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This paper is a postprint of Cortesi, A., Colpaert, M., Saint-Eve, A., Maurice, B., Yannou-Le Bris, G., Souchon, I., Pénicaud, C., 2023. Contribution of consumer practices to the environmental impacts of pizzas. Sustainable Production and Consumption 37, 26–38. https://doi.org/10.1016/j.spc.2023.02.002

Contribution of consumer practices to the environmental impacts of pizzas

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Abstract

The production and consumption of food are responsible for high environmental impacts. While the impacts of the agricultural production of food have been widely studied, less is known about the environmental effects associated with household food preparation by consumers. This study thus had two main goals: to (i) evaluate the influence of consumer practices at home on the environmental impacts of a food product, (ii) to compare the environmental performance of a single type of food prepared using different manufacturing methods (industrial, homemade, and assembled at home). These environmental profiles were also compared to consumers' perceptions and preferences regarding these products. Pizza was chosen as a study model. Sixty-nine participants were recruited to prepare, consume and evaluate six pizzas at home (one ham-and-cheese pizza and one mixed-cheese pizza, prepared using each of the three methods). Participants were asked to complete questionnaires related to their habits, the preparation of the six pizzas, and their perceptions and preferences. Their answers were used to assess the environmental impacts of the pizzas via life cycle assessments (LCA) in SimaPro software using two different functional units (FUs): one pizza and 1 kg of pizza. Our results revealed that consumer practices can vary greatly among consumers which has a significant influence on the environmental impacts of pizza. For both FUs studied, the responsibility of the recipe and of the manufacturing are preponderant on certain indicators of the environmental profile. Thus the manufacturing has a decisive influence on the values of the indicators sensitive to electricity consumption. Consumers tend to prefer homemade pizzas and think that they are have less impact on the environment, which is not necessarily in line with our results. This study demonstrates the importance of incorporating consumer practices into environmental assessments of food products in order to adequately describe their environmental impacts.

Keywords

LCA; food processing; food consumption; environmental assessment; sustainability

1. Introduction

Reducing the environmental impacts of human activities is one of the major challenges of the 21st century. In 2015, the United Nations established 17 sustainability goals, of which one was "responsible consumption and production" (United Nations, 2020). Production and consumption of food for human use contributes to 20 to 30% of environmental impacts worldwide (Tukker et al. 2006). For this reason, numerous studies have focused on environmental assessments of food products, with the goal of finding ways to decrease their impacts. Life cycle assessment (LCA) is a well-recognized approach that is widely used by the research and business communities as well as public authorities. It has been standardized in the ISO 14040 to ISO 14044 standards (EN ISO, 2006) and is recommended by the European Commission in the Product Environmental Footprint (PEF) framework (2013/179/EU Commission Recommendation). This multi-criteria assessment method takes into account the entire life cycle of a product and is generally the chosen method when it comes to assessing the environmental impacts of food products (Cucurachi et al., 2019).

The majority of studies on the environmental impacts of food products have concluded that agricultural production is a main contributor to the final product environmental impacts. For example, Weidema et al. (2008) showed that livestock breeding made the single largest contribution to the environmental impacts of dairy and meat products. Similarly, Dijkman et al. (2018) reviewed studies focusing on the environmental impacts of meat, cheese, and bread, and concluded that the agricultural stage was a major hotspot. However, the food consumption step—in other words, the activities related to the use of the food by consumers (including for example home storage or cooking)—is frequently excluded from the scope of the studied systems, generally due to a lack of data. This introduces a comparison bias between products that are manufactured completely outside of the home and those that are manufactured (at least in part) in the home. An exception to this is found in the study of Sonesson et al. (2005), who included the use step in a comparison of the environmental impacts of the same meal produced in different ways: homemade (prepared by boiling, frying and baking), semiprepared, and ready-to-eat microwave preparation. Those authors concluded that, in terms of environmental impacts, the overall differences among the three types of meal preparation were small: the ready-to-eat meal consumed the most energy but the homemade meal had a higher impact on eutrophication and global warming. That study did not address, however, the effect of variability in consumption practices, such as the use time of household equipment, on the final environmental impacts of the product. Instead,

Gruber et al. (2016) studied the environmental impacts of potatoes, rice, and milk studied in three different scenarios of consumer behavior: a base scenario (including, e.g., transport by car and cooking in an uncovered pot with heat reduction after boiling point), a conscious scenario (e.g., transport by walking and cooking in a covered pot with heat reduction after boiling point), and a careless scenario (e.g., transport by car and cooking in an uncovered pot without heat reduction after boiling point). The results showed that the use step can become the main contributor to the environmental impacts of food products when using the careless scenario which means that the consumer practices can have a strong influence of the product environmental impacts.

A strong influence of consumer behavior on the environmental impacts of food was also highlighted by Matar et al. (2020) in a study of 132 scenarios of home storage of strawberries. In particular, the authors reported that the consumers' habit of opening the packaging before storing berries at home undermined the environmental benefits of modified atmosphere packaging in reducing food waste.

Consumer practices can differ from one household to another for several reasons, one being the type of household equipment available. For example, in France in 2015, 61% of households had a dishwasher and 84% owned a car (INSEE, 2019). However, practices regarding food can be shaped by many other factors such as habits or compromises with other constraints (e.g., time constraints). Consumers are increasingly attentive to the environmental impact of the food products they consume (Esmailpour and Rajabi, 2018), even if this is not usually considered a main criterion for food choices (Campbell et al., 2016). However, consumer knowledge regarding the environmental impacts of food is globally low. For example, Macdiarmid et al. (2016) highlighted a lack of consumer knowledge about the link between meat consumption and environmental impacts. Similarly, consumers tend to underestimate the energy consumption and greenhouse gas emissions associated with their food (Camilleri et al., 2019). Therefore, the way in which consumers perceive the environmental impacts of food products might not be consistent with the actual environmental performance. For this reason, it is important to have and disseminate informative data on the impact of consumer practices on the environmental impacts of products, and to understand consumers' perceptions of these impacts in order to help them make more environmentally friendly choices.

The goal of the current study was to investigate the influence of real consumer practices on the environmental impacts of a food product. Pizza was chosen as the study model, for three main reasons. The first is that pizza is a product that can be prepared in different settings, such as in an industrial facility or at home, and each method is associated with different practices at the use step. The second reason is that pizza is particularly appreciated in France, where its consumption is about 10 kg per capita each year; indeed, France has the largest per capita consumption of pizza in the world, along with the USA (PIC International, 2020). The third reason is that our team has already assessed the environmental impacts of 80 industrial pizzas (Cortesi et al. 2022a; Cortesi et al., 2022b), which provided a strong basis for the methodological choices in this study.

Here, different methods for preparing pizza—industrial, assembled at home from industrial ingredients, and homemade—were assessed by LCA, together with the variability in use practices of 69 consumer households. Consumers' perceptions of the environmental impacts of the different pizzas were also investigated in order to identify whether or not these were consistent with the environmental impacts calculated by LCA. Finally, data on consumers' overall appreciation of the different pizzas and perceptions of their impact on health were evaluated so that these could be compared to the perceptions of environmental impacts.

2. Materials and methods

2.1. Pizza manufacturing methods

Three manufacturing methods were studied.

Manufacturing method 1 - Industrial pizza. An industrial pizza was bought at the supermarket and baked by the consumer at home.

Manufacturing method 2 – Pizza assembled at home. Industrial pizza dough, industrial tomato sauce, and all the toppings were bought at the supermarket. The consumer assembled all the ingredients, and baked the pizza at home.

Manufacturing method 3 - Homemade pizza. All the ingredients needed to make the pizza dough and the tomato sauce, as well as all the toppings, were bought at the supermarket. The consumer prepared the dough and the tomato sauce at home and assembled the pizza before baking it.

These three manufacturing methods were investigated using two study models: a ham-and-cheese pizza (Nutri-Score B (Hercberg et al., 2022)) and a mixed-cheese pizza (Nutri-Score D). These two study models were selected because ham-and-cheese and mixed-cheese pizzas are the most popular types of pizza in France and because we wanted pizzas with different nutritional qualities in order to assess the potential impact of nutritional quality on the LCA results. For the sake of practicality, we will use the codes presented in Table 1 for describing the six pizzas used in this study.

Table 1. Pizza codes used in this study.

