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Green Lean Six Sigma in the food industry: a systematic literature review

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Abstract

Purpose – The current paper aims to discuss the implementation of Green Lean Six Sigma (GLSS) in the food industry to improve sustainable practices. The focus is more specifically on dairy processors to ascertain the current state of the literature and aid future research direction.

Design/methodology/approach – Utilising a systematic literature review (SLR), the paper addresses various terms and different written forms in the literature. The study characterises the current deployment of GLSS in the food industry and explains the reported benefits of this approach.

Findings – GLSS, a concept that has yet to be fully explored in the food industry, as in other sectors, holds significant potential to enhance the food industry's sustainability practices. The dairy sector, a subsector of the food industry known for its high greenhouse gas emissions, is a prime candidate for the application of GLSS. In instances where it has been applied, GLSS has demonstrated its effectiveness in improving sustainability, reducing waste, lowering greenhouse gas emissions and minimising water usage. However, the specific tools used and the model for GLSS implementation are areas that require further study, as they have the potential to revolutionise food industry operations and reduce their environmental impacts.

Practical implications – Benchmarking of this research by the food industry sector and by academics can aid understanding of the practical application of GLSS tools and aid implementation of these practices to evolve the dairy processing sector in the next decade as sustainability champions in the sector.

Originality/value – This study extensively analyses GLSS in the food industry, with a particular focus on dairy processors.

Keywords Green lean six sigma, Sustainability, Waste reduction

Paper type Literature review

1. Introduction

Climate change – the significant shift in climate measures such as temperature and rainfall lasting decades or longer – is undoubtedly a major global issue that is progressing at an unprecedented rate (Fakana, 2020). The factors impacting climate change are various, and although some climate change is natural, anthropogenic factors are heavy contributors, and actions can be expressed in terms of their global warming potential (GWP). Whilst the overall

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food manufacturing system is responsible for an estimated 21–37% of emissions globally, agriculture is an outsized contributor, accounting for around half of total anthropogenic CH4 and around three-quarters of anthropogenic N_2O (Rosenzweig *et al.*, 2020). Indeed, it seems that much of the progress towards the 2030 and 2050 targets can be made at the farm level – in the dairy industry, agricultural activities associated with milk production account for 80.8–97.3% of the overall GWP of dairy product manufacture (Finnegan *et al.*, 2017). Lean and Six Sigma (LSS) tools have been used effectively in the food manufacturing space for decades and may represent an opportunity with regard to sustainability initiatives (Naik *et al.*, 2023). By their nature, LSS tools would appear to be a natural fit for green and sustainability initiatives.

However, compared to other industries, the deployment of LSS in the food industry is relatively immature due to a number of characteristics inherent to food manufacturing processes that do not naturally lend themselves to standardisation (Costa *et al.*, 2018). These include seasonality of raw material composition and supply, product demand and a strong requirement to meet food safety requirements at all costs, which may lead to over-processing, for example (Costa *et al.*, 2018, 2020). The use of LSS, specifically with sustainability goals in mind, has been termed "Green Lean Six Sigma" (GLSS) and has been deployed to varying degrees across different industrial sectors. Whilst LSS combined reduce non-value added waste and reduce process variation, when integrated with Green, there is a corresponding reduction of waste, emissions, energy and greenhouse gas (GHG) (Gilligan *et al.*, 2023; Trubetskaya *et al.*, 2023). Within the food industry, the topic of sustainability is a key concern, particularly for dairy processors. The majority of the environmental impacts of the dairy industry originate at the farm level, much of which is not in the direct control of the dairy companies (Almås and Brobakk, 2012; Green *et al.*, 2017). Whilst most of the governmental and national efforts are concentrated on agricultural improvements, there are also steps that dairy processors can take to contribute to the sector targets, as well as their sustainability ambitions (Sharma *et al.*, 2015). Whilst GLSS will not be a cure-all for sustainability challenges, it represents, for the most part, a methodology entirely within the hands of the dairy processors themselves. In Ireland, for example, a research partnership exists between the Dairy Processing Technology Centre (DPTC), headquartered at the University of Limerick, and most of the large dairy processors, focussing on reducing water usage, improving energy efficiency, reducing and treating waste and valorising dairy side stream (Dairy Processing Technology Center, 2015).

