Home Potato Processing

Sustainability and Nutritional Impacts

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Abstract

Potatoes are the world's fourth most consumed crop. Their versatility and long shelf-life make them a staple food for millions of people worldwide. Still, the increasing consumption of highly processed potato products in developed countries has damaged the public's appreciation of potatoes as a valuable source of essential nutrients. Additionally, as public awareness of environmental sustainability increases, the average consumer is more likely to value processing methods that mitigate environmental damage.

Researchers simulated several home storage and processing conditions to find out how nutrition and environmental impact are affected by the home processing timeline. Then, a nutrient analysis, life cycle analysis, and cost analysis were conducted to determine the optimal combination of storage and processing that will provide consumers with the most favorable combination of cost, environmental impact, and nutritional quality. The storage analysis indicated that shorter storage times in less refrigeration-intensive conditions were optimal for maintaining moisture content and minimizing environmental impact. The cooking analysis indicated that baking potatoes leads to the highest nutrient retention and is nearly tied with boiling potatoes for the lowest environmental impact and cost. On the other hand, frying has the highest values for calorie and fat content, and it has the highest overall cost and environmental impact of any of the processes due to the input of vegetable oil. Based on these results of a data envelopment analysis, which normalized the values for cost, sustainability, and nutrition into a single score, a consumer recommendation graphic was created to show the comparative consequences of choosing between different processing methods. A consumer survey was written to gauge the values and practices of consumers and consumer response to the recommendation graphic. The testing for the survey is still in progress at the time of writing.

1 Introduction

"He's dead. The dog won't have to sleep on his potatoes any more to keep them from freezing"

–William Carlos Williams, "Death."

Several health crises are simultaneously plaguing the human population in the modern world. In the developing world, malnutrition and lack of access to healthcare lead millions to premature death. In the developed world, consumption of heavily processed foods causes heart disease and cancers in record numbers. These health problems are only exacerbated by climate change, which destroys ecosystems and displaces large populations. In recent years, it has become clear to consumers that their behaviors can have significant impacts on their health and the planet's health. However, it has also become clear that problems are often highly complex. To understand the real impact of consuming a product, many different aspects of the production, transportation, and consumption process must be considered. Terms like "life cycle cost" and "circular economy" have grown in popularity among academic researchers and the general public as consumers become more conscious of the full scope of their behaviors' impacts.

Potatoes are one of the most commonly consumed food crops in the world. Their versatility has led to their ubiquity but has also led them to a problematic reputation among consumers, especially in the developed world, where the majority of potatoes consumed are in heavily processed forms such as chips and French fries [1]. Potatoes in these forms often contribute unhealthy fat and sodium levels to western diets, which can cause heart disease and high blood pressure. However, to write off potatoes as unhealthy is to ignore an affordable and versatile source of key nutrients. Still, processing plays a significant role in what nutrients are available and what amount [1]. The environmental impact of potato farming can be mitigated by using mixed crop systems and organic agriculture methods [3]. The transportation distance (fossil fuel use) and retail storage conditions (preventing unnecessary waste) can also affect the total environmental impact. However, the home processing stage is where consumers have the most agency over the food's nutritional and environmental impacts.

Potatoes have played a significant role in the human diet for hundreds of years. It has previously been observed that the long shelf-life of potatoes relative to other vegetables contributes to their importance as a global food crop [5]. The increased prevalence of processed potato products such as potato chips and French fries in the human diet has led many to believe that potatoes are an unhealthy food [1], but the potato in any form can contribute significant essential nutrients to the human diet [2].

Previous research seeking connections between nutrition with home potato processing has established that cooler storage temperatures help potatoes retain moisture and prevent sprouting [6]. The University of Idaho has indicated that the optimal storage condition for potatoes is a dark space with high humidity and cool temperature [7]. Research has also found that potatoes processed in different ways vary highly in nutritional content, with fried potato products having the highest amounts of calories, fat, and sodium [8]. Research has also been conducted regarding the environmental impact of potato processing. A life cycle analysis for potato production found that the consumer processing stage accounts for 47% of the impact of fresh potato processing. Most of this impact comes from vegetable oil use, which is associated with frying [10].

Although there is significant research regarding potato processing and nutrition, there is a lack of currently available research that comprehensively evaluates the home processing timeline from purchase to consumption with regard to environmental sustainability, nutrition, and cost. Additionally, no available studies assess consumer response to recommendations concerning home potato processing. This study addresses the gaps in current research with two objectives. Firstly, the study aims to track the potato's nutrition as it moves through the home processing timeline, from the grocery store to the table, to determine which interactions of processing factors have the most significant impact on the final nutritional content of the potato. Secondly, the study aims to determine each processing method's environmental impact and the cost of the inputs for each process. Toward this end, a sustainability analysis will be conducted using OpenLCA software to determine each processing method's environmental impact, and an analysis of input costs will be performed. A recommendation will be developed from this data, considering the nutrition and sustainability data and the trade-offs preferred by consumers. Finally, the study aims to gauge participants' priorities concerning potato processing and participant response to the recommendation formulated in the study by conducting an online survey of potato consumers.

2 Literature Review

Before the evaluations detailed in this project were carried out, a thorough survey of the relevant literature in the field was conducted. The review covered several different aspects of potato processing that play a significant part in this project: the role that potatoes play in the modern human diet, the impact of cooking techniques on potato nutrition, the impact of storage conditions on potato nutrition, and the energy use and sustainability implications of different stages in potato processing.

2.1 Potatoes and the human diet

Potatoes have played a significant role in the diet of modern humans worldwide since they were brought to Europe from the Andean highlands of South America in the 16th century. Today, potatoes provide a higher percentage of daily calories in the developed world than in the developing world [4], but potatoes' versatility and long shelf-life make them an exceptionally reliable source of calories and nutrients in developing countries [5]. As of 2019, 49.4 loss-adjusted pounds of potatoes per year per capita are available in the United States. This availability makes them the most consumed vegetable (tomatoes have the next highest loss-adjusted availability at 31.4 lb/year/capita) [16]. Worldwide, potatoes are the fourth most consumed crop after corn, rice, and wheat [1]. Although potatoes are rarely prepared without other ingredients, they contribute significant amounts of vitamin C, carbohydrates, dietary fiber, and potassium to human diets. This contribution is important in areas where malnutrition is prevalent, including urban food deserts where food is available but fresh vegetables are scarce. In these areas, even highly processed potatoes such as French fries and chips can provide the nutrients required for survival [2].

2.2 Impacts of storage on nutrition

Experiments have been conducted to determine the effects of different storage and processing methods on the nutritional content of potatoes. One such study found that low temperatures (1-4°C) helped Kexin No. 1 variety potatoes maintain moisture content and prevent germination. Conversely, potatoes stored at temperatures at or above 10 °C began to shrivel and germinate after 30-90 days [6]. In addition, an article published by the University of Idaho research extension indicated that the best temperature and humidity conditions for long-term home potato storage are 55 °F and 90-95% relative humidity, respectively [7]. These cool and moist conditions mimic the environment of a basement or root cellar. However, these conditions are difficult to achieve in homes without basements, as is the case for most homes in Northwest Arkansas (where this research is being conducted).

2.3 Impacts of cooking on nutrition

One of the appeals of potatoes is that they can be cooked in many different ways with significantly different tastes and textures. However, more appealing flavors often come at the cost of increased caloric and fat content. Based on data from the United States Department of Agriculture (USDA) FoodData database, calories and fat content in a 100g sample of potatoes can vary from 86 kcal and 0.1 g fat in a sample of boiled potato to 196 kcal and 13 g fat in a sample of French fries [8]. United States Dept. of Agriculture recommends that calories from fat make up no more than 35% of daily caloric intake, which works out to about 77g of fat per day in a 2000 calorie diet [9]. Additionally, potatoes in highly processed forms such as chips and French fries often contain high amounts of sodium. Excess sodium and fat intake are associated with increased blood pressure and cardiovascular disease [9]. Home processing of fresh potatoes gives consumers the agency to limit the amount of these unfavorable nutrients in the potatoes they eat [1].

2.4 Energy and environment

The environmental impact of potato processing and consumption is variable. It fluctuates wildly based on how potatoes are sourced and prepared, especially considering that potatoes are rarely served without toppings or auxiliary ingredients (butter, salt, cheese, ketchup, etc.). One life cycle analysis study found that the consumer stage of processing accounts for about 47% of the total impact of fresh potato consumption. The major factors in consumer processing contributing to greenhouse gas emissions were vegetable oil use, electricity, and transportation [10]. Vegetable oil is primarily used in the frying of potatoes, so it can be inferred that boiled and baked potatoes have a lower environmental impact. Electricity use is inherently tied to refrigerators and cooking appliances' cooking time and efficiency.

The study by Parajuli et al. also found that waste losses were higher across the supply chain for processed potatoes (frozen French fries, chips, and dehydrated potato flakes) than fresh potatoes. [10]. The Center for Food Loss and Waste Solutions has detailed possible solutions to help mitigate these losses. Many of these solutions, such as local composting and food donation programs, would directly involve action by consumers. Reducing food losses can reduce greenhouse gas emissions, freshwater use, and land use [11].

3 Materials and Methods

3.1 Methodological framework

Figure 1 shows a visual representation of the methodological framework for the project. The project was broken into six main steps. In the first step, a literature review was conducted to find the ideal design conditions for the experiment so that the data is as applicable as possible (1.0). Secondly, using the design conditions established by the literature review, the experiment was conducted by storing and processing the potatoes as prescribed in the processing section (2.0). Samples from the experiment were then taken to the Central Analytical Lab for analysis, and a nutrient profile was constructed for each sample (3.0). Using OpenLCA software, a lifecycle analysis was conducted to determine the endpoint impact results of each processing technique (4.0). From the data gathered in steps 3.0 and 4.0, the trade-offs between different processing techniques and their impacts on nutritional and environmental metrics were analyzed and organized into educational material that displays each processing method's inherent costs and benefits (5.0). This material was presented to a group of consumers, who evaluated the costs and benefits of each processing method based on their values and decided which option they would choose (6.0). Finally, all the data was compiled, and conclusions were drawn based on the study results.

