Does environmental impact vary widely within the same food category? A case study on industrial pizzas from the French retail market

Adeline Cortesi, Caroline Pénicaud, Anne Saint-Eve, Louis-Georges Soler, Isabelle Souchon

This paper is a postprint of the article: Cortesi et al. 2022. Journal of Cleaner Production 336, 130128. https://doi.org/10.1016/j.jclepro.2021.130128

Does environmental impact vary widely within the same food category? A case study on industrial pizzas from the French retail market

Adeline Cortesi[1], Caroline Pénicaud[1,*], Anne Saint-Eve[1], Louis-George Soler[2], Isabelle Souchon[3]

[1] Université Paris-Saclay, INRAE, AgroParisTech, UMR SayFood, 91120, Palaiseau, France

[2] Université Paris-Saclay, INRAE, UR ALISS, 94205, Ivry-sur-Seine, France

[3] Avignon Université, INRAE, UMR SQPOV, 84000, Avignon, France

* corresponding author

Abstract

There is an urgent need to reduce the strong environmental impact of food production and consumption, which are expected to increase in the coming years due to the growing world population. Life cycle assessment (LCA) is a known method for environmental evaluation worldwide. In the case of food products, LCA are often carried out on a single representative of a food category, which does not allow an understanding of possible variations in the environmental impact between products belonging to the same category. We aimed to assess and compare the environmental impact of a wide range of food products belonging to the same food category. The study model chosen was industrial pizza, because of its high consumption worldwide and its large range of recipes, as well as its various storage conditions (fresh or frozen), distributors, and nutritional content. Thus, we assessed the environmental impact of 80 pizzas representative of the 2010 French retail market by LCA, using 1 kg of ready-to-eat pizza as the functional unit and the EF 3.0 method for impact characterization. LCA showed ingredient production to be the stage of pizza production with the highest impact. Moreover, statistical analysis of the results showed that the sector and distribution mode of the pizzas do not appear to have an influence on their environmental impact. On the contrary, the pizza recipes have a significant influence on the environmental impact of industrial pizza. Indeed, pizzas containing beef have a significantly higher environmental impact than the others and the cheese content of pizzas positively correlates with their environmental impact. Finally, we observed that the higher the protein, fat, and saturated fatty acid content of the pizzas studied, the greater their environmental impact in most of the studied environmental impact categories. These results could be useful for LCA practitioners who want to strengthen our knowledge on the environmental impact of food and companies that want to develop more sustainable products, as well as for consumers who want to make more sustainable choices.

Keywords: life cycle assessment (LCA), food industry, supply chain, processed food, recipe

1. Introduction

Food production is among the human activities with the highest environmental impact, accounting for 20 to 30% of the environmental impact in Europe (Tukker et al., 2006). For example, the United Nations (2021) estimates that it is responsible for a third of global greenhouse gas emission worldwide. The situation is all the more alarming because of the predicted increase in the global population, which the United Nations estimates will reach 9.8 billion by 2050 (UN, 2017). For this reason, the United Nations include "responsible consumption and production" as one of its 17 sustainable development goals (UN, 2020) and the European commission included the goal to "lead a global transition towards competitive sustainability from farm to fork" in its European Green Deal Program (European commission, 2019).

Improving the environmental performance of food production is therefore a key issue for the overall reduction of the environmental impact of human activity. Two complementary options can be considered to achieve this goal (Desorge et al., 2017). The first is to encourage food manufacturers to produce more environmentally friendly products. This would likely require the creation of tools that would encourage the reformulation of products through, for example, new standards, regulations, or taxes. The second option focuses more on consumers and consists of encouraging them to consume more environmentally friendly products through better consumer information. Improving consumer information could also encourage manufacturers to modify their offer, as shown for nutritional labeling (Van der Bend et al., 2020).

Consumer interest in the environmental performance of the products they consume has increased in recent years (L'Obsoco, 2021). Indeed, a study carried out in several European countries showed that, on average, two thirds of the people questioned declared that they were ready to change their eating habits to benefit the environment. The main changes they are willing to make are eating more seasonal fruits and vegetables and limiting domestic food waste. Nevertheless, the consumers questioned are clearly less inclined to replace certain foods by others or to reduce their consumption of foods that have a particularly high impact on the environment. Thus, only one of three declared that they were ready to reduce their consumption of red meat and only 20% to reduce their consumption of dairy products (BEUC, 2020).

Improving the environmental quality of our diets should not, however, come at the expense of the nutritional quality of the foods, which plays a predominant role in preventing_many diseases such as cancers (Kerschbaum et al., 2019) and heart diseases (Houston et al., 2018). The nutritional quality of food products is a more important choice criterion for consumers than its environmental quality (Saint-Eve et al. 2021).

Hence, the environmental impact of food products is not yet a major choice criterion for consumers, coming after price and nutritional criteria (Desorge et al., 2017). It is unlikely that consumers will radically change their eating habits to reduce their impact on the environment. They would probably be more inclined to replace a usually consumed product by one belonging to the same product category but with a lower environmental impact (Soler et al., 2020).

The main objective of this study is to answer the following question: could the substitution of a product by an equivalent product within the same food category improve the environmental performance of food choices? To answer this question, we studied if it is possible to discriminate between products belonging to the same category according to their environmental impact. We also studied links between the environmental and nutritional performance of food products.

We addressed these questions using pizza as a study model. By definition, pizza is "a dish of Italian origin, consisting of a flat round base of dough baked with a topping of tomatoes and cheese, typically with added meat, fish, or vegetables" (Lexico, 2021). France, along with the United States, is the largest consumer of pizza in the world and its consumption is estimated to be 10 kg per person per year (PIC International, 2020). Pizzas can be divided into several groups, mainly homemade pizzas, artisanal pizzas, and industrial pizzas. We chose industrial pizza as our study model because it covers a multitude of products that can vary in terms of their recipe and filling (for example with or without meat), distributor, mode of preparation, and even sector (fresh/frozen).

In this context, our goal was to study the possible variability in the environmental impact within the same category of food products: industrial pizzas sold in the French retail market. We also wanted to identify the hotspots, i.e., the stages, of pizza production/consumption with the highest environmental impact and determine the parameters that influence the environmental impact of pizzas. Another objective was to understand the potential link between environmental performance and the nutritional quality of industrial pizza.

Several methods are available to measure environmental impact, although there is no international consensus for any of them. In this study, we used life cycle assessment (LCA), the most scientifically recognized environmental analysis tool worldwide, standardized by the ISO 14044, 2006 standard (EN ISO 14044, 2006). As detailed in section 2, it is widely used in the agrifood sector.

The originality of this work lies in the fact that no study has thus far investigated the variation of environmental impact within a large sample of food products belonging to the same category. The results of this study may be useful for LCA practitioners, who will gain insights into the most important points to consider when measuring the environmental impact of products within the same food category. The results may also be of interest for pizza manufacturers who wish to design more environmentally friendly pizzas, as well as of use to help consumers to make more sustainable food choices.

2. LCA in the agrifood sector: a brief overview

LCA is widely used for studies in the agrifood sector, with a steady increase in the number of food products that have been analyzed (Cucurachi et al., 2019). LCA is performed for products in the agrifood sector for two main purposes: to identify hotspots in the production of the product and to compare products or production scenarios between them.

2.1. Identification of the hotspots of a production system

This type of analysis provides a better understanding of the environmental performance of a production system, while also making it possible to increase efforts on the most environmentally damaging stages. A literature review of the LCA of several food products, such as industrial food products (i.e., bread, tomato ketchup), dairy and meat products, and other products, such as rice or potatoes, showed that the stage of agricultural production is often that with the highest environmental impact (Roy et al., 2009). This conclusion has been confirmed by more recent studies. For example, milk production was shown to be by far the largest hotspot in the production of Grana Padano cheese (Bava et al., 2018). Similarly, a literature review of 23 articles on the LCA of olive oil production chains showed that the phase with the highest impact was generally the agricultural phase (Espadas-Aldana et al., 2019). This was notably due to the fertilization and irrigation of the soil during olive production, as well as pesticide use.

However, observations may differ between studies. For example, packaging (metal cans) was shown to be the stage with the highest environmental impact in the manufacturing of tomato puree for all impact categories, except acidification and eutrophication (Shahvarooghi Farahani et al., 2019). For those two indicators, tomato cultivation was the hotspot.

2.2. Comparison of different production methods for the same product

LCA is also widely used in the food industry to compare the environmental performance of different production scenarios. For example, it was found that high moisture extruded patties had a lower environmental impact than low moisture extruded patties and that this method of extruding vegetable proteins should be encouraged to reduce the environmental impact of extruded meat substitutes (Saerens et al., 2021). LCA has also been used to compare production scenarios at different scales (home baking, local bakery, and two different industrial bakeries) for bread production, showing that industrial production contributes the most to global warming, acidification, and eutrophication (Andersson and Ohlsson, 1999).

2.3. Comparison of two different products

LCA is also used to compare the environmental impact of different products. For example, Bianchi et al. (2021) compared the environmental impact of white, dark, and milk chocolate by LCA. Their study concluded that dark chocolate is that with the lowest environmental impact and that the environmental impact of white and milk chocolate is quite similar. Furthermore, because animal-based foods are considered to have a particularly high environmental impact, several studies compared the environmental impact of animal-based food products to their plant-based alternatives. For example, plant-based burger patties were shown to have an impact that was at least 10 times lower than that of meat burgers (Saerens et al., 2021). This was also shown by Grant and Hicks (2018), who compared the environmental impact of cow's milk to that of plant milk (almond and soy). They showed dairy milk to have the highest environmental impact for six of the 12 impact categories studied in the article.

