Assessing the sustainability of fresh stuffed pasta supply chain through Life Cycle Assessment

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Abstract: The critical conditions of our planet are moving industries and consumers to an increased sensitivity to sustainability. Agrifood supply chains, which contribute to one third of global greenhouse gas emissions, are complex systems that require a holistic approach. Life Cycle Assessment, by enabling the quantification of environmental impacts and the identification of hotspots along the whole supply chain, helps identifying mitigation strategies to improve sustainability performance. In recent years, leading pasta companies worldwide have recognized the importance of communicating their environmental performance and started to adopt the Life Cycle Assessment approach. However, the environmental impact of alternative pasta supply chains, such as fresh stuffed pasta, remains poorly investigated. In this study, an Italian pasta company has been involved in assessing the life cycle of fresh stuffed pasta, in order to test viable mitigation strategies to reduce the environmental impact of its supply chain. In terms of GWP impact, the hotspots of fresh stuffed pasta's supply chain resulting from the assessment are: (i) the distribution stage, due to the need for refrigeration; (ii) the ingredients production stage, due to the supply of durum wheat, eggs, and cheese; (iii) the consumption stage, due to the energy required to bring water to boil and cook the pasta. The effects on GWP impacts of the implementation of some possible mitigation strategies are then presented and discussed. The outcome of this study suggests that reduction of environmental impacts for fresh stuffed pasta supply chains is strictly connected to the supply of raw materials and energy, resources on which companies and consumers should focus their efforts in terms of commitment to sustainability. Further research should extend the analysis to additional case studies within and outside the specific sector, in order to complete and enrich available Life Cycle Assessment database.

Keywords: Supply Chain Management; Pasta Supply Chain, Life Cycle Assessment.

I. INTRODUCTION

The dreadful conditions in which our planet is today, intensified by the continuous increase of environmental pressure, are moving industries and consumers to an increased sensitivity to environmental impacts [8]. Hence, an urgent need for sustainable innovations and improvement strategies emerges, to ensure a positive return on the environment. In this scenario, food production is one of the primary drivers of global environmental concerns, since food production uses a large amount of fossil fuels and non-renewable sources, by also exploiting land and water, causing biodiversity loss and greenhouse gas emissions [8].

Agrifood Supply Chains (SCs) are complex systems that require to be studied by taking into consideration the entire ecosystem, from primary production to end of life [19]. This makes the transition to sustainable food SC extremely challenging. When it comes to considering the multiple dimensions of the world's food systems, intertwined challenges of food security and climate change show highest priority [4].

Pasta production represents one of the core industries in the global and Italian food systems.

Besides, due to the growth of the overall world's population, the global demand for high-quality food made of durum wheat has been increasing (see Figure 1). Therefore, the importance of maximizing products sustainability in terms of environmental perspectives is clear and can play a pivotal role in the choices of many consumers [4].

The constant growth in pasta production and consumption, together with the tendency of pasta industries to integrate their supplies with products coming from abroad, make agrifood a sector with a potentially significant environmental impact. Cereal products, including pasta, occupy the largest share of people's dietary patterns and recently weather conditions, fertilizer costs and energy requirements have negatively impacted on their production [21]. Therefore, according to the Food and Agriculture Organization agency of the United Nations (FAO), food security in terms of availability and affordability is threatened. For this reason, the identification of hotspots along the agrifood SC can also help understand the efficiency potential of some actions on ensuring the resilience of the system.

To make a change toward sustainable food and beverage production, it is important to make strategic choices. One of the tools that is successfully being implemented by several companies in the food industry to support these kinds of decisions is Life Cycle Assessment (LCA, see [1]), a method that enables a quantitative study of the environmental performance of SCs. LCA helps identify the life cycle phases that are responsible for the most relevant environmental impacts, improving food production performance and opening the door to better alternatives to minimize ecological consequences [17].