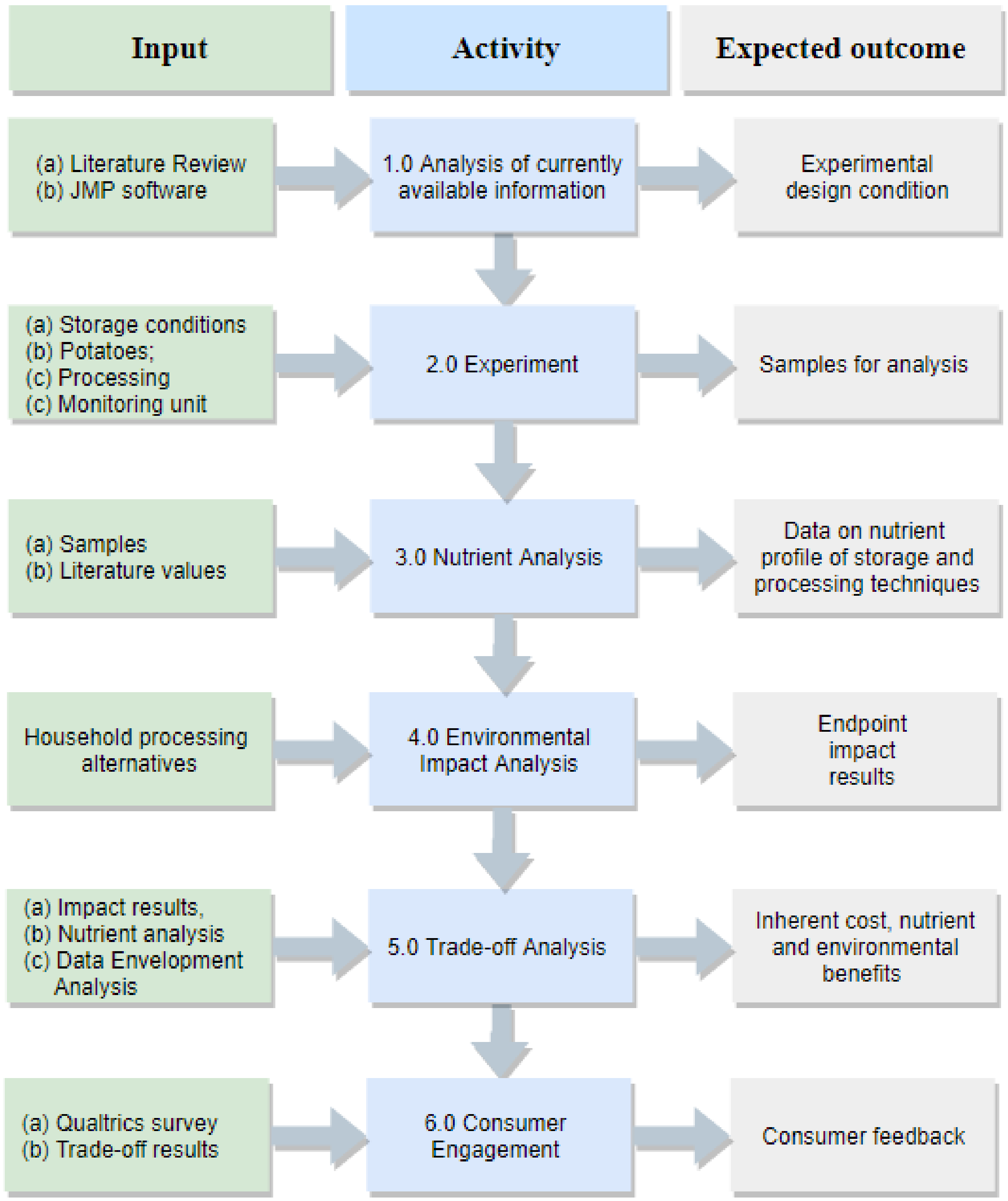

Figure 1: Methodological framework for the study

3.2 Experimental design

Table 1 presents the experimental variables for the complete factorial design. This table was created using JMP software, which details the different combinations of factors and levels. The dependent variables in the experiment were nutritional content and environmental impact. A major benefit of the full factorial design is that it accounts for all combinations of factors. Documenting the interactions of the three independent variables is the basis for this research.

Table 1: Combinations of experimental variables for complete factorial design

Pattern	Type of storage	Processing	Time of storage
143	Ideal	Raw	33 days
343	Fridge	Raw	33 days
232	Cupboard	Baking	17 days
133	Ideal	Baking	33 days
321	Unstored	Frying	0 days
142	Ideal	Raw	17 days
313	Fridge	Boiling	33 days
332	Fridge	Baking	17 days
112	Ideal	Boiling	17 days
113	Ideal	Boiling	33 days
233	Cupboard	Baking	33 days
213	Cupboard	Boiling	33 days
341	Unstored	Raw	0 days
132	Ideal	Baking	17 days
242	Cupboard	Raw	17 days
331	Unstored	Baking	0 days
333	Fridge	Baking	33 days
323	Fridge	Frying	33 days
123	Ideal	Frying	33 days
322	Fridge	Frying	17 days
223	Cupboard	Frying	33 days
243	Cupboard	Raw	33 days
222	Cupboard	Frying	17 days
312	Fridge	Boiling	17 days

122	Ideal	Frying	17 days
342	Fridge	Raw	17 days
311	Unstored	Boiling	0 days
212	Cupboard	Boiling	17 days

This experiment utilizes a full factorial experimental design in which two replicate samples are taken and tested at each combination of the three independent variables (time, storage condition, and cooking method). The levels for each factor are as follows:

a) Time
   i. Unstored
   ii. 17 days
   iii. 33 days
b) Storage condition
   i. Ideal [48 degrees F, 90% relative humidity, the closest approximation of (Woodell et al., 2009)]
   ii. Refrigerator (average 31 degrees F, 40-60% relative humidity)
   iii. Cupboard (average 68 degrees F, 30-45% relative humidity)

c) Processing meth**od**
   i. raw/uncooked
   ii. baked
   iii. boiled
   iv. fried

3.3 Experimental setup

A bag of Russet potatoes was purchased from Walmart to simulate the experience of an average consumer (following the results of a preliminary self-conducted survey). Three potatoes from the bag were placed in each storage condition. Temperature readings for each storage condition were measured with Kestrel Drop sensors.

The potatoes were then removed from storage at the 17-day and 33-day mark and cooked as prescribed in the processing section.

3.4 Sampling

After the first storage period (17 days), the potatoes were removed from each storage condition. Next, half of the potato mass (approximately 1 ½ potatoes from each condition) was cut and prepared for cooking as prescribed in the processing section. The remaining potato mass was returned to storage until the 33-day mark, when the remainder of the potatoes were removed and processed. Samples were taken after the storage period in each condition and after each cooking process. The weight of the samples was measured after storage and before cooking to estimate the mass loss.

3.5 Processing

The three storage conditions were simulated as follows:

a) Cupboard: an open container in a dark cabinet with central heating set to 70 °F.
b) Refrigerator: An open container was placed in a refrigerator with the temperature setting on medium.
c) Ideal conditions (48 °F, 90% humidity): A closed container containing a potassium chloride salt solution was placed in a refrigerator on the lowest setting. Wood blocks were placed around the container to minimize temperature change from the refrigerator's on/off cycle.

Humidity and temperature were tracked using Kestrel Drop sensors placed in each storage condition throughout the experiment. The samples taken were then subjected to one of four cooking conditions:

a) Raw/uncooked–The samples were cut from the potato and tested without any further processing
b) Fried–Samples were cut into circles ¼ inch thick and fried in canola oil at 300° F for 7 minutes, then removed and fried at 400 °F for two more minutes, as informed by the Melchione recipe [20].
c) Baked–Samples were cut into circles ¼ inch in thickness and placed into a preheated 400 °F oven for 17 minutes, adapted from the Melchione recipe [20].
d) Boiled–samples were cut into circles ¼ inch in thickness and placed into boiling water for 15 minutes.

The cooking temperatures were measured using a Taylor brand temperature probe placed in the cooking vessel along with the potatoes.

3.6 Nutrient analysis

The nutritional analysis was performed by the University of Arkansas Central Analytical Lab. The following are the methods used by the Central Analytical Lab to measure the given nutrients:

a) Dry matter content: Dry matter content was determined by drying a 2g sample of potato in a 110 °C drying oven overnight.
b) Fat content: The fat content was determined using the AOCS AM 5-04 method of fat extraction, which uses petroleum ether to remove triglycerides from the sample.
c) Caloric content: The calorie content was measured using a Parr 6200 Automatic Adiabatic bomb calorimeter.

d) Complete Mineral Analysis: The complete mineral analysis was performed by digesting a 0.25 g dried powdered sample with 3 ml nitric acid and 1 ml hydrogen peroxide, then analyzing the resulting mixture using an ICP-OES spectrometer.

Comparative nutritional data was gathered from the USDA FoodData database [8]. This database collects data regarding the nutrition of common foods from different sources. When there were several entries for the same product, one was chosen and corroborated with the others to ensure that it was a reasonable estimate. This data accounts only for cooking, not storage. There is no information available regarding the impact of storage on nutritional metrics such as calories and micronutrients.

3.7 Environmental impact analysis

The environmental analysis was conducted using OpenLCA software. This software allows the user to analyze the impact of product processing on specific environmental health indicators such as global warming potential, carcinogens, etc., based on energy consumption and required materials. Within the program, the Agribalyse database was used for modeling the system inputs. This database was chosen because it has an extensive selection of products and processes that aid in estimating the overall impact of each input for the entire processing method. The ReCiPe Midpoint (H) analysis method and ReCiPe endpoint (H) analysis method were used for the impact analysis.

3.7.1 Goal, scope, functional unit, and system boundaries

To use the software, the boundaries of the system must be defined. For this project, the system boundary includes only the home processing portion of the overall life cycle, as would be experienced by the average consumer buying potatoes from the store and disposing of them in a typical municipal waste collection system. The pre-retail harvest and storage were not considered, so the data would be comparative rather than holistic. This system boundary is shown in Figure 2.