Organisations that embrace GLSS now may reap greater benefits in aiding compliance with regulations (Lim *et al.*, 2014) than if they are forced to scramble later to implement initiatives in response to ever-tightening regulatory requirements. However, some food industry characteristics, such as having to comply with strict food regulations, heavy cleaning requirements and frequent line changeovers, have sometimes deterred LSS applications (Azalanzazllay *et al.*, 2020). Systematic literature reviews are a well-established and utilised tool for literature research and have guidelines to allow some level of standardisation across studies (Page *et al.*, 2021). These types of studies have been effectively used in the past to summarise the application of LSS tools in the food industry (Costa *et al.*, 2018; Lim *et al.*, 2014), but to the author's knowledge, no systematic review of the application of GLSS in the food industry, particularly within the dairy industry, has yet been undertaken. Analysing the research in the food industry in relation to sustainable practices can aid in enhancing sustainable practices, and the dairy industry can benchmark the wider food industry.

The aims of this project were twofold:

RQ1. What GLSS tools have been used in the food industry?

RQ2. What are the results of GLSS in the food industry?

RQ3. What sustainability or sustainable practices have been addressed through GLSS tools in the food industry?

RQ4. What are the opportunities for future research?

Section 2 discusses the background of the study; Section 3 represents the methodology of a systematic literature review (SLR), whilst the results and discussion are presented in Sections 4 and 5. Finally, Section 6 outlines the study's conclusion.

2. Background to study

Originally used as the basis of the Toyota Production System, Lean manufacturing principles are based on identifying and eliminating waste, enhancing standardisation and increasing efficiency across the manufacturing process and supply chain (Jones *et al.*, 1990). Often used in tandem with Lean, Six Sigma encompasses a set of tools and behaviours aimed at controlling manufacturing processes to identify and eliminate sources of process variability and product defects (Snee, 2010). LSS has been beneficially deployed in the food industry, with value stream maps, cause-and-effect diagrams and 5S programmes widely used to reduce waste, increase productivity and improve financial performance (Costa *et al.*, 2018). There are also examples of the successful application of LSS in dairy applications, with higher customer satisfaction, improved process up-time, waste reduction and better employee motivation reported (Arslankaya and Atay, 2015; Noorwali, 2013).

Several literature reviews have been conducted in the area: Rathi *et al.* (2022) developed and validated a framework to reduce waste and emissions in manufacturing; Singh and Khamba (Singh *et al.*, 2021) summarised the key performance parameters for GLSS in manufacturing, and Kannan *et al.* (2022) created a framework for the success of green manufacturing based on identifying the main challenges and then employing a corresponding critical success factor (CSF). Some common themes emerge, including the importance of clear and specific green targets, e.g. extent of emissions reduction or the degree of waste removal. However, as mentioned previously, the food industry has inherent characteristics that differentiate it from other sectors, and whilst there are undoubtedly transferrable principles, the learnings from these studies cannot necessarily be applied to the food or dairy industry.

There is another driver that may compel companies towards green initiatives, be it through GLSS principles or otherwise. Sustainability is an increasingly important topic from a consumer perspective, and there may be an opportunity for producers to exploit a "green price premium", which may encourage companies to invest in GLSS (Yang *et al.*, 2020). Past studies have suggested that the motivation for employing LSS initiatives is linked to the benefits realised by a company. Brannstrom-Stenberg and Deleryd (1999) surveyed 83 Swedish companies across various industries. They reported that firms that introduced LSS voluntarily discovered the greatest benefits. In contrast, organisations that introduced LSS to address an external influence – e.g. regulatory requirements – were more likely to see only short-term improvements. One of the potential reasons for this is that companies that voluntarily introduce LSS are probably doing so with a specific focus on improvement and, therefore, will have linked the initiatives to business targets, which will invariably bring cost savings along with other benefits (Zu *et al.*, 2008).

Whilst diversification of the activities of dairy companies will contribute to improved sustainability, this is more realistically a medium- to long-term measure for most organisations. Within Ireland, for example, most of Ireland's major dairy companies, including Kerry Foods and Dairygold, offer plant-based alternatives to traditional dairy products, and Tirlán, Ireland's largest dairy processor, has a growing portfolio of oat-based ingredients and applications (Tirlan, 2022).