Pasta industries have started to evaluate their environmental footprint by means of LCA and, in some cases, to communicate them through Environmental Product Declarations (EPD). These documents show to other businesses and customers the environmental impact of products and systems based on detailed documents [14]. The reasons for the development and use of these kinds of declarations reside in the increasing attention of final consumers toward traceability information and environmental issues, and in the need of comparing products based on their sustainability.

The remainder of this paper is structured as follows: in section II a literature review is provided. Section III explains the methodology of the study, while section IV introduces the case study, which represents the kernel of the work. Results are described and discussed in section V and finally, conclusions are drawn, as well as practical implications are suggested in section VI.

II. LITERATURE REVIEW

Even though LCA represents one of the most standardized tools to evaluate the environmental performance of a product or a process, it still involves some limitations and challenges [21].

This literature review addresses the identification of relevant findings concerning the application of LCA methodology in the agrifood SC, highlighting the relevant challenges and opportunities.

Regarding the challenges of LCA related to agrifood SC, despite LCA seems to be a powerful tool able to improve and guide both innovations development and food industry ameliorations, with positive returns for the environment [9], several methodological aspects of LCA still need further improvement.

Six LCA studies address different dry durum-wheat pasta: [1], [5], [6], [12], [23], [30]. After the first LCA study performed by Bevilaqua et al. [1], the evaluation of durum-wheat pasta environmental performance drew the attention of academics. In the papers mentioned above, the origin of raw materials is said to be Italy, stressing the peculiarities of the durum-wheat variety selected and the agricultural practices required by this cereal**.**

Most LCA studies on pasta SC present similar choices in terms of functional units, that are the quantities related to the product object of study on the basis of which the impacts are calculated. Indeed, all the functional units selected in literature are based on mass, mainly 1 kg of packaged pasta, while system boundaries generally include all the stages of the SC, from agriculture to end of life. However, to properly compare different types of food and diets, LCA studies could rely on alternative functional units such as the delivery of calories (energy content of food), on single nutrients delivery (i.e., proteins), in composite indicators based on multiple nutrients (e.g., protein, fiber, different types of vitamins, etc. see [20]).

All the six studies mentioned above include the stages of durum-wheat cultivation, milling and semolina processing, while differences remain in the inclusion of auxiliary stages and downstream processes as packaging and distribution, cooking and consumption, and disposal. However, less attention has been paid to the stages that can be influenced directly by the consumer, which include preparation, last mile (customer's shopping route) and packaging, underlining the role of downstream phases in the overall environmental performance [19].

According to Welling and Ryding [29], there are two main challenges related to LCA analysis: the need for specific inventory dataset to tackle the specificities of agrifood product systems and the lack of dataset, within the existing database, related to the Italian context. The availability of comparatively large dataset in a common structure would be crucial for the analyses and could be facilitated through the digitalization of LCA information and environmental product declaration [29].

Indeed, for what concerns agrifood databases, greater transparency of data collection is required, together with the harmonization of the different existing databases, and with the incorporation of geographical variability, which is extremely significant [9].

The creation of a LCA inventory, e.g. the collection of the data related to the energy and material flows connected to the system under study, is an extremely complex and time-consuming phase especially in the case of agrifood systems, and it requires collaboration between several stakeholders along the SC. These actors include suppliers and customers of several tiers, for example suppliers of grains to the mill in the case of pasta and suppliers that provide packaging material producers with granulate plastics.

While a wide range of sustainability practices along the agrifood SC can bring benefits to all actors, there are still some barriers in communication and data sharing. Amongst the solutions proposed for the collection of inventory data, there is an integrated data collection process and strategy, demonstrating the potential role of global companies to quickly get engaged and act as powerful enablers to unlock latent data [9]. Moreover, multinational companies play a pivotal role in supporting SC practices not only by driving practices but also in providing critical resources and collaboration among partners across the SC [6].

