 15 key barriers for lean and green, most of which related to knowledge, skills, leadership, costs and funding. Barriers are used as the second part of the framework.

5.3 Practices implemented

The common production process is an interesting feature of this sector. In workshops, brewers readily communicated with one another at the level of material and process detail without the need for context. In discussing improvements, the language of lean (process thinking, terminology, tools, etc) was not used although a lean practitioner would recognise the alignment to lean. This latter point is interesting for how those outside the brewing sector need to use the efficiency language of brewers to communicate any principles from 'standard' lean and resource efficiency approaches.

The material and consumable flows are simple and waste from the process will be materials that have little perceived value (e.g. spent grain), however, some brewers challenge this and will reuse (e.g. extracting further value from hops in a second brew, using bread as an input, creating bread or dog biscuits from the output). The water and energy supplies are not obviously visible on input or loss, however, significant attention was given to these. Brewers sought to use less on input and extract further value on output. The level of attention given to these in breweries has potential for learning in other production systems, especially discrete, where these resources receive less attention and are commonly considered as 'free issue' on the shop floor. Returning to an earlier point, the mindset of resource efficiency was more in evidence than the mindset of lean production. While there is a literature that argues the importance of lean in contributing to a decrease in pollution and minimising climate change (e.g. Chugani et al., 2017, Gusmao Caiado et al., 2019) and others talking about the impact of JIT and TQM (e.g. Green et al., 2019) we did not find much reference to Lean, Six Sigma, JIT and TQM. Possibly this is because the majority of the people we spoke to were not coming through traditional manufacturing and operations management career paths – so while taking out waste was important to them, they did not couch this in the language of lean or six sigma.

Of the numerous practices collected, most are low cost changes that deliver cost reduction and most are within the direct control of the brewer. Many practices were to prevent or reduce and some to recycle. Whilst some brewers spoke of data collection and analysis to drive improvement, others spoke directly of changes that would deliver expected benefit. This perhaps suggests that smaller brewers can see opportunities and have the authority to quickly implement based on process knowledge rather than detailed analysis. In workshops, participants listened to practices used by others and considered directly implementing them. Helped by commonality of production process this does suggest that the smaller brewers could be more endorsement and action driven rather than analysis driven. A few brewers described process intensification whereby plant more heavily and continuously used would improve environmental metrics through both production efficiency as well as facility efficiency. Practices form the third part of the framework.

5.4 Measuring change to realise benefits

There are differences between the benefits cited (Table 1) and the metrics offered on data collection (Table 2). For example, raw material consumption was a potential visible waste in the production process and was minimised but this was not a headline metric. Conversely energy consumption was discussed even though it is a "non-visible" resource. Whilst none of the brewers was knowingly wasteful, this anomaly could reflect controllable environmental performance drivers. While product material resource efficiency was measured, it was not expressed as an environmental metric. There was a common clarity in input, process and output language and metrics used which are common with other literature (e.g. Winroth et al., 2016).

Many of the metrics offered by brewers were common, e.g. water use. Those that offered more granular metrics offered more examples of practice improvements and would relate the metric and practice improvement to one another. However, the range of metrics offered would not intuitively lead to all the practices offered. It is proposed that it is the purposeful management and process knowledge that are significant drivers in change, supported by the metrics. Whilst this would need further investigation to ascertain, it again suggests that external interventions to support brewers need to reflect the values and approaches used. Metrics and separately benefits therefore form the next two parts of the framework.

5.5 Communities of practice to support change

Sharing is common in the sector and is supported by organisations that communicate examples of good environmental practice. Individually, breweries detailed help obtained from others and during workshops breweries volunteered practices openly. Within the sector it is common to work with other brewers prior to starting up a new brewery (sharing practice) or support cuckoo or gipsy brewing where one brewer uses another brewer's equipment (sharing resource). There was one example of a brewer letting another see the detail of significant cost saving achieved (sharing knowledge) in process energy. The level of collaboration and trust between brewers was observed to be high, especially when geographically separated. Cooperative behaviour was observed by Danson (2015) in the swapping of casks between breweries to diversify sales. The brewing community exhibits the characteristics of a "communities of practice" which according to Iyalomhe et al. (2013) "grow out of members' common interest and concern, and develop relationships that interlink competences and experiences (or reifications) through shared practice."