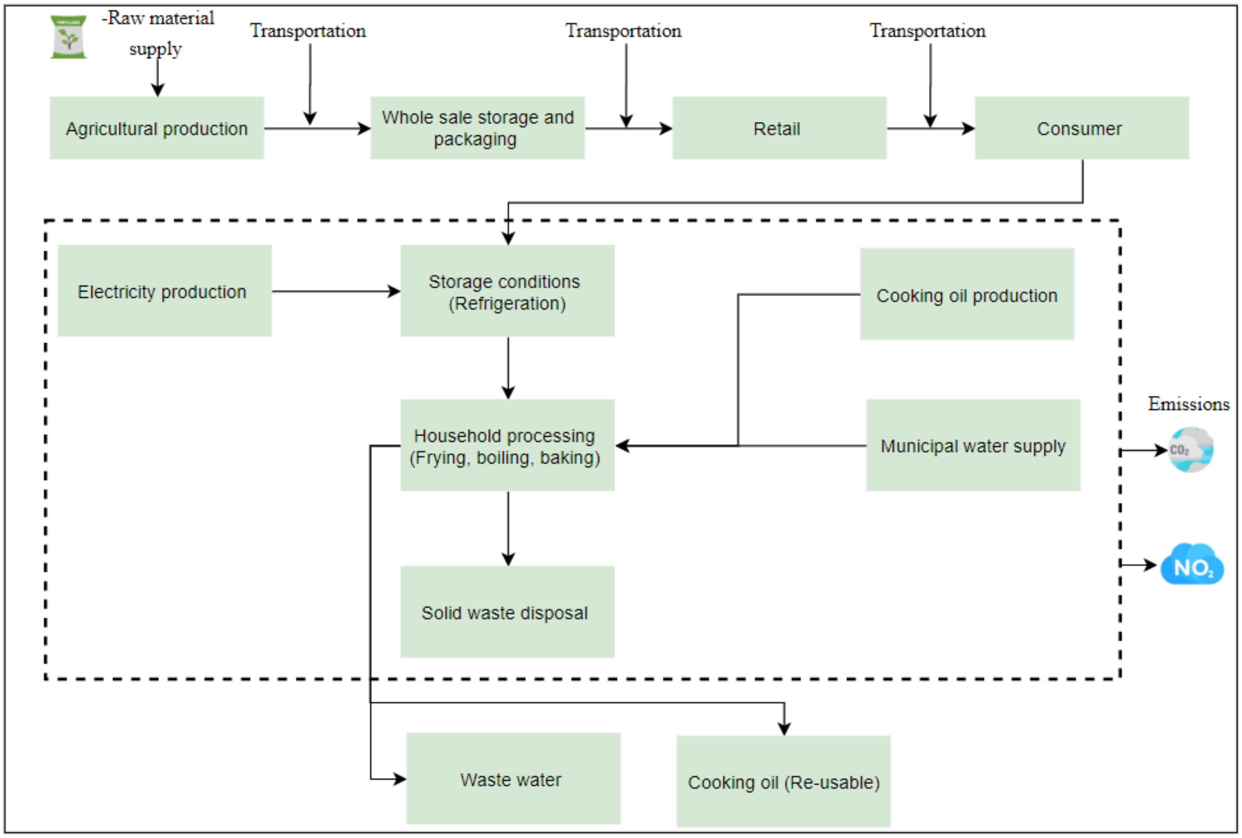

Figure 2: System boundaries for the potato processing life cycle analysis

Additionally, the Life Cycle Assessment (LCA) requires the establishment of a given mass as a functional unit for the analysis. Our functional unit for this project is 1 kg. However, this functional unit must consider mass losses due to each cooking process. The mass losses calculated in our experiment and subsequent required functional units are recorded in

Table 4. A summary of inputs to the OpenLCA program is shown in Appendix B.

3.7.2 Modeling household processing and Energy Estimations:

To estimate refrigerator energy use over the storage period, the percent of fridge space dedicated to cooling potatoes was based on the Bureau of Labor Statistics Consumer Expenditure Survey [19], from which it was extrapolated that potatoes take up approximately 0.64% of refrigerator space at any given time (assuming the consumer stores their potatoes in the refrigerator). The low setting on the refrigerator was used for the ideal storage temperature (48 °F), and the medium setting was used for the refrigerator storage temperature (34 °F). The low setting on the refrigerator consumes 1.1 kWh/day, while the medium setting consumes 1.5 kWh/day [12].

The energy estimations for baking and frying were performed using heat transfer equations. The baking calculations assumed that the energy consumption was based more on the energy required to maintain the oven temperature than the energy needed to cook the food. For detailed explanations and calculations for each of these values, see Appendix A.

3.7.3 Impact analysis

The impact analysis was conducted using the ReCiPe Midpoint (H) method and ReCiPe endpoint (H) analysis. The midpoint method considers the life cycles of the different system inputs and returns a list of impact scores, quantifying the impact that the total process has on each of 18 impact categories by converting the impact to a base equivalent unit (for example, global warming potential impact scores are reported in kg CO_2). Only the average top five normalized impact categories are considered in this study.

The Endpoint method operates similarly but translates the results to impacts on three categories: damage to human health, damage to ecosystems, and contribution to resource scarcity. Only the damage to human health endpoint impact was considered for this study. The ReCiPe method was chosen over other impact analysis methods (such as TRACI) because it has both midpoint and endpoint analysis capability. Midpoint and endpoint analysis have benefits that impart insight to the final results. The general public understands the endpoint results easily, but the midpoint results are more certain.

3.7.4 LCA sensitivity and uncertainty analysis

Because life cycle analysis involves a significant degree of inherently imprecise estimation, using any life cycle analysis software comes with a degree of uncertainty. OpenLCA quantifies this uncertainty in a pedigree matrix that considers contributions to overall uncertainty resulting from five factors: reliability, completeness, temporal correlation, geographic correlation, and other technological correlation. The pedigree matrix returns a geometric standard deviation that can be used to model uncertainty in the system. This uncertainty can be modeled using a Monte Carlo simulation. The Monte Carlo simulation feature in OpenLCA shows the variation in the impact results from running 1000 different simulations in which inputs like electricity, water use etc., are changed within a 95% confidence interval, and the results are recalculated. The results for these 1000 runs are compiled into a histogram which plots the results against the number of occurrences of results falling into a numerical range. If this histogram shows a compact bell curve shape, it can be inferred that the results are relatively certain.

The uncertainty simulation also returns a numerical indicator in the coefficient of variation (CV), which gives an indication of the precision of the impact estimate based on the formula

$$CV = \frac{std.dev\ (A_i)}{m(A_i)}$$

Where std. dev (A_i) and m(A_i) are the standard deviation and mean of the ordered sample, respectively. The CV is a good indicator of the certainty of the results. If the CV is around 10% or less, then the impact analysis results for the given inputs are reasonably certain. OpenLCA completes this analysis based on the impact results from the ReCiPe Midpoint (H) analysis.

The uncertainty analysis indicates the degree of certainty in the results based on the variability in the possible outputs. On the other hand, the sensitivity analysis is conducted to gauge how certain the results are based on the change in response variables corresponding to a change in the input values. For example, the values for the different inputs were changed by ± 10%, and the corresponding difference in the top five normalized impact categories was measured. If the measured difference in the result is 10% or higher, then the impact score is very responsive to the change in input, and the confidence in the certainty of the results is undermined. However, if the difference measured in the results is low, there is a high degree of certainty in the results.

3.8 Cost analysis and trade-off analysis

For the cost analysis, the electricity and water costs are based on values for Fayetteville, AR. The cost for cooking oil is based on the price of a 1-gallon jug of Great Value brand vegetable oil as listed on walmart.com. It was assumed for this study that the electricity consumption for storage and cooking were additive (i.e., the energy use for the combined storage-cooking process is exactly equal to the sum of the energy use for storage and cooking).

The trade-offs between environmental impact, nutritional quality, and cost for cooking and storage methods were analyzed using a data envelopment analysis calculation. A data envelopment analysis was also calculated for storage. However, nutritional quality was not included because of the high likelihood that nutritional quality varies independently of storage condition, as discussed in section 3.2.4. The data envelopment analysis assigns a normalized numerical value for the value corresponding to each condition in every category using the formula:

$$N_{ij} = \frac{X_i}{\sqrt{\sum_{j=0}^{n} X_j}}$$

Where *i* is the value associated with one individual condition and *n* is the number of conditions in each category. The normalized values for each condition can then be added to return a holistic normalized sustainability-nutrition-cost score that can be compared between categories. The data used for nutrition is from the Central Analysis Lab data, except for fiber and vitamin C, which are from the FoodData database [8]. There are many different ways to consider the outcomes, but for this case study, it is assumed that the lowest values for calories, fat, electricity, and cost are ideal, while the highest values for fiber and micronutrients are ideal. For a sample calculation, see Appendix C.

3.9 Consumer recommendation and survey

Based on the data envelopment analysis scores, a consumer recommendation graphic was constructed using draw.io software. For each processing method, the combined sustainability-nutrition-cost score out of 10 was displayed on a chart along with a color corresponding to the relative score (green for the best scores, yellow and orange for medium scores, and red for the worst scores).

A survey was then constructed to gauge consumers' current practices and values and their response to the recommendation graphics. The recommendation graphics were presented in the survey, and participants were asked whether or not their current practices align with their environmental, nutritional, and financial values. Participants were also asked how likely they were to change their storage and cooking practices based on the information provided. The complete survey is listed in Appendix D.

4 Results and Discussion

4.1 Processing

The storage conditions for the potatoes were measured with Kestrel Drop sensors. Figure 3, Figure 4, and Figure 5, show the data for the temperature fluctuations over the storage period in the refrigerator, ideal conditions, and cupboard, respectively. These fluctuations indicate the on-off cycles of the refrigerators for the ideal and refrigerator conditions and the air conditioning unit for the cupboard condition.