	Ham-and-Cheese	Mixed-Cheese
Manufacturing method 1: Industrial pizza	Pizza Ind_H/C	Pizza Ind_C
Manufacturing method 2: Pizza assembled at home	Pizza Ass_H/C	Pizza Ass_C
Manufacturing method 3: Homemade pizza	Pizza Hom_H/C	Pizza Hom_C

The homemade and assembled-at-home pizzas were formulated to be as similar as possible to the industrial versions in terms of nutritional and sensorial characteristics. For example, Ind_H/C contained 208 kcal/100 g, so the assembled-at-home and homemade ham-and-cheese pizzas were formulated to be close to this value (203.4 kcal /100 g for Ass_H/C and 188.5 kcal/100 g for Hom_H/C). The nutritional values considered during the formulation process were the amounts of energy, fat, saturated fat, carbohydrates, sugar, fiber, protein, and salt. More details related to the selection of the two industrial pizzas and the recipes of the assembled-at-home and homemade pizzas are available in the associated data paper (Dataset no.4).

2.2. Consumer recruitment

Sixty-nine consumers were recruited and asked to prepare and consume each of the six pizzas. The consumers were recruited through an agency specialized in sensory analysis located in France (Ile-de-France region). Participants were selected to be representatives of the French population in terms of age and sex.

The study lasted for three weeks; each week, each participant consumed two different pizzas. The ingredients and/or products required for the preparation of two pizzas were delivered to the consumer's house on a weekly basis. The order of consumption was balanced across participants and organized so that in a given week each participant did not consume the same type of pizza (H/C and C) or the same manufacturing method (Ind, Ass, Hom) more than once. More details related to consumer selection and the study schedule are available in the associated data paper (first paragraph of section 2.4. Inventory and data collection).

2.3. Questionnaires

Data related to consumers' household equipment, their consumption habits, the preparation of the pizza, and their perceptions were collected through three online questionnaires. The questionnaires are available in the associated data paper (datasets no.1-3) and are summarized in the following sub-sections.

Questionnaire 1 (21 questions). This questionnaire was completed before the study began. The main topics were:

- Model and brand of different types of household equipment (in order to estimate electrical consumption);
- Distance between the consumer's home and the supermarket, and the type of transportation generally used to go grocery shopping.

Questionnaire 2 (44 questions). This questionnaire was completed after the preparation and consumption of each pizza (a total of six times). The main topics were:

- Pizza preparation (i.e. baking time, household equipment used);
- Pizza consumption (perceptions);
- Management of leftovers.

Questionnaire 3 (28 questions). This questionnaire was completed at the end of the study (after each consumer had prepared and consumed the six different pizzas). The main topic was:

- Ranking of the six pizzas based on different criteria (i.e. liking and perceptions of nutritional value, manufacturing processes, and environmental impacts). Only the data associated with liking scores and perceptions of environmental and health impacts will be presented in this paper, together with the LCA results. The other data collected in this section will be presented in a separate, dedicated paper.

The answers to these questionnaires were analyzed in order to investigate variability in consumer practices regarding transportation between the home and the supermarket, home storage of pizzas/ingredients, at-home preparation of the dough and tomato sauce (only for homemade pizzas), the baking of the pizza, and the cleaning of any equipment/utensils used to make/consume the pizza. The results related to the variability observed are presented in section 3.1. These answers were then used to generate the inventory data for the environmental impact assessment and to compare the perceptions of consumers regarding the six pizzas.

2.4. Environmental impact assessment

The environmental impacts of the pizzas were calculated using LCA following the standard steps (EN ISO, 2006): goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation of results.

2.4.1. Goal and scope definition

The goals of the LCAs were (i) to identify the main hotspots of the pizzas' environmental impacts as a function of the manufacturing method, (ii) to quantify the influence of consumer practices on the environmental impacts of the pizzas, and (iii) to compare the effects of the different manufacturing methods on the environmental impacts of the pizzas. The system perimeter included all steps from the agricultural production of the primary ingredients to consumption, and is shown in Figure 1.

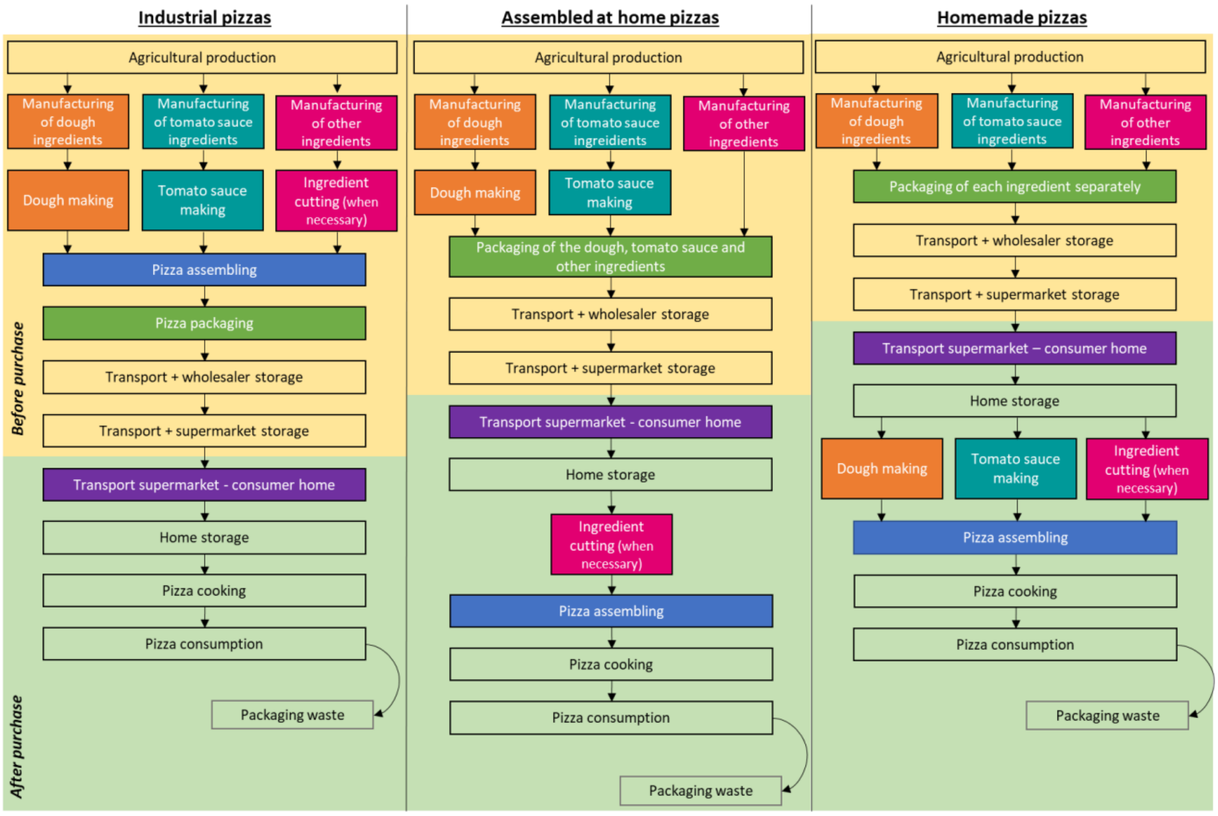


Figure 1. Steps included in the system perimeter for each manufacturing method (industrial, assembled at home, homemade). The yellow and green backgrounds delineate steps that took place before and after purchase, respectively. The other colors were used to highlight steps that occurred in a different order depending on the manufacturing method.

Because in this study consumers were asked to prepare and consume one pizza at a time, we chose a functional unit (FU) of one pizza after baking. However, the weights of the pizzas were different from one pizza to another. Therefore, the results obtained with a FU of one pizza are compared to those obtained with a FU of 1 kg of pizza in the results section.

2.4.2. Life cycle inventory analysis

2.4.2.1. Data collection

The main flows taken into account in this study were: primary materials (for ingredients and packaging), packaging waste, electricity, gas, water, and transportation. Background data from the databases AGRIBALYSE 3.0 and Ecoinvent 3.6 were used. Inventory data for the steps occurring before purchase were based on hypotheses in the AGRIBALYSE 3.0 database and a pizza LCI dataset (Cortesi et al., 2022b) adapted to the six pizzas studied here. Inventory data for the steps occurring after purchase were based on consumer answers to the questionnaires. More details about the collection of life cycle inventory data are available in the associated data paper. The transport step from the supermarket to the consumer's home was treated in a specific way. Since consumers did not go to the supermarket themselves (we provided them the ingredients and the pizzas necessary for the experiment), we modeled this step using their answers in questionnaire 1 (distance between their home and the supermarket, means of transportation used for grocery shopping). Furthermore, the majority of consumers stated in the questionnaire that they typically buy groceries once a week. We thus modeled a scenario in which each shopping trip provides for 14 meals (two meals per day for seven days). We also judged that a more typical frequency of pizza consumption was one pizza per week instead of the two eaten during the study period. Therefore, an allocation of 1/14 was used for the transport step to estimate the environmental impacts of transportation between the home and the supermarket that were attributable only to the pizza or to the ingredients needed to make the pizza.