2.4. Comparison of products within the same food category

LCA of food products are often performed for only one or a few specific products and the values obtained are therefore assumed to reflect the environmental impact of all products belonging to the same category. This is true, for example, for a study conducted by Stylianou et al. (2020), who compared one representative of vegetarian pizzas to one of meat pizzas and concluded that meat pizzas are responsible for the emission of more greenhouse gases than vegetarian pizzas. Several authors have also compared food products to each other based on the environmental impact value of a single representative of a product category, such as Saarinen et al. (2017), who, compared the category of Emmental cheese to that of grilled sausage. The main conclusions of these authors, who wanted to compare the environmental performance of different protein sources, were that meat products and cheese are responsible for a greater climate impact than fish and plant-based proteins (peas, soybeans, etc.) for a functional unit based on 100 g of product. Such an approach does not account for the wide variety of products that may exist within the category of Emmental cheese or worse, grilled sausage. Although a few studies have investigated the environmental impact of different products within the same category, the number of products analyzed has been very limited and is far from being representative of all products in the category on the market. For example, a study conducted by Dalla Riva et al. (2017) compared the environmental impact of two types of mozzarella, one considered to be high-moisture and the other low-moisture. However, there is often a wide variety of products within the same product category, especially for processed products composed of a large number of ingredients. A better understanding of the possible differences in the environmental impact between products belonging to the same category could help to improve the overall environmental quality of our food through recommendations of reformulations to food manufacturers and/or advice to consumers on how to substitute one product for another.

2.5. Environmental impact of food and nutrition

The nutritional properties of foods are highly important for consumer health and are therefore a significant criterion for consumers when purchasing food products (Desorge et al., 2017). For this reason, several studies on the environmental impact of the food sector have also included the nutritional values of products to better understand the relationship between these two dimensions. This has been done at different scales.

At the scale of the food product, for example, the variability of the impact of different seafoods consumed in Sweden was studied (Hallström et al., 2019). The environmental impact (greenhouse gas emissions) and nutritional quality did not correlate for all species and the authors found that pelagic species were a good compromise, both for their nutritional interest and their moderate effect on the climate. Masset et al. (2014) also examined the relationship between environmental impact, environmental quality, and the price of 363 food products representative of the average French diet. Among the foods considered, they showed that those with a high environmental impact (greenhouse gas emissions, acidification, and eutrophication) tend to have lower nutritional quality (SAIN and LIM indicators).

At the meal scale, for example, the nutritional and environmental benefits of different Spanish tapas meals was assessed (Batlle-Bayer et al., 2020). Environmental performance was evaluated according to three environmental indicators: global warming potential (GWP), blue water footprint (BWF), and land use (LU), taking into account the energy and nutrient content within the functional unit. The results show that switching to more plant-based tapas can significantly reduce their impact on the evaluated environmental indicators. Similarly, a method to evaluate university canteen meals according to environmental and nutritional recommendations has been proposed (Cooreman-Algoed et al., 2020). This method aims to integrate both nutritional and environmental recommendations to help students make meal choices. One hundred meals from a Belgian canteen were classified according to their environmental impact (ReciPe single score) and their nutritional interest based on different nutrients to promote or limit their consumption. The results showed that dishes containing fish received the best grades and those containing meat from ruminant animals the worst.

At the diet level, it was shown that the northern regions of Spain have a better diet from a nutritional point of view and generated less greenhouse gases due to higher consumption of fruits and vegetables than in other regions (Chapa et al., 2020). Through the NutriNet study, Baudry et al. (2019) showed the consumption of organic food to be associated with higher consumption of plant-based food and lower consumption of animal-based food and better overall nutrition. They also showed that increased consumption of organic products tended to reduce the impact on greenhouse gas emissions, cumulative energy demand, and land occupation. In addition, it has also been shown that changes in food consumption patterns to meet French national dietary recommendations could reduce the overall impact of our diets on the environment by 50% (Kesse-Guyot et al, 2020), suggesting that there is a positive correlation between nutritional and environmental performance at the diet level.

3. Materials and methods

3.1. Product selection

In total, 80 pizzas representative of the French retail market in terms of composition, nutritional content, and economic value were selected from among 392. Details concerning the methodology used for the selection of the 80 pizzas are available in the "ANNEXE 4". The 80 selected pizzas belong to different families, sectors, and distributors. Families refer to the professional nomenclature of the pizzas and are based on the pizza filling. For example, the filling of "cheese" pizzas includes various types of cheese but no meat- or fish-based ingredients. Eight families are represented: *ham-cheese* (n = 24), *cheese* (n = 20), *margarita* (n = 4), *seafood* (n = 4), *meat* (n = 5), *Bolognese* (n = 5), *vegetables* (n = 3), and *cold cuts* (n = 15). Sectors refer to the storage method, in this case, fresh (n = 33) or frozen (n = 47). Distributors refer to the brand of the pizza. It can be a national brand (n = 20), a private brand (n = 39), the brand of a specialized distributor (for example from a supermarket specialized in frozen products) (n = 11), or a hard discount brand (n = 10).

3.2. System boundaries and functional unit

The stages of pizza production that we considered were ingredient production, manufacturing, transport of the pizza, distribution, and use (Figure 1). The assumptions associated with each of these stages are detailed in the associated data paper.

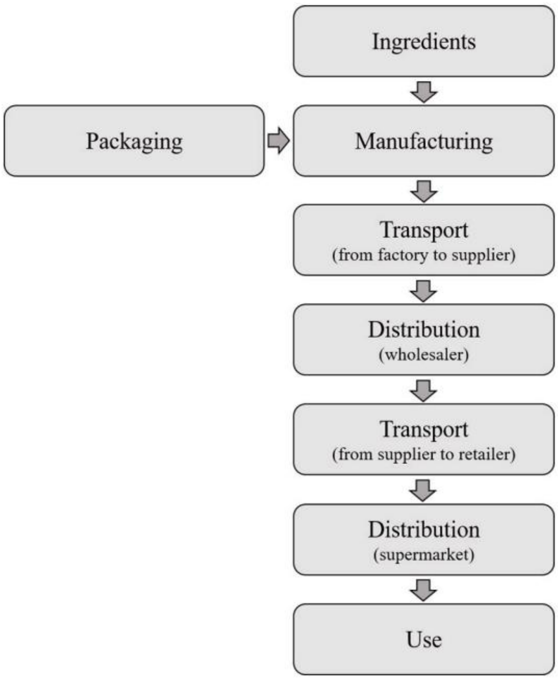

Figure 1. Steps in pizza production considered in the LCA

We considered that all the pizzas were produced in the same place, in France, and during the year 2010.

As the weight of the 80 pizzas studied varied, we chose not to compare the pizzas one by one but rather to compare identical masses of pizza. In addition, mass functional units are the most commonly used functional units for LCA of food products. We thus chose a functional unit of 1 kg of ready-to-eat pizza, i.e., pizza, fresh or frozen, after cooking at the residence of the consumer.

3.3. Data inventory

The inventory data used in this study were obtained in various ways. Details on the collection of all inventory data are available as supplementary tables in the co-submitted data-paper and are briefly summarized here.

3.3.1. Ingredients

The weights of the various ingredients were estimated from the ingredient lists and nutritional data on the packaging of each pizza.

3.3.2. Pizza manufacturing

The energy and water consumption data for the pizza manufacturing process were estimated using the technical data sheets for the machines used to produce the pizzas. If the technical data sheets did not allow estimation of the consumption of a machine, experts of food industrial processes were contacted to estimate the missing data.

3.3.3. Packaging

The weight of the packaging for each pizza was measured experimentally using a laboratory balance (± 0.1 g).

3.3.4. Transport

We assumed that the distance of transport of the pizzas from the factory to the wholesaler and from the wholesaler to the supermarket was the same for all pizzas: 1,000 km between the pizza factory and the supplier and 200 km between the supplier and the retailer.

3.3.5. Distribution

The duration of storage of the pizzas at the wholesaler and the supermarket, as well as the associated consumption, were estimated from the scientific literature (DEFRA, 2008).

3.3.6. Use

Data sheets of refrigerators, freezers and electric ovens were used to estimate the electrical consumption related to the storage and cooking of pizzas in the consumer's home.

3.4. Characterization of the environmental impact

LCA is a methodology defined as the evaluation of all inputs and outputs of the life cycle of a product system to assess its potential environmental impact (EN ISO, 2006). The LCA of the 80 pizzas were performed using SimaPro 9.1.0.11 software. The characterization method used was the EF 3.0 Method (adapted) V1.00 / EF 3.0 normalization and weighting set (Fazio et al., 2018). This characterization method was developed under the control of the European Commission and allows the calculation of 16 midpoint environmental indicators These environmental indicators are climate change, ozone depletion, ionizing radiation, photochemical ozone formation, particulate matter, human toxicity non-cancer, human toxicity cancer, acidification, eutrophication marine, eutrophication freshwater, eutrophication terrestrial, ecotoxicity freshwater, land use, water use, resource use fossils and resource use minerals and metals. Each indicator is calculated using a specific method. Details about the calculations used to obtain these different indicators are available in Fazio et al. (2018). This method also allows the calculation of a score that aggregates all the environmental indicators using normalization and a weighted set (according to the reliability of each indicator) by the European Commission. All the midpoint impact categories available in this method and the single score were calculated. The results are all available as supplementary tables in the co-submitted data-paper. Nutritional data were obtained as explained in 3.1 and are available as supplementary tables in the co-submitted data-paper.