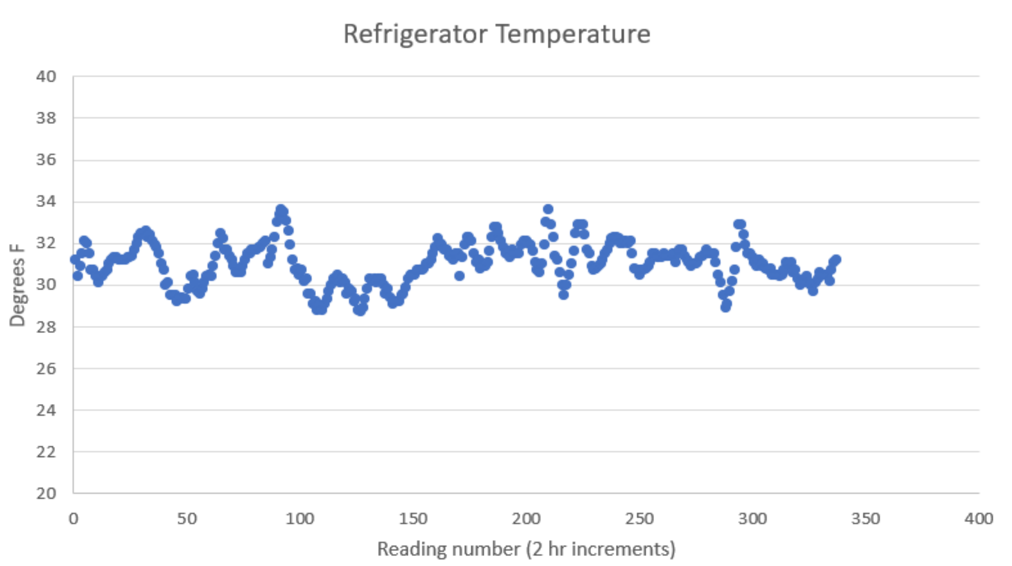

Figure 3: Graph showing temperature fluctuation over the 33-day storage period in the refrigerator

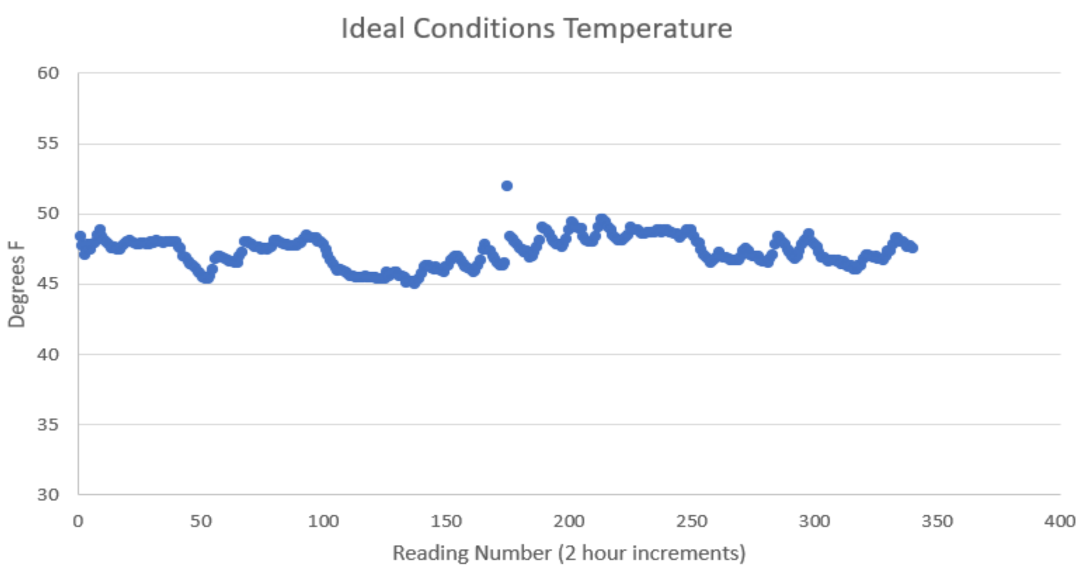

Figure 4: Graph showing temperature fluctuation over the 33-day storage period in the ideal conditions

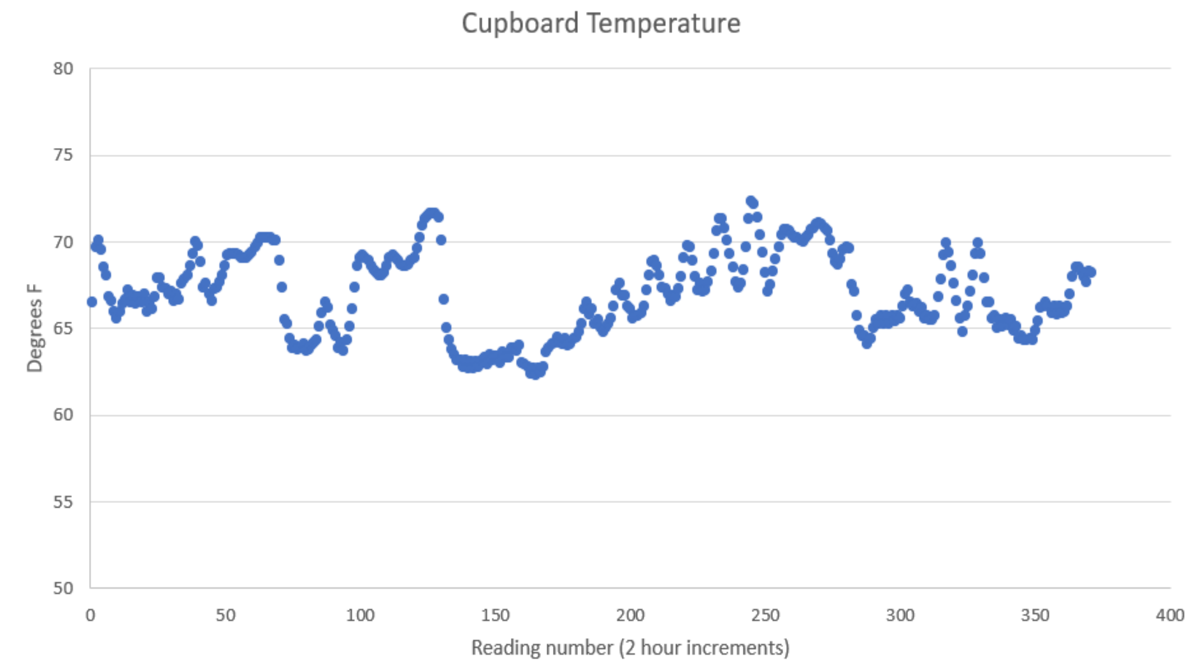

Figure 5: Graph showing temperature fluctuation over the 33-day storage period in the cupboard

The cooking temperatures were measured using a Taylor brand temperature probe. The temperature fluctuations over the cooking process for each batch are shown in Figure 6, Figure 7, and Figure 8. for boiling, baking, and frying, respectively. For boiling, all potatoes were boiled at 100 °C. For baking, the potatoes were cooked in two batches. The first batch contained the unstored potatoes and all of the potatoes that were stored for 17 days in the cupboard, fridge, and ideal condition. The second batch contained all the potatoes stored in the cupboard, fridge, and ideal condition for 33 days. The fried potatoes were fried in separate batches based on their time and storage condition.

