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Sustainable Production and Consumption 16 (2018) 110–120

Contents lists available at ScienceDirect

Sustainable Production and Consumption

journal homepage: www.elsevier.com/locate/spc

Research article

Sustainability checklist in support of the design of food processing

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ARTICLE INFO

Article history:
Received 6 December 2017
Received in revised form 25 June 2018
Accepted 30 June 2018
Available online 2 July 2018

ABSTRACT

To source food ingredients produced by best practice, reducing food loss in the processing line and implementation of new technologies are some examples of changes in the management in the food and drink sector that may offer advantages from a sustainability perspective. There are several tools and methods for evaluating sustainability for a food processing technology but often specific methodological knowledge is essential and many companies may not be able to carry out such a study due to time constraints and lack of data. The aim of this paper is to provide a tool with the format of a qualitative sustainability checklist, based on existing Life Cycle Assessment theory. The checklist is devoted to the design and adaptation of processing in the food industry to clarify the potential hot spots in new process design and is focused on environmental sustainability, although other aspects were conferred as well to demonstrate its potential. To identify the potential of this kind of checklist, it was tested by four food companies. The participant feedback was in general positive. The companies highlighted the benefits of creating awareness of sustainability issues within the company and providing a good overview without data collection. From a scientific point of view, the approach can help to overcome several challenges in sustainability assessment in the agri-food sector, especially some modeling issues and spatio-temporal resolution.

1. Introduction

The food and drink industry is a leading manufacturing sector in Europe (FoodDrinkEurope, 2017a) representing a central part of the agri-food chain that produce food and bio-based products (e.g. biochemicals, biofuels, biopackaging). Food processing provides added value to final products by enhancing their functional, nutritional, sensorial and safety properties. At the same time these processing steps face various challenges with regards to the sustainability of food systems such as environmental concerns (e.g. climate change, biodiversity, waste management, water and soil quality preservation), and encompassing a range of issues such security of supply, health, safety, quality, and affordability. Food production needs to increase; globally approximately 795 million people go hungry and about 2 billion people are malnourished. It is projected that world food supply will increase by 70% to feed almost 10 billion people by 2050. Simultaneously, approximately 30% of the global adult population is overweight or obese, and circa 30% of food produced worldwide is lost or wasted. The food sector has been reported to account for around 30% of the world's total energy consumption and around 22% of total Greenhouse Gas emissions (UN Sustainable Development Goals, 2018). Greenhouse gas emissions of the food supply chain have been calculated to be mainly due to the agriculture stage (70%), as has been reported for single food items (Corson and van der Werf, 2012), followed by food manufacturing (10%), logistics (about 7%), packaging (5%), use (5%), and waste disposal (4%) (Notarnicola et al., 2017).

One option to reduce the sustainability footprint of a food product is to improve or substitute the technology used in the processing step. The environmental benefits can be increased processing efficiency, but also to allow processing of raw materials produced more efficiently (Meynard et al., 2017). New food processing technology can also create new high quality food products (e.g. products with lower sugar or fat levels). A change in technology can also result in economic gains (directly on production site or indirectly by improving the performance in the food chain further downstream). To fully evaluate food processing technology changes, an assessment of the environmental, economic and social sustainability impacts would be needed, along with the more common criteria such as quality, food safety and expected return on investment.

Life Cycle Thinking, i.e. going beyond the traditional focus on the production site and the manufacturing processes per se, to include

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https://doi.org/10.1016/j.spc.2018.06.008

environmental, social and economic impacts of a product over its entire life cycle and value chain, is recognized as fundamental for addressing the sustainability of food systems (Notarnicola et al., 2017). In addition, the Environmental management standard (ISO 14001:2015, 2015), substituting (ISO 14001:2004, 2004), require that organizations identify environmental aspects of activities, products and services that it can control and curb, taking into account a life cycle thinking, and measure those having a significant environmental impact using established methods. The new version of the standard has also sharpened its requirements urging organizations to take into account other stakeholders' potential interests and needs. This change will require organizations to look at the environmental impact of their activities in a broader perspective than before. This increases the need for tools that can provide a quick and easy evaluation of the sustainability aspects of supply chains and product portfolios.