3.5. Treatment of the results

A number of statistical analyses were performed on the LCA results using the statistical software XLStat (version 2020, 5.1.1043).

Principal component analysis (PCA) is a descriptive representation that allows visualization of the groups of pizzas identified by clustering. PCA was performed on the total impact calculated for the production of each of the pizzas for various categories of environmental impact to obtain an overview of their global distribution. In particular, we wanted to determine whether pizzas cluster differently depending on their family, distributor, and sector.

Partial least squares regression (PLS-R^2) was used as a complement to PCA to study the relationships between all environmental indicators and the nutritional and composition indicators. Partial least squares regression is a decisional statistic that makes it possible to establish explanatory models to identify which combinations of variables explain what discriminates these groups.

The nutritional and compositional indicators considered were protein content (g/100 g), fat content (g/100 g), saturated fatty acid content (g/100 g), sugar content (g/100 g), sodium content (g/100 g), fiber content (g/100 g), filling mass to dough mass ratio, and animal product mass to vegetable product mass ratio. Finally, the correlations between all environmental indicators studied and the percentage of cheese, meat and fish, vegetables, and tomato sauce and dough were studied using PLS-R^2.

The mean value of each pizza family was also calculated. The 80 pizzas were then ranked according to the average environmental impact of their families to estimate whether such ranking would be representative of the ranking of the true environmental impact of the pizza or not.

4. Results and Discussion

Each indicator of the EF3.0 method was considered to determine (i) the steps with the highest impact and (ii) correlations between the environmental impact of pizzas and their various characteristics, including nutritional and compositional characteristics.

4.1. Definition of the steps with the highest impact

The relative impact of each production step of one pizza among the 80 according to the various environmental impact indicators is shown in Figure 2, as an example. The distribution of the contribution of the various stages was similar for all pizzas. The detailed results are available as supplementary tables in the co-submitted data-paper.

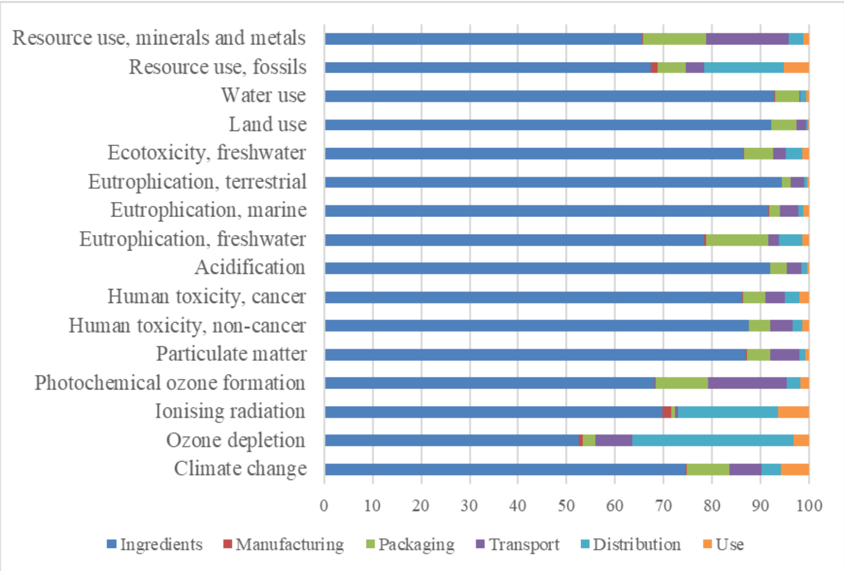

Figure 2. Contribution of each step of pizza production to each category of environmental impact computed using the EF3.0 method (example of one pizza: Ham-cheese, fresh, private brand)

The production of the ingredients is the step with the greatest impact for all studied environmental indicators (Figure 1). This observation was confirmed for all 80 pizzas studied. As for the other stages, the weight of the ingredient-production step on the total impact of the pizza varies according to the environmental indicator. For example, the ingredient-production stage is responsible for 41.1 to 92% of the total impact for the climate change indicator, depending on the pizza, representing an average of 74.8% (average over the 80 pizzas). This stage is followed by packaging (7.7% on average, from 2 to 19.6%), transport of the pizza (6.1%, from 2.7 to 11.2%), use (5.6%, from 1.6 to 13.6%), processing (3.0%, from 0.1 to 11.1%), and, finally, distribution (2.9%, from 1.2 to 5.7%). Even for the ozone depletion indicator, for which the relative contribution of the production of the ingredients is the lowest relative to the other indicators (Figure 1), the average contribution of each stage is as follows: ingredients (58.7% on average, from 23.3 to

84.4%), distribution (19.4%, from 5.1 to 42.2%), processing (7.2%, from 0.4 to 22.7%), transport of the pizza (6.7%, from 2.7 to 12.2%), use (4%, from 1.4 to 7.3%), and packaging (3.9%, from 0.8 to 11.9%). Such predominance of the ingredient-production stage on the environmental impact is in accordance with the observations of Weidema et al. (2008), who showed that the stage with the greatest impact in the production of dairy and meat products was the agricultural stage. However, several studies have shown that this predominance may vary depending on the impact category considered. For example, Kim et al. (2013) evaluated the environmental impact of mozzarella and cheddar cheeses for nine impact categories and showed that the agricultural phases (including inputs and agricultural activities) were responsible for more than 60% of the total environmental impact for seven. For the two remaining impact categories, namely cumulative energy demand and human toxicity, more than 50% of the total impact was attributed to activities after the agricultural phases, with a strong impact of the manufacturing and consumption stages for human toxicity. Dijkman et al. (2018) reviewed a number of studies, allowing them to conclude that the agricultural stages were major hotspots for different types of products, including meat, cheese, and bread, consistent with our results, as these products are important constituents of pizza. It is also consistent with the results of Roy et al. (2009), Bava et al. (2018), and Espadas-Aldana et al. (2019), who also concluded that the agricultural phase has the greatest impact on the environment.

However, we can qualify this statement because it is likely that the impact of the processing step is often underestimated due to the lack of data on this aspect. Indeed, as explained by Dijkman et al. (2018), as the first LCA conducted on food products showed that the agricultural phase had the greatest impact, most studies have since focused on this phase. This phenomenon explains the current lack of data on processing stages. Therefore, it would be informative to carry out on-site measurements to better account for the environmental impact of the processing stage of pizza production.

4.2. Environmental impact of the 80 pizzas

The repartition of the 16 environmental indicators for the 80 pizzas studied is shown in Figure 3.A. The repartition of the 80 pizzas (added to the PCA as supplementary observations) in Figure 3.A is shown in Figure 3.B. Each point in figure 3.B represents one pizza, with the color indicating the family. The same data as in Figure 3.B is shown in Figures 3.C and 3.D, but with the color indicating the distributor (Figure 3.C) or sector (Figure 3.D).

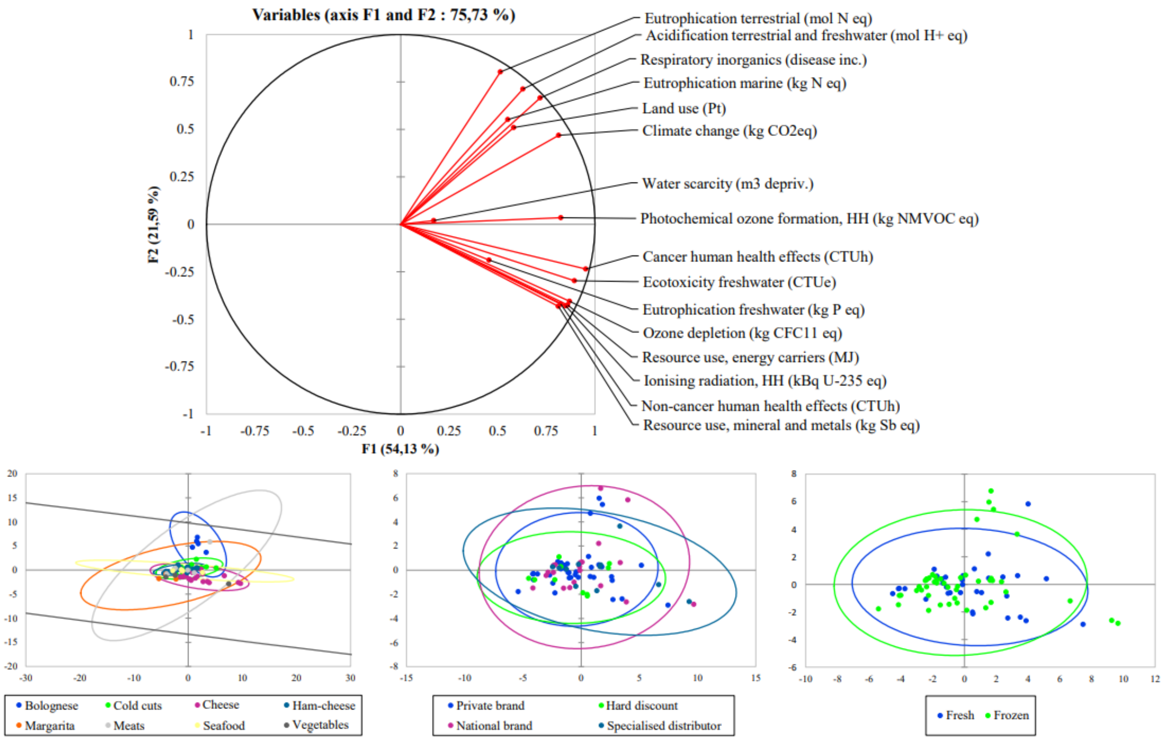

Figure 3. Principal component analysis (PCA) of the impact of the 80 pizzas on various environmental indicators (A) and scatter plots representing pizzas from different families (B), distributors (C), and sectors (D).