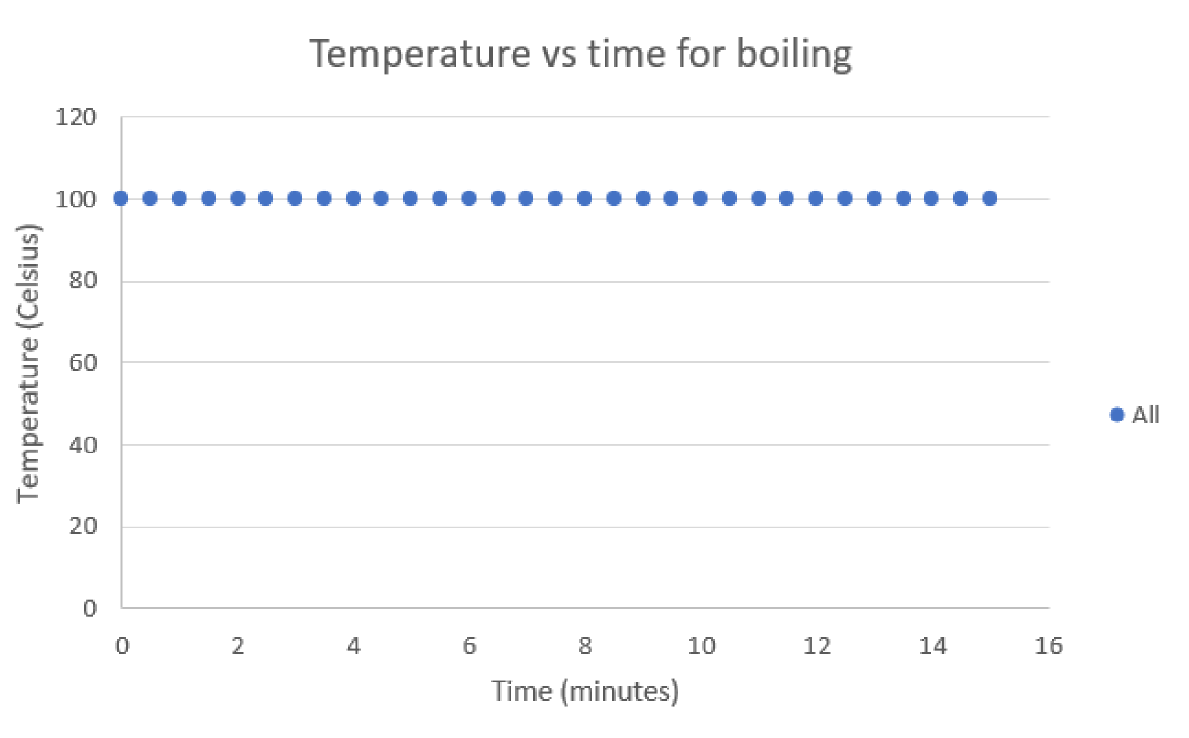

Figure 6: Graph of temperature fluctuation through boiling process

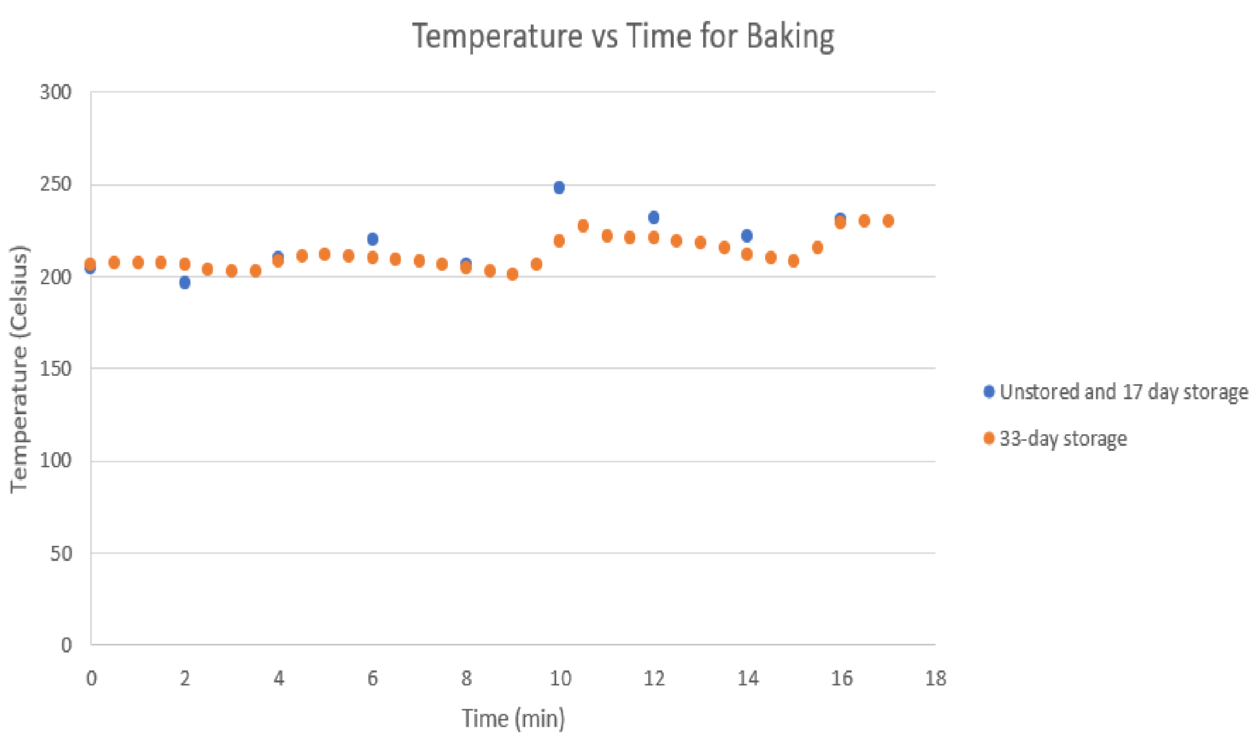

Figure 7: Graph of temperature fluctuation through baking process

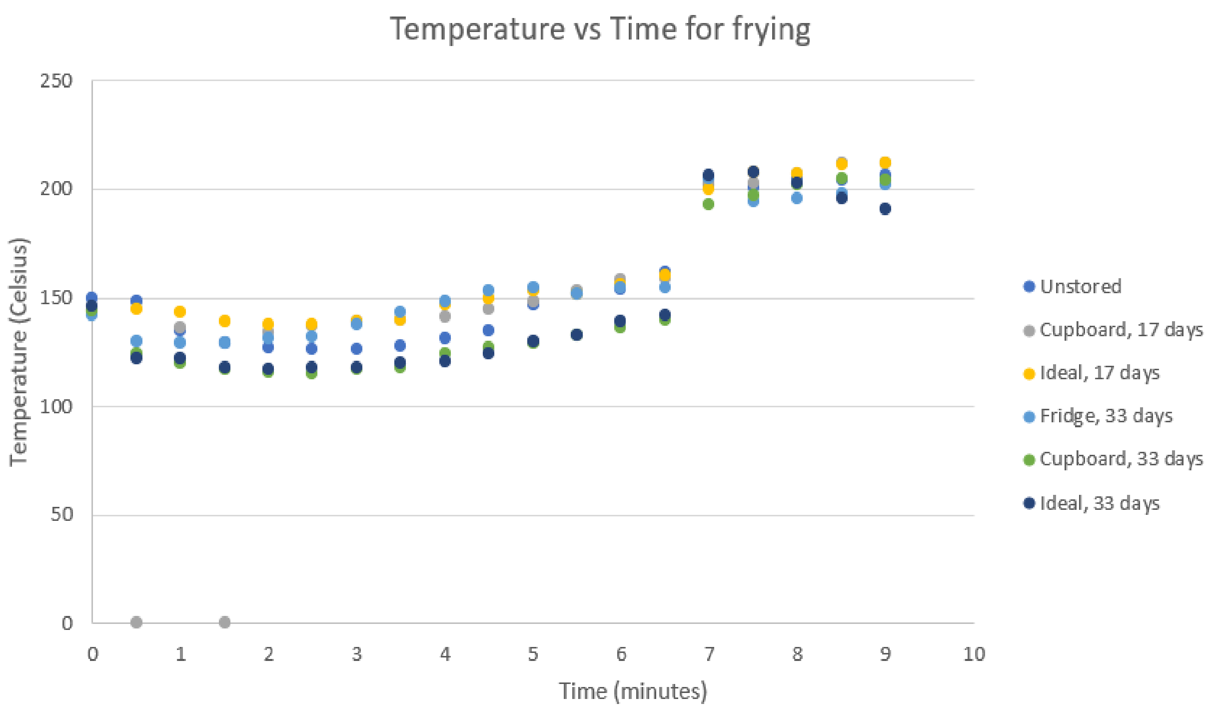

Figure 8: Graph of temperature fluctuation through the frying process

The mass loss over the cooking process was measured for each batch. The mass losses for each cooking process are detailed in Table 2.

Table 2: Mass loss data for each cooking process

Type	Percent weight loss through cooking (avg)	Required mass for 1 kg functional unit
Fried	47% loss	1.89 kg
Boiled	7.7% gained	0.929 kg
Baked	35% loss	1.538 kg

The energy inputs for refrigeration and cooking are calculated in Appendix A. Figure 9 shows the total energy consumption dedicated to cooling potatoes for the different storage conditions and times. The figure indicates that lower refrigerator settings and shorter storage times correspond to lower energy consumption.