The close relationships between brewers and ready endorsement of approaches can be explained within current theory. Communities of practice theory refers to, amongst other things, a virtual or informal group that facilitates sharing and learning (Cox, 2005). Brown & Duguid (1998) describe communities that endorse knowledge to encourage others to rely on it and promote the 'stickiness' in the use of practices. They focus on the socially embedded knowledge that allows both the 'what' as well as the 'how' of the practice to be transferred. Gherardi (2009) make a similar point, distinguishing between the knowledge of a practice and the actual practice itself. This returns to the earlier distinction made about the literature being strong on the "know what" of a practice and weak on the "know how" of practice implementation. "Know how" is considered as a collective work practice that does not circulate with the relative ease of "know what" but is "critical in making knowledge actionable and operations" and hindered by hierarchical structures (Brown & Duguid, 1998). Communities of practice is seen by Bodrožić & Adler (2018) as part of the current technology revolution in which the organisation is a linked network across internal and external boundaries.

The brewers were observed to align to the features of a community of practice as described by Cox (2005) of: voluntary, large, tight knit, friendly and geographically situated group and demonstrating many of Wenger's (2002) indicators of: sustained mutual relationships, absence of introductory preambles, quick setup of problem to be discussed, knowing what others know, mutually defined identities, short cuts to communication and shared perspective on the world.

Duguid (2005) particularly emphasises that the knowing how is rooted in the flow of practices within communities and not some as yet uncodified tacit knowledge.

Communities of practice complements the structured company and supply chain communication in Seuring & Müller's (2008) framework. The close relationship between brewers with their shared approaches enables the flow of that knowledge to accompany the technical practice and they become practices of the brewing community. An improvement culture and the engagement in improvement projects can be considered as typical for any company, however, it was notable that the level of cooperation was high. Brewers were willing to work together, share practices and help develop the skills of those outside their company. This cooperation extends to collaboration with other activities such as gypsy brewing, sharing resources and co-development of beers. This supply tier collaboration complements the dominant general supply chain collaboration research (e.g. Pakdeechoho & Sukhotu, 2018).

In summary, the brewers shared practices, shared knowledge and shared resource. The sharing of practices ("know what") was evident in the specific ways of operating such as reuse of others' wastes, minimising cycle time and minimising packaging (taken from Table 3). The sharing of knowledge ("know how") was evident from their detail of how to analyse process cost, how to influence employee behaviour and the detail of operational performance. The sharing of resource was evident in sharing materials, helping another short of materials and cross-selling of product. This learning forms the final part of the framework to be proposed. A community of practice is not an independent element but represents the way that the practices, metrics and benefits are shared within the sector.

5.7 A framework for environmental practice adoption

Collating the values, barriers, practices, metrics, benefits, metrics and community from the above findings supported by clusters of literature, a framework for environmental practice advance is proposed (Figure 1). The framework adapts the supply chain conceptualisations from Seuring & Müller's (2008) framework to present change from the perspective of an enterprise with the external influences (barriers and supporting community) with additional detail of what is happening within the focal company that leads to the company performance. Importantly, the external pressures to for change were not captured in this research and are therefore omitted.

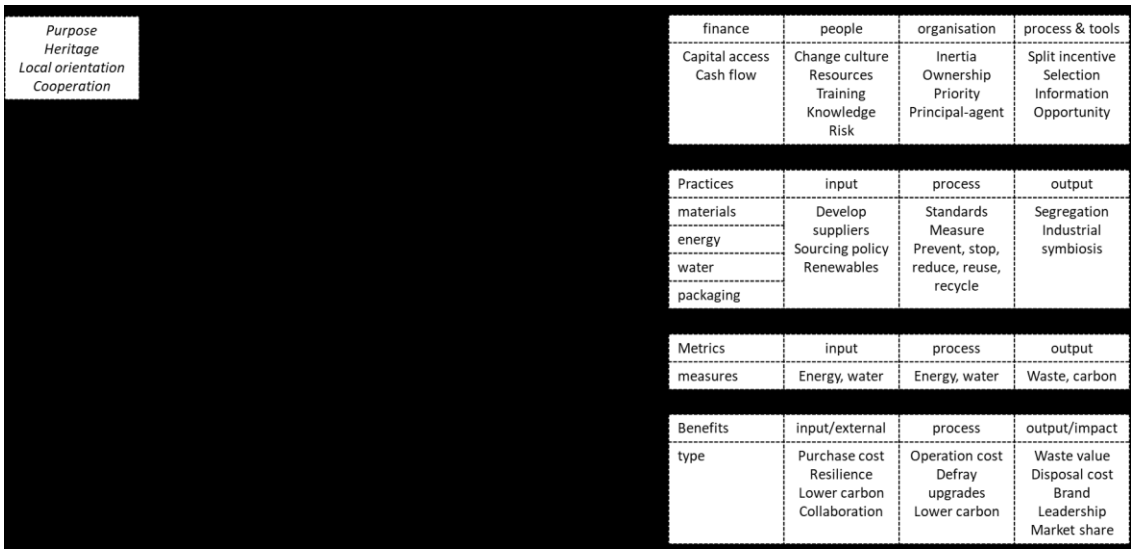

Figure 1. Framework for environmental practice adoption in manufacturing operations