There are several tools and methods for evaluating sustainability for a food processing technology and the most recognized environmental assessment method is Life Cycle Assessment (LCA). Life Cycle Assessment is a standardized methodology (ISO 14040:2006, 2006) which allows quantifying the environmental impacts of a product, process or service along its whole life cycle. This approach is widely used for food production systems and their supply chains (Roy et al., 2009). Life Cycle Assessment can highlight hotspots (e.g., ISO 14040:2006, 2006), key stages to optimize or re-design the system, or can be a basis to compare different existing or under-development scenarios (e.g. Davis and Sonesson, 2008; Pardo and Zufia, 2012; Aronsson et al., 2012). As mentioned, sustainability performance addresses not only environmental but also economic and social issues and complementary life cycle approaches have also been developed such as CALCAS (Klöpffer, 2003), Life Cycle Costs (LCC) for economic sustainability, and more recently social Life Cycle Assessment (sLCA) for social sustainability. There is also ongoing work on how to combine all three pillars in one approach in a Life Cycle Sustainability Assessment (LCSA). The Life Cycle Sustainability Triangle developed by Hofstetter et al. (1999) and the Life Cycle Sustainability Dashboard by Traverso and Finkbeiner (2009) are two examples of this. However, the application of LCSA is still limited, and the majority of studies undertaken investigate the interface of environmental and economic aspects (Zamagni et al., 2013). Nevertheless, sustainability can be fully assessed following the triple bottom line by combining the existing LCA methods for each pillar, or by using an LCSA approach.

LCA studies require knowhow of the methodology and can be time consuming with large amounts of data to collect. A company may not have the resources to carry out such a study and subcontracting a specialized consultancy firm is not always possible, both for economic and confidentiality reasons. This is especially true in SMEs, which constitute more than 99% of food and drink European companies, and account for more than 63% of food and drink European employment (FoodDrinkEurope, 2017b). The food and drink industry is based mainly on traditional recipes, products and processes and is lagging behind other manufacturing sectors when it comes to product and process innovations (Langelaan et al., 2013). Hillary (1999) identified SME resources (mainly time, costs and human resources), attitudes and company culture (beliefs, scepticism) and low awareness (environmental legislation, support organizations, sources of information) as internal constraints and barriers for successful implementation of environmental improvements. Even though Hillary (1999) published the possible barriers almost 20 years ago they are still relevant today.

As previously mentioned data collection for a LCA analysis can be time consuming and data are not always available or reliable, either because they are difficult to acquire or because they do not exist yet, which is often the case when innovations are under development. This is a drawback, because when a new product or process is designed, the decisions taken during its early development phase widely determine its future impacts (McAloone and Tan, 2005). Will the new product or process result in a more sustainable food system? It could serve us well to reflect on this question from the very beginning (Buchert et al., 2015). This type of evaluation needs to be considered through the whole product or process development phase, regardless if it is in the development of new or the optimization of existing products or processes.

Due to the challenges stated above there is a need for less demanding eco design tools particular in the early design process (Hallstedt et al., 2013). It has been reported that three key-factors should make up an eco-design tool: early integration of environmental aspects (and, by extension, sustainability aspects) into the design process; the life cycle approach and a multi-criteria approach (Bovea and Pérez-Belis, 2012). Whereas a quantitative assessment (such as LCA according to the ISO standard) fail to fulfill this purpose when there is a lack of data, qualitative tools can meet this challenging task, by providing a better understanding of the system performance from the very beginning, even before any quantitative data becomes available.

Among existing qualitative methods, checklists have been developed for both assessment and design which include the early stages of product development (Pigosso et al., 2016). Checklists consist of a series of questions that are formulated to help designers to work in a systematic manner when addressing sustainability issues during the design process. A common approach in an eco-design checklist is to focus on environmental issues (Brezet et al., 1997). It is also common that it is life-cycle-based, that it focuses on the environmental dimension and is mainly devoted to manufactured products. Simplified guidelines have also been developed, for example eco-design of packaging (French Packaging Council, C.N.E., 2012). These guidelines include a checklist defined by experts in the packaging industry. The checklist's questions are grouped according to several key-points related to a packaged product's life cycle.

The main difficulty when developing a checklist is to identify the key-points that has to be covered. To include all three pillars of sustainability in an assessment or design tool is a challenging task but such tools are under development for certain industries (Feil et al., 2015). Generic indicators for measuring sustainability in micro and small industries have been suggested in the furniture area by combining literature review, text mining, and analysis of expert skills (Hallstedt, 2017). However, it has also been stated that sustainability criteria are company specific and most likely even branch specific (Arena et al., 2009). Furthermore, for a given sector, it is necessary to know what is meant by sustainability, how it can be achieved and how it can be measured (Arena et al., 2009). There are quantitative simplified LCA tools for the food industry (Arzoumanidis et al., 2017), but according to our knowledge there is as yet no tool for a qualitative sustainability assessment for food processing development.

The aim of this paper is to investigate the possibility to qualitatively include sustainability considerations in food processing design at early stage of the design process, and especially when a new food processing technology is implemented. With this purpose, the relevant sustainability issues for the agri-food sector have been identified, based on both literature review and practitioners interviews and surveys. The items have been formalized in as a qualitative sustainability checklist. The aim of the qualitative checklist is to be used as a first screening that will give some initial insight into what aspects are important to consider when it comes to the sustainability performance of food processing. It was structured to cover the three pillars of sustainability: environmental, social and economic, in a life cycle approach. The scientific contribution of the approach, both for practitioners and sustainability assessment science, is also discussed.

Table 1
The checklist development procedure.