All environmental indicators positively correlate with each other, the correlation mainly being explained by the construction of the F1 axis, (54.13% of the variance). This result indicates the agreement between various environmental indicators, meaning that they similarly characterize the studied pizzas.

However, two groups could be distinguished along the F2 axis, although it only accounted for 21.59% of the variance (Figure 3A). The first group (located above the F1 axis) mainly includes the indicators that are the most affected by agricultural production, such as climate change, land use, marine eutrophication, terrestrial eutrophication, and acidification. The second group (located below the F1 axis) includes the indicators most affected by electrical consumption, such as ozone depletion, ionizing radiation, or resource use indicators (energy, carriers, and minerals and metals). This means that these two groups of indicators slightly discriminate between the pizzas.

4.3. Influence of differences between pizzas on their environmental impact

4.3.1. Impact according to pizza family

Additional variables (*ham-cheese*, *cheese*, *Bolognese*, *margarita*, *vegetables*, *cold cuts*, *meats*, *seafood*) were added to the PCA analysis to better visualize the impact of pizza families. The resulting scatter plot is shown in Figure 3B. Pizzas from the *Bolognese* family are well separated from those of other families, especially the "cheese" and "seafood" families. There is no clear separation between the other families. This may be due to the various representative proportions between the families. As a consequence, certain families of pizzas are less represented than others (especially the *vegetables*, *margarita*, and *seafood* pizzas, which are among the least represented). The large confidence ellipse observed for the *vegetable* pizzas can be explained by the fact that these pizzas are poorly represented and that they can contain a large possibility of recipes.

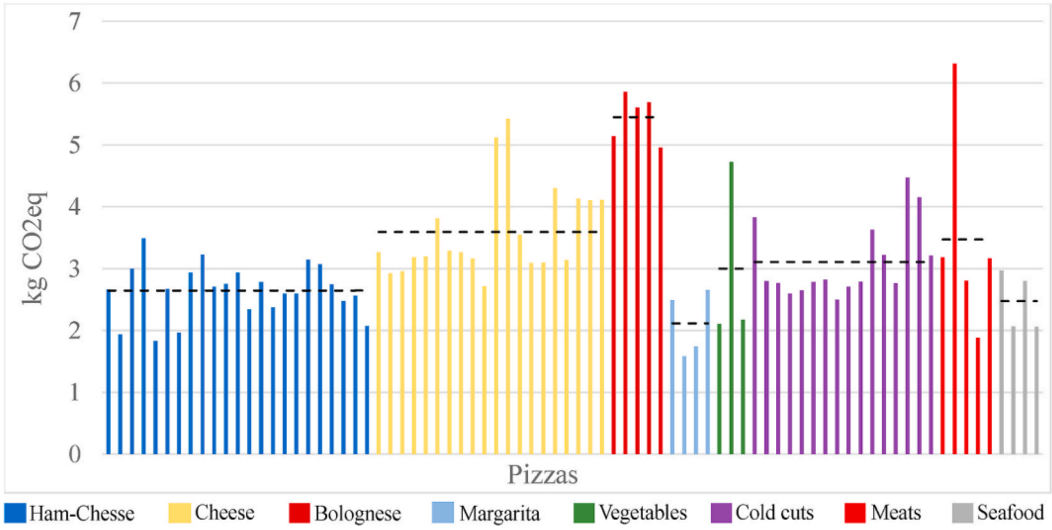

Figure 4. Impact of the 80 pizzas grouped by family on the climate change indicator (kg $CO2_{eq}$). The different pizza families are indicated by different colors and their average values by the dotted lines.

The *Bolognese* family and one pizza from the *meats* family had the highest values for the climate change indicator (Figure 4), due to the presence of beef. The *Bolognese* family is thus that with the highest impact on climate change (5.45 kg $CO2_{eq}$/kg of pizza on average), as well as on the indicators particulate matter, acidification, terrestrial eutrophication, and land use. This result is consistent with that of the study conducted by Weidema et al. (2008), which showed that beef had an environmental impact up to five times higher than that of pork. In addition to pizzas containing beef, *cheese* and *vegetables* pizzas also showed a high impact on climate change (3.59 and 3.00 kg CO2eq/kg of pizza, respectively).

Based on the average impact on climate change of each of the families studied, we established the following ranking in descending order of impact: *Bolognese* (5.45 $kgCO2_{eq}$), *cheese* (3.59 $kgCO2_{eq}$), *meats* (3.47 $kgCO2_{eq}$), *cold cuts* (3.10 $kgCO2_{eq}$), *vegetables* (3.00 $kgCO2_{eq}$), *ham cheese* (2.65 $kgCO2_{eq}$), *seafood* (2.47 $kgCO2_{eq}$), and *margarita* (2.11 $kgCO2_{eq}$).These values are slightly higher than the $CO2_{eq}$ emissions values calculated by Stylianou et al. (2020): from 1.28 to 3.21 kg CO2eq/kg of pizza vegetarian pizzas and from 4 to 5,21 kg $CO2_{eq}$/kg of pizza for meat pizzas (depending on the selected database). However, Stylianou et al. (2020) only considered the ingredient-production step, explaining why their values are lower than ours.

Each pizza was compared to the others to establish whether the ranking based on mean values of each family was similar to the ranking of the pizzas individually. More than 20% of the pizzas were misclassified using a ranking based on average impact. The percentage of misclassified pizzas depended on the family. Indeed, only a small number of pizzas were misclassified among the pizzas at the two extremes, *Bolognese* and *margarita* pizzas, with only 1.33% (x/80) and 9.8% (x/80) misclassified. Among the other families of pizzas, the frequency of misclassification was 15% for *cheese* pizzas, 32% for *meat* pizzas, 26% for *cold cut* pizzas, 37% for *vegetable* pizzas, 21% for *ham cheese* pizzas, and 25% for *seafood* pizzas. Thus, with the exception of the *Bolognese* family for certain environmental indicators, the environmental impact of a pizza is not dependent on its family and a ranking based on pizza family is not adequate. The specificity of each recipe must be considered independently of the family to which the pizza belongs. However, currently, comparisons on the basis of the average or only one representative of the category are performed in most studies, like for mozzarella (Dalla Riva et al., 2017) or pizzas (Stylianou et al., 2020) environmental assessments for example. This may lead to inappropriate conclusions.

We performed a partial least squares regression (PLS) in which the indicator climate change was explained by the variable percentage of cheese, percentage of tomato sauce and vegetables, percentage of dough, and percentage of meat and fish to identify ingredients with a large impact on climate change (Figure 5).

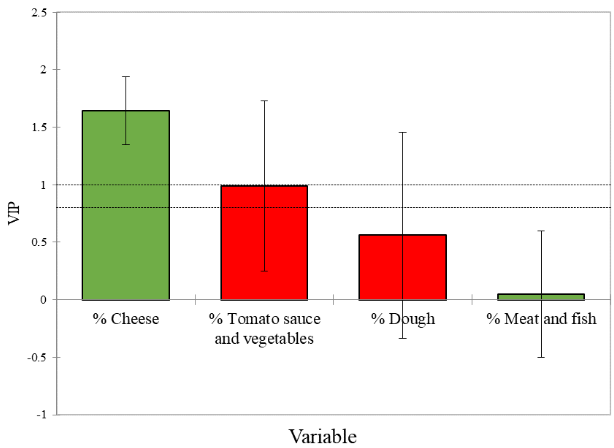

Figure 5. Importance of the variables in the projection (VIP) representing the indicator climate change explained by the amounts (%) of various types of ingredients in pizzas (green: positive correlation; red: negative correlation)

The impact of pizzas on climate change significantly correlated with the percentage of cheese, tomato sauce, and vegetables in the pizzas. The correlation was positive for the percentage of cheese (as well as the percentage of meat and fish) and negative for the percentage of tomato sauce and vegetables (as well as the percentage of dough). Thus, pizzas containing less cheese and more tomato sauce and vegetables have a globally lower impact on climate change. The low correlation observed between the percentage of meat and fish and the impact of pizza on climate change is certainly because most pizzas do not contain meat or fish but still have a relatively high impact on climate change due to the amount of cheese. On the contrary, all the pizzas studied contain cheese in varying proportions (Figure 6). We observed a positive correlation between cheese content and the impact on climate change of the 80 pizzas (R^2 = 0.19).