2.4.2.2. LCI scenarios

Since some consumers returned incomplete questionnaires, we were not able to accurately assess the environmental impacts of each pizza prepared by each consumer. Therefore, different LCI scenarios were constructed to analyze the results.

Baseline scenario. Based on all the answers available, we calculated a weighted average for each variable of interest for each pizza. For instance, an average was calculated for the use time of the ovens used to cook the pizzas. When practices differed among consumers, weighting was applied. For example, since 24 of the 69 consumers used a small gasoline car for grocery shopping, a weighting of 24/69 was used for this means of transportation in the baseline scenario (the remaining 45/69 being distributed among the other practices such as walking, large diesel car, etc.).

Best and worst scenarios. From all the available consumer answers, best and worst practices were modeled for each method of pizza preparation based on the authors' knowledge on the links between consumer practices and environmental impacts. For instance, for the baking step, the best practice was associated with the shortest oven use whereas the worst practice was associated with the longest oven use.

Random scenarios. In order to study the significance of the differences observed among the six pizzas using the baseline scenario, 69 random draws were performed of the available data collected through the questionnaires for each pizza. The datasets obtained mimicked the practices of the 69 participants of the study. For data following a normal distribution (Shapiro-Wilk test), the draws followed a normal distribution. The same was true for data following a log-normal distribution. For data not following a normal or log-normal distribution, draws followed a uniform distribution (distributions are available in datasets 7, 8, 10, 13).

Each of the different LCI scenarios was used for a different purpose. The baseline scenario was used for the definition of hotspots. The best and worst scenarios were used to assess the influence of variability in different consumer practices on the environmental impacts of the pizzas. The 69 random scenarios were used to assess the influence of the manufacturing method on the pizzas' environmental impacts.

2.4.3. Life cycle impact assessment

All the LCAs presented in this study were performed using SimaPro 9.1.0.11 software and the characterization method "EF 3.0 Method (adapted) V1.00 / EF 3.0 normalization and weighting set". All the midpoint impact categories available in this method were calculated, but only a subset are discussed here: climate change, ozone depletion, ionizing radiation, photochemical ozone formation, particulate matter, acidification, eutrophication (marine), eutrophication (freshwater), eutrophication (terrestrial), land use, water use, resource use (fossil), and resource use (minerals and metals). The three remaining indicators (i.e., human toxicity, non-cancer; human toxicity, non-cancer; and ecotoxicity-freshwater) were not included in the study since they are poorly modeled (Sala et al. 2018).

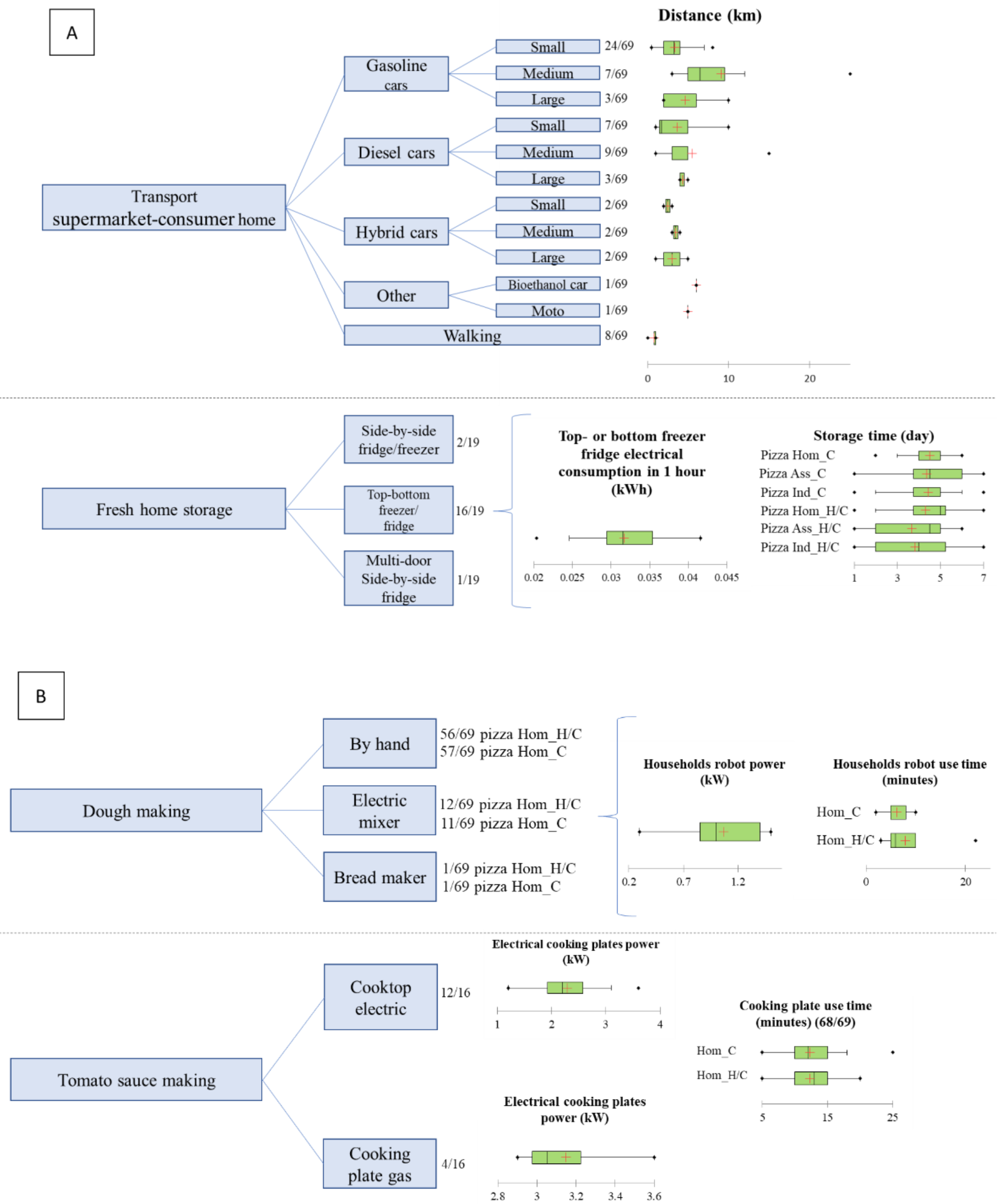
2.4.4. Statistical treatment of the results

The normality of the data collected through the questionnaires was assessed using a Shapiro-Wilk test carried out in XLStat software (version 2020, 5.1.1043).
The significance of differences observed among the six pizzas was assessed using a Kruskal-Wallis test associated with a Dunn test on the 69 LCAs calculated for each of the pizzas.

3. Results and discussion

3.1. Variability in consumer practices

This section will discuss the variability in consumer practices as reported in the questionnaires. Figure 2 shows the different practices reported by the study participants for each preparation step and the proportion of participants using each practice. The dispersion of the practices are illustrated using boxplots. For each boxplot, the extreme points represent the extreme values, the horizontal bars represent the quartiles and median while the red cross represent the mean value. All the associated numerical values are available in the associated data paper (datasets 7 and 8).