Jordan ([16]) highlights the role played by environmental policies. In fact, a political environment setting incentives for an intra-sectoral exchange on the environmental impact of production promotes the creation of sectoral life cycle data sets. This reduces the transaction costs for the creation of sectoral EPDs and is thereby conducive to the diffusion of labels that inform about the environmental impacts embodied in products.

The downstream stages (waste management and consumption) involve LCA studies that rely on standardized data. However, discrepancies in the approaches adopted to model food loss and food waste at consumer gate have been observed [7, 22], limiting the reliability of LCA as a decision support tool for assessing food production systems.

The final aim of many studies (see for example Klopffer and Grahl 2014, [18]) is to identify the most impacting phases of the entire product lifecycle along the SC, to suggest appropriate mitigation actions. When analyzing the results of LCA studies aiming to the identification of hotspots along the agrifood SC, almost all the authors report cultivation of durum wheat in intensive fields as the major cause of environmental impact [11].

Italian pasta industry annually produces about 3.4 million tons of pasta, which accounts for 6% of total national turnover [22]. Therefore, it is mandatory to provide technological innovations and improvement strategies to increase the sustainability, productivity, and quality of flours, pasta, bread, and bakery products. Some authors highlight the importance of organic practices in lowering the environmental impacts associated with the agricultural phase [11]. Other authors suggest eco-sustainable pasta cooking procedure, as passive cooking, or reducing distances with the creation of shorter SC [21]. At the consumption stage, an additional advice is to cook pasta with low-power setting and a small amount of water. However, to make the pasta SC more sustainable, a contribution comes not only from innovative and eco-friendly strategies of SC management, but also from technological innovation, and from initiatives and actions pointing to change consumer behavior [19].

LCA can be used to comparatively analyze different SCs. However, when comparing two different pasta SCs – like high-quality and conventional pasta – the outcomes can be different. On the one hand, the organic agricultural practices applied to small scale allow to reduce the greenhouse gas emissions generated upstream. On the other hand, the limited efficiency in the manufacturing and distribution stages increases greenhouse gas emissions downstream [29]. Hence, the possibility of comparing two different products is not always a viable option since different recipes and consumption habits affect the overall environmental footprint. Furthermore, differences in effect factors, such as exposure mechanisms and sensitivity, can vary significantly across geographical contexts [29], suggesting the need for a regionalized database.

III. METHODOLOGY

In order to assess and evaluate the environmental impact of a specific pasta SC, namely fresh stuffed durum wheat pasta, a cradle-to-grave LCA study has been performed. The object of the study is a fresh pasta with a cheese filling produced by an Italian family business operating in the area of Varese, Italy (VA). All the stages of the SC from raw materials production up to end of life have been taken into account, and the functional unit has been defined as 1 kg of packed pasta. Primary data, all related to the year 2021, have been retrieved directly from the company through questionnaires, while secondary data have been taken from the Agribalyse database, implemented on the open-source software OpenLCA. PCR (Product Category Rules, [14]) guidelines for EPD have been followed in the development of the study, in order to obtain results that one the one hand can be fairly compared with other potential analogue studies and on the other can be used by the company for the development of a type III Environmental certification (EPD). Once the hotspots of the SC in terms of environmental impact are identified, some possible mitigation strategies are proposed and tested according to the LCA model developed.

IV. CASE STUDY

In this section, the system under study is described and the rationale underneath the LCA model is explained. Finally, the results of the LCA impact assessment are presented, and the hotspots in terms of Global Warming Potential (GWP) are identified in order to define and test relevant mitigation actions.

A. Process description

The product under study is a fresh stuffed pasta produced by an Italian family business. It consists of fresh egg durum-wheat pasta stuffed with Parmigiano Reggiano filling and packaged in 200-gram portions.