Figure 6. Increase in the impact on climate change of the 80 pizzas according to their cheese content (in orange: pizzas from the cheese family, in blue: pizzas from other families)

Nevertheless, not all cheeses have the same impact on climate change, which can explain the variation of environmental impact between pizzas containing the same amount of cheese. For example, hard cheeses, such as Grana Padano (Bava et al., 2018), have a higher impact than soft cheeses, such as mozzarella (Dalla Riva et al., 2017). The "cheese" family shown in Figure 4 includes pizzas with a high content of cheese. Nevertheless, because not all cheeses have the same environmental impact, pizzas from the *cheese* family are not necessarily those with the highest impact on climate change. These results show that pizza recipes have a major influence on the environmental impact of pizza. Recipes can vary highly between pizzas, even between those from the same family, thus explaining why pizzas are not possible to rank solely based on their family.

4.3.2. Variability of impact according to the distributor

The various pizza distributors (national brands, private brands, hard discount, and specialized distributors) were added as additional variables to the PCA presented in Figure 3A. The resulting scatter plot is shown in Figure 3B.

Pizzas from the same type of retailer do not appear to cluster together and are relatively homogeneously distributed around 0, regardless of the retailer. Thus, the type of distributor does not appear to have any influence on the environmental impact of pizzas. This result is not surprising because the differences in the recipes between pizzas selected in this study from the various distributors were not large, and the environmental impact of the pizzas is mainly due to the ingredients.

4.3.3. Variability of impact according to the sector

The pizza sector (fresh or frozen) was added as an additional variable to the PCA (Figure 3C). The points representing frozen pizzas are very close to those representing fresh pizzas and relatively centered around 0. Surprisingly, there appears to be no difference between fresh and frozen pizzas in terms of environmental impact. Our calculations were made based on the assumption that the storage time at the consumer's home was two days for both fresh and frozen pizzas. However, this assumption is questionable, especially as frozen pizzas can be stored for much longer. We evaluated the influence of our hypothesis of two days of home storage for both types of pizzas by studying an additional scenario consisting of a long storage scenario in which fresh pizzas are stored for seven days and frozen pizzas for one year. The LCA results obtained for these two scenarios are shown in Figure 7 for all 80 pizzas for the climate change impact category. The values obtained using the initial scenario (two-day storage) are shown by solid-colored bars and the values obtained for the long-storage scenario by unfilled black bars superimposed on the colored bars.

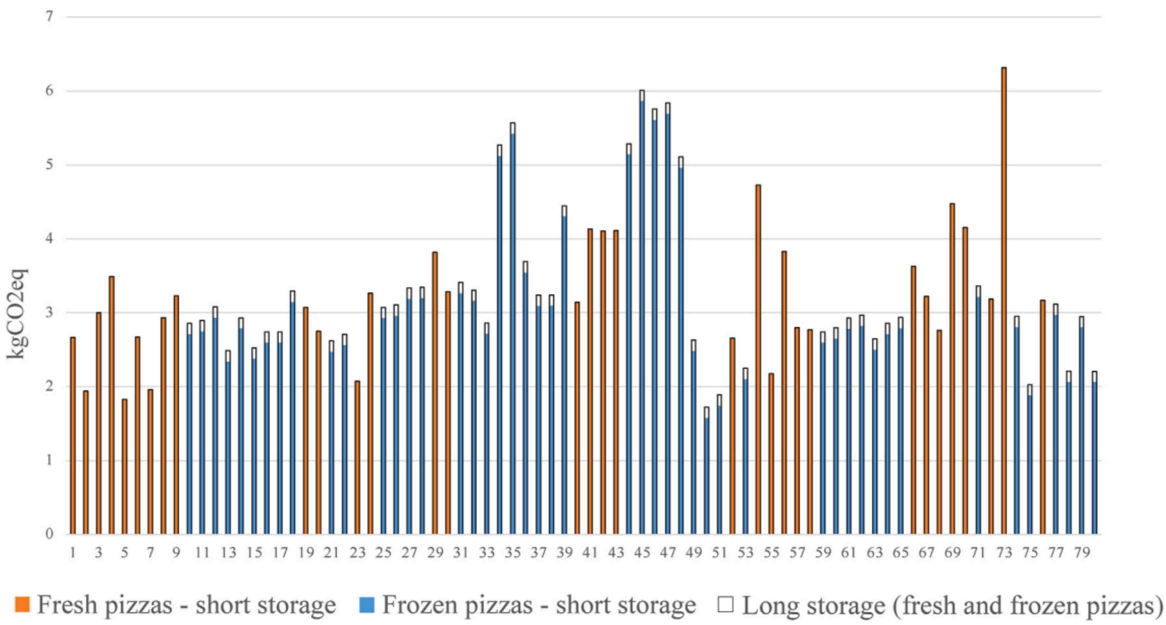

Figure 7. Impact of the 80 pizzas on climate change according to the two-day storage scenario (solid bars) versus the long-storage scenario (unfilled bars). Long storage is not visible for fresh pizzas because the values for the two scenarios are very close.

For fresh pizzas, longer storage of seven days results in an increase of $1.3.10^{-3}$ kg $CO2_{eq}$/kg pizza relative to two days of storage at home. For frozen pizzas, longer storage of one year leads to an increase in emissions of $1.15.10^{-1}$ kg $CO2_{eq}$/kg pizza relative to storage for two days. Long-term storage led to increases of less than 0.25% for fresh pizzas for all impact categories. However, we observed the following increases for storage of one year versus two days for frozen pizzas: 28% for ionizing radiation, 23% for fossil resource use, 15% for ozone depletion, from 1% to 5% for marine eutrophication, water use ecotoxicity, acidification, particulate matter, photochemical, human toxicity - noncancer, human toxicity – cancer, freshwater eutrophication, and climate change, and < 1% for terrestrial eutrophication, land use, and the use of mineral and metal resources. Thus, an increase in the duration of storage by a factor of 3.5 (fresh pizzas) leads to a maximum increase of 0.25% in the environmental impact of the pizza and an increase by a factor of 182.5 results in a maximum increase of 28%. Thus, the duration of storage of pizzas from both sectors (fresh and frozen) has little influence on the total environmental impact of the product.

The environmental impact related to the overall cold production to maintain the integrity of the food products has been reported to be significant; according to James and James (2010) the food cold chain is responsible for approximately 1% of CO_2 emissions worldwide. In our study, only the electrical consumption of the preservation equipment (refrigerators for fresh pizzas and freezers for frozen pizzas) was considered. Thus, it would be informative to conduct more comprehensive LCA that consider flows other than electrical consumption and, in particular, the materials used in the construction of such equipment (domestic refrigerators and freezers), as well as the management of their end of life. Moreover, we selected equipment of one size, which was the same for both refrigerators and freezers and thus not representative of the variety of sizes of refrigerators and freezers in French households. Finally, a 50% fill assumption was used for both types of equipment. However, the energy consumption of a refrigerator varies depending on how full it is (Belman-Flores et al., 2019). It would therefore also be informative to conduct an additional study to determine the variability in fullness and the average percentage of fullness of domestic freezers and refrigerators, as well as their variability in terms of size and respective average sizes to obtain values that are more representative of reality.

4.4. Link between the environmental impact of pizzas and two global nutritional indicators: energy content and the NutriScore

We studied the relationship between the environmental impact of pizzas and their nutritional content by evaluating the correlation between the impact of pizzas on various environmental indicators (the midpoint indicators and the aggregated indicator Single Score) and two global nutritional indicators (energy content (kcal) and the NutriScore). We studied these two indicators because they are both considered to represent the global nutritional quality of food products. Thus, a correlation between one of these nutritional indicators and environmental indicators would allow us to make simple recommendations for pizza formulation and consumer choice. The correlation coefficients obtained for midpoint indicators are presented in Table 1. The point clouds representing the evolution of the Single Score as a function of the NutriScore and energy content of the pizzas are presented in Figure 8.

Table 1. Correlation coefficients between various environmental indicators and energy content (kcal) and the NutriScore

	Energy (kcal)	NutriScore
Climate change (kg $CO2_{eq}$)	0.42	0.22
Ozone depletion (kg $CFC11_{eq}$)	0.35	0.48
Ionizing radiation, HH (kBq $U\text{-}235_{eq}$)	0.28	0.39
Photochemical ozone formation, HH (kg $NMVOC_{eq}$)	0.22	0.20
Particulate matter (disease inc.)	0.32	0.14
Human toxicity, non-cancer (CTUh)	0.24	0.40
Human toxicity, cancer (CTUh)	0.41	0.50
Acidification (mol $H+_{eq}$)	0.32	0.13
Eutrophication, freshwater (kg P_{eq})	0.24	0.30
Eutrophication, marine (kg N_{eq})	0.39	0.23
Eutrophication, terrestrial (mol N_{eq})	0.27	0.07
Ecotoxicity freshwater (CTUe)	0.23	0.38
Land use (Pt)	0.14	-0.01
Water use (m3 depriv.)	0.06	0.13
Resource use, fossil (MJ)	0.28	0.39
Resource use, mineral and metals (kg Sb_{eq})	0.35	0.47

There were no significant correlations between environmental indicators and energy content or the NutriScore. Nevertheless, there was a trend towards a positive overall correlation between the energy content and the NutriScore of pizzas and their environmental impact.