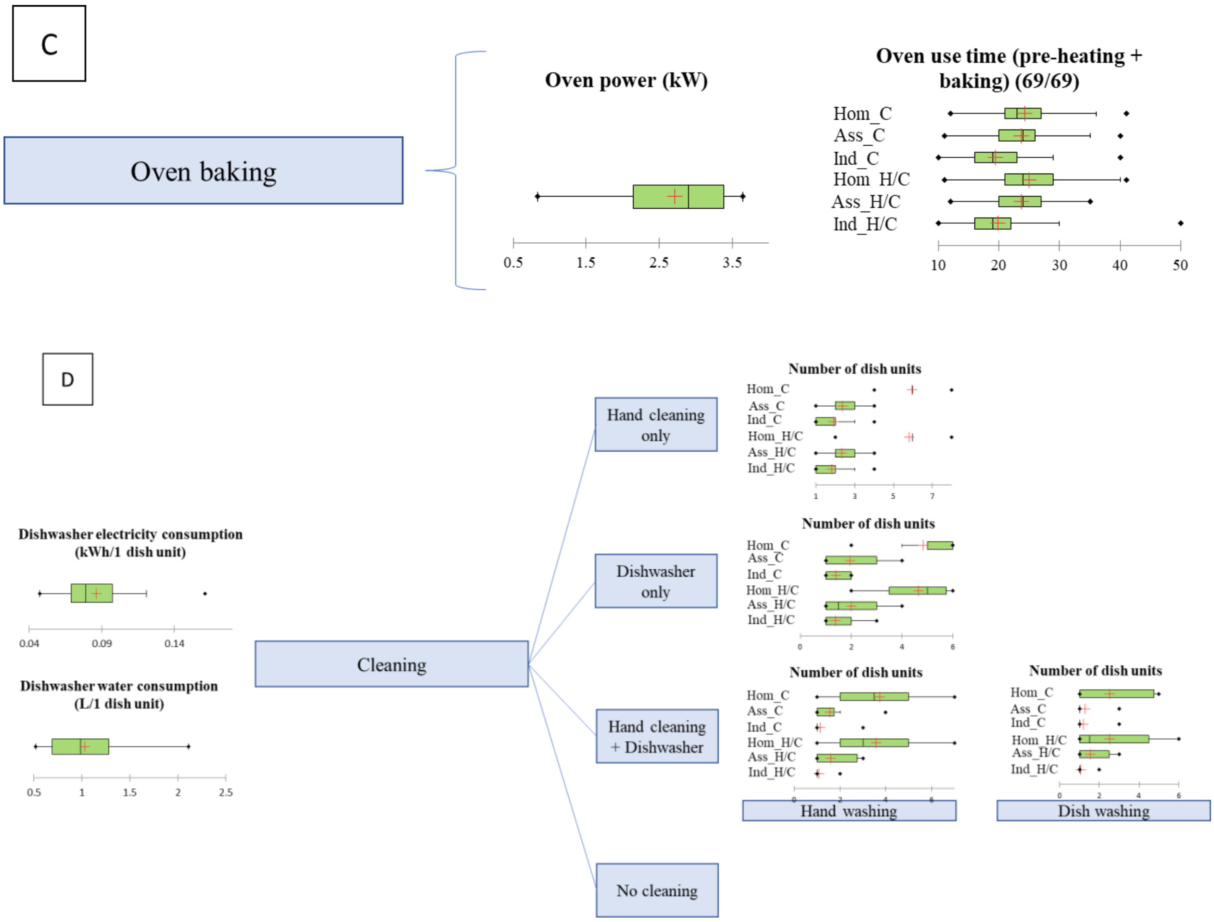


Figure 2. Representation of the different practices of the consumers in this study, with the proportion who used each practice (n/n_{total}). The variability in the responses is depicted using boxplots. A: transport and storage; B: preparation of dough and tomato sauce for homemade pizza; C: pizza baking; D: equipment cleaning

3.1.1. Transport from supermarket to home

Figure 2.A shows the variability in consumer practices for transporting food from the supermarket to the home. All 69 consumers reported their most commonly used means of transportation for grocery shopping as well as the distance between their home and their usual supermarket. Twelve means of transportation were identified (gasoline car (small, medium, large), diesel cars (small, medium, large), hybrid cars (small, medium, large), bioethanol car, moto and walking) and the most frequently used was the small gasoline car (24/69). The distances between a consumer's home and his or her usual supermarket ranged from 0.3 to 25 km.

3.1.2. Home storage

Figure 2.A shows the variability in consumer practices with respect to storage of the pizza or the fresh ingredients needed to make the pizza. Participants were asked to report the power of their fridge (or at least the brand and model) and how full it typically is. Nineteen consumers answered this question

and three main types of fridge were identified: Side-by-side freezer/fridge, top- or bottom-freezer fridge, and multi-door side-by-side fridge. Figure 2.A also presents the variability in the electricity consumption of the most frequently mentioned fridge model (combined fridge) and the variability in the storage times for all pizzas.

3.1.3. Dough making

Figure 2.B presents the variability in consumer practices regarding homemade dough making. To prepare the dough at home, participants either mixed it by hand or using household equipment. For pizza Hom_H/C, 13 consumers reported that they used electrical equipment, while 12 did so for pizza Hom_C. Of these, one person used a bread maker while the others used an electric mixer. For pizza Hom_H/C, the use time of the electric mixer ranged from 3 to 22 minutes and from 2 to 10 minutes for pizza Hom_C. For the participant who used a bread maker, the use time was 85 minutes for both pizzas.

3.1.4. Tomato sauce making

Figure 2.B presents the variability in consumer practices for making the homemade tomato sauce. Of the participants who provided information on their cooking method, 12 used electric cooktops and 4 used gas cooktops. As reported by 68 of the consumers, the cooking time for the tomato sauce was typically approximately 10 to 15 minutes for both pizzas, but ranged from 5 to 20 minutes for pizza Hom_H/C and from 5 to 25 minutes for pizza Hom_C.

3.1.5. Pizza baking

Figure 2.C focuses on the variability in consumer practices for baking the pizzas. All 69 consumers reported the time they used their oven for baking the pizza (including pre-heating and cooking time). The oven use times were quite variable among participants, up to a factor of 5 in the case of pizza Ind_H/C (range: 10 to 50 min). On average, the cooking time for industrial pizzas was shorter than that of the homemade or assembled at home pizzas, which makes sense because industrial pizzas are pre-baked. Globally, the use time of ovens was above the recommended cooking times (between 6 and 8 min for pizza Ind_H/C). This was due to the fact that the preheating time varied greatly depending on the consumer's oven, but may also have been longer than necessary.

3.1.6. Dish cleaning after pizza preparation/consumption

Figure 2.D depicts the variability in consumer practices for cleaning dishes after pizza preparation/consumption. All 69 participants provided information on the cleaning method used (no cleaning, dishwasher cleaning only, hand-cleaning only, or both) as well as the number of dishes units cleaned. One dish unit represents the equivalent of one plate, one fork, and one knife. The number of dish units represented by the different types of kitchen equipment used are available in the associated data paper (dataset no.13). The proportion of participants who used each cleaning method varied

among the different pizzas. Figure 2.D also presents the variability in electricity and water consumption per dish unit as estimated for the different dishwashers, taking into account the reported program and capacity used. For handwashing, the type of water heater (electric or gas-based) was taken into account but we did not model any variability in the water and energy consumption per dish unit. More details on the proportions of consumers with electric and gas water heaters are available in the associated data paper (dataset no.12).

3.2. Hotspot definition

This section describes the relative contribution of different life cycle steps to a pizza's impact on 13 environmental indicators, calculated using the baseline scenario (described in section 42.2.2.2). Figure 3 presents the results obtained for pizza Ass_H/C. The agricultural step includes the production of the primary ingredients and, for meat ingredients, includes slaughter. Ingredient transformation refers to the transformation of agricultural products into ingredients. The packaging step includes packaging materials as well as the transportation of those materials to the factory. Distribution includes the storage of ingredients at the wholesale facility and at the supermarket as well as the transportation related to distribution. The transport step refers to the transportation of pizzas/ingredients from the supermarket to the home. The home cooking step includes both pre-heating and baking. The dish cleaning step includes the cleaning of the utensils used for the preparation and consumption of the pizza. Finally, the step called "other" includes dough making, tomato sauce making, waste, and fresh storage in the house. These steps were grouped because of their low contribution to the overall environmental impacts.

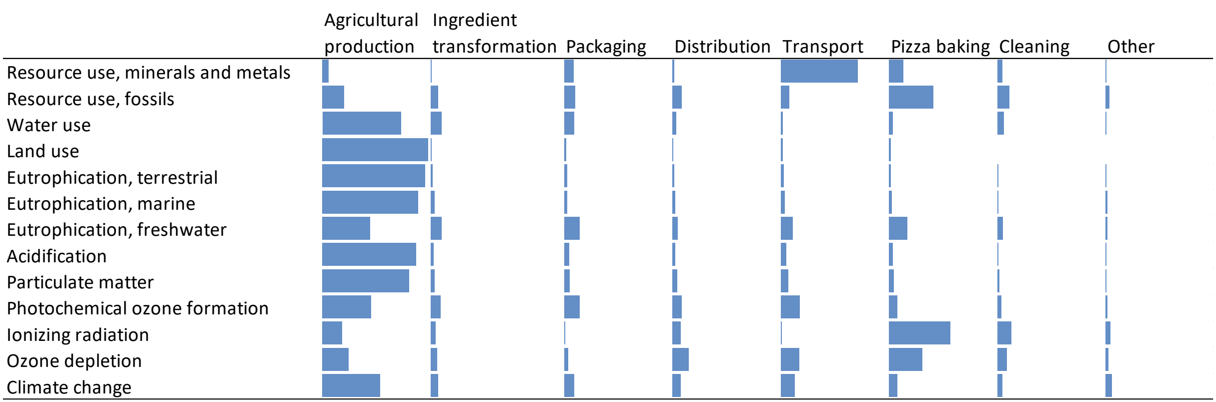


Figure 3. Contributions of the main production steps of pizza Ass_H/C (baseline scenario) to 13 environmental indicators calculated using the EF3.0 method.