3. Methodology: systematic literature review

In order to ensure transparency and scientific robustness, a systematic literature review (SLR) was carried out (Chaudhary *et al.*, 2021; Kraus *et al.*, 2022). The systematic nature of this

type of literature review enables a detailed review, screening and analysis of the available literature (Dezi *et al.*, 2018; Madanaguli *et al.*, 2022). The method utilised was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 (PRISMA) guidelines (Page *et al.*, 2021). The PRISMA statement, published in 2009, was designed to help systematic reviewers transparently report why the review was done, what the authors did and what they found (Page *et al.*, 2021).

The project followed the following stages:

(1) Planning stage;

(2) Screening stage;

(3) Analysis stage and

(4) Reporting and discussion stage and framework proposal.

An outline of a flow chart for the review process is highlighted in Figure 1 below:

3.1 Planning stage

In the planning stage, a high-level review of review papers was conducted through the Scopus platform and by reviewing governmental and United Nations websites in order to understand the main challenges that sustainability is required to address, as well as the existing knowledge on GLSS in food and other industries. This was in order to be able to formulate the research questions to be answered by the project, which were developed as:

(1) What GLSS tools have been used in the food industry, and what sustainability challenges have been addressed?

(2) What are the key activities that could form the basis of a dairy industry GLSS project framework?

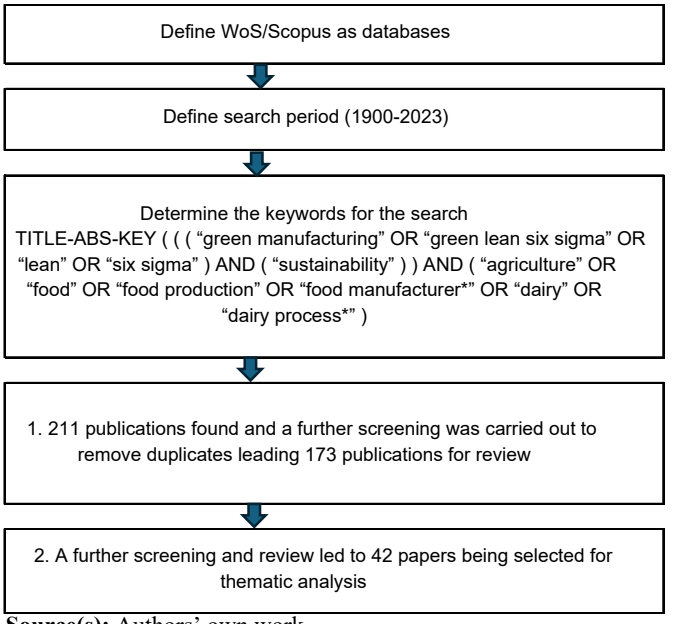


Figure 1.
The SLR process flow

Source(s): Authors’ own work

To answer these questions, a systematic literature review was conducted using the Scopus and Web of Science databases. The search terms were initially developed based on past LSS literature review searches, but with a trial-and-error aspect as the initial investigations returned results numbering in the thousands. To return a reasonable number of results with as much relevance as possible, searches were limited to matching terms in the title, abstract and keywords, and results were restricted to only English-language research papers and reviews. The search terms were developed to encompass LSS, sustainability and food production. The LSS terms used in the final search included "green manufacturing" OR "green lean Six Sigma" OR "lean" OR "six sigma", with the assumption that any relevant paper would consist of at least one of these terms in the title, keywords or abstract. The food terms used were "agriculture" OR "food" OR "food production" OR "food manufacturer*" OR "dairy" OR "dairy process*", in order to capture as many relevant areas of activity as possible. The wildcard functionality was used for "food manufacturer*" as this could then capture similar variants of the same concept – i.e. manufacture, manufacturing, manufactured, etc. Similarly, the term "dairy process*" was used to capture terms including processing, processor and processed. The term "sustainability" was included alongside the LSS and food words to maximise relevance in the search results, giving final search query strings outlined below. As Scopus and Web of Science use slightly different search term formatting, the query strings were structured slightly differently but constituted the same request. The Web of Science search below includes the operator "AB" at the start, requesting to search article abstracts only; this search was also repeated using the operator's "TI" and "KP" to search titles and keywords, respectively.