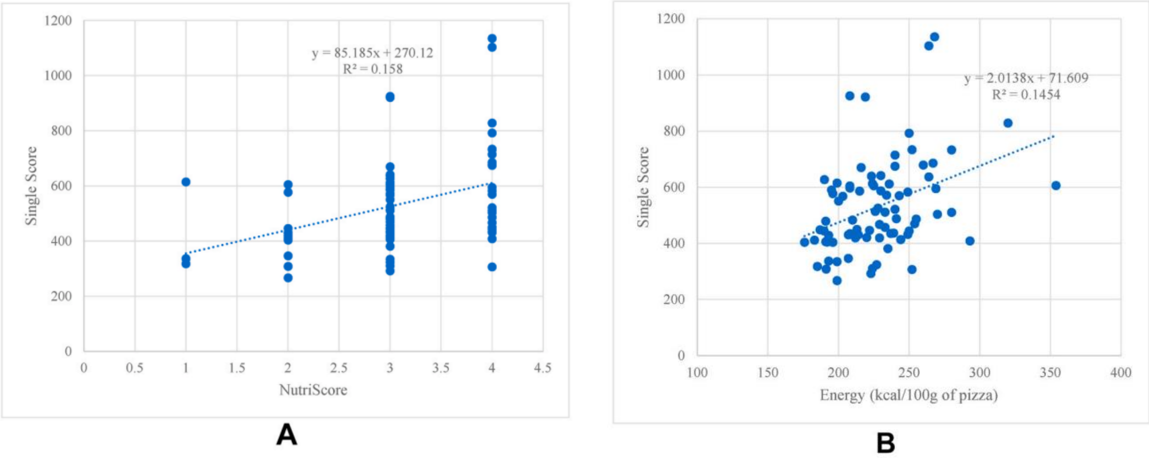

Figure 8. Graphs representing the evolution of the Single Score as a function of the NutriScore (A) and the energy content of the product (B)

Thus, that nutritional content appears to positively correlate with the impact of pizzas for almost all environmental indicators. This finding contradicts the results of Vieux et al. (2013), who showed that greenhouse gas emissions negatively correlated with the energy density of the products studied. This difference may be due to the fact that the ingredients with the highest energy density for the pizzas selected for this study are also those with the highest environmental impact (notably beef and cheese), which was not the case in the study of Vieux et al. (2013), who compared a large number of different food products. This difference could also be explained by the fact that Vieux et al. (2013) compared different items from a diet and not food products belonging to the same category. It would therefore be informative to determine which nutrients are particularly responsible for this correlation.

4.5. Link between environmental indicators and various nutritional and composition indicators

The environmental impact of pizzas appears to strongly correlate with their global nutrient content. We thus decided to study how the environmental impact of pizzas can be modeled based on their composition and nutritional quality using partial least squares (PLS) regression. The considered nutritional and compositional indicators were as follows: protein content (g/100 g), carbohydrate content, fat content (g/100 g), saturated fatty-acid content (g/100 g), sugar content (g/100 g), sodium content (g/100 g), fiber content (g/100 g), ratio of the mass of dough/mass of filling, and ratio of the mass of ingredients of animal origin/mass of ingredients of plant origin. All environmental indicators presented in Figure 3A were considered in this analysis. The results are presented in Figure 9. In such a representation, the closer an explanatory variable (here, the nutritional and composition indicators) is to a variable to be explained (here, the environmental indicators), the more the explanatory variable contributes to the variable to be explained. Thus, according to Figure 9, the environmental indicators appear to positively correlate with the protein, fat, and saturated fatty-acid content of the pizzas. Conversely, the environmental impact of pizzas does not appear to positively correlate with the carbohydrate, sugar, or fiber content for any of the impact categories studied.

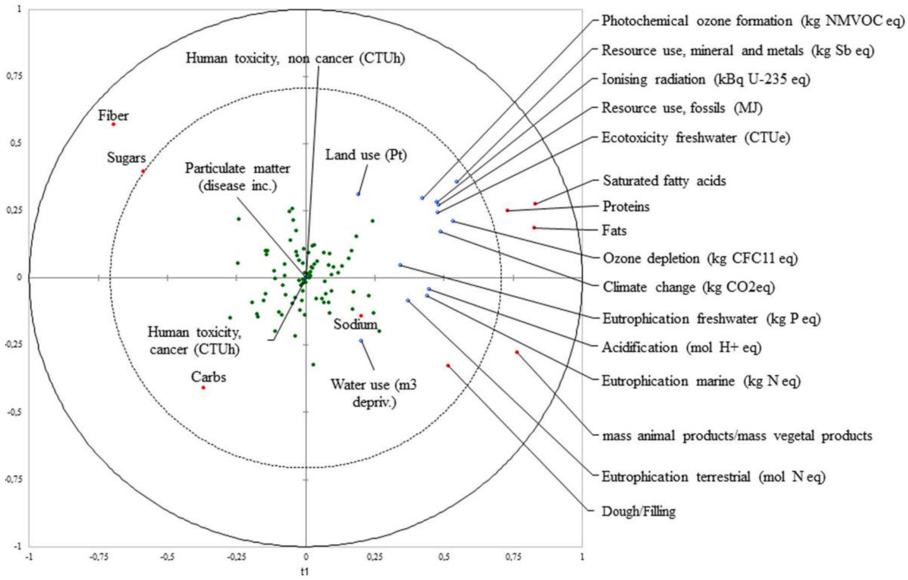

Figure 9. Partial least squares (PLS) regression considering several environmental and nutritional indicators (Q^2 Comp1 = 0.311 and Comp2 = -0.004)

For the pizzas studied, protein and fat are mainly provided by the cheese and meat ingredients they contain. Therefore, the results appear to be consistent with our findings above, as well as those of several studies that have highlighted the significant environmental impact of animal products. This is, for example, true of the study conducted by Tukker et al. (2006), who showed that the two food categories with the highest impact on the environment are the categories "meat and meat products" and "dairy products". Several studies have also shown the environmental interest of substituting animal products with plant products, such as a study conducted by Rabès et al. (2020), in which various types of diets containing varying proportions of animal products, ranging from omnivorous to vegan, were studied. This study concluded that a vegan diet containing no animal products is the diet with the lowest impact on climate change, land use, and cumulative energy demand. The literature review by Reynolds et al. (2014) also showed that reducing the consumption of meat products in favor of increasing fruit and vegetable consumption decreased the environmental impact of our diet in most cases.

4.6. Impact of substituting pizza on the scale of the total diet

Among the 80 pizzas, the one with the lowest impact on climate change emits 1.58 kg CO_2eq/kg of pizza, whereas that with the highest impact emits 6.31 kg CO_2eq/kg. We calculated the effect of substituting the pizza with the greatest impact with that with the least impact on the scale of the total diet of an average human being over one year. Thus, with a current consumption estimated to be 10 kg of pizza/person/year in France (PIC International, 2020), the substitution of the pizza with the greatest impact on climate change with that with the least in our study would lead to a reduction of 63.1-15.8 = 47.3 $kgCO_2eq$/person/year. As total greenhouse gas emissions are estimated to be 1,856 $kgCO_2eq$/person/year for a person on a conventional (non-organic) diet (Pointereau et al., 2019), such a substitution would lead to a 2.6% reduction in annual food-related greenhouse gas emissions, which is not negligible. This result is even greater if big consumers of pizzas are considered. Indeed, based on the consumption data (mean consumption and standard deviation) of "sandwiches, pizzas, pies, pastries, and salted biscuits" given by the INCA 3 study (ANSES, 2017), a coefficient of variation has been calculated. We hypothesized that the coefficient of variation calculated for the category "sandwiches, pizzas, pies, pastries, and salted biscuits" is the same for only pizzas. Once applied to the average 10 kg, we estimated that the biggest pizza consumers can eat up to 53.1 kg of pizza each year. For these consumers, the replacement of the pizza with the highest impact on climate change with that with the lowest impact would lead to a reduction of 251 kg CO_2eq/person/year, translating into a 13.5% reduction in annual food-related greenhouse gas emissions. This result shows how important the substitution of food products with those with a smaller impact from the same category can be to reduce the impact on climate change.

4.7. Recommendations in light of this study

4.7.1. Improving the reliability of environmental data on food products

Integrating detailed pizza recipes in the environmental calculation would provide a relatively representative estimate of reality and make it possible to rank pizzas with relatively high confidence. The main contributor to the environmental impact is indeed the ingredients, although pizzas vary in many characteristics: recipe, production plant (highly industrialized or not), packaging, transportation, preservation method, and shelf life at the consumers residence. Most studies related to environmental impacts of processed food products also concluded that the stage with the most environmental impacts is the agricultural production stage. For example, Bava et al. (2018) showed that milk production was the most impactful stage for the production of Grana Padano cheese. Nevertheless, when comparing products, environmental impacts are often studied for a single representative of a category independently of the possible variations in recipes existing between the different products that make up this category (Saarinen et al.,2017). The present study shows that recipe variations of pizzas had a direct influence on their environmental impacts and that not taking these recipe variations into account could lead to erroneous conclusions. Furthermore, the environmental impact of pizzas mainly correlates with their animal product content, especially beef and cheese. The consideration of these two parameters would be a minimum for a more representative environmental assessment of all pizzas. However, distinguishing industrial pizzas by their family, sector, or distributor does not provide reliable information about their true environmental impact. The importance of a detailed recipe to provide individual environmental impact has been shown to be lower for other product categories, especially those with few ingredients, such as tomato sauce (Soler et al., 2020). Indeed, pizzas are highly complex food products that can, as shown here, vary greatly, especially in terms of their recipe, which may contain a large number of ingredients in varying proportions. However, this is not true of other food products, which are derived from the transformation of a main ingredient and for which the recipe is more homogeneous within the food category. For such products, the processing stage may be the most important for ranking them, as the variability between such products is due more in their processing than the recipe.