For the pizza represented in Figure 3 (ham-and-cheese, assembled at home), the agricultural production of ingredients was the main contributor to its impact on nine environmental indicators: climate change, photochemical ozone formation, particulate matter, acidification, eutrophication (freshwater), eutrophication (marine), eutrophication (terrestrial), land use, and water use. This is logical because these environmental indicators are all linked to agricultural practices. For example, the greenhouse gas (GHG) emissions from farm animals and farm machinery make notable contributions to climate change (Dollé et al., 2011), while eutrophication is increased by the spreading of manure (Le Moal et al. 2019). In this, our result is consistent with the current literature (Cucurachi et al., 2019).

The home cooking step was the main contributor to this pizza's impact on ozone depletion, ionizing radiation, and resource use (fossil), which makes sense since these indicators are sensitive to electricity consumption. Here, electricity consumption was modeled with a French electricity mix, which is heavily based on nuclear power (67%) (RTE, 2021); this likely explains the strong influence of the cooking step on ionizing radiation (generated by the nuclear production of electricity (Frischknecht et al., 2000)) but the relatively small impact on climate change (less than 10% for all pizzas). In this, our study differs from that of Frankowska et al. (2020), who concluded that the cooking step could be responsible for 6% (for pre-cooked food products) to up to 61% (for raw products) of the total GHG emissions of a food product. This difference might be due to the fact that those authors based their calculations on the UK electricity mix, which is mainly composed of GHG-producing fossil fuels such as natural gas (42%) and coal (9%) (Energy UK, 2022), with only 21% of electricity derived from nuclear power. Even though the impact of the cooking step on climate change was relatively minor in this case, this step was still a major hotspot for other environmental indicators, especially those, like ionizing radiation, that are sensitive to nuclear electricity production. Optimization of this step might therefore be a potential means of reducing the environmental impacts of food products.

Transportation from the supermarket to the home was the main contributor to the impact on resource use (minerals and metals), which reflects for example the use of metals to make and maintain cars. However, this study did not examine either the materials used to manufacture home appliances/equipment or those used for food processing at factories, which could lead to an underestimation of the impact of these steps on this indicator, and therefore a overestimation of the home transport contribution.

The results were globally similar for the other five pizzas, although the contribution of tomato sauce making (included in "other") for the homemade pizzas resulted in stronger impacts on some environmental indicators for homemade pizzas (up to 14% of ionizing radiation for pizza Hom_C) (dataset no.15 in the associated datapaper).

3.3. Influence of variability in consumer practices on the environmental impacts of pizzas

Next, we investigated how sensitive the LCA results were to different scenarios based on the practices reported by study participants (Figure 2). In this section, we will present the parameters for which variations in inventory data generated the most change in LCA results: cooking time, transportation between the home and the supermarket, and management of pizza leftovers.

3.3.1. Influence of baking time

The influence of cooking time on the environmental impacts of pizzas was investigated by comparing the LCA results obtained with the shortest baking time (best scenario), baseline baking time, and the longest baking time (worst scenario). Figure 4 shows the environmental impacts of pizza Ind_H/C (chosen because it had the widest reported range of cooking times) in each of these three cases. The environmental impacts associated with the best and baseline scenarios were expressed as a percentage of those found in the worst scenario.

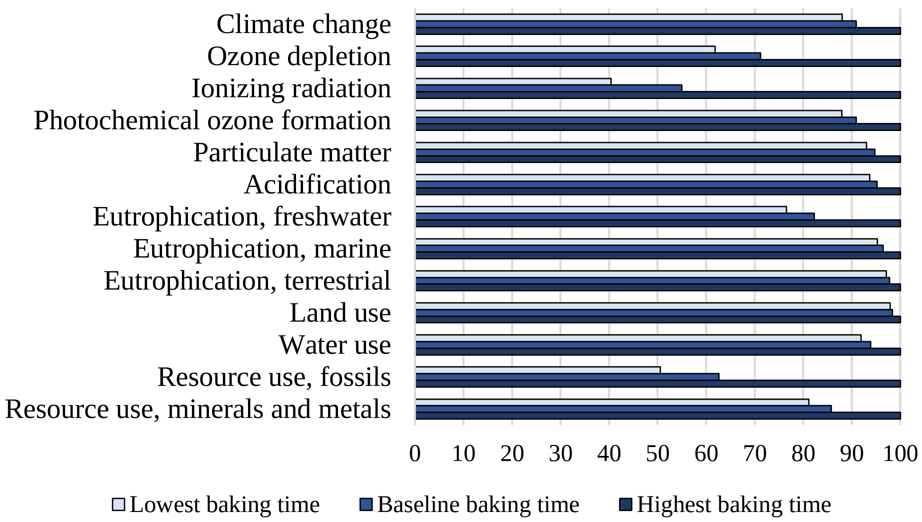


Figure 4. Differences in the environmental impacts of pizza baked for the shortest cooking time (light blue), the baseline cooking time (medium blue), and longest cooking time (dark blue) reported by consumers (Pizza Ind_H/C). Ind: Industrial; Ass: Assembled at home; Hom: Homemade; H/C: Ham-and-cheese; C: Mixed-cheese.

As shown in Figure 4, it is clear that a reduction in the time of oven use at home (including pre-heating and baking) was accompanied by a reduction in the pizza's impacts on all studied environmental indicators. The magnitude of the reduction between the best and worst scenarios varied depending on the indicator, ranging from 2% (land use) to almost 60% (ionizing radiation). Ozone depletion, ionizing radiation, and resource use (fossil) were the most sensitive indicators to variations in cooking time, which is consistent with the fact that the cooking step was a major contributor to the impact on these indicators (discussed in section 3.2). Reductions in the duration of home oven use can thus lead to notable reductions in the environmental impacts of a food product, especially for environmental indicators that are sensitive to electricity consumption.

3.3.2. Influence of transportation from the supermarket to the home

3.3.2.1. Influence of distance

As highlighted in Figure 3, the transportation of a pizza (or its ingredients) from the supermarket to the home has a non-negligible effect on its environmental impacts; indeed, this step was the main contributor to the use of mineral and metal resources. To investigate the influence of the distance between the supermarket and the home, we modeled the most frequently reported means of transportation (gasoline car) and two extreme scenarios: a best scenario of the shortest distance reported by gasoline car users (1 km roundtrip) and a worst scenario of the longest distance reported by gasoline car users (16 km roundtrip). Figure 5 depicts the comparison between the best and worst scenarios and the baseline scenario (calculated using the average distance reported by users of small gasoline cars).

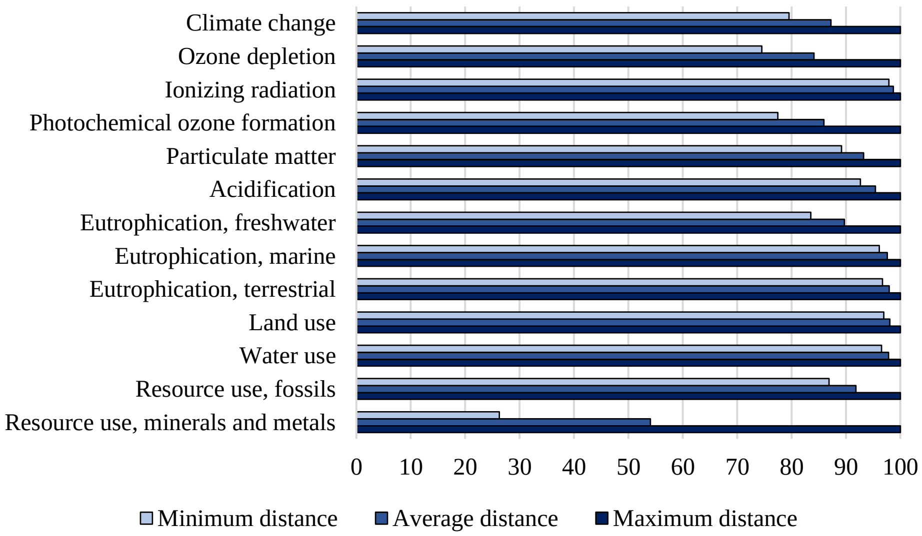


Figure 5. Comparison of the impacts of pizza Ind_H/C on 13 environmental indicators as modeled using the shortest (best scenario), average (baseline scenario), and longest (worst scenario) transportation distances reported by gasoline car users. Ind: Industrial; Ass: Assembled at home; Hom: Homemade; H/C: Ham-and-cheese; C: Mixed-cheese.