For Scopus:

TITLE-ABS-KEY (((“green manufacturing” OR “green lean six sigma” OR “lean” OR “six sigma”) AND (“sustainability”)) AND (“agriculture” OR “food” OR “food production” OR “food manufacturer*” OR “dairy” OR “dairy process*”)).

For Web of Science:

AB=(((“green lean six sigma” OR “lean” OR “six sigma” OR “green manufacturing”) AND “sustainability”) AND (“agriculture” OR “food” OR “food production” OR “food manufacturer*” OR “dairy” OR “dairy process*”)).

These searches returned a total of 211 articles for further screening to confirm their relevance. The exclusion criteria were set for any article that:

(1) Discussed LSS in a general sense or a context outside of sustainability;

(2) Discussed sustainability but had no clear focus on LSS tools or principles;

(3) Discussed GLSS outside of the food context and

(4) Otherwise clearly irrelevant, e.g. including the term "Lean" in the context of lean meat food processing or low-fat lean food, for example.

3.2 Screening stage

The first stage of screening was to remove duplicate entries, which were identified by transferring all of the article details to Microsoft Excel and using the conditional formatting function to visually highlight repeat entries of titles (Al-Zubidy and Carver, 2019). In this process, 39 articles were removed, and the titles and abstracts of the remaining 173 were reviewed for relevance against the exclusion criteria. Of these, 4 were released as they were unrelated to the food industry, 19 did not focus on LSS, 19 did not deal with sustainability and 74 were removed for having incomplete reference information or being otherwise clearly irrelevant. The remaining 58 sources were then sought for further review, and that yielded 42 articles remaining for detailed analysis. Each paper was assessed for general characteristics,

including year of publication, country of origin of the lead institute, area of sustainability addressed and type of food manufacturing activity involved. To address the research questions, the papers were assessed for the types of LSS tools used and for which applications – i.e. CO^2, GHG and energy reduction, waste reduction or water usage reduction. This information was transferred to an Excel-based database to facilitate data analysis and thematic coding (Cascio *et al.*, 2019).

3.3 Analysis stage

The data generated in the screening stage were analysed to identify any notable trends in the research in the area, understand the applications of the different tools and summarise the sustainability benefits reported. Studies were classified based on whether they were primary studies of GLSS in food, if they were review papers or if they were related to GLSS in food but did not fit in either of the previous two categories. Visualisation was carried out using JMP software (JMP, 2021).

3.4 Reporting and discussion stage

The summarised and analysed data were examined to understand the general findings, as well as their potential significance in the dairy industry, using coding and memoing (Birks *et al.*, 2008; Cascio *et al.*, 2019). The content analysis utilising the aforementioned techniques enable a thorough understand of the literature themes (Ramos Cordeiro *et al.*, 2023).

4. Results

4.1 Summary of final selected papers

Around 13 primary research papers were identified, and analysis revealed that value stream mapping, kaizen, life cycle analysis (LCA) and structured problem-solving methodologies were the most commonly used tools. The majority of the case study applications took place in larger enterprises (LEs) with over 250 employees, as these organisations had larger budgets and resources to deploy in GLSS projects (see Table 1).

VSM and kaizen were also previously identified as two of the most common LSS tools in the food industry (Costa *et al.*, 2018), so, unsurprisingly, these more established practices have been the most common port of call for the initial GLSS journey.

Various structured problem-solving methodologies were also reported (Figure 2), including plan-do-check-act (PDCA), define-measure-analyse-improve-control (DMAIC), root-cause-analysis (RCA) and A3 problem-solving. For the current review, these four tools could have been grouped as "structured problem solving", but it is valuable to understand which instruments are used most. Interestingly, there was an even spread of usage in this case. In practical terms, the differences between PDCA and DMAIC are minor. In general, PDCA is a simpler tool to use and, like A3 problem-solving, can be more based around a Lean mindset, whereas DMAIC and RCA tend to be more data driven. The one or ones that an organisation may choose to employ could depend on their LSS maturity or simply the complexity of the issue with which they are faced. Still, regardless of the tool selected, it is surprising that almost half of the studies included structured problem-solving rather than relying on more holistic approaches such as Value Stream Mapping (VSM).