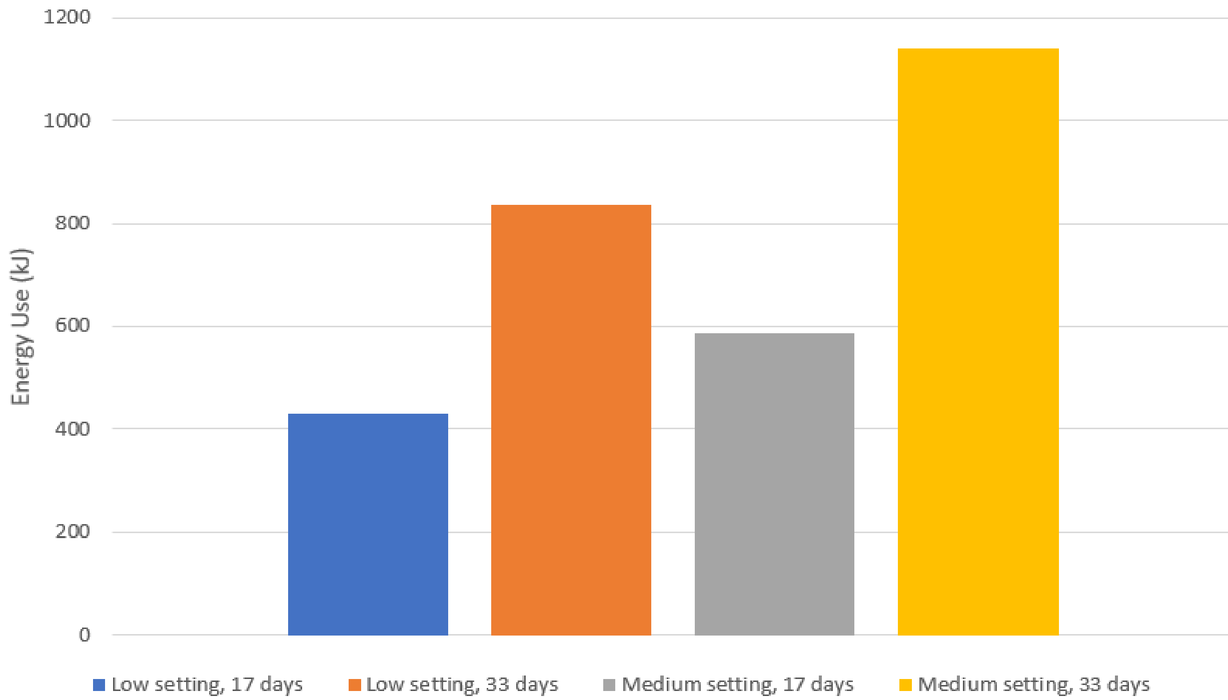

Figure 9: Refrigerator energy use by temperature setting

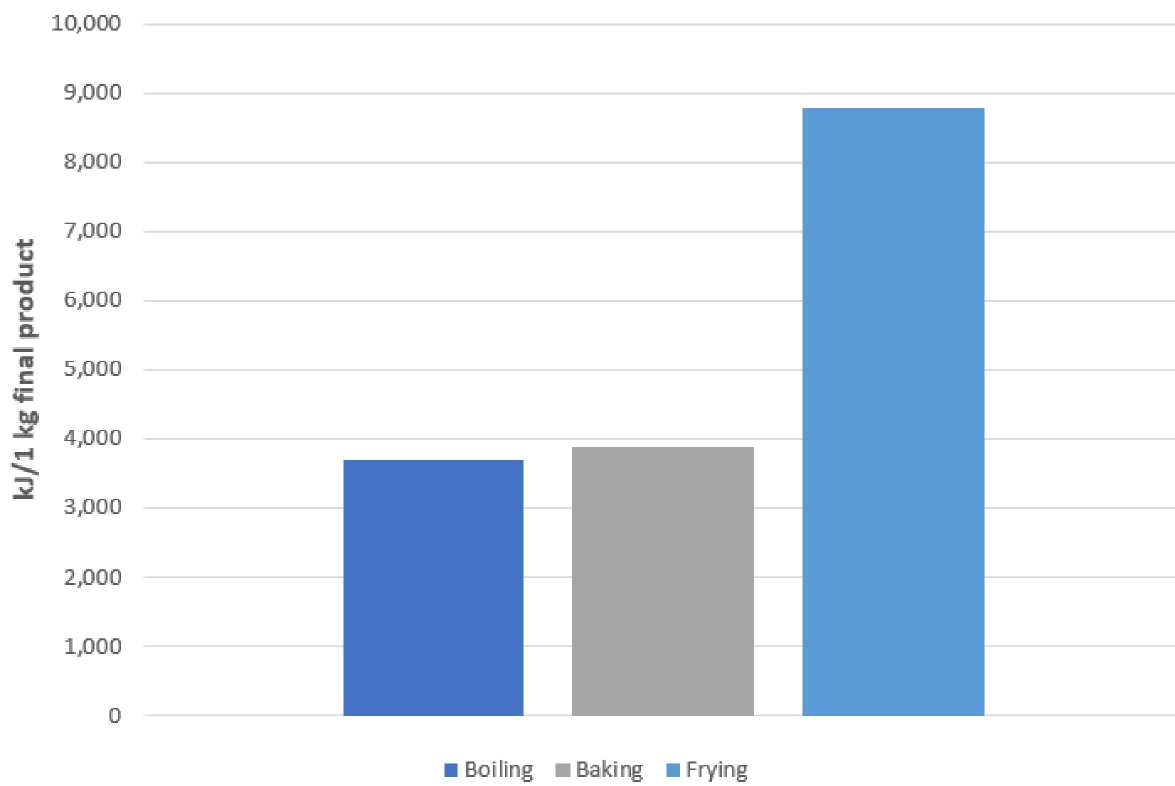

Figure 10: Energy consumption for each cooking process

Figure 10 shows the energy input required for each of three methods (baking, boiling, and frying) to produce 1 kg of cooked potato, accounting for mass losses in the cooking process. Frying requires the most energy for two reasons: (a) the mass of the potato being cooked greatly affects the energy requirement for frying, and (b) frying results in the most extreme mass loss of any of the cooking methods. Boiling required the least energy input, likely because of the very low mass loss that occurs during the boiling process. Baking leads to a large mass loss, but due to most household ovens' size and heating capacity, the energy input isn't affected as much by the mass of potato being cooked.

4.2 Life cycle impact analysis

A life cycle analysis was conducted using these energy inputs and data from the Agribalyse database in the OpenLCA program. The impact analysis was performed using the ReCiPe Midpoint (H) method, and the impacts were normalized using the World (2010) H method. The categories with the highest normalized impact are (1) marine ecotoxicity, (2) freshwater ecotoxicity, (3) human carcinogen toxicity, (4) freshwater eutrophication, and (5) terrestrial ecotoxicity. The global warming potential impact is also included in the data sets and shown in the paper because it is the most recognizable and understandable impact to consumers. The global warming potential impact is shown in Figure 11a*,* and the impacts are broken down by cooking method in Figure 11b, Figure 11c, and Figure 11d.

The data shows that frying has a considerably higher global warming potential than the other forms of cooking. However, it should be noted that the data is comparative, so the effects of potato production prior to the home processing stage are not considered. Cooking oil production and electricity production are the largest sources of impact. When broken down by cooking method, the difference in impact can be attributed to the storage technique, where lower refrigerator settings and lower storage times led to a lower global warming impact. The tables showing the data for the other top normalized impact categories are shown in Appendix E, but all demonstrate a similar trend in which the comparative impact from frying far exceeds the comparative impact from baking and boiling