The difference in the environmental impact between the best and worst scenarios ranged from 2% (ionizing radiation) to 25% (ozone depletion), with the exception of mineral and metal resource use for which the difference was close to 75%. It is thus clear that a reduction in the distance traveled by passenger car can significantly reduce the environmental impacts of a pizza.

3.3.2.2. Influence of grocery shopping practices

In all analyses presented thus far, an allocation factor of 1/14 was used for transportation between the supermarket and the home because we assumed that only a single shopping trip was made per week (2 meals per day, see section 2.4.2). However, even if this practice was used by the majority of consumers (46/69), other habits were also reported: grocery shopping twice a week (11/69), twice a month (8/69), once a month (1/69), less than once a month (1/69), or more than twice a week (1/69). We thus decided to examine the influence of grocery shopping habits on the environmental impacts of the pizzas, specifically by comparing three practices: grocery shopping once a month (1 pizza = 1 of 60 total meals (2 meals each day)), grocery shopping twice a week (1 pizza = 1 of 7 total meals), and a shopping trip specifically made to buy only one pizza. In other words, we analyzed the impact of the following allocations: 1/60, 1/7, and 1. Figure 6 shows the comparison of the influence of these three grocery shopping practices on the environmental impacts of pizza Ind_H/C (baseline scenario).

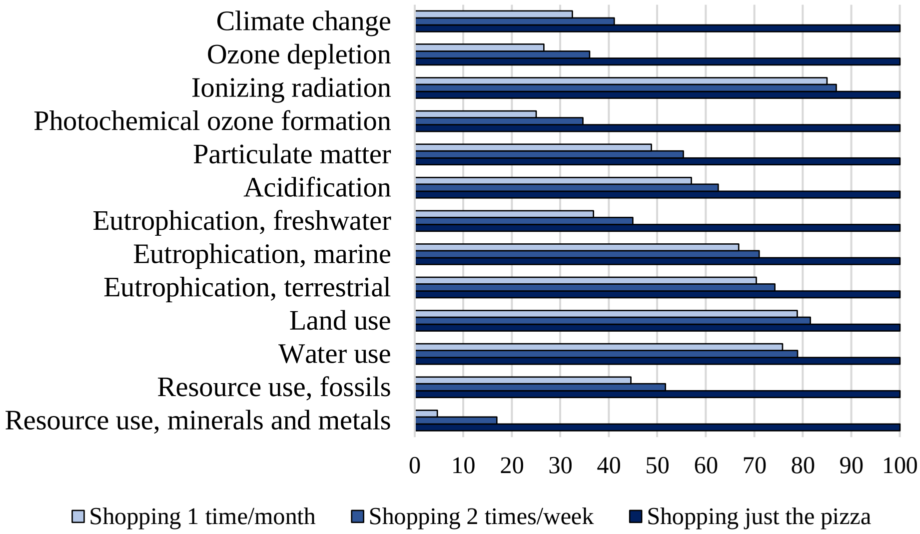


Figure 6. Comparison of the environmental impacts of pizza Ind_H/C with three different shopping habits. Ind: Industrial; Ass: Assembled at home; Hom: Homemade; H/C: Ham-and-cheese; C: Mixed-cheese.

From Figure 6 it is clear that grocery shopping habits can have a large influence on the environmental impacts of food products, with a single shopping trip per month being associated with lower impacts than grocery shopping twice a week. A trip to the store for the sole purpose of buying a pizza was by far the worst-case scenario: the pizza's impact on five environmental indicators was at least double compared to a scenario in which grocery shopping occurs twice a week. From this, it is evident that planning their shopping trips to buy food for as many meals as possible is an important way in which consumers can reduce the environmental impacts of food products. This topic was also addressed by ADEME (2017), who reported that the optimization of transportation habits can have a stronger influence on the environmental impacts of a product than the distances traveled. In other words, the transport of a given product over a long distance in an optimized manner can result in lower greenhouse gas emissions than transport over a shorter distance in an unoptimized manner (such as in a partially empty vehicle, for example).

In our study, this argument is particularly relevant because the majority of consumers used their car to go grocery shopping. However, this is not the case for the French population as a whole, and practices can differ greatly among different environments. For example, in suburban areas, more people tend to use a car to go shopping (84% for large stores and 56% for small/medium stores) than in the city center (51% for large stores and 54% for small/medium stores) (Cerema, 2020).

3.3.3. Influence of the management of pizza leftovers

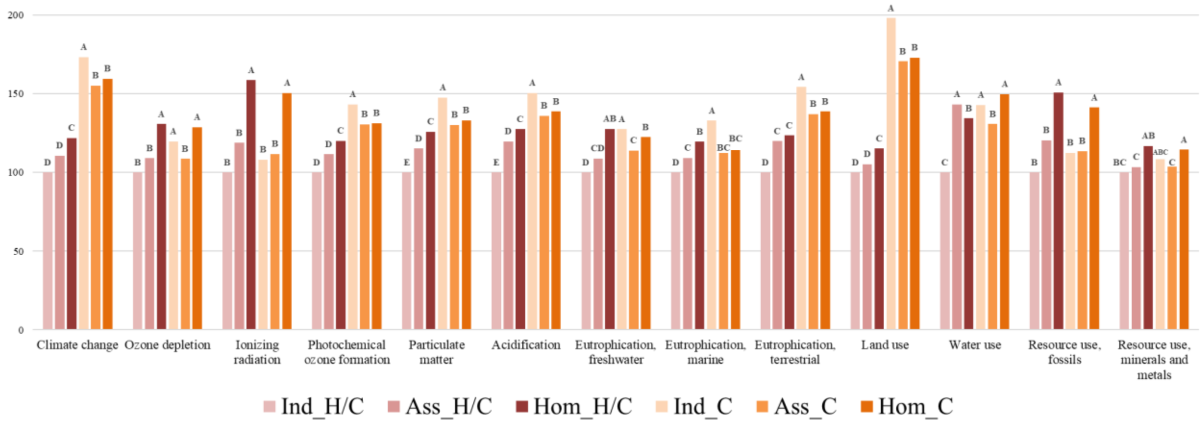
By analyzing the questionnaire 2 data, it was noted that the number of participants who reported having leftovers after their meal was 19 for Ind_H/C, 19 for Ind_C, 23 for Ass_H/C, 20 for Ass_C, 22 for Hom_H/C, and 24 for Hom_H/C. Several options were then possible: storing leftovers in the fridge before re-heating (microwave or electric oven) and consuming them, throwing leftovers away, or giving leftovers away. The environmental impacts of leftovers varied depending on their fate.

Storing and cooking leftovers in a microwave oven had lower environmental impacts than storing and cooking leftovers in an electric oven due to the lower use time of the equipment (10 s–4.5 min for microwave, 5–38 min for electric oven, all pizzas taken together). Indeed, re-heating leftovers in a microwave only slightly increased the overall environmental impacts of the pizzas (i.e. less than 4% for pizza Ass_H/C on all indicators for the longest storage time and the longest microwave use), while re-heating leftovers in the oven could have a significant impact, especially for indicators that are sensitive to electrical consumption. For example, re-heating leftovers of pizza Ass_H/C in the oven for 38 min induced an increase of almost 87% of the pizza's impact on ionizing radiation and more than 62% on fossil resource use, while with a 5-min oven use time, re-heating generated an increase of only 11% for ionizing radiation and 8% for fossil resource use. Therefore, from an environmental point of view, leftovers should preferably be reheated in a microwave or at least using the oven for only a short amount of time.