The framework captures by category the key factors that influence the take up of environmental practices. The typical values of social purpose, heritage, local orientation and cooperation

influenced the justification category to start environmental practice implementation. Ultimately, they sought to realise the benefits (Table 1) that included, resilience, lower costs and brand recognition. The justification initiates the application of resource efficiency practices (Table 3) in the areas of materials, energy, water and packaging which may be tempered by barriers (Table 4) relating to finance, people, organisation and process and tools. As a result of the approach, new practices are implemented that result in changed resource efficiency performance according to the metrics of input, process and output (Table 2) that feature improvements in energy, water and carbon footprint.

Influencing the justification and approach to changing practice is a community of practice that shares specific practices (know what), knowledge of those practices (know how), and sometimes resource. Communities of practice is not recognised within environmentally sustainable, resource efficient manufacturing field yet it was found to be a significant feature of the brewing sector and a rapid exchange of practice was observed.

The framework in figure 1 has been developed from a general sustainable manufacturing, resource efficiency knowledge base and used findings from the brewing sector to detail. Whilst the framework has been drawn from a specific manufacturing food and drink sector, it has potential for application in other sectors. In particular, the mechanisms of sharing of practices, knowledge of those practices and resources used by those practices has potential for wider application and impact in manufacturing.

5.8 Limitations

Limitations in the research conducted can be identified and used to trigger future research. Firstly, the sample was from UK breweries. There is potential for other drink manufacturers (e.g. soft, gin, whisky and wine) as well as testing these findings in other countries. Secondly, with the growth in UK craft brewing, many of those in the sample were small companies. It was noted that many brewers were collaborative and open to sharing. The willingness to collaborate according to brewer size as well as comparing with other industrial sectors could uncover ways to instigate change in a sector. Thirdly, there was no attempt to assess the maturity of brewers' sustainability journeys. It is likely that the journey stage affects the responses given by brewers. For example, a brewer initiating environmental actions could be more challenged by internal change whereas a brewer who has made significant environmental progress could be more challenged by changing other parts of the supply chain. Finally, the research drew from the one or two lead individuals in each brewery. This was necessary as for many breweries there will only be one lead, whether it is the managing director, head brewer or environmental champion (in some breweries these three roles are taken on by the same person). It would therefore be of interest to examine the leadership style of that person to understand how their traits impact on the pathway that the business takes.

6 Conclusion

This research sought to explain how good environmental practice is advanced, in particular: how can environmental practice be adopted in manufacturing operations? The work focused on how companies can increase their resource efficiency and reduce their environmental impact. Relevant, widespread literature on what practices are adopted includes sustainable supply chain management, eco-efficiency, barriers and communities of practice but there is absence of literature covering the conditions that foster practice adoption. This gap extends to knowledge of environmental practice in manufacturing through the lens of the UK brewing sector.

The paper documents grounded research to learn through practice. Data on breweries' environmental activities was gathered, coded and clustered. Given the common processing technology, the common supply chain structure and readily identifiable markets it was possible to establish a picture of a single supply chain tier. With emphasis on the tools, practice, barriers and supply chain literature, the paper presents findings on motivations for environmental focus, the

dominance of resource efficiency actions and organisational barriers for further progress. Additionally, the open and collaborative nature of brewers points to communities of practice sharing knowledge and the actions of practices. Whilst the behaviours of brewers can be readily explained by lean and environmental language it is not explicitly expressed in such terms.

For researchers, the work extends operations management knowledge on why companies, in this case brewers, focus on environmental impact, and what they implement. But the more significant contribution is in shining light on how they go about the changes and what hinders their progress. For practitioners, the work presents a framework that includes common metrics that assess eco-efficiency, environmental manufacturing activity outcomes. The learning on practice adoption can guide those in operations on how to improve resource efficiency to reduce impact and cost as well as forewarn of barriers to prompt mitigating actions. The findings could be used to explain what will hinder wider general adoption and how this can be overcome rather than what enables prominent leaders to advance further. Finally, the community that these companies foster provides insight to a pathway to wider industry advance.