Concerning the processing stages, our study is based on data from data sheets and the scientific literature, resulting in similar processing between pizzas. It is likely that the environmental impact between pizzas would have varied if true flow measurements had been carried out at each of the production sites of the 80 pizzas. Such detailed processing data could moderate the importance of the recipes. Indeed, although several studies have shown that the processing stage product is only responsible for a small proportion of the total impacts of the finished product (Roy et al., 2009), improvements in the manufacturing process can significantly reduce the total environmental impacts of the product, as for wafer biscuit (Ismayana et al., 2020). Thus, it could be informative for future research to compare different production sites to see how they can affect the environmental impact of pizza.

4.7.2. Links between the nutritional and environmental performance of food

Although the fat content of the selected pizzas correlated with their overall environmental impact, the fiber, sodium, and sugar contents did not. Current French nutritional recommendations aim to promote an increase in fiber consumption and a reduction in that of sodium, sugar, and saturated fatty acids (Ministry of Solidarity and Health, 2019). The nutritional recommendations are thus not identical to those that would be made following our observations of the environmental performance of pizzas according to various impact categories. These results are quite divergent from those obtained by Kesse-Guyot et al. (2020), who showed that adapting a diet to the nutritional recommendations of the French government could significantly reduce the overall environmental impact of food. This difference may be due to the fact that these studies were not performed at the same scale; the study of Kesse-Guyot et al. (2020) focused on the total diet scale, whereas ours focused on the product scale. However, a study by Masset et al. (2014) also focused on the product scale and showed that among the 363 foods considered, those with a high environmental impact tend to have lower nutritional quality. They studied a substantial number of different food product (363) chosen to be representative of the average French diet. Thus, our results on the correlation between environment and nutrition are not generalizable to more global scales, probably because we studied a unique food category that is not representative of the overall diet. Furthermore, studies that consider average foods neglect the impact of existing diversity within the same product group. As human and environmental health are currently both of major concern, it would be useful to consider how to easily identify the best trade-offs in terms of both nutritional and environmental performance. To do so, methods, such as that presented by Cooreman-Algoed et al. (2020), who managed to classify canteen meals according to both their nutritional and environmental values, could be useful to develop at the product scale. Such a method could help consumers to select food products with both favorable environmental and nutritional properties.

Nevertheless, our study could be useful for pizza reformulation in consideration of both environmental and nutritional dimensions. We show that the higher pizza content in cheese and beef is, the higher is the environmental impact of the pizza. Cheese is generally rich in fat and sodium. Hence, from a nutritional point of view, limiting its consumption is recommended (Ministry of Solidarity and Health, 2019). However, a detrimental effect of cheese on health has not been proven. Indeed, the opposite may be true. Cheese appears to have a neutral or even small beneficial effect on health, probably due to the probiotics it contains (Guo et al. 2017). The overconsumption of red meat, including beef, has been proven to have a negative effect on health (Wolk, 2017). Hence, lowering beef and, to a lesser extent, cheese content in pizzas could be beneficial both for the environment and health.

5. Conclusion

In conclusion, this study shows that different food products belonging to the same category can have a varying environmental impact. Most of the impact comes from the ingredients used. In the case of pizzas, we observed no effect of the sector, distributor, or family on environmental impact, with the exception of the *Bolognese* family, which has a higher impact on certain environmental indicators due to the high beef content of such pizzas. In addition, we observed that differences in the length of time the pizza is stored in the consumer's home would have only a minimal influence on the overall environmental impact of the pizza. We also show that the environmental impact of a pizza appears to positively correlate with its protein, fat, and saturated fatty-acid content for most of the environmental indicators studied. On the contrary, the fiber, sugar, and sodium content appear to have only a small influence on the environmental impact of pizza. Logically, we show that the environmental impact of a pizza positively correlates with the percentage of cheese, which contains high levels of protein, fat, and saturated fatty acids, for several environmental indicators. As pizza is a product that is highly consumed in France, the systematic substitution of pizza responsible for the most greenhouse gas emissions by that responsible for the least would lead to a decrease in greenhouse gas emissions linked to the diet of an average human being for a year by 2.6%, which is not negligible. Such results are encouraging in terms of the interest of reformulating common processed products for the overall improvement of the environmental performance of our food.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to thank Vincent Monclus, Anna Woodhouse, and Hélène Bidault for their contributions to the preliminary version of this work. The authors would also like to thank Alex Edelman & Associates for revision of the English. The authors acknowledge funding by the INRA metaprogramme DID'IT.

References

Andersson, K., Ohlsson, T., 1999. Life cycle assessment of bread produced on different scales. Int. J. LCA 4, 25–40. https://doi.org/10.1007/BF02979392

ANSES, 2017. Etude individuelle nationale des consommations alimentaires 3 (INCA 3) [Online]. Available. https://www.vie-publique.fr/rapport/36772-etude-individuelle-nationale-des-consommations-alimentaires-3-inca-3 (Accessed 9 February 2021).

Batlle-Bayer, L., Bala, A., Roca, M., Lemaire, E., Aldaco, R., Fullana-i-Palmer, P., 2020. Nutritional and environmental co-benefits of shifting to "Planetary Health" Spanish tapas. Journal of Cleaner Production 271, 122561. https://doi.org/10.1016/j.jclepro.2020.122561

Baudry, J., Pointereau, P., Seconda, L., Vidal, R., Taupier-Letage, B., Langevin, B., Allès, B., Galan, P., Hercberg, S., Amiot, M.-J., Boizot-Szantai, C., Hamza, O., Cravedi, J.-P., Debrauwer, L., Soler, L.-G., Lairon, D., Kesse-Guyot, E., 2019. Improvement of diet sustainability with increased level of organic food in the diet: findings from the BioNutriNet cohort. The American Journal of Clinical Nutrition 109, 1173–1188. https://doi.org/10.1093/ajcn/nqy361

Bava, L., Bacenetti, J., Gislon, G., Pellegrino, L., D'Incecco, P., Sandrucci, A., Tamburini, A., Fiala, M., Zucali, M., 2018. Impact assessment of traditional food manufacturing: The case of Grana Padano cheese. Science of The Total Environment 626, 1200–1209. https://doi.org/10.1016/j.scitotenv.2018.01.143

Belman-Flores, J.M., Pardo-Cely, D., Gómez-Martínez, M.A., Hernández-Pérez, I., Rodríguez-Valderrama, D.A., Heredia-Aricapa, Y., 2019. Thermal and Energy Evaluation of a Domestic Refrigerator under the Influence of the Thermal Load. Energies 12, 400. https://doi.org/10.3390/en12030400

BEUC, The European Consumer Organisation, 2020. One bite at a time: Consumers and the transition to sustainable food. Analysis of a survey of European consumers on attitudes towards sustainable food.

Bianchi, F.R., Moreschi, L., Gallo, M., Vesce, E., Del Borghi, A., 2021. Environmental analysis along the supply chain of dark, milk and white chocolate: a life cycle comparison. Int. J. Life Cycle Assess. 26, 807–821. https://doi.org/10.1007/s11367-020-01817-6

van der Bend, D.L.M., Jansen, L., van der Velde, G., Block, V., 2020. The influence of a front

of pack nutrition label on product reformulation: A ten-year evaluation of the Dutch Choice programme. Food Chem. X 6, 100086. https://doi.org/10.1016/j.fochx.2020.100086

Chapa, J., Farkas, B., Bailey, R.L., Huang, J.-Y., 2020. Evaluation of environmental performance of dietary patterns in the United States considering food nutrition and satiety. Science of The Total Environment 722, 137672. https://doi.org/10.1016/j.scitotenv.2020.137672

Cooreman-Algoed, M., Huysveld, S., Lachat, C., Dewulf, J., 2020. How to integrate nutritional recommendations and environmental policy targets at the meal level: A university canteen example. Sustainable Production and Consumption 21, 120–131. https://doi.org/10.1016/j.spc.2019.10.004

Cucurachi, S., Scherer, L., Guinée, J., Tukker, A., 2019. Life Cycle Assessment of Food Systems. One Earth 1, 292–297. https://doi.org/10.1016/j.oneear.2019.10.014

Dalla Riva, A., Burek, J., Kim, D., Thoma, G., Cassandro, M., De Marchri, M., 2017. Environmental life cycle assessment of Italian mozzarella cheese: Hotspots and improvement opportunities. J. Dairy Sci. 100, 7933–7952. https://doi.org/10.3168/jds.2016-12396

DEFRA, 2008. Greenhouse Gas Impacts of Food Retailing (Research Project FO0405 No. Greenhouse Gas Impacts of Food Retailing), DEFRA Department for the Environment Food and Rural Affairs, London.

Desorge, M., Lacroix, A.M., Muller, L., Pernin, C., Potdevin, C., Ruffieux, B., 2017. L'étiquetage au service d'une alimentation durable: le point de vue des consommateurs. [Rapport de recherche] CLCV / INRA. 2017, 50 p. + annexes. halshs- 01537806f

Dijkman, T.J., Basset-Mens, C., Antón, A., Núñez, M., 2018. LCA of Food and Agriculture, in: Hauschild, M.Z., Rosenbaum, R.K., Olsen, S.I. (Eds.), Life Cycle Assessment: Theory and Practice. Springer International Publishing, Cham, pp. 723–754.