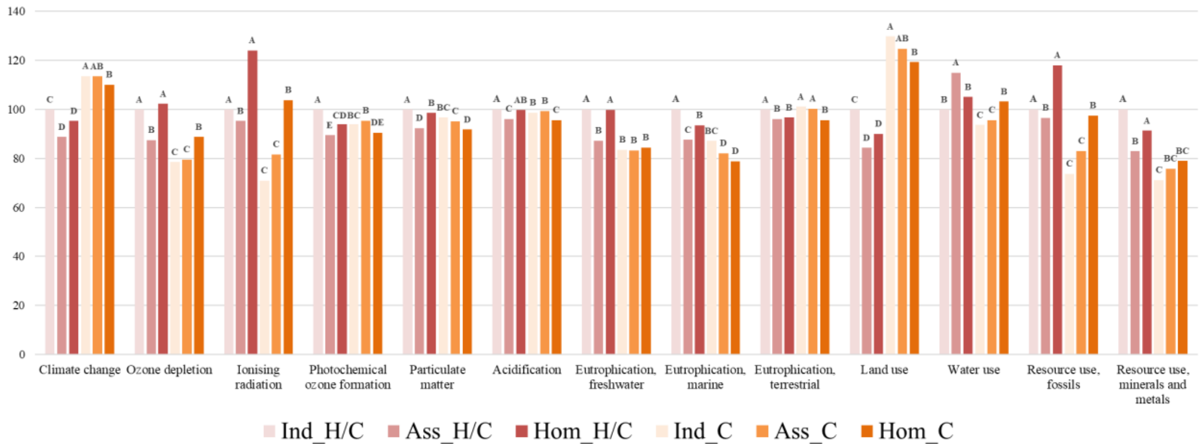
Even though storing and re-heating leftovers generates an additional environmental impact, throwing them away is not a better option. Among the participants in this study, 9 admitted throwing away the leftovers (pizza, crust, or topping) of pizza Ind_H/C, 4 for pizza Ind_C, 5 for pizza Ass_H/C, 5 for pizza Ass_C, 9 for pizza Hom_H/C, and 12 for pizza Hom_C. Among the consumers who threw away their leftovers, the average amount discarded was 21.5% (w/w) of the pizza. If we take the example of the two industrial pizzas, 21.5% (w/w) represents 81.7 g of pizza Ind_H/C, i.e. 170 kcal, and 124.7 g of pizza Ind_C, i.e. nearly 300 kcal. When leftovers are consumed, they are used as part of a second meal. However, when leftovers are discarded, the consumer must consume another food product at the next meal, which creates an additional environmental impact. The average total energy intake of an adult aged 18 to 79 years amounts to 2 144 kcal per day (ANSES, 2017), which is responsible for the emission of about 5 kg CO_2 eq per day (Pointereau et al. 2019). In this case, the additional environmental impacts due to discarding the pizza leftovers amounted to 0.4 kg CO_2 eq for pizza Ind_H/C and 0.7 kg CO_2 eq for pizza Ind_C, that is to say an increase of 8% and 14%, respectively, of the daily emissions of CO_2 eq related to food.

3.4. Influence of manufacturing method on the environmental impacts of pizzas

As described in section 3.3, variability in consumer practices can have a strong influence on the environmental impacts of a pizza. To analyze the environmental impacts among different pizzas, we controlled for this variability using random scenarios (explained in section 2.4.2.2). Furthermore, since the six pizzas differed in weight due to differences in the availability of nutritionally and sensorially similar products in the French retail market, we also examined the results using a standardized functional unit (FU): 1 kg of weight. Therefore, the same 69 random draws were analyzed twice: once using an FU of 1 pizza, and a second time using an FU of 1 kg of pizza. The results for both FUs are presented in Figure 7.



FU = 1 pizza



FU = 1kg of pizza

Figure 7. Comparison of the environmental impacts of all six pizzas using the baseline scenario (FU of 1 pizza or 1 kg of pizza). The significance of differences was evaluated using a Kruskal-Wallis test associated with a Dunn test performed on the 69 LCIAs obtained for each pizza using random scenarios. The letter “A” corresponds to the pizza with the highest average impact using the 69 random scenarios. Ind: Industrial; Ass: Assembled at home; Hom: Homemade; H/C: Ham-and-cheese; C: Mixed-cheese.

The pizzas’ impact on climate change and land use seemed to be more influenced by their ingredients than by the manufacturing method: for both FUs, and regardless of the manufacturing method, the mixed-cheese pizzas had higher environmental impacts than the ham-and-cheese pizzas. This makes sense because these two indicators are strongly influenced by agricultural production. Other environmental categories that are tied to agricultural production—such as photochemical ozone formation, particulate matter, acidification, and terrestrial eutrophication—followed the same trend:

with a FU of 1 pizza, the mixed-cheese pizzas appeared to have stronger overall effects than the ham-and-cheese pizzas. However, when the FU was 1 kg of pizza, the pattern for these indicators shifted, meaning that the observed differences were linked more to the difference in weight among pizzas (Ind_H/C: 380 g; Ass_H/C: 474 g; Hom_H/C: 486 g; Ind_C: 580 g, Ass_C: 520 g, Hom_C: 551 g) than to the pizza recipes.

Instead, manufacturing method appeared to have an influence on the environmental indicators ionizing radiation, ozone depletion and resource use fossils. For both ham-and-cheese and mixed-cheese pizzas and for both FUs, the homemade pizzas tend to have higher impacts than the industrial or assembled-at-home pizzas on these indicators when looking at the baseline scenarios. However, the difference is not significant in some cases (e.g., between homemade and industrial mixed-cheese pizzas for an FU of 1 pizza on the indicator ozone depletion) and even reversed in one case (between homemade and industrial ham-cheeses pizzas for an FU of 1 kg on the indicator ozone depletion). This means that, the trend observed with the baseline scenario can be reversed depending on the consumers practices. These higher impacts for homemade pizzas compared to the others make sense because homemade pizzas tend to require more electricity to prepare (mostly due to a longer cooking time) than industrial pizzas, and electrical consumption generally has a strong influence on ionizing radiation and fossil resource use. However, these findings differ from those of Sonesson et al. (2005), who, after comparing the environmental impacts of the same meal prepared in different ways, concluded that the ready-to-eat meal (industrially prepared) were more energy-intensive than the homemade version.

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3.5. Comparison of consumer preferences and perceptions of the studied pizzas

In questionnaire 3, consumers were asked to rank the six pizzas according to their preferences and their perceptions of the environmental and health impacts of each one. The average ranking obtained for each pizza for each of the three questions is represented in Figure 8. For all three questions, the higher the ranking, the more positive the preference/perception.

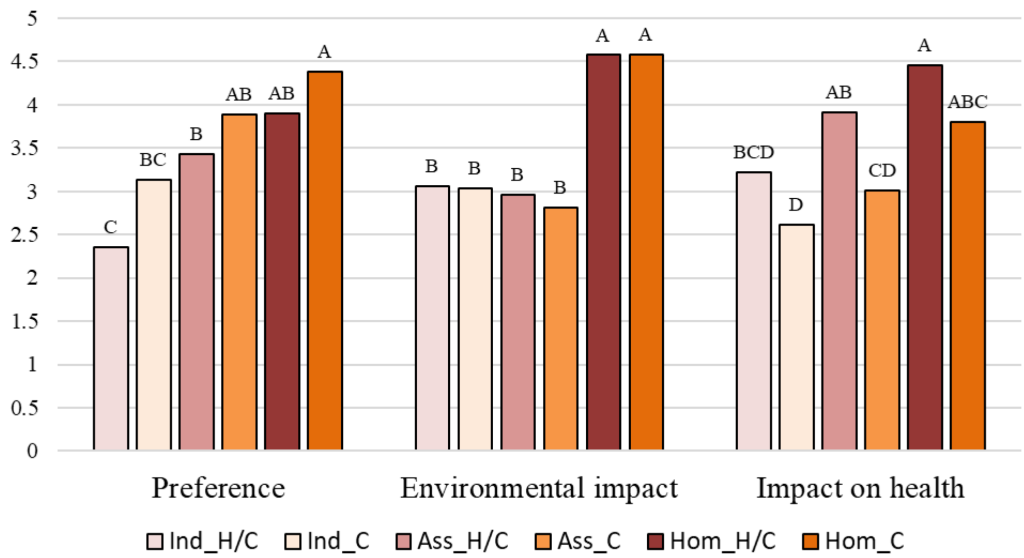

Figure 8. Comparison of the average ranking of the six pizzas with respect to consumers' perceptions and preferences. The significance of differences was assessed using a Kruskal Wallis test followed by a Conover-Iman test; different letters indicate a significant difference. Ind: Industrial; Ass: Assembled at home; Hom: Homemade; H/C: Ham-and-cheese; C: Mixed-cheese.

For both the ham-and-cheese and the mixed-cheese pizzas, the homemade version was generally the most preferred, followed by the one assembled at home and finally the industrial product. It is likely that the homemade pizzas were globally preferred because home cooking is associated with distinct social, cultural, and emotional (e.g., nostalgia) dimensions (Mills et al., 2020). Furthermore, homemade food products are often perceived as more “natural” than more-processed food products, and the “naturalness” of food is very important for the majority of consumers (Román et al., 2017). This could also explain why homemade pizzas tended to be preferred over the assembled-at-home and industrial versions.

For both recipes, homemade pizzas were perceived to have the lowest impact on the environment, with the industrial and assembled pizzas considered nearly equivalent. This could be due to the high amount of packaging needed in the latter two preparations. Indeed, Lea and Worsley (2008) showed that consumers view a reduction in packaging as the most important way to reduce the environmental impacts of food products. Furthermore, the association of a homemade product with “naturalness” can also extend to a low environmental impact in consumers’ minds (Román et al., 2017). With respect to health, industrial pizzas were on average perceived as the worst, while homemade pizzas were perceived as the best. This association between industrial preparation and unhealthy food echoes the message of a current national health and nutritional program in France which recommends increasing the consumption of homemade meals and reducing that of highly processed food (Ministère des solidarités et de la santé, 2019). In their literature review, Pinto et al. (2021) also reported that processed foods tend to be seen as bad for health.