Step	Tasks	How?	Results
Background research	Problem identification	Review of management science literature	Issue of considering sustainability concerns at early stage of design process
	Review of impacts of food production	Review of LCA literature	Formulation of checklist categories based on LCA impact categories and literature (Section 2.1)
	Setting up design criteria	Review of existing tools	Design criteria and evaluation criteria (Section 2.2)
Draft version based on checklist categories	Evaluation and feedback	Feedback from two research groups and one SME	Section 3.1
First version	Evaluation of the up-dated checklist and feedback	Feedback from two research groups and two SMEs	Section 3.1
Final version (Table 3)	Evaluation of usability and relevance for the companies based on feedback questions	Feedback from one large company and three SMEs	Section 3.1

2. Materials and methods

The work was conducted in a step by step process which is summarized in Table 1.

2.1. Assessment of relevant impacts of food production

Many studies exist on the environmental impact of food production. With input from published studies (Roy et al.; Arvin Mosier et al., 2004; Ulén et al., 2007; Hoekstra and Mekonnen, 2012; Ölmez, 2014; Wang, 2014; Sonesson and Davis, 2005; Marsh and Bugusu, 2007; Naturvårdsverket, 2008; Wakeland et al., 2012; Williams and Wikström, 2011; James and James, 2010, 2014; James et al., 2009; Dobbs et al., 2011; Gustavsson et al., 2011; Green and Johnston, 2004; Adenso-Diaz and Mena, 2011; Koellner et al., 2013; Delai and Takahashi, 2011) an assessment of what environmental burden is relevant to consider in food production systems was conducted. A limited selection of literature was also explored for identifying issues regarding social and economic performance (Delai and Takahashi, 2011; Steger et al., 2007; W.H.O., 2015). The findings are summarized below.

2.1.1. Environmental performance

The main environmental hotspot for food production is generally the primary production stage (agriculture, aquaculture or fishing stage) where the food ingredients are produced. The main environmental impact from the primary production is connected to the use of mineral fertilizer and their subsequent nitrous oxide emissions, organic manure use and handling which also gives rise to nitrous oxide emissions and methane emissions from ruminants' enteric fermentation. Energy use (e.g. diesel for fishing boats or tractors, drying grain etc.) also contributes to the farm stage environmental impact. Depending on the location water use can have a large impact as well as the effects on biodiversity.

After the production stage follows the processing of raw material. At the processing stage energy use is often of importance and packaging materials can have a potential impact as well. The transport stage is often not considered a hotspot unless a fresh product is transported by air. At retail, energy use for storing the food product can be of importance and also the use of refrigerants in cooling equipment. The consumer stage and disposal stage of a food product can be difficult to act on or control from a food producer's perspective but the food producer plays a crucial role in influencing the environmental impacts occurring in these stages. For instance, a producer can choose to use recyclable packaging material which will be a key factor to drive consumer behavior and thus the disposal stage. Also, if a food product needs to be cooked or only reheated is a design choice by the producer which will influence the energy consumption at the consumer stage.

It is important to be aware that even though the major environmental impact for a food product generally occurs before it reaches the food processing plant, this does not mean that the food processor cannot have an effect on the environmental life cycle performance of the product. On the contrary, the food processor can make choices that are crucial to the overall life cycle impacts. For example, by enhancing the utilization rate of raw materials, fewer raw materials can be used per produced food item reducing the impact from primary production, hence playing a notable role for the total impact.

To assess the environmental impact in LCA, an impact assessment method is used. There are impact categories linked to the impact assessment method which divides the environmental impact into categories, such as climate change, eutrophication, acidification etc. From the explored studies of environmental impacts of food products (Roy et al.; Arvin Mosier et al., 2004; Ulén et al., 2007; Hoekstra and Mekonnen, 2012; Ölmez, 2014; Wang, 2014; Sonesson and Davis, 2005; Marsh and Bugusu, 2007; Naturvårdsverket, 2008; Wakeland et al., 2012; Williams and Wikström, 2011; James and James, 2010, 2014; James et al., 2009; Dobbs et al., 2011; Gustavsson et al., 2011; Green and Johnston, 2004; Adenso-Diaz and Mena, 2011; Koellner et al., 2013; Delai and Takahashi, 2011) and using environmental impact categories from the ReCiPe methodology (Goedkoop et al., 2009) we created checklist categories covering all the important impacts from food production. The questions in the checklist corresponds to the checklist categories, see Table 2.

2.1.2. Social performance

A socially sustainable workplace ensures employee safety, health and well-being, human capital development, rural development and labor practices (e.g. no child labor, no discrimination, freedom of association, and access to health care). The role of the company in society is also important and within this framework the corporate social responsibility (CSR) is a concept that is becoming more and more important for the private sector to integrate the economic, social, and environmental imperatives of their activities. Despite the efforts of trying to incorporate social issues in evaluating sustainability only a few tools cover the three pillars of sustainability. Social consequences are typically less quantifiable and less easily measured than economic and environmental

Table 2
An illustration to show that the most important environmental impact categories for food production are included in the checklist. From LCA methodology (ReCiPe), environmental impact categories relevant for food production and processing, links with contributing sources in the food system for each category and the corresponding checklist categories.