EN ISO 14044, 2006. Environmental Management. Life Cycle Assessment. Requirements and Guidelines (ISO 14044;2006)

European Commission, 2019. Agriculture and the Green Deal: A healthy food system for people and planet [Online]. Available. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/agriculture-and-green-deal_en (Accessed 28 July 2021).

Espadas-Aldana, G., Vialle, C., Belaud, J.-P., Vaca-Garcia, C., Sablayrolles, C., 2019. Analysis and trends for Life Cycle Assessment of olive oil production. Sustainable Production and Consumption 19, 216–230. https://doi.org/10.1016/j.spc.2019.04.003

Fazio, S., Castellani, V., Sala, S., Schau, E., Secchi, M., Zampori, L., Diaconu, E., 2018. Supporting information to the characterisation factors of recommended EF Life Cycle Impact Assessment method. EUR 28888 EN, Eur. Comm. JRC109369, Ispra.

L'Obsoco (Observatoire Société & Consommation), 2021. Observation de la consommation responsable. Analyse détaillée.

Grant, C.A., Hicks, A.L., 2018. Comparative Life Cycle Assessment of Milk and Plant-Based Alternatives. Environ. Eng. Sci. 35, 1235–1247. https://doi.org/10.1089/ees.2018.0233

Guo, J., Astrup, A., Lovegrove, J.A., Gijsbers, L., Givens, D.I., Soedamah-Muthu, S.S., 2017. Milk and dairy consumption and risk of cardiovascular diseases and all-cause mortality: dose–response meta-analysis of prospective cohort studies. Eur J Epidemiol 32, 269–287. https://doi.org/10.1007/s10654-017-0243-1

Hallström, E., Bergman, K., Mifflin, K., Parker, R., Tyedmers, P., Troell, M., Ziegler, F., 2019. Combined climate and nutritional performance of seafoods. Journal of Cleaner Production 230, 402–411. https://doi.org/10.1016/j.jclepro.2019.04.229

Houston, M., Minich, D., Sinatra, S.T., Kahn, J.K., Guarneri, M., 2018. Recent Science and Clinical Application of Nutrition to Coronary Heart Disease. J. Am. Coll. Nutr. 37, 169–187. https://doi.org/10.1080/07315724.2017.1381053

Ismayana, A., Ibrahim, O.A., Yani, M., 2020. Life cycle assessment of wafer biscuit production. IOP Conf. Ser.: Earth Environ. Sci. 472, 012065. https://doi.org/10.1088/1755-1315/472/1/012065

James, S.J., James, C., 2010. The food cold-chain and climate change. Food Res. Int., Climate Change and Food Science 43, 1944–1956. https://doi.org/10.1016/j.foodres.2010.02.001

Kerschbaum, E., Nuessler, V., 2019. Cancer Prevention with Nutrition and Lifestyle. Visc. Med. 35, 204–209. https://doi.org/10.1159/000501776

Kesse-Guyot, E., Chaltiel, D., Wang, J., Pointereau, P., Langevin, B., Allès, B., Rebouillat, P., Lairon, D., Vidal, R., Mariotti, F., Egnell, M., Touvier, M., Julia, C., Baudry, J., Hercberg, S., 2020. Sustainability analysis of French dietary guidelines using multiple criteria. Nat Sustain 3, 377–385. https://doi.org/10.1038/s41893-020-0495-8

Kim, D., Thoma, G., Nutter, D., Milani, F., Ulrich, R., Norris, G., 2013. Life cycle assessment of cheese and whey production in the USA. Int. J. Life Cycle Assess. 18, 1019–1035. https://doi.org/10.1007/s11367-013-0553-9

Lexico, 2021. Dictionary [Online]. Available. https://www.lexico.com/en/definition/pizza (Accessed 23 July 2021).

Masset, G., Soler, L.-G., Vieux, F., Darmon, N., 2014. Identifying Sustainable Foods: The Relationship between Environmental Impact, Nutritional Quality, and Prices of Foods Representative of the French Diet. Journal of the

Academy of Nutrition and Dietetics 114, 862–869. https://doi.org/10.1016/j.jand.2014.02.002

Ministry of Solidarity and Health, 2019. Programme National Nutrition Santé (PNNS) 2019-2023.

PIC International, 2020. La croissance retrouvée du marché de la pizza - News commerce - 701 [Online]. Available. https://www.pic-inter.com/actualites-commerce/news-commerce/la-croissance-retrouvee-du-marche-de-la-pizza-701.html (Accessed 9 February 2021).

Pointereau P., Baudry J., Couturier C., Kesse-Guyot E., Hamon X., Hercberg S., Luzzi H., Lairon D., Langevin B., Le Manach F., Seconda L., 2019. Le revers de notre assiette : Changer d'alimentation pour préserver notre santé et notre environnement. Solagro.

Rabès, A., Seconda, L., Langevin, B., Allès, B., Touvier, M., Hercberg, S., Lairon, D., Baudry, J., Pointereau, P., Kesse-Guyot, E., 2020. Greenhouse gas emissions, energy demand and land use associated with omnivorous, pesco-vegetarian, vegetarian, and vegan diets accounting for farming practices. Sustainable Production and Consumption 22, 138–146. https://doi.org/10.1016/j.spc.2020.02.010

Reynolds, C.J., Buckley, J.D., Weinstein, P., Boland, J., 2014. Are the Dietary Guidelines for Meat, Fat, Fruit and Vegetable Consumption Appropriate for Environmental Sustainability? A Review of the Literature. Nutrients 6, 2251–2265. https://doi.org/10.3390/nu6062251

Roy, P., Nei, D., Orikasa, T., Xu, Q., Okadome, H., Nakamura, N., Shiina, T., 2009. A review of life cycle assessment (LCA) on some food products. Journal of Food Engineering 90, 1–10. https://doi.org/10.1016/j.jfoodeng.2008.06.016

Saarinen, M., Fogelholm, M., Tahvonen, R., Kurppa, S., 2017. Taking nutrition into account within the life cycle assessment of food products. J. Clean. Prod. 149, 828–844. https://doi.org/10.1016/j.jclepro.2017.02.062

Saerens, W., Smetana, S., Van Campenhout, L., Lammers, V., Heinz, V., 2021. Life cycle assessment of burger patties produced with extruded meat substitutes. Journal of Cleaner Production 306, 127177. https://doi.org/10.1016/j.jclepro.2021.127177

Saint-Eve, A., Irlinger, F., Pénicaud, C., Souchon, I., Marette, S., 2021. Consumer preferences for new fermented food products that mix animal and plant protein sources. Food Quality and Preference 90, 104117. https://doi.org/10.1016/j.foodqual.2020.104117

Shahvarooghi Farahani, S., Soheilifard, F., Ghasemi Nejad Raini, M., Kokei, D., 2019. Comparison of different tomato puree production phases from an environmental point of view. Int. J. Life Cycle Assess. 24, 1817–1827. https://doi.org/10.1007/s11367-019-01613-x

Soler L.G., Van de Werf H.M.G., Muller L., Gascuel C., Colomb V., Rimbaud A., Mousset J., 2020. L'affichage environnemental des produits alimentaires: Quelles modalités, quelles données, quels usages? Document de travail.

Stylianou, K.S., McDonald, E., Fulgoni III, V.L., Jolliet, O., 2020. Standardized Recipes and Their Influence on the Environmental Impact Assessment of Mixed Dishes: A Case Study on Pizza. Sustainability 12, 9466. https://doi.org/10.3390/su12229466

Tukker A., Huppes G., Geerken T., Nielsen P., 2006. Environmental Impact of Products (EIPRO): Analysis of the life cycle environmental impacts related to the final consumption of the EU-25. Technical Repport Series.

United nations, 2017. La population mondiale devrait atteindre 9,8 milliards en 2050 et 11,2 milliards en 2100, selon l'ONU [Online]. Available. https://news.un.org/fr/story/2017/06/359662-la-population-mondiale-devrait-atteindre-98-milliards-en-2050-et-112-milliards (Accessed 9 February 2021).

United Nations, 2020. Sustainable development GOALS [Online]. Available. https://www.un.org/sustainabledevelopment/sustainable-development-goals/ (Accessed 28 July 2021).

United Nations, 2021. Shifting to Sustainable Diets [Online]. Available. https://www.un.org/en/academic-impact/shifting-sustainable-diets (Accessed 26 July 2021).

Vieux, F., Soler, L.G., Touaziz, D., Darmon, N., 2013. Impact carbone et qualité nutritionnelle de l'alimentation en France [Online]. Available. https://agriculture.gouv.fr/impact-carbone-et-qualite-nutritionnelle-de-lalimentation-en-france (Accessed 18 February 2021).

Weidema, B.P., M. Wesnæs, J. Hermansen, T. Kristensen, and N. Halberg. 2008. In Environmental improvement potentials of meat and dairy products, eds. Eder, P. and L. Delgado. Report EUR 23491 EN, European Commission, Joint Research Centre (DG JRC), Institute for Prospective Technological Studies. Sevilla, Spain.

Wolk, A., 2017. Potential health hazards of eating red meat. Journal of Internal Medicine 281, 106–122. https://doi.org/10.1111/joim.12543