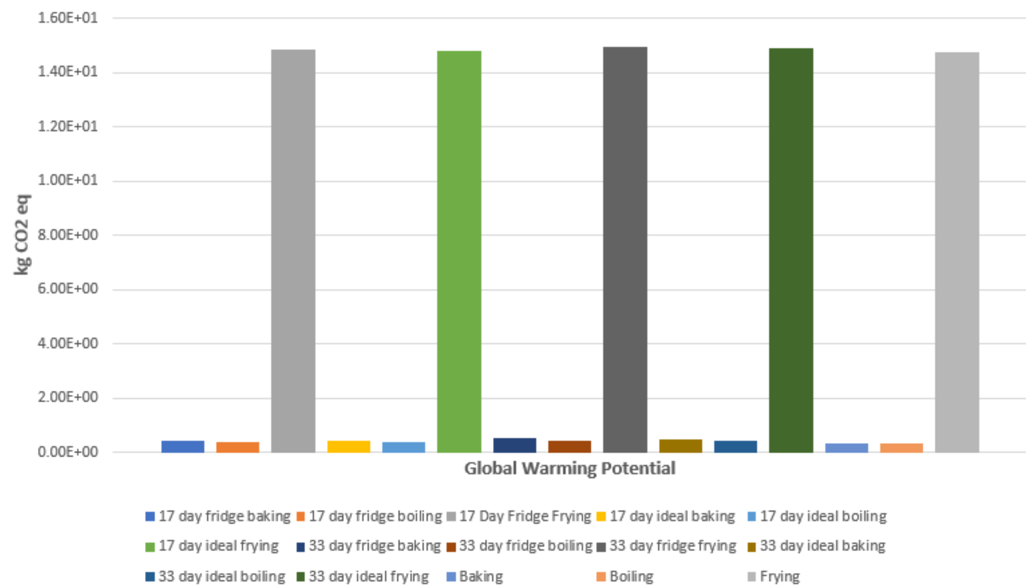

Figure 11a: Global warming potential for each treatment combination

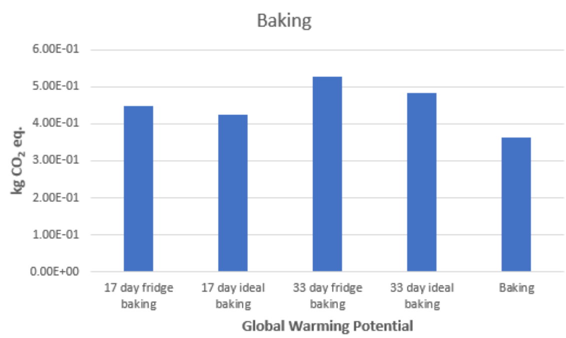

Figure 11b: Baking-specific GWP results

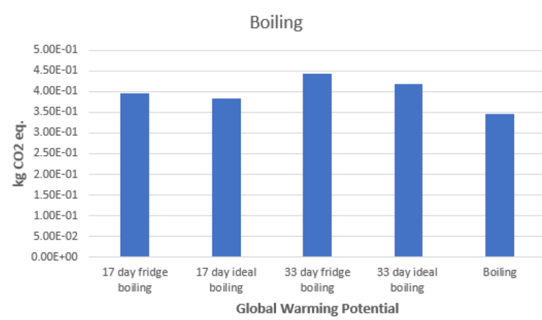

Figure 11c: Boiling-specific GWP results

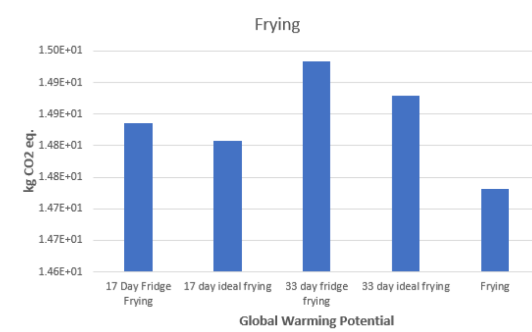

Figure 11d: Frying-specific GWP results

Figure 11: Global warming potential overview and by processing condition

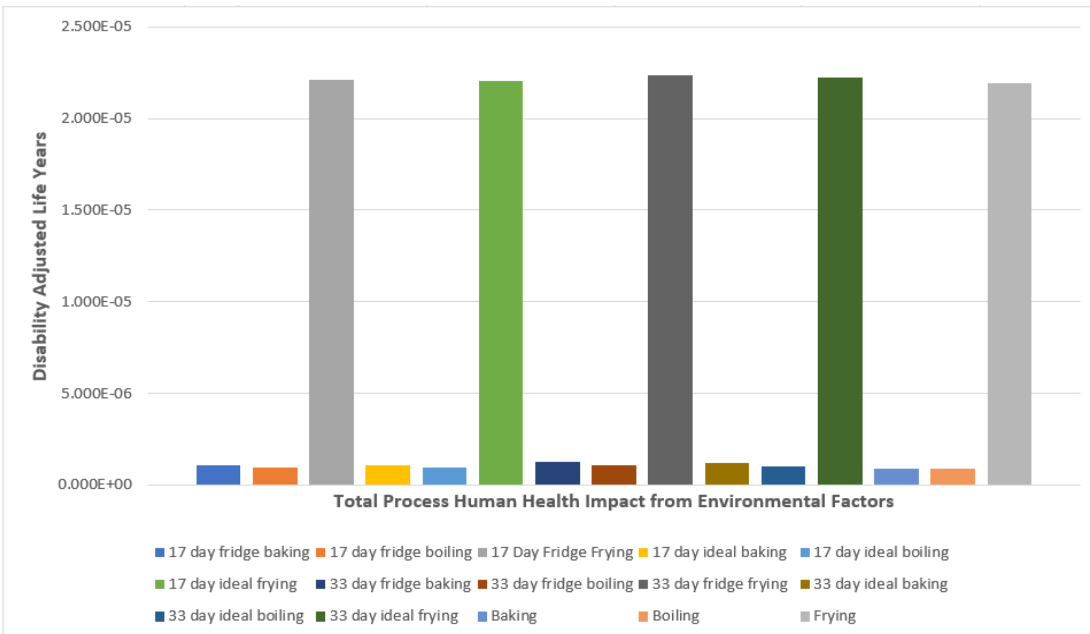

Figure 12a: Endpoint human health impact for each treatment combination

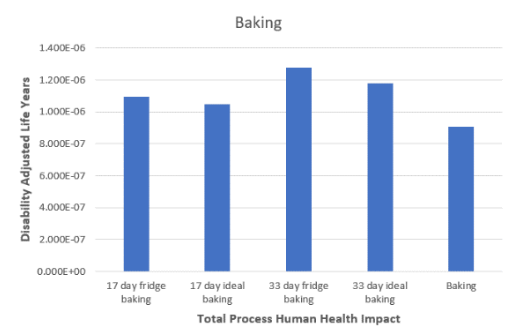

Figure 12b: baking-specific health impact

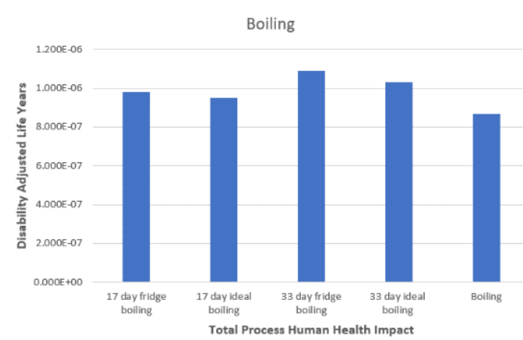

Figure 12c: Boiling-specific health impact

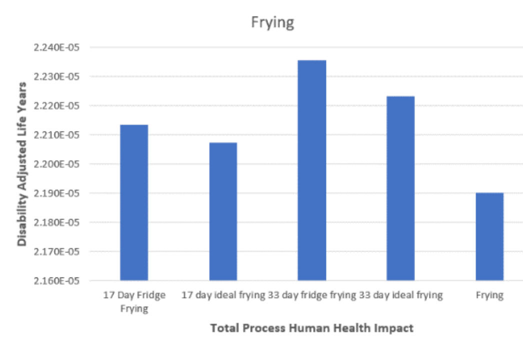

Figure 12d: Boiling-specific health impact

Figure 12: Human health endpoint impact overview and by processing condition

The endpoint impact on human health is displayed in Figure 12a, and the impacts are broken down by cooking method in Figure 12b, Figure 12c, and Figure 12d. This impact category considers all environmental impact categories that contribute to human health degradation and estimates an impact in disability-adjusted life years (DALY) removed from the human lifespan due to each process. Again, the frying process contributes a significantly higher comparative impact than boiling or frying due to the impact of cooking oil production. When broken down by the cooking method, the impact increases with the length of storage and refrigeration intensity.

4.2.1 Uncertainty and sensitivity analysis for life cycle assessment

An uncertainty analysis was performed using the Monte Carlo simulation function in OpenLCA. The uncertainty analysis revealed that for baking and boiling, the CV is relatively low (below 10%) for all of the impact categories. The variation is higher for frying, likely due to the increased number of contributing factors in cooking oil production. An example of the Monte Carlo simulation histogram is shown for a low-variation treatment combination (17-day fridge storage and baking) in Figure 13 and a high-variation treatment combination (33-day fridge storage and frying) in Figure 14. The increased variation can be seen in the higher occurrences of significant high and low results and the comparative lack of a distinct bell curve shape in Figure 14.

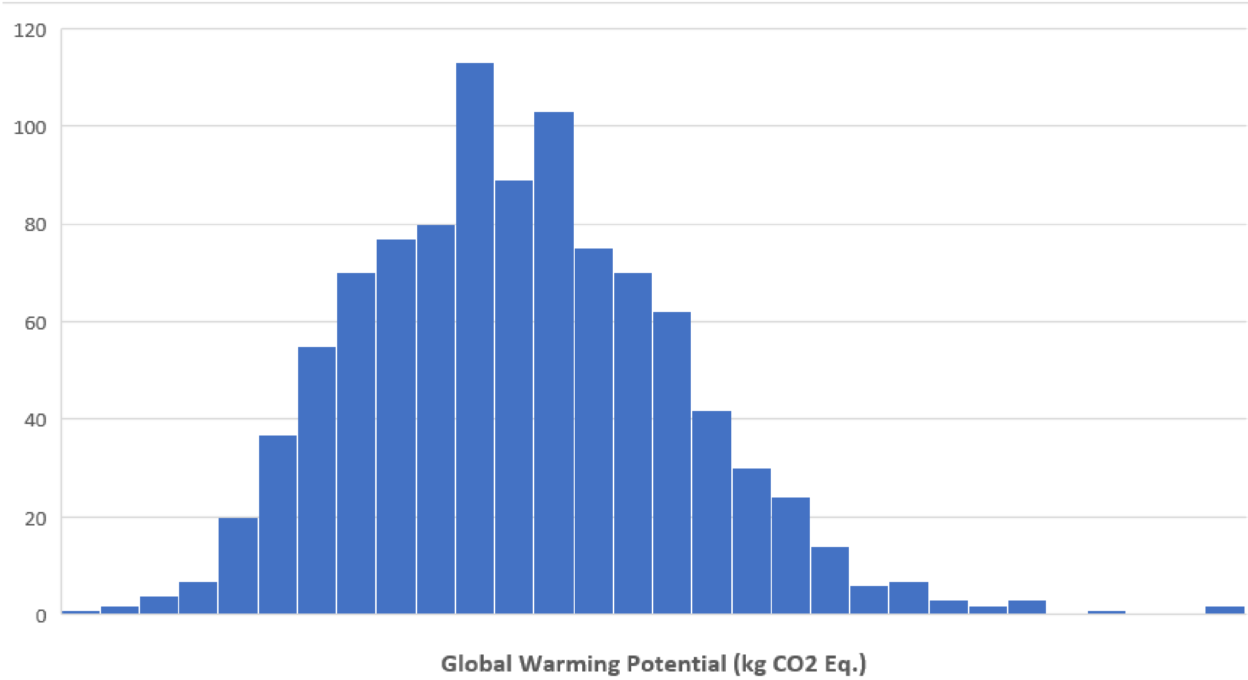

Figure 13: Monte Carlo results for 17-day fridge storage and baking (low variability)

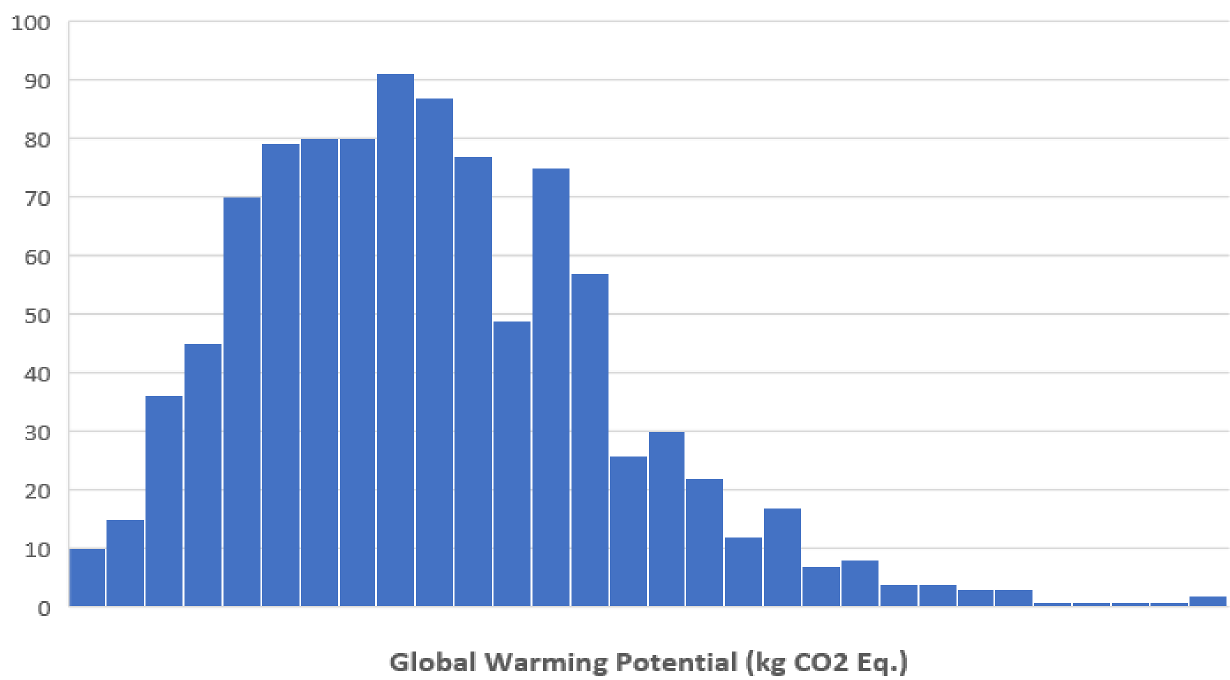

Figure 14: Monte Carlo results for 33-day fridge storage and frying (high variability)

The highest level of variation can be seen in the global warming impact category, in which the CV for the impact of frying exceeds 14% (which is still not very high, as this is a relatively simple analysis). Figure 15 shows the CV distribution for the impact of the different treatment combinations on global warming potential. Figure 16, on the other hand, shows the CV distribution for freshwater eutrophication, the category with the lowest variation between the coefficients of variation for the different treatment combinations.

The variation in the CV values for frying indicates that the impacts of some of the processes that are unique to frying have more variation in their impacts than the common processes between the frying, baking, and boiling processes. However, it should also be acknowledged that the variation could be due to an error in the model. The frying model is the most complex since it includes the cooking oil production life cycle, so there is more room for an error in the model.