References

Amienyo, D., and Azapagic, A. 2016. "Life cycle environmental impacts and costs of beer production and consumption in the UK." *International Journal of Life Cycle Assessment* 21(4): 492-509.

Anon. 2012. *Research on the Carbon Footprint of Beer*, Beverage Industry Environmental Roundtable.

Anon. 2015. *2015 Sustainability Benchmarking Report*, Brewers Association: Colorado, USA.

Argyris, C. 1993. *Knowledge for Action: A Guide to Overcoming Barriers to Organizational Change*, Jossey-Bass Inc, San Francisco, USA.

Azevedo, S.G., Carvalho, H., Duarte, S., and Cruz-Machado, V. 2012. "Influence of Green and Lean Upstream Supply Chain Management Practices on Business Sustainability." *IEEE Transactions on Engineering Management* 59(4): 753-765.

Baines, T., Brown, S., Benedettini, O., and Ball, P. 2012. "Examining green production and its role within the competitive strategy of manufacturers." *Journal of Industrial Engineering Management* 15(1): 53-87.

Ball, P. and Lunt, P. 2019. "Enablers for Improving Environmental Performance of Manufacturing Operations." *IEEE Transactions on Engineering Management* 66(4): 663-676.

Ball, P. and Lunt, P. 2020. "Lean eco-efficient innovation in operations through the maintenance organisation." *International Journal of Production Economics* 219: 405-415.

Bansal, P., and Roth, K. 2000. "Why companies go green: a model of ecological responsiveness." *The Academy of Management Journal* 43: 717-736.

BBPA. 2014. "Brewing Green, Our commitment towards a greener future for Britain's beer and pubs", *British Beer & Pub Association.*

Beamon, B.M. 2008. "Sustainability and the future of supply chain management." *Operations and Supply Chain Management* 1(1): 4-18.

BEIR. 2012. "Research on the Carbon Footprint of Beer", *Beverage Industry Environment Roundtable*.

Bellgran, M., Kurdve, M., and Hanna, R. 2019 "Cost driven green kaizen in pharmaceutical production – creating positive engagement for environmental improvements." *Procedia CIRP* 81: 1219-1224.

Beske, P., Land, A., and Seuring, S. 2014. "Sustainable supply chain management practices and dynamic capabilities in the food industry: A critical analysis of the literature." *International Journal of Production Economics* 152: 131-143.

Blok, V., Wesselink, R., Studynka, O., and Kemp, R. G. M. 2015. "Encouraging sustainability in the workplace: A survey on the pro-environmental behaviour of university employees." *Journal of Cleaner Production* 106: 55-67.