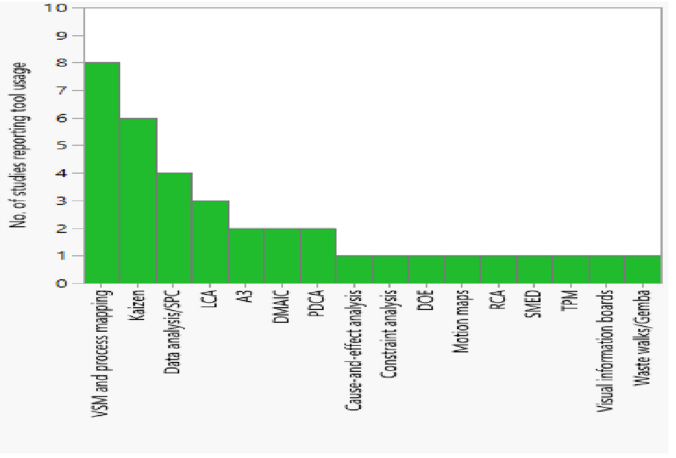
Three studies included life cycle analysis (LCA), an important tool for understanding and verifying sustainability improvements. In the next decade, the extent of LCA studies can increase exponentially as sustainability becomes a priority for food manufacturers.

Most of the tools reported in only one study originated from a survey of 34 Swedish farms conducted to understand the extent of GLSS implementation before, during and following an education and training programme (Barth and Melin, 2018). Although over a dozen tools were

Study	GLSS tools used	Industry application area	Sustainability benefit
Antomarioni *et al.* (2018)	VSM and kaizen	Food processing	GHG/energy reduction
Chabada *et al.* (2013)	VSM and LCA	Food processing	Waste reduction
Valenti *et al.* (2020)	LCA	Waste handling	GHG/energy reduction and waste reduction
Baca-Nomberto *et al.* (2021)	PDCA and kaizen	Supply chain	Waste reduction
Folinas *et al.* (2014)	VSM, SPC, kaizen and takt time	Food processing	Water reduction and GHG/energy reduction
Amani *et al.* (2015)	DMAIC, process mapping, DOE, SPC 5 whys	Food processing	Waste reduction
Srinivasan *et al.* (2023)	Mathematical modelling	Food processing	Waste reduction
Powell *et al.* (2017)	VSM, DMAIC, SOP SPC and RCA	Food processing	Waste reduction
Oglethorpe and Heron (2010)	VSM and LCA	Supply chain and food processing	Waste reduction and GHG/energy reduction
Kazancoglu *et al.* (2021)	VSM and kaizen	Food processing	Waste reduction
Barth and Melin (2018)	VSM, PDCA, 5S, A3, motion mapping, SMED, TPM, cause and effect, SOP, waste walks, bottleneck management and visual information boards	Milk production	Waste reduction and GHG/energy reduction
Marques *et al.* (2022)	Gemba, kaizen and A3	Food retail	Waste reduction
Viles *et al.* (2021)	Run charts	Food processing	Water reduction

Source(s): Authors' own work

Table 1. Summary of studies reporting the use of LSS tools for sustainability



Note(s): The field "data analysis/SPC" also encompasses run and control charts for ease of comparison

Source(s): Authors' own work

Figure 2. Summary of the number of studies that reported the usage of each LSS tool

reported to be used by the farmers interviewed, 5S, standard operating procedures and visual information boards were the most commonly used lean tools. To see these tools being most widely used is expected – farmers will have naturally removed much, high-level waste from their processes, and the tools highlighted here serve to understand and optimise the essential activities that remain.