Environmental impact category	Contributing sources in the food system	Checklist categories
Climate change (CC)	Mineral fertilizer use, Energy, cold media, transport, food waste, livestock emissions	Raw materials, Energy, Packaging, Storage, Transport, Waste
Ozone depletion (OD)	Cold media, Fertilizer production	Raw materials, Storage, Transport
Terrestrial acidification (TA)	Organic manure application	Raw materials
Freshwater eutrophication (FE)	N and P-leaching soil from agricultural activities, transport	Raw materials, Transport, Waste
Marine eutrophication (ME)	N and P-leaching soil from agricultural activities,, transport	Raw materials, Transport, Waste
Human toxicity (HT)	Pesticide use	Raw materials, Transport, Waste
Photochemical oxidant formation (POF)	Transport, storage	Transport, Storage
Particulate matter formation (PMF)	Transport	Transport
Terrestrial ecotoxicity (TET)	Pesticide use	Raw materials
Freshwater ecotoxicity (FET)	Pesticide use	Raw materials
Marine ecotoxicity (MET)	Pesticide use	Raw materials
Ionizing radiation (IR)	Transport	Energy, Transport
Agricultural land occupation (ALO)	Land use	Raw materials, Spatial planning
Urban land occupation (ULO)	Land use	Raw materials, Spatial planning
Natural land transformation (NLT)	Land use, land use change	Raw materials, Spatial planning
Water depletion (WD)	Water use	Raw materials, Water
Mineral resource depletion (MRD)	Fossil fuel use	Raw materials, Energy, Transport, Storage
Abiotic resource depletion (ARD)	Fossil fuel use, energy use	Raw materials, energy use, Transport

effects. Companies can have difficulties in setting benchmarks and following up on indicators if the core business is in conflict with commitments to protect the environment and supporting broader societal structures.

Another aspect of social concerns relates to the impact of foodstuffs on the consumer (e.g. health). These aspects are hard to realize from an industrial point of view; despite this, it is important to raise the question and bear it in mind.

2.1.3. *Economic performance*

A company will only invest in a new technology if it will contribute to increased revenue. This will be assessed on a company level. Here we try to assess the potential of the technology in a wider perspective. As for the social indicators described above it is a very tentative assessment only including three aspects: economic growth, trade and food security. The contribution to economic growth is assessed by raising the question of whether the new technology will lead to future investments. The contribution to an increased trade is assessed by looking into the potential effect on export and import on the European market.

2.2. *Setting up design criteria*

Based on the review described in Section 2.1, a set of indicators was developed and a corresponding checklist covering different categories (energy, transport etc.) was created. The checklist is devised on a chosen set of criteria, partly inspired by the findings from Hallstedt et al. (2013) presenting a set of key criteria for successful implementation of the sustainability perspective in the early phases of innovation.

A list of the selected design criteria for the checklist:

- Not to provide 'answers' on what *is* - or *is not* sustainable, but to raise awareness for the user on what is important to consider, and why
- Based on life cycle thinking
- Possible to use early on in design processing, even when data might not be available
- Include all three pillars on sustainability: environmental, social and economic aspects
- Based on up-to-date knowledge on sustainability aspects of food production

A list of the selected evaluation criteria for the checklist:

- Easy to use for non-LCA experts
- Relatively quick to use

2.3. *Iterative development of checklist with practitioner feedback*

The checklist was developed in three stages following the practitioner feedbacks that were obtained at each stage.

The first draft was tested by stakeholders (one SME and two research groups).

The next round of feedback was conducted from two research groups and two SMEs.

The final version of the checklist was then tested by a large company and three SMEs:

A: Company producing food and feed products, 10 000 employees

B: Company producing dried herbs, less than 250 employees

C: Company developing food processing technology, less than 250 employees

D: Company developing food processing technology, less than 250 employees

The companies were asked to test the checklist and then to fill out the following feedback questions:

- How do you implement/take into consideration sustainability when developing new projects/processes / products today?
- How relevant would it be for you to use a tool like this checklist?
- How much time would you spend to use this form?
- What are the benefits of this form?
- What are the drawbacks of this form?
- Which work role(s) in your organization would benefit from using this form? Does he/she have the skills to answer the questions?
- Are the questions easy to understand?
- Do you think some other questions should be included?

The number of companies which provided feedback is very low compared to the number of companies in the food and drink industry. This limited sample test was chosen to focus on the method development and will be scaled up at a later date.