Bodrožić, Z., and Adler, P.S. 2018. “The Evolution of Management Models: A Neo-Schumpeterian Theory.” *Administrative Science Quarterly* 63(1): 85-129.
Brown, J.S., and Duguid, P. 1998. “Organizing Knowledge.” *Californian Management Review* 40(3): 90-111.
Caldera, H.T.S., Desha, C., and Dawes, L. 2019. “Evaluating the enablers and barriers for successful implementation of sustainable business practice in ‘lean’ SMEs.” *Journal of Cleaner Production* 218: 575-590.
Cherrafi, A., Elfezazi, S., Chiarini, A., Mokhlis, A., and Benhida, K. 2016. “The integration of lean manufacturing, Six Sigma and sustainability: A literature review and future research directions for developing a specific model.” *Journal of Cleaner Production* 139: 828-846.
Cherrafi, A., Elfezazi, S., Garza-Reyes, J.A., Benhida K., and Mokhlis A. 2017. “Barriers in Green Lean implementation: a combined systematic literature review and interpretive structural modelling approach.” *Production Planning & Control* 28(10): 829-842.
Choi, T.-M., Lo, C.K.Y., Wong, C.W.Y., and Yee, R.W.Y. 2012. “Green manufacturing and distribution in the fashion and apparel industries.” *International Journal of Production Economics* 135(2): 531.
Claro, D.P., Laban Neto, S.A., and Borin de Oliveira Claro, P. 2013. “Sustainability drivers in food retail.” *Journal of Retailing and Consumer Services* 20(3): 365-371.
CO2PE! 2017. *Cooperative Effort on Process Emissions in Manufacturing*, https://www.co2pe.org. Accessed 9 August 2017.
Cox, A. 2005. “What are communities of practice? A comparative review of four seminal works.” *Journal of Information Science* 31(6): 527-540.
Danson, M., Galloway, L., Cabras, I., and Beatty, T. 2015. “Microbreweries and entrepreneurship: the origins, development and integration of real ale breweries in the UK.” *Entrepreneurship and Innovation* 16(2): 135-144.
Davies, A.J., and Kochhar, A.K. 2000 “A framework for the selection of best practices.” *International Journal of Operations & Production Management* 20(10): 1203-1217.
Despeisse, M., Mbaye, F., Ball, P.D., and Levers, A. 2012. “Emergence of sustainable manufacturing practices.” *Production Planning and Control* 23(5): 354-376.
Dieste, M., Panizzolo, R., and Garza-Reyes, J.A. 2020. “Evaluating the impact of lean practices on environmental performance: evidences from five manufacturing companies.” *Production Planning and Control* 31(9):739-756.
Dubey, R., Gunasekaran, A., and Samar, S.A. 2015. “Exploring the relationship between leadership, operational practices, institutional pressures and environmental performance: A framework for green supply chain”. *International Journal of Production Economics* 160(2): 120-132.
Dües, C.M., Tan, K.H., and Lim, M. 2013. “Green as the new lean: how to use lean practices as a catalyst to greening your supply chain.” *Journal of Cleaner Production* 40: 93-100.
Duguid, P. 2005. “‘The Art of Knowing’: Social and Tacit Dimensions of Knowledge and the Limits of the Community of Practice.” *The Information Society* 21:2, 109-118.
Ehrenfeld, J. 2009. *Sustainability by Design: A subversive strategy for transforming our consumer culture*, Yale University Press.
EPA. 2017. *Sustainable manufacturing*, https://archive.epa.gov/sustainablemanufacturing/web/html/ Accessed 9 August 2017.
Fercoq, A., Lamouri, S. and Carbone, V. 2016. “Lean/Green integration focused on waste reduction techniques.” *Journal of Cleaner Production* 137:567-578.
Florida, R. 1996. “Lean and green: The move to environmentally conscious manufacturing.” *California Management Review* 39(1): 80-105.
López-Torres, G.C., Garza-Reyes, J.A., Maldonado-Guzmán, G., Kumar, V., Rocha-Lona, L., and Cherrafi, A. 2019. “Knowledge management for sustainability in operations.” *Production Planning & Control* 30(10-12): 813-826.
Garetti, M., and M. Taisch. 2012. “Sustainable Manufacturing: Trends and Research Challenges.” *Production Planning & Control* 23(1-2): 83–104.

Garza-Reyes, J.A., Betsis, I.E., Kumar, V., and Al-Shboul, M.A.R. 2018. “Lean readiness - the case of the European pharmaceutical manufacturing industry.” *International Journal of Productivity and Performance Management*, 67(1): 20-44.

Gherardi, S. 2009. “Introduction: The Critical Power of the ‘Practice Lens’.” *Management Learning* 40(2): 115-128.

Gopal, P.R.C. and Thakkar, J. 2016. “Sustainable supply chain practices: an empirical investigation on Indian automobile industry.” *Production Planning & Control* 27(1): 49-64.

Gopalakrishnan, K., Yusuf, Y.Y., Musa, A., Abubakar, T., and Ambursa, H.M. 2012. “Sustainable supply chain management: a case study of British Aerospace (BAe) Systems.” *International Journal of Production Economics* 140 (1): 193-203.

Gieskes, J.F.B., Hyland, P.W., and Magnusson, M.G. 2002. “Organisational learning barriers in distributed product development: observations from a multinational corporation.” *Journal of Workplace Learning* 14(8): 310-319.

Glover, J.L., Champion, D., Daniels, K.J., and Dainty, A.J.D. 2014. “An Institutional Theory perspective on sustainable practices across the dairy supply chain.” *International Journal of Production Economics* 152: 102-111.

Green, K., Inman, R., Sower, V., and Zelbst, P. 2019. "Impact of JIT, TQM and green supply chain practices on environmental sustainability." *Journal of Manufacturing Technology Management* 30(1): 26-47.

Grimm, J.H., Hofstetter, J.S., and Sarkis, J. 2014. “Critical factors for sub-supplier management: A sustainable food supply chains perspective.” *International Journal of Production Economics* 152: 159-173.

Giuinipero, L.C., Hooker, R.E., and Denslow, D. 2014. “Purchasing and supply management sustainability: Drivers and barriers.” *Journal of Purchasing & Supply Management* 18(4): 258-269.