The steps considered in the modelling stage are ingredients production (wheat grain, eggs, cheese, whey), milling, packaging, pasta production, distribution, consumption and waste management. The ingredients production stage comprehends the cultivation of wheat grain and the production of eggs and filling ingredients (cheese and whey). The milling phase includes both the milling activity and the transport of cereals to the mill. The packaging phase incudes the production of materials for both primary and secondary packaging, together with their transport to the pasta production facility; the primary packaging for each final confection is made of multilayer PET/EVOH/PE trays with cover lid, while secondary packaging consists of carton board boxes. Pasta production comprehends the transport of raw materials from the mill to the plant and the manufacturing process, while the following step is the distribution, also comprehending the product's storage, which takes place in Italy and requires refrigerated lorries to be carried out. The final phases are consumption, which depends on the water and energy used for cooking the pasta, and waste management, where the disposal of the packaging and of the food waste are included.

B. LCA results

The results of the LCA are in line with traditional durum wheat dry pasta, except for some peculiarities that characterize this alternative pasta product.

Results of the impact assessment in terms of carbon footprint reveal that the total impact of 1 kg fresh stuffed pasta cradle-to-grave is 3,51 kg CO_2 equivalent expressed in GWP, the largest contribution to the overall impact being given by the production of ingredients, including eggs and parmesan cheese, and by the distribution stage, due to refrigeration needed while transporting fresh products. Detailed information about the impact of single SC stages is presented in Figure 2.

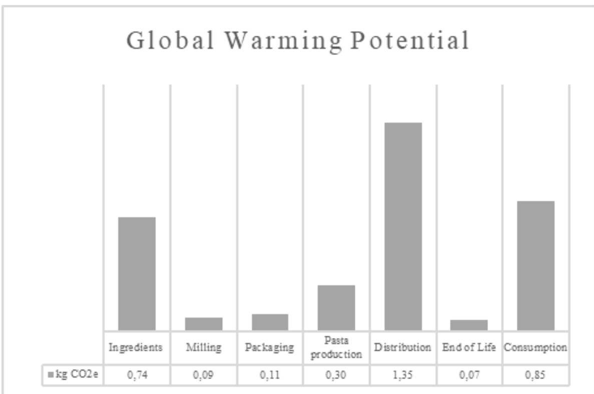

Figure 2. GWP impact

The high impact of the distribution phase is due to the significant amount of energy required for the storage and the refrigerated transport of the product. On the other hand, most of the impacts coming from the production of ingredients are due to the presence in the recipe of animal products such as eggs and parmesan cheese which, despite representing a small percentage of the whole product mass, have a considerable impact on the GWP impact category. Moreover, in line with previous LCA studies on pasta, the consumption phase constitutes a hotspot along the SC, mainly due to the use of electric energy to heat up the cooking water.

C. Mitigation actions

In this section, potential mitigation actions are discussed that could help decreasing the environmental impact of the product. These actions have been selected based on the most impactful phases, namely ingredients production, distribution, and consumption.

First of all, the recipe requires different ingredients, including eggs and cheese that have a large impact on GWP; thus, a potential solution is to substitute ingredients of animal origins. For this reason, a comparison with a vegan recipe for fresh stuffed pasta present in the company’s portfolio was evaluated. The alternative vegan option, with a filling mostly made of mushrooms, can lead to a 14,77% savings of kg CO_2 eq.

Since one of the main hotspots is the consumption phase, a mitigation action that can be suggested to limit this impact is the use of an alternative cooking strategy. For the base case, the impact has been calculated relying on data (referred to water and energy use) specified on the PCR, which are standard data equal for any pasta product. For this reason, the effect of pan cooking, method suggested by the company on the product’s label as an alternative with respect to the traditional boiling was tested: the resulting improvement for the cooking phase in terms of CO_2 eq. is of 20,5% with respect to situation as is.