3. Results and discussion

3.1. Checklist evaluation by practitioners

3.1.1. Draft version

In the draft version the checklist was set up so that the user only had the option to answer 'yes', 'no' or 'no change' to each question when changing from one processing practice to another. One example was: does the new process require more energy?

The draft version was used as a part of a three step model in order to support the development of sustainable preservation technologies in the project PRESERF (PRESERF FP7 Grant Agreement 245280). The three step model consisted of the draft version of the checklist, a semi qualitative tool based on selected parameters and indicators. Complete LCAs was to be carried out in conjunction during the development phase of a new technology. Three novel process technologies were developed and assessed using the three step model. The process technologies investigated were Freeze protection, CPT (CO_2 pasteurization) or CPT-HPU (CO_2 pasteurization combined with Ultra Sound) and CO_2 drying (Final Report Summary PRESERF, 2018).

It was concluded that by comparing the qualitative results to the quantitative LCA results, qualitative indicators can work well as a quick screening tool to evaluate possible effects of changes on process and supply chain level, provided that the person/s filling out the checklist have good knowledge about the process technology.

The draft version in this case thus served as an educating tool; by supporting the dialog between the teams developing the process technology and the team evaluating the sustainability. The use of the checklist highlighted the impact on a systemic level rather than focusing solely on the direct changes in the process step and supported the setup of supply chains for the semi quantitative LCA and finally the complete LCAs.

The 3-step "model" created in the project was shown to have benefits and disadvantages. Specifically, the benefits of the qualitative checklist and the semi-quantitative tool are that they are simple and cheap but a disadvantage was that it only provides 'food for thought' in early stages of development. In addition, the feedback on the checklist itself showed that the option to answer 'no change' was difficult to interpret, and that there was too much explanatory text in the checklist. The users were not able to pinpoint any hotspots in their system. Consequently, an updated version was developed.

3.1.2. First version

The first version of the checklist was designed differently; the ambiguous option to answer "no change" was omitted. The explanatory texts were condensed to the most vital aspects, to make it easier for the user to follow. This time the users found it easier to respond to the questions, but still thought that the format could be made more appealing, and that some questions were unclear. Hence, this first checklist has been fine-tuned into the final version.

3.1.3. Final version

The final version of the checklist is presented in Table 3. The feedback on the final version of the checklist provided by the participating companies is compiled in Table 4. For confidentiality reasons, answers are anonymous and have been synthesized in the table.

The participating companies took sustainability into consideration when developing new processes or products, except for one SME which only did early research. The concerns identified by participating companies were for environmental and economic sustainability. The use of raw materials and company costs were especially important issues. The participating companies were different; nevertheless the feedback was quite consistent. The main benefit of the checklist was that it provided awareness of food sustainability concerns by giving a detailed overview in a life cycle approach, including less obvious aspects.

The main selected design criteria for the checklist was clearly pinpointed by the companies: life cycle thinking, including all three pillars of sustainability, devoted to food production, raising awareness of what is important to consider and why, useful early in the design process, easy and quick to use.

The relevance of the checklist was highlighted by the participating companies, especially because it provides supporting elements to address sustainability earlier in the design process than the companies are currently addressing. We envisage that using a checklist similar to ours delivers value in terms of being a first step forward in sustainability thinking for a food company interested in acquiring more knowledge of sustainability issues in their business. As described by Buchert et al. (2015) there are different phases in the design process and the kind of checklist developed in this paper is best utilized in the early stages: during the clarification of the task and the conceptual design, whereas for the later stages of embodiment design and comprehensive design more detailed guidance is better suited. Buchert et al. (2015) suggests providing development engineers with a 'library' of different sustainability assessment methods with complementary information on what each method can deliver in terms of results so that the most suitable method is selected for each development stage. We agree with this approach, but also argue that a small food company might not have access to a range of methods, nor the capacity to undertake the methods. For these companies, a simple checklist like the one presented here, serves as a good starting tool to learn about relevant sustainability issues in the company's supply chains.

Making the checklist easy to understand has been emphasized. It is an important point because the staff that would benefit from using the checklist is broad and not necessarily experts in sustainability: managers, process engineers, sales persons. At the same time, the difficulty to answer these types of questions has also been highlighted. First, it can be difficult to understand upstream and downstream processes. Second, the result depends to a large extent on which benchmark is applied. Third, it can be difficult to know the answers early on in a project. The targeted user group for the checklist is process developers working with improving their process line. Nevertheless, to overcome the difficulties identified by the companies, it would clearly be an advantage if the checklist is discussed together in a group of people working on food processing design, either on an operational or strategic level, and skilled in different domains: technology, sourcing, food engineering and sales. The ability of the checklist to generate debate among different stakeholders would thus be beneficial for sustainability consideration in food processing design.

The time spent on the checklist has been estimated to 30 min to 1 h. We assume that the time constraint of a food producer varies widely as feedback showed contradicting opinions. One company felt it was time-consuming, while another company was prepared to invest even more time on it if it were to become an auditing tool for the company's sustainability goals.