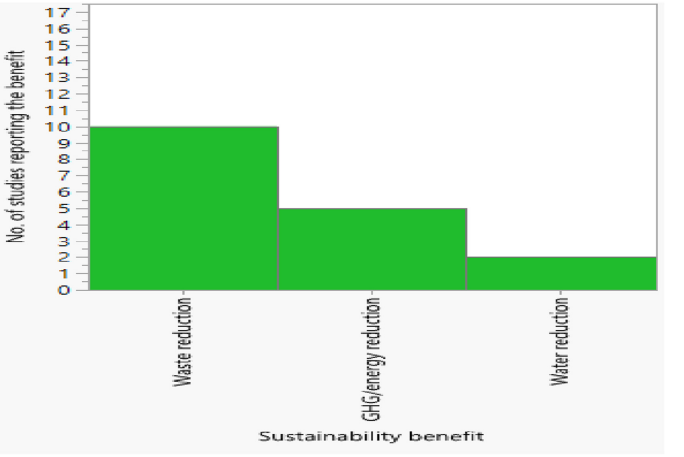
Some Lean tools were not reported in the studies, including Kanban and just-in-time; however, these are already common operational tools in the food industry (Costa *et al.*, 2018) and are more directly related to operational efficiency than addressing specific sustainability issues. Although a mixture of Lean and Six Sigma tools was used in the studies analysed, it is clear that the emphasis was mostly on lean tools. Only four studies reported data analysis-type activities in Six Sigma, which may represent a major opportunity for future improvements in GLSS. However, as mentioned for VSM, it will be vital to have reliable measures of sustainable practices to benchmark, set targets and verify and sustain the improvements.

One tool that was not captured in any study but that could be one of the most vital to the ongoing success of a GLSS initiative is Hoshin Kanri. However, two studies by McDermott *et al.* (2022a, b) on using LSS in MedTech and Pharma industries found Hoshin Kanri the least utilised. Utilising Hoshin Kanri can aid in integrating sustainability goals into the key organisational goals and help the implementation of GLSS and associated resources have a much higher chance of success.

Finally, the Barth and Melin (2018) study served to highlight an inherent limitation of literature reviews such as the current one, in that some GLSS activities will already be underway at farm, processing and supply chain levels but will go unreported in the literature unless they are the subject of an empirical study. So, whilst GLSS is not extensively embedded in the food industry, its application will undoubtedly be more widespread than it may appear from publicly available information. In this sense, food manufacturers would be well-served by mutually sharing learnings and best practices, for example, in government-led pre-competitive industry-academic forums.

4.2 Analysis of environmental benefits

As expected, the most common benefit reported was waste reduction (Figure 3), with 10 studies reporting an improvement. As mentioned, waste reduction is a key tenet of Lean and is the most natural fit for GLSS initiatives. Almost half of the studies reported reduced GHG



Source(s): Authors' own work

Figure 3.
Summary of the number of studies that demonstrate benefits in each sustainability area

emissions and reduced energy usage, a lower rate than expected considering the emphasis on carbon reduction in the overall discussion around sustainability. This is a focus area for the food industry, with hard limits to comply with by 2030, so GLSS may be an important resource to support the carbon goals. Surprisingly, only two studies focussed on the benefits of reduced water usage. As we approach a water crisis, industry must reduce its reliance, and much work remains to be done to optimise processes.

4.3 Analysis of review articles

Several interesting review papers were identified during the present study, which did not focus on all relevant aspects but contained valuable insights (Table 2). In many cases, the limiting factor for the study, in the context of the current review, was a lack of discussion of LSS tools – instead, the articles tended to focus on more conceptual approaches to GLSS. In the cases where GLSS tools were discussed, the reviews only touched briefly on the food industry, if at all. The most comprehensive and relevant review was by Muñoz-Villamizar *et al.* (2019), who focused on Green Lean-focussed papers but found only four articles relating green and lean to the agri-food sector. Interestingly, across all of the 117 documents reviewed, this study also found VSM to be the most commonly applied LSS tool, owing to its focus on distinguishing value from waste. LCA was also a widely reported tool. However, the study noted that using this in food systems is not straightforward due to a lack of understanding of many environmental mechanisms.

5. Discussion

Unsurprisingly, as Industry 4.0 and digitalisation are still starting to be embraced (Antony *et al.*, 2021), GLSS is still an emerging area within the literature. Similar SLR studies related to Lean 4.0, LSS 4.0, Lean Supply Chain (LSC) 4.0 and Green 4.0 have highlighted the same dearth of literature in relation to operational excellence topics and Industry 4.0 (Antony *et al.*, 2022a, b; Rossini *et al.*, 2022).