Finally, a third test can be performed regarding the distribution stage. This phase of the SC accounts for 1,35 kg CO_2 eq. contributing to 38,46% of the total impact of the product in terms of GWP, mainly due the electricity needed for storage. A test has been performed hypothesising to consider electricity from renewable sources, more specifically wind, instead of the Italian default mix considered in the base case. With this substitution, the impact of the electricity decreases from 1,17 to 0,04 kg CO_2 eq, leading to a reduction in the impact of the distribution phase of 87%. This is a theoretical scenario, but it highlights the major role played by the electricity source for fresh products SCs.

V. CONCLUSIONS

The worldwide amount of pasta produced in 2021 accounted for about 52,8 billion metric kilograms and considering an average impact on GWP of 2,2 kg CO_2 per kg pasta, the overall amount of CO_2 equivalent generated in one year can reach up to 116,1 tons CO_2 equivalent (Statista 2022). Indeed, pasta production represents one of the core industries of the food sector, with about 22% of global volume produced in Italy. Durum wheat production involves more than 250.000 farmers, while the industrial sector – which represents almost 6% of the total Italian agri-food industry turnover – is made of semolina and pasta production. Moreover, the global demand for high-quality food made from durum wheat has been increasing, which poses a challenge in the face of climate change. Consequently, the importance of maximizing durum wheat sustainability in terms of environmental footprint emerges as a priority. With reference to the SC of fresh stuffed pasta, the main differences with respect to average dry pasta profiles present in literature in terms of environmental impact are due to the refrigerated distribution phase. The electricity consumed in the cold chain proved to mostly contribute to the overall impact. Another relevant difference with respect to dry durum wheat pasta is due to the presence of ingredients with higher scores in terms of GWP; on the other side, these ingredients also lead fresh pasta to have more complete nutritional values, and in the end be more satiating than dry pasta, which instead requires complementary food products.

The analysis of the LCA results and the identification and testing of possible mitigation actions highlight different aspects connected to the environmental impact of this type of SCs. As previously highlighted through the literature review, on the one hand, there is the necessity of promoting more sustainable consumption habits between consumers, due to the high impact that the consumption phase has been proven to have. On the other hand, the source of ingredients has to be taken into consideration from manufacturing companies as the most critical one in terms if impact: sustainable agricultural practices should be promoted, and a shift from animal products to vegetable ones should be fostered, always balancing nutritional aspects. Finally, it has been highlighted that SCs that deal with fresh products do require refrigeration, which cannot be avoided; in this sense, the focus should be put on electricity production and sourcing, due to the significant difference this aspect can make on the overall impact.

For what concerns the data inventory, it is confirmed to be the most critical phase of the LCA, due to data availability and lack of regionalized datasets for agricultural production. Moreover, the cradle-to-grave analysis of a product requires the involvement of multiple stakeholders, who may be placed in different geographical locations. For this reason, a more extended communication between the commissioner of the LCA study, its suppliers, and its customers is advisable. More collaborative actions are required throughout the SC to foster and accelerate the collection of primary data and to make the results of the assessment robust.

A. Limitations and future research

Concerning LCA analysis, the results have been drawn from the assessment of one specific product and company. Since production practices, supplier selection, distribution methods and operational decision patterns may vary significantly among companies of the same sector, future research should focus on collecting data coming from many manufacturers of similar food products. Moreover, only GWP has been considered, while future research should consider a wider range of impact categories in order to give a more complete picture of the environmental impact.

Future possible comparative research should the one hand focus on different products manufactured by the same company, to highlight eventual environmental differences more clearly. Moreover, future research should evaluate the environmental impact based on nutritional scores, and satiating capacity of the product under analysis.

In the future, incentives for the drafting of environmental product declarations should be extended to primary suppliers, to engage them in LCA process. Indeed, the final obtainment of the environmental product declaration can give advantages to all these actors, such as customer fidelity and improvement of agricultural practices.

Finally, future research should concentrate on the development of complete and regionalized datasets, especially concerning the supply of electricity, which is one of the most relevant inputs, and of raw materials, due to the significantly high variability and geographical dependence that characterizes agricultural practices.

VI. References

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