Two companies wished that the checklist provided quantitative results, or at least an option of answering intermediate response between "yes" and "no". Qualitative results make it difficult to confront what is small and big in terms of impact and improvement potential. It is also not possible to compare one impact to another (i.e. to evaluate potential trade-offs between e.g. economic performance and environmental performance). Finally, the checklist does not allow the identification of the most efficient improvement parameters i.e. responding to questions like: What has the greatest potential to increase the sustainability performance? Do

Table 3
The final version of the checklist.

Business sustainability can be defined as ''adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today while protecting, sustaining and enhancing the human and natural resources that will be needed in the future'' (47Deloitte and Touche 1992). But an SME that have not previously worked with sustainability issues can have difficulties to know where to start as there are a number of approaches to measuring, monitoring and assessing an enterprise progress towards sustainability.
Sustainability addresses not only environmental issues but also economic and social issues. A quantitative methodology (such as Life Cycle Assessment – LCA) allows quantification and more precise estimation of potential negative or beneficial consequences. Application of a qualitative method, such as this form, on the other hand, provides some understanding of the system performance from the very beginning, even before any quantitative information becomes available. When a new technology or process is introduced to the business it can be beneficial to start reflecting on the sustainability issues. Will the new technology result in a more sustainable product?
This checklist is developed with the aim to raise awareness of the factors that are important from a sustainability perspective when introducing a new technology to the business. New technologies may provide new high quality food products. They may also improve the performance of a process considerably from both environmental aspects (directly on production site or indirectly by improving the performance in the food chain further downstream) and from social aspects. The economic gains may be related to a product with higher quality or to a more efficient process. The checklist can also be used to raise awareness of how an existing process can be improved.
Instructions on how to fill in the checklist: Tick yes, if it is possible to improve this aspect; tick no if not, and explain in the comment field the reasoning behind. Once you have gone through all the questions, all the parts you have ticked 'yes' will give you a summary of the parts you can improve in terms of sustainability performance.

1. Raw materials	General information: The production of raw material causes significant environmental impact: use of fuel for the tractors, production of fertilisers, leakage of nutrients from fertiliser application, ecotoxic effects from pesticides, biogenic emissions from the animals in the case of animal husbandry, land and water use. Therefore, an efficient raw material usage is key in sustainable practise; saved raw material means less environmental impact. For most food products, the farm stage is the life cycle step which causes the most environmental impact, compared to other life cycle steps.						
	Upstream		*Process*		*Downstream*		*Comments*
	Yes	*No*	*Yes*	*No*	*Yes*	*No*	
Is it possible to reduce the amount of raw material required by the process?							
Can the process result in reducing or eliminating … … pesticides … … fertilizers … … biogenic emissions … … used in primary production?							
2. Water	General information: The availability of water differs significantly between different parts of the world. Extracting water in a dry area can cause severe damages to both ecosystems and human health.						
	Upstream		*Process*		*Downstream*		*Comments*
	Yes	*No*	*Yes*	*No*	*Yes*	*No*	
Can the amount of water used be reduced?							
Can cleaning operations be optimized?							
3. Energy	General information: Energy use can be a significant contributor to the environmental impact of a product, especially the carbon footprint. In general, energy coming from renewable resources (hydropower, solar, geothermal, biomass) is more sustainable than energy coming from fossil resources (coal, hydrocarbon, nuclear).						
	Upstream		*Process*		*Downstream*		*Comments*
	Yes	*No*	*Yes*	*No*	*Yes*	*No*	
Can the electricity and/or heat needed (steam, hot water…) for … product treatment … … cleaning operations … … be reduced?							
Is it possible to use energy coming from renewable resources?							

(*continued on next page*)

we increase our raw material utilization or reduce the energy use in our process operations? It is not possible to answer these questions by using a checklist; a more in-depth assessment would be required (e.g. a LCSA). A natural subsequent step would be to explore quantitatively how the sustainability performance may be improved. Perhaps the best driver for a company to work with sustainability issues is to answer to the need of their customers; if the customer demands sustainability performance information, the company has a business case for delivering this. In order to do that, quantitative measures are most likely needed, at least in order to be able to show how the products perform in comparison to a competitor. Nevertheless, as a first step, the kind of support like

Table 3 (*continued*)