Gusmão Caiado, R.G., Gonçalves Quelhas, O.L., Mattos Nascimento, D.L., Anholon, R., and Filho, W.L. 2019. “Towards sustainability by aligning operational programmes and sustainable performance measures.” *Production Planning & Control* 30(5-6): 413-425.

Hagelaar, G.J.L.F., and van der Vorst, J.G.A.J. 2002. “Environmental supply chain management: using life cycle assessment to structure supply chains.” *International Food and Agribusiness Management Review* 4: 399-412.

Hajmohammad, S., Vachon, S., Klassen, R.D., and Gavronski, I. 2013. “Lean management and supply management: their role in green practices and performance.” *Journal of Cleaner Production* 39: 312-320.

Hami, N., Muhamad, M.R., and Ebrahim, Z. 2015. “The impact of sustainable manufacturing practices and innovation performance on economic sustainability.” *Procedia CIRP* 26: 190-195.

Hami, N., Yamin, F.M., Shafie, S.M., Muhamad, M.R., and Ebrahim, Z. 2019. “Sustainable manufacturing practices among SMEs in Malaysia.” *International Journal of Technology* 8: 1658-1667.

Hartini, S., and Ciptomulyono, U. 2015. “The relationship between lean and sustainable manufacturing on performance: literature review.” *Procedia Manufacturing* 4:38-45.

Hicks, B.J. and Matthews, J. 2010. “The barriers to realising sustainable process improvement: A root cause analysis of paradigms for manufacturing systems improvement.” *International Journal of Computer Integrated Manufacturing* 23(7): 585-602.

Iyalomhe, F., Jensen, A., Critto, A., and Marcomini, A. 2013. “The Science–Policy Interface for Climate Change Adaptation: the Contribution of Communities of Practice Theory.” *Environmental Policy and Governance* 23: 368–380.

Jabbour, C.J.C., Mauricio, A.L. and Jabbour, A.B.L. 2017. “Critical success factors and green supply chain management proactivity: shedding light on the human aspects of this relationship based on cases from the Brazilian industry.” *Production Planning & Control* 28(6-8): 671-683.

Jaffe, A.B., and Stavins, R.N. 1994. “The energy-efficiency gap: What does it mean?” *Energy Policy* 22: 804-810.

Johansson, M.T. and Thollander, P. 2018 “A review of barriers to and driving forces for improved energy efficiency in Swedish industry - Recommendations for successful in-house energy management.” *Renewable and Sustainable Energy Reviews* 82: 618-628.

King, A.A., and Lenox, M.J. 2001. “Lean and Green? An empirical examination of the relationship between lean production and environmental performance.” *Production and Operations Management* 10(3) 244-256.

Kissock, K. and Eger, C. 2008. “Measuring industrial energy savings,” *Applied Energy* 85(5): 347-361.

Klassen, R.D. 2000. “Exploring the linkage between investment in manufacturing and environmental technologies.” *International Journal of Operations & Production Management* 20(2): 127-147.

Kleindorfer, P.R., Singhal, K., and Van Wassenhove, L.N. 2005. “Sustainable Operations Management.” *Production and Operations Management* 14(4): 482-492.

Kotter, J. 1995. “Leading change: Why transformation efforts fail,” *Harvard Business Review* 73: 59-59.

Kurdve, M., Zackrisson, M., Wiktorsson, M., and Harlin, U. 2014. “Lean and green integration into production system models - experiences from Swedish industry.” *Journal of Cleaner Production* 85: 180-190.

Leat, P., and Revoredo-Giha, C. 2013. “Risk and Resilience in Agri-food Supply Chains: The Case of the ASDA Pork Link Supply Chain in Scotland.” *Supply Chain Management: An International Journal* 18(2): 219-231.

Lunt, P., Ball, P., and Levers, A. 2014. “Barriers to industrial energy efficiency.” *International Journal of Energy Sector Management* 8(3): 380-394

Macchion, L., Da Giau, A., Caniato, F., Caridi, M., Danese, P., Rinaldi R. and Vinelli, A. 2018. “Strategic approaches to sustainability in fashion supply chain management.” *Production Planning & Control* 29(1): 9-28.

Martínez-Jurado, P.J., and Moyano-Fuentes, J. 2014. “Lean Management, Supply Chain Management and Sustainability: A Literature Review.” *Journal of Cleaner Production* 85:134-150.