Study	Aim of review	Gaps, in terms of GLSS in food
Xian *et al.* (2017)	Discuss how production lines can be made greener by employing "eco-materials."	Did not discuss specific LSS tools
Muñoz-Villamizar *et al.* (2019)	Discuss overlap and gaps between traditional lean and green lean approaches	Only four papers focused on lean green in an agri-food context
Lange and Meyer (2018)	Discuss the pros and cons of using biorefinery products to contribute to the circular economy	Did not discuss specific LSS tools
Kaswan and Rathi (2020)	Propose a framework for GLSS integration	It was not specific to the food. industry
Choirun *et al.* (2020)	Discuss sustainability risks in the agri-food supply chain	Did not discuss specific LSS tools
Caicedo Solano *et al.* (2020)	Propose a conceptual model for integrating lean into agricultural production systems	Did not discuss specific LSS tools
Mutabuki and Chirinda (2020)	Propose waste minimisation techniques in various food manufacturing industries	Did not discuss specific LSS tools
Yadav *et al.* (2021)	Discuss the current GLSS Application in industry	It was not specific to the food industry
Rodrigues and Franco (2023)	Understand sustainability practices and concerns for SMEs through interviews	Did not discuss specific LSS tools

Source(s): Authors' own work

Table 2. Summary of review articles referencing GLSS

5.1 Implementation prospects for GLSS in the food industry

In reviewing the tools most prominently used in the primary studies, it is striking that the most common techniques (e.g. VSM and kaizen) are approaches that are already quite common to many areas of the food industry. This is a promising finding, as it suggests that implementing GLSS should not be radically different from implementing a general LSS program. This is not to say that it would not be without its challenges, but any existing staff training and experience would be directly transferrable to GLSS projects. One exception may be the use of LCA – this tool is unlikely to be familiar to the average food industry LSS practitioner, and specific education and training may be required. Similarly, an additional requirement for an effective GLSS may be recruiting a sustainability champion. This would be an expert who can advise on the business's challenges, the most appropriate projects to select and the most relevant metrics to measure. Finally, projects may also require the input and training of team members with specialised knowledge of the plant but who may not have previously been regularly part of LSS initiatives, e.g. experts in the plant's water usage and energy requirements.

One topic that has not been directly discussed is the enablers of successful GLSS implementation and the most prominent barriers. The primary studies reviewed did not include enough specific information or discussion around these topics to allow them to be considered in any depth. However, enablers and barriers to LSS, in general, have previously been discussed at length elsewhere in the literature (Costa *et al.*, 2018, 2020). It is safe to assume that many of the same factors will apply to GLSS, including the importance of management support, staff training, the LSS maturity level of the organisation and employee engagement. However, as mentioned previously, an additional barrier that may be more consequential to GLSS is the potential lack of reliable sustainability measures around which to design improvement projects (Arun *et al.*, 2021).

5.2 Potential unrealised opportunities

A clear lack of Six Sigma application was identified in the primary studies, which may represent a significant untapped opportunity for the food industry. In particular, design of experiments (DOE) could be a vital tool in developing more sustainable processes in manufacturing environments by first employing screening experiments to identify the primary contributors to a given metric before using targeted experiments to devise mathematical optimisation models (Granato and de Araújo Calado, 2014). This approach would not necessarily be new to the dairy industry (Galvis *et al.*, 2022). However, the focus would be more specialised, and some training would be required in organisations not experienced in using the tool. The dairy industry continues to grow and operations continue to expand, and whilst retroactively introducing changes to existing operations could potentially be challenging, DOE is ideally suited to the upfront design and optimisation of new processes to take a sustainability-centred quality-by-design approach.

6. Conclusion

The topic of sustainability is a key concern for the food industry, particularly for dairy processors. The theoretic implications of the study are that it responds to calls from both the literature and industry to address how GLSS can be utilised to improve the sustainability strategy within the food industry. Benchmarking this research by academics can analyse the practical application of GLSS tools and aid their implementation to evolve the dairy processing sector into the next decade as sustainability champions. This study has practical implications for government policy to leverage the learnings as food, and in particular, dairy producers will require some government and academic support in their high-level sustainability goals, especially in emerging areas like waste valorisation.

Future research on the use of GLSS in the food industry should enable studies into the barriers to GLSS in the food and dairy industry. Also, research could investigate how the availability of sensors and data to detect and quantify – for example, energy waste by excessive heat loss in the production environment can aid GLSS.

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