4. Packaging	General information: The word "packaging" refers to every product made of any materials of any nature to be used for the containment, protection, handling, delivery and presentation of goods from the producer to the consumer. It consists of primary packaging (conceived so as to constitute a sales unit to the final user or consumer), secondary packaging (constitutes a set of several sales units), tertiary packaging (conceived so as to facilitate the handling and transportation of several sales units). In general, packaging made from renewable resources are more sustainable than packaging made from fossil resources, but reuse and recycling can also be ways of improving the packging.						
	Upstream		*Process*		*Downstream*		*Comments*
	Yes	*No*	*Yes*	*No*	*Yes*	*No*	
Can the process reduce the use of packaging material for… … primary packaging? … secondary packaging? … tertiary packaging?							
Can the process provide properties (rheological, chemical…) to the product that makes it possible to pack the product in …							
… re-usable … … recyclable … … bio-degradable … … material?							
5. Transport	General information: Transports burn fossil fuels contributing to carbon footprint, acidification and smog. Distribution from warehouse to retail is often less energy efficient due to many stops and low load factor. The final transport step between retail store and household is probably the least efficient, since a significant share of these transports is performed by car. Concerning cold transport, the leakage of the cold media HCHFs contributes to ozone depletion and climate change; these are phased out in most developed countries but are still present in developing countries.						
	Upstream		*Process*		*Downstream*		*Comments*
	Yes	*No*	*Yes*	*No*	*Yes*	*No*	
Is it possible to decrease or eliminate … … airfreight … … cold … … transports?							
Is it possible to reduce transport distances?							
6. Storage	General information: Concerning cold storage, the leakage of the cold media HCHFs contributes to ozone depletion and climate change; these are phased out in most developed countries but are still present on some fishing vessels and in developing countries.						
	Upstream		*Process*		*Downstream*		*Comments*
	Yes	*No*	*Yes*	*No*	*Yes*	*No*	
Can the need for cold storage be reduced or eliminated by … … product's volume decrease … … storage duration decrease … … storage temperature increase … … thanks to the process?							
7. Waste	General information: Food is wasted in all stages in the food chain. As described above, a significant share of the overall environmental impact of a food product occurs already in the primary production. Therefore, an effective measure to reduce a food product's environmental footprint is to reduce wastage of the product.						
	Upstream		*Process*		*Downstream*		*Comments*
	Yes	*No*	*Yes*	*No*	*Yes*	*No*	
Is the process likely to reduce waste in relationship with … … perishable nature of food? … packaging? … cleaning operations? … production planning? … storage conditions? … consumer behaviour? … supply chain coordination?							

(*continued on next page*)

Table 3 (*continued*)

8. Spatial planning	*Upstream*		*Process*		*Downstream*		*Comments*
	Yes	*No*	*Yes*	*No*	*Yes*	*No*	
Can the process prevent the establishment of new roads and /or factories on agricultural land of significance?							
Can the process prevent the transformation of natural land to agricultural land?							
Can the process lead to investment of new infra-structure in the community?							
9. Work	*Upstream*		*Process*		*Downstream*		*Comments*
	Yes	*No*	*Yes*	*No*	*Yes*	*No*	
Can the process contribute to better working conditions in terms of … … working hours …. … air pollution … …. noise …. …. smell … … for employees?							
Can the process increase skills and level of knowledge among the employees?							
Can the process lead to the creation of new jobs?							
10. Health	*Upstream*		*Process*		*Downstream*		*Comments*
	Yes	*No*	*Yes*	*No*	*Yes*	*No*	
Can the process make food healthier?	N/A	N/A			N/A	N/A	
Can the process improve food safety (i.e. reduce risk of microbiological or chemical contamination)?							
11. Economy	*Upstream*		*Process*		*Downstream*		*Comments*
	Yes	*No*	*Yes*	*No*	*Yes*	*No*	
Can the process lead to new investments in the food chain?							
Can the production costs per kg of product be decreased by the process?							
Can the process improve the European export market?							
Can the process lead to an increased independency on imported … … raw materials? … energy?							
Can the process improve food security (i.e. increase the access to food for the human population)?							

the checklist presented in this paper, gives better understanding of what is important when it comes to striving towards more sustainable processing practices, and could also work as an inspiration, also when communicating with customers.

Considering the limited number of companies involved in checklist development, the results can be considered as a sample test. The positive feedback suggests that the checklist could benefit from being tested on a larger group of food companies. In that case the checklist may be further developed for companies that are already ahead in their sustainability work and simplified for those having less experience with sustainability issues. Future development may also be directed towards equipment providers or process engineers to serve as a tool in their daily work or as a tool for strategic discussions on a higher organizational level. The checklist may also simply be used to serve as a discussion support in meetings between LCA practitioners and professionals who work with food processing design. When tailoring to the needs of a specific user group, focus should be ascribed to understanding the needs of the users in an interactive development process as well as on making it more attractive and dynamic for the user.

3.2. Checklist evaluation with regards to sustainability assessment challenges

Sustainability assessment in the agri-food sector is a broad research area in which LCA is widely used. The qualitative checklist presented in this study keeps some significant advantages of relevant sustainability assessment methods such as LCA. First, it has been developed in a life cycle thinking approach, recognized as

Table 4
Feedback from the four participating companies.