May, G., Stahl, B., and Taisch, M. 2016. “Energy management in manufacturing: Towards eco-factories of the future - a focus group study.” *Applied Energy* 164: 628-638.

Meinlschmidt, J., Schleper, M.C. and Foerstl, K. 2018. “Tackling the sustainability iceberg: A transaction cost economics approach to lower tier sustainability management.” *International Journal of Operations & Production Management* 38(10): 1888-1914.

Melnyk, S.A., Sroufe, R.P., Montabon, F.L., and Hinds, T.J. 2001. “Green MRP: Identifying the material and environmental impacts of production schedules.” *International Journal of Production Research* 39(8): 1559-1573.

Miller, G., Pawloski, J., and Standridge, C. 2010. “A case study of lean, sustainable manufacturing.” *Journal of Industrial Engineering and Management* 3(1): 11-32.

Mollenkopf, D., Stolze, H., Tate, W.L., and Ueltschy, M. 2010. “Green, lean, and global supply chains.” *International Journal of Physical Distribution & Logistics Management* 40(1/2): 14-41.

Montabon, F., Pagell, M., and Wu, Z. 2016. “Making sustainability sustainable.” *Journal of Supply Chain Management* 52(2): 11-27.

Murillo-Luna, J.L., Garcés-Ayerbe, C., and Rivera-Torres, P. 2011. “Barriers to the adoption of proactive environmental strategies.” *Journal of Cleaner Production* 19: 1417-1425.

Ng, R., Low, J.S.C., and Song, B. 2015. “Integrating and implementing Lean and Green practices based on proposition of Carbon-Value Efficiency metric.” *Journal of Cleaner Production* 95:242-255.

Oliveira Neto G.C., and Lucato, W.C. 2016. “Production planning and control as a tool for eco-efficiency improvement and environmental impact reduction.” *Production Planning & Control* 27(3): 148-156.

Pagell, M., and Wu, Z. 2009. “Building a more complete theory of sustainable supply chain management using case studies of 10 exemplars.” *Journal of Supply Chain Management* 45(2): 37-56.

Pakdeechoho, N. and Sukhotu, V. 2018. “Sustainable supply chain collaboration: incentives in emerging economies.” *Journal of Manufacturing Technology Management* 29(2): 273-294.

Pande, B. and Adil, G.K. 2019. “A value chain framework for assessment of sustainable practices in manufacturing firms.” *European Journal of Sustainable Development* 8(3): 95-107.

Perez-Sanchez, D., Barton, J.R., and Bower, D. 2003. “Implementing environmental management in SMEs.” *Corporate Social Responsibility and Environmental Management* 10: 67-77.

Piercy, N., and Rich, N. 2015. “The relationship between lean operations and sustainable operations.” *International Journal of Operations & Production Management* 35(2): 282-315.

Rahman, T., Ali, S.M., Moktadir, M.A., Kusi-Sarpong, S. 2020. “Evaluating barriers to implementing green supply chain management: An example from an emerging economy.” *Production Planning & Control* 31(8): 673-698.

Rothenberg, S., Pil, F.K., and Maxwell, J. 2001. “Lean, green and the quest for superior environmental performance.” *Production and Operations Management* 10(3): 228-243.

Rusinko, C. 2007. “Green manufacturing: an evaluation of environmentally sustainable manufacturing practices and their impact on competitive outcomes.” *IEEE Transactions on Engineering Management* 54(3): 445-454.

Sarkis, J. 2001. “Manufacturing’s role in corporate environmental sustainability - concerns for the new millennium.” *International Journal of Operations & Production Management* 21(5/6): 666-686.

Seuring, S., and Müller, M., 2008. “From a literature review to a conceptual framework for sustainable supply chain management.” *Journal of Cleaner Production* 16: 1699-1710.

Schmidheiny, S. 2000. *Eco-efficiency – Creating More Value with Less Impact*. Geneva: World Business Council for Sustainable Development.

Schmidt, M., and Schwegler, R. 2008. “A recursive ecological indicator system for the supply chain of a company.” *Journal of Cleaner Production* 16: 1658-1664.

Schrettle, S., Hinz, A., Scherrer-Rathje, M., and Friedli, T. 2014. “Turning sustainability in action: Explaining firms’ sustainability efforts and their impact on firm performance.” *International Journal of Production Economics* 147(A): 73-84

Simmonds, J. 2019 “UK Craft beer boom sobers up – adds just eight breweries versus 390 the previous year”, UHY Hacker Young, https://www.uhy-uk.com/news-events/news/uk-craft-beer-boom-sobers-up-adds-just-eight-breweries-versus-390-the-previous-year/ accessed 15/07/19.