Within each manufacturing method, the mixed-cheese pizza was more appreciated than the ham-and-cheese one. However, in each case, the ham-and-cheese pizza was perceived as being the more healthful of the two, which was consistent with their Nutri-Scores (B for ham-and-cheese vs. D for mixed-cheese). It thus appeared that the participants viewed the mixed-cheese pizzas as the “pleasurable” choice—better tasting but with a negative impact on health—while the ham-and-cheese pizzas were seen as a more responsible—less preferred but more healthful—choice. Between the manufacturing method and the recipe, the manufacturing method had a stronger influence on consumer perceptions for all studied questions. In other words, to improve the nutritional and environmental quality of their meal, consumers tended to think that substituting an industrial pizza with a homemade one would have more of a benefit than substituting a ham-and-cheese pizza with a mixed-cheese pizza (or vice-versa). From a nutritional point of view, this is not necessarily the case, since the homemade and assembled-at-home pizzas were formulated to be as similar as possible to the industrial products. Therefore, in this study, there were more nutritional differences between the two recipes than between an industrial pizza and a homemade one. The effect of differences between pizza recipes was recently demonstrated by Adjibade et al. (2022), who reported that substituting a typical pizza with one with a different recipe formulation (less calories, higher vegetable content, and a dough based on whole grain) reduced the risk of type 2 diabetes. From an environmental point of view, as discussed in section 3.4., the choice is not necessarily as straightforward, which demonstrates the necessity of educating consumers on the environmental impacts of their food.

3.6. Recommendations

3.6.1. Recommendations for consumers

Our results revealed that consumer practices can have a strong influence on the environmental impacts of a food product, especially for environmental indicators that are sensitive to electricity consumption. For example, one way for consumers to reduce the environmental impacts of food consumption could be to ensure that they do not preheat the oven for too long. When possible, it could also be a good idea to cook different food products at the same time in order to reduce the total oven use time, especially for a large oven. Another factor that played an important role in determining the environmental impacts of the pizzas examined here was the transport of the pizza or its ingredients from the supermarket to the home. One obvious recommendation would be to walk whenever possible. If this is not feasible, the use of public transportation like a bus instead of a passenger car is associated with a notable reduction in CO_2 emissions, as shown by Ribeiro and Fonseca (2022) in a study of students traveling from their homes to their universities. It is also recommended to optimize the trip to the supermarket as much as possible by purchasing food for multiple meals and avoiding specific trips for only one food item.

Finally, minimizing waste of food leftovers and eating them in a subsequent meal can reduce the CO_2 eq emissions of a day's food intake. ADEME (2020) recently estimated that, if the greenhouse gas emissions associated with global food waste were compared with the amounts generated by individual countries, food waste would rank third on the list of global producers. Food waste is therefore a major environmental issue, with 10 million tons of edible food being wasted each year in France. For this reason, the French government has made it an explicit goal to reduce food waste by 50% by 2025 (ADEME, 2020). In this, consumer practices can play an important role; for example, each year the average French person throws away 7 kg of food products that are still in their original packaging. However, as demonstrated by our results, even if it is always preferable to eat leftovers rather than throw them out, care must be taken when reheating leftovers in order to minimize the use time of appliances and thus avoid high impacts on environmental indicators that are sensitive to electricity consumption.

3.6.2. Recommendations for public policies

Although consumer practices can have a strong influence on the environmental burden imposed by food production and consumption, consumers seem to have biased perceptions regarding the impacts of their food choices and practices. For example, the consumers in our study tended to perceive the homemade pizzas as having fewer environmental impacts than the other products, but the LCA results showed that this was not necessarily true. A similar pattern was noted in a study of meat production that reported that consumers had difficulty estimating the environmental impacts of their food (Hartmann and Siegrist, 2017). Therefore, there seems to be a need for public policies that improve consumers' understanding of environmental issues. Even if there is still a great deal of nuance in the scientific literature, several global tendencies are well supported, such as the high contribution of animal-based ingredients to the environmental impacts of food products. Other examples could be the importance of optimizing shopping trips that require the use of a vehicle, eating leftovers, or optimizing the use time of electrical devices. Improved dissemination of knowledge on these issues could benefit consumers' understanding of their own environmental impacts. Food companies could also be encouraged to communicate about good environmental practices related to the use of their products such as avoiding unnecessary oven pre-heating.

3.6.3. Recommendations for future LCAs

Currently, assessments of the environmental impacts of a food product often exclude the steps occurring after purchase. However, our results demonstrate that consumer practices can have a large influence on a product's environmental impacts. Therefore, the inclusion of these steps in future LCA studies of food products could enable more realistic modeling of environmental performance.

Another important finding of this study is that there is a considerable amount of variability in consumer practices related to food production and consumption, which must be kept in mind when analyzing the results of a food product LCA. Here, we limited ourselves to examining different consumer practices and did not analyze variability in industrial practices, which could be an interesting avenue for future study This type of research would facilitate more-realistic comparisons of industrial and homemade food products. In addition, this study highlighted a gap between published cooking instructions and the real-world practices of consumers, especially regarding the cooking step (oven was generally used longer than the recommended time). Models that are based on recommended cooking times from a manufacturer may thus underestimate the effects of home cooking on the environmental impacts of a product.

Another aspect in which variability among consumers had a notable influence on the results was related to the transportation of the pizza or its ingredients from the place of purchase to the home. As yet, there is no consensus on the best allocation option for the domestic transportation of food products. Further research on this topic could be useful in determining recommendations for the preferred allocation.

Finally, we observed different results depending on whether we used a functional unit of one pizza or 1 kg of pizza. Therefore, we believe that it could be useful to calculate LCAs with different FUs when comparing the environmental impacts of two food products (especially when the products have significant weight differences). Such an analysis could help prevent misleading conclusions and lead to a better understanding of the origin of the differences observed.

4. Conclusion

This study demonstrates that different stages of a pizza's life cycle after its purchase by a consumer in a supermarket can make a significant contribution to its environmental impacts and therefore should not be neglected. Indeed, the cooking step was the main hotspot for two of the environmental indicators examined here, while transport from the supermarket to the home was the main hotspot for another. For the other 10 environmental indicators analyzed in this study, agricultural production was the main hotspot. One of our main findings is that certain consumer practices were highly variable and this variability had a significant influence on the environmental impacts of the product. A comparison of the environmental effects of pizzas produced with different manufacturing processes (industrial, assembled at home, homemade) revealed that there were no major differences with respect to the environmental indicators studied here. Nevertheless, homemade pizzas tended to have a stronger impact than the other products on electricity-sensitive indicators; this makes sense because in this study the homemade pizzas required more electrical energy than the others. Instead, indicators that are more sensitive to the agricultural phase were more strongly affected by variations in ingredients and the proportions of ingredients.

This study represents a first step toward understanding the contribution of consumer practices to the environmental impacts of food products. Our data were obtained using questionnaires, and although we made an effort to be as comprehensive as possible in their design, it is possible that they may have contained inaccurate information (e.g., errors, misunderstanding of the question, social desirability bias, etc.). In future research, it would very interesting to address this issue by carrying out measurements directly in participants' homes. Likewise, here the consumption values were estimated, but on-site measurements would allow us to obtain more reliable and precise values. Finally, it could be illuminating to complement analyses of variation in consumer practices with assessments of variability in manufacturing practices.

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.

Acknowledgments

This research was funded, in whole or in part, by ANR-IC-Qualiment, TransfoQuaPe project.
The authors would like to thank David Forest for his help during the experiment and Lindsay Higgins from English Services for Scientists for professional revision of the English.

CRediT authorship contribution statement

Adeline Cortesi: Methodology, Formal analysis, Investigation, Writing – original draft. Marine Colpaert: Methodology, Formal analysis, Investigation, Writing – review & editing. Anne Saint-Eve: Conceptualization, Methodology, Resources, Funding acquisition, Writing – review & editing. Bastien Maurice: Methodology, Formal analysis, Resources, Writing – review & editing. Gwenola Yannou-Le Bris: Methodology, Formal analysis, Writing – review & editing. Isabelle Souchon: Conceptualization, Methodology, Funding acquisition, Writing – review & editing. Caroline Pénicaud: Conceptualization, Methodology, Funding acquisition, Formal analysis, Writing – review & editing, Supervision.

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