Feedback question	Answer
Considerations of sustainability when developing new processes/products today	Always in the background. Long term thinking, not only cost saving but limited availability of raw material. Product development has guidelines for sustainability. Always look at benefits of a technology. Quantify energy use etc. to compare technologies Not at all*
Easy to understand	Easy to understand but not easy to answer
Relevance	Can be relevant, possibly gain a lot from it, worth testing, address sustainability earlier in the process than before
Time spent	Less than 30 min 30 min–1 h Spend more time on it if becoming auditing tool for the company's sustainability goals
Benefits	Creates awareness Easy way to inventory without doing an extensive LCA Covering some less obvious aspects resulting in a good overview of sustainability issues
Drawbacks	Specify more clearly the definition of upstream and downstream processes The result depends on the benchmark that is used Time consuming "yet another form" Difficult to know the answers early on in a project Not quantified results (reply from two companies) No middle ground, only yes or no answers possible
Staff that would benefit from using the form and with knowledge to use it	Managers, Product development manager, project managers, process engineers, sales persons
Other questions to be included	No further additions (reply from three companies) More questions would make it too long

necessary to address the assessment of the sustainability of food production and consumption. Second, it follows a triple bottom line approach, it is thus able to address not only environmental aspects but also economic and social traits. Third, it fosters multi-stakeholder involvement, allowing the consideration of their interests, values and concerns. This makes the checklist a management approach for long-term changes in a bottom-up approach (De Luca et al., 2017).

It has recently been reported that LCA still has to face many challenges in agri-food sector (Notarnicola et al., 2017). We believe that the approach described in this paper can help to overcome several of these challenges, especially some modeling issues, spatio-temporal resolution and issues difficult to quantitatively assess.

The checklist prevents tricky modeling issues, in particular functional unit and allocations which often are very difficult to solve, especially in the food sector. The functional unit can be based on mass, or defined by integrating nutritional, economic, or cultural value of food. This is always a complicated choice, and it has a big impact on the quantitative result of an LCA. In the same way, co-production is a usual situation in food sector, and can be approached by mass or economic allocation, with a significant impact on the LCA results. The approach presented in this paper does not model the system quantitatively and so avoids such issues.

In addition, the checklist makes it easier to consider local resolution than for quantitative methods for which available data is mostly non-spatially resolved. For the checklist quantitative data are not necessary. The company often has "local" knowledge, i.e. will consider local situation with regards to sustainability concerns. For the same reasons, variability due to seasonal activities can also be more easily included than in quantitative methods.

The checklist addresses with the same importance sustainability issues that are both very well and very little described with quantitative methods (e.g. GHG emissions and e.g. working conditions). This is of utmost interest because it avoids a natural bias that quantitative methods possesses, in which the more data and models we have, the more impacts we observe, which does not necessarily fits to the real situation.

However, a checklist does not solve all challenges in a sustainability assessment. When the discussion around the checklist has been done, there is not a direct result or answer or any other synthesis of the results. Decision support is not directly given to the users to deal with trade-offs. This is at the same time a strength and a weakness of the approach. It is a strength because the company can completely deal with the trade-offs according to their own interests, concerns and values. It is a weakness because it can be helpful for them to benefit from guidance, to get an objective view of the issues and to balance their own point of views. To provide such guidance, methods for multi-criteria decision analysis have to be connected to assessment methods (De Luca et al., 2017).

4. Conclusion

In this paper, the sustainability assessment in food processing design was examined to consider sustainability concerns at early stage of the design process, and especially when it is a new food process. A qualitative sustainability checklist has been developed to be used as a first screening that will give some initial insight into what aspects are important to consider when it comes to the sustainability performance of food processing. It was structured in a life cycle thinking approach, to cover the three pillars of sustainability: environmental, social and economic.

The main strength of such a tool is its ease of use by stakeholders. A limited trial of the checklist by practitioners showed that it is worth further pursuing the development of this kind of tools, since:

- It opens up for capturing other sustainability aspects than just environmental;
- It contributes value to companies without quantification;
- It can benefit companies in raising awareness on sustainability aspects;
- It can be adapted for different user groups (at the moment technology development is in focus).

From a scientific point of view, the approach can help to overcome several challenges in sustainability assessment in the agri-food sector, especially some modeling issues, spatio-temporal resolution and issues specific to the food sector (e.g. land use), which is currently difficult to assess and other common impacts being difficult to quantitatively assess (e.g. working conditions).

By connecting the tool to a multi-criteria decision analysis tool a more complete qualitative tool can be developed.

Acknowledgments

The authors acknowledge funding from the European Commission (FUTUREFOOD H2020 Grant Agreement 635759 and PRESERF FP7 Grant Agreement 245280). Caroline Pénicaud received support from the AgreenSkills fellowship programme funded by the European Commission (FP7 Grant Agreement 267196).

Author Contributions

AW, KÖ and JD conceived and designed the checklist; CP contributed to literature review, refining the checklist and writing of the paper, JD and KÖ collected feedback from the companies and AW and JD wrote the paper.

Conflict of interest

The authors declare no conflict of interest.

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