Sorrell, S., Schleich, J., Scott, S., O'Malley, E., Trace, F., and U. Boede, U. 2000. *Reducing barriers to energy efficiency in public and private organizations*, SPRU.

Stewart, H., and Gapp, R. 2014. “Achieving effective sustainable management: A small-medium enterprise case study.” *Corporate Social Responsibility and Environmental Management* 21: 52-64.

Sturm, B., Butcher, M., Wang, Y., Huang, Y., and Roskilly, T. 2012. “The feasibility of the sustainable energy supply from bio wastes for a small scale brewery - a case study.” *Applied Thermal Engineering* 39: 45-52.

Subramanian, N., and Gunasekaran, A. 2015. “Cleaner supply-chain management practices for twenty-first-century organizational competitiveness: Practice-performance framework and research propositions.” *International Journal of Production Economics* 164: 216-233.

Sureeyatanapas, P., Yang, J.-B. and Bamford, D. 2015. “The sweet spot in sustainability: a framework for corporate assessment in sugar manufacturing.” *Production Planning & Control* 26(13): 1128-1144.

Tucker, A.L., Nembhard, I.M., and Edmondson, A.C. 2007. “Implementing new practices: an empirical study of organizational learning in hospital intensive care units.” *Management Science* 53(6): 894-907.

Turesky, E., and Connell, P. 2010. “Off the rails: understanding the derailment of a lean manufacturing initiative.” *Organization Management Journal* 7(23): 110-132.
Wenger, E., McDermott, R., and Snyder, W.M. 2002. *Cultivating Communities of Practice,* Harvard Business School Press.
Wiesner, R., Chadee, D., and Best, P. 2018. “Managing change toward environmental sustainability: a conceptual model in small and medium enterprises. *Organization and Environment* 31(2): 1-26.
Williamson, D., Lynch-Wood, G., and Ramsay, J. 2006. “Drivers of environmental behaviour in manufacturing SMEs and the implications for CSR.” *Journal of Business Ethics* 67(3): 317-330.
Winroth, M., Almström, P. and Andersson, C. 2016. “Sustainable production indicators at factory level.” *Journal of Manufacturing Technology Management* 27(6): 842-873.
Yacob, P., Wong, L.S., and Khor, S.C. 2019. “An empirical investigation of green initiatives and environmental sustainability for manufacturing SMEs.” *Journal of Manufacturing Technology* 30(1): 2-25.
Management,
Yang, M.A., Hong, P., and Modi, S.B. 2011. “Impact of lean manufacturing and environmental management on business performance: an empirical study of manufacturing firms.” *International Journal of Production Engineering* 129(2): 251-261.
Yao, X., Huang, R., and Song, M. 2019. “How to reduce carbon emissions of small and medium enterprises (SMEs) by knowledge sharing in China.” *Production Planning & Control* 30(10-12): 881-892.
Zhu, Q., and Sarkis, J. 2004. “Relationships between operational practices and performance among early adopters of green supply chain management practices in Chinese manufacturing enterprises.” *Journal of Operations Management* 22(3): 265-289.
Zollo, M., Cennamo, C., and Neumann, K. 2013. “Beyond what and why understanding organizational evolution towards sustainable enterprise models.” *Organization & Environment* 26(3): 241-259.

Bibliographic notes

Professor Peter Ball belongs to the People, Operations and Marketing Group at the University of York Management School where he is Director for Business and Community Engagement. His research focuses on how manufacturing operations can be designed and improved. Application areas span manufacturing, supply chain and service. He researches the practices used in manufacturing operations as well as researches modelling and simulation techniques to understand the performance of those operations. Environmental sustainability and resource efficiency feature strongly. Prior to moving to York, Peter was Director of Education for his school in Cranfield University.

Professor Jill MacBryde is Professor of Innovation and Operations Management in the department of Design, Manufacturing and Engineering Management at the University of Strathclyde. The theme throughout Jill's work is operations management in changing environments. Jill engages in collaborative research, often reaching across disciplinary boundaries. Jill’s “laboratory” is industry and she engages in useful research whilst at the same time helping to bring about significant improvements in business performance. Jill strives to ensure that her academic research, teaching and knowledge exchange activities feed off each other. Prior to moving to DMEM in Strathclyde Jill was Deputy Dean and Head of the Operations Management Group at The York Management School and earlier was Vice-Dean for Knowledge Exchange at Strathclyde Business School.