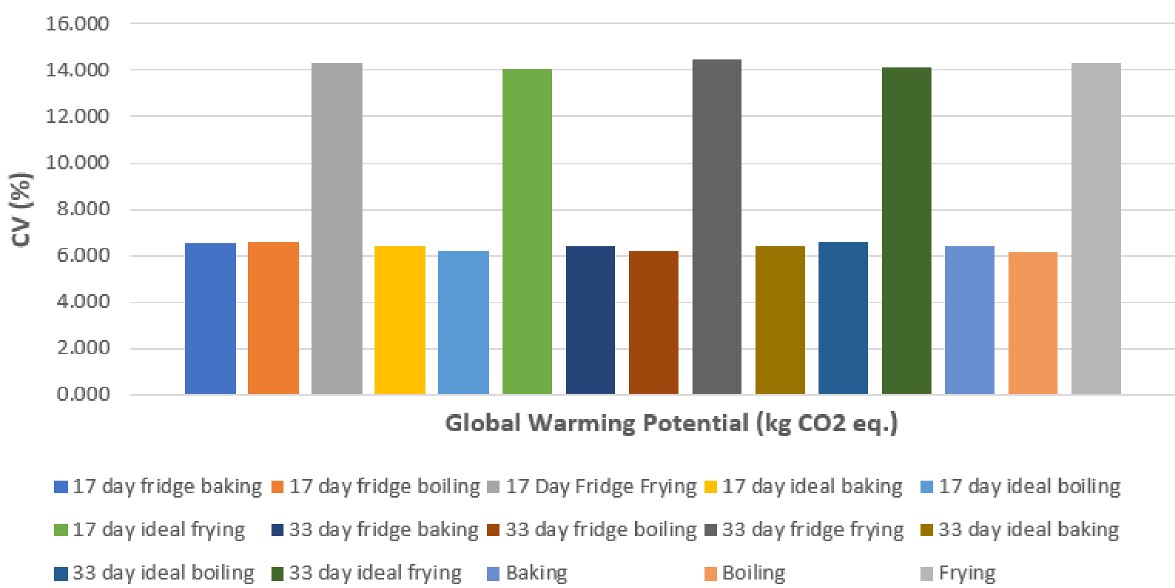

Figure 15: Graph showing variation level in global warming potential impact results by treatment combination

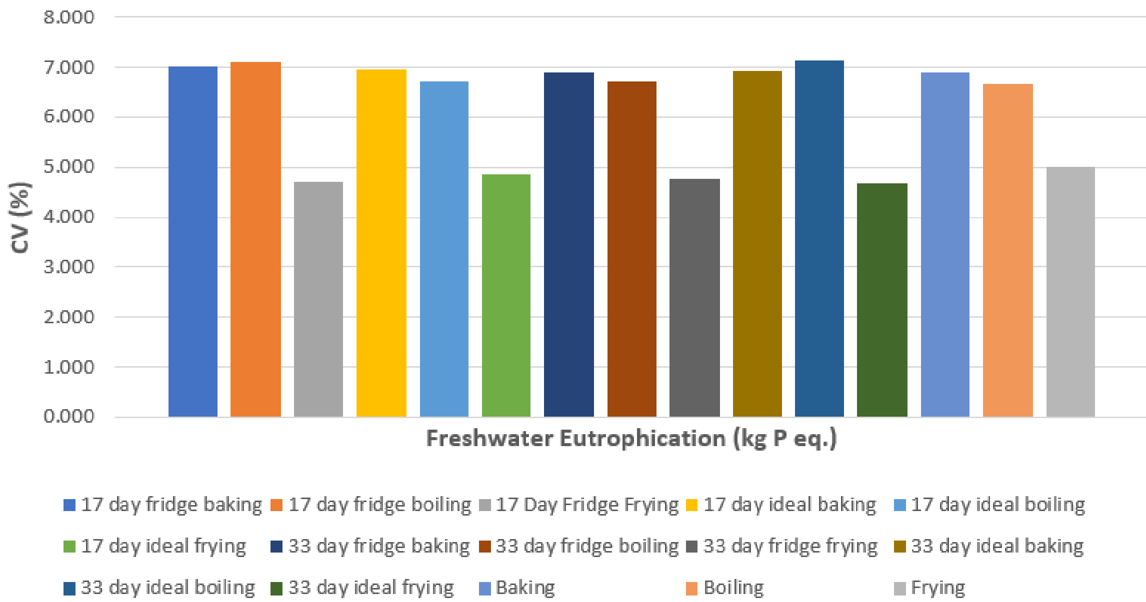

Figure 16: Graph showing variation level in freshwater eutrophication impact results by treatment combination.

The sensitivity analysis was conducted by changing the storage and cooking processes inputs by ±10% and running the recipe analysis with these new inputs. It should be noted that this only returned useful results for the frying process and the boiling process, as the baking and storage processes only use one input (electricity). Interestingly, the sensitivity analysis for the boiling process revealed that water doesn't impart any significant contribution to any of the impact parameters. The sensitivity of different impact parameters to the change in electricity use and cooking oil use in the frying process is shown in Figure 17 and Figure 18, respectively. The tables for this data are shown in Appendix F.

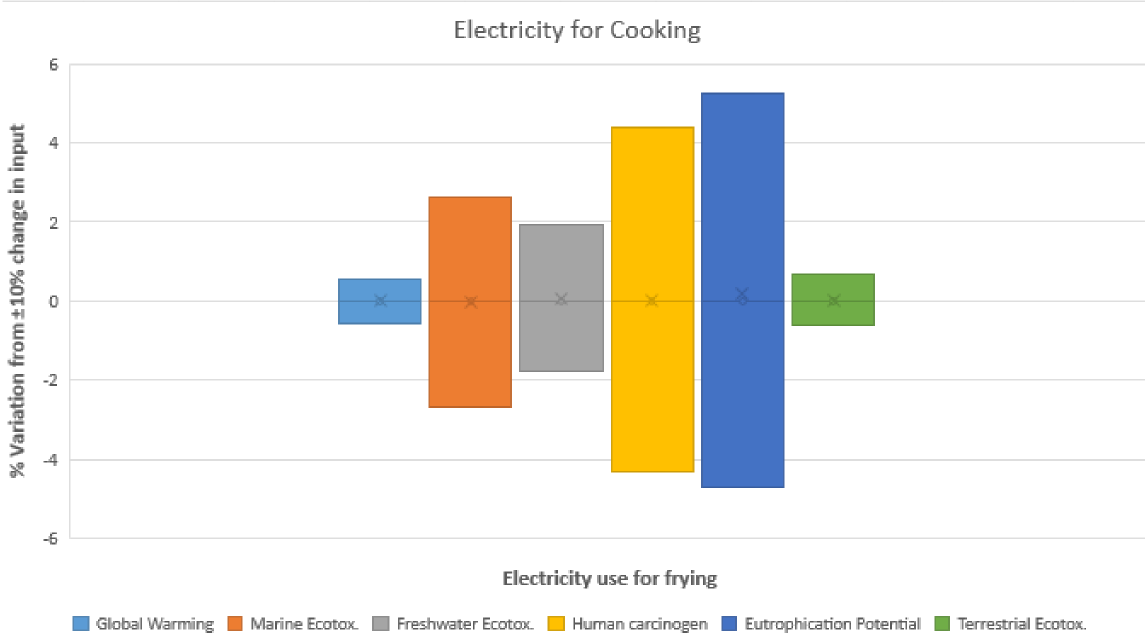

Figure 17: Sensitivity analysis for electricity input on frying process impacts

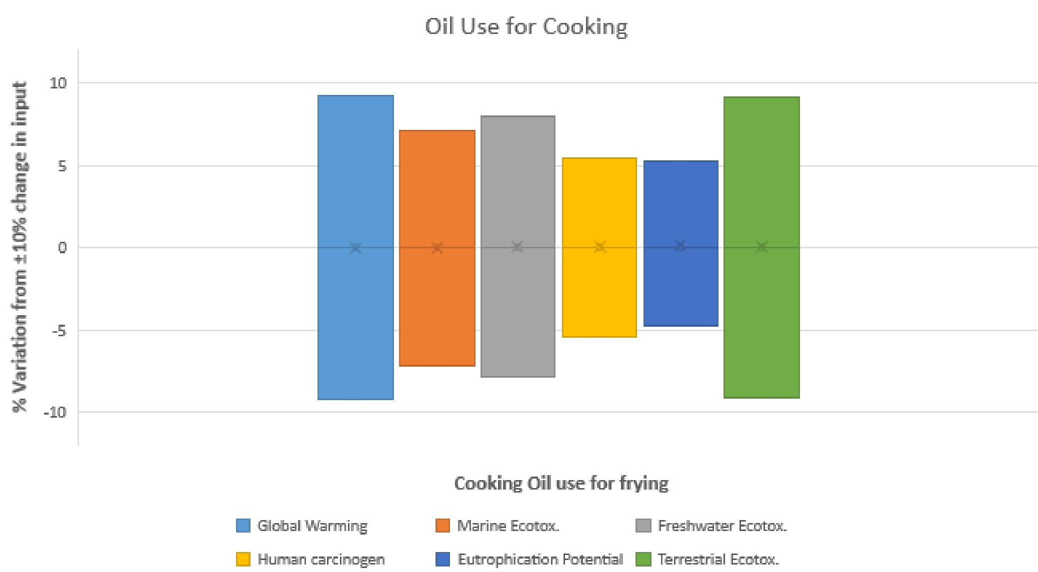

Figure 18: Sensitivity analysis for cooking oil input on frying process impacts

4.3 Nutrient analysis

The nutrient data from the Central Analytical Lab is presented in Table 3. The USDA FoodData database [8] has nutritional information for potatoes processed in all prescribed ways. To compare the analyzed data to publicly available nutrient data, a table is included of data from the FoodData database (

Table 4). The data from the Central Analytical Lab does not include values for vitamin C and fiber or a breakdown of protein and fat content, but these were included in

Table 4 because they are essential nutrients that potatoes provide to the human diet. Most of the data is similar between the literature values and measured values. Still, even where data is different, the data follows a trend where fried potatoes have low moisture content and a much higher fat content and caloric content, and boiled potatoes have a low potassium content. Additionally, the Central Analysis Lab data contains possible confounding factors in the influences of storage condition on nutrient content, as discussed in section 3.2.5.

Table 3 and

Table 4 show the values for the major nutrients found in a 100g sample of raw, fried, baked, and boiled potatoes. The comparatively low values of calories, carbohydrates, fat, and protein in raw and boiled potatoes can be attributed to the high moisture content since the samples are taken by weight. The low potassium and vitamin C levels in boiled potatoes can be attributed to the leaching of water-soluble nutrients into the cooking water during the boiling process.

Table 3: Nutrient summary for potatoes cooked in different ways from Nutrient Analysis

Nutrient	Raw	Fried	Baked	Boiled
Moisture	77.3 g	45.48 g	62.8 g	82.9 g
Calories	82.2 kcal	256.8 kcal	135.9 kcal	63.1 kcal
Fat	0.07 g	9.7 g	0.07 g	0.04 g
Potassium	258.8 mg	461.9 mg	401.9 mg	103.4 mg

Table 4: Nutrient summary for potatoes cooked in different ways from FoodData online database

Nutrient	Raw	Fried	Baked	Boiled
Moisture	81.6 g	65.1 g	74.4 g	77.5 g
Calories	69 kcal	196 kcal	95 kcal	86 kcal
Carbohydrates	15.7 g	18.5 g	21.4 g	20 g
Fat	0.08 g	13.1 g	0.13 g	0.1 g
Protein	1.68 g	1.93 g	2.63 g	1.71 g
Fiber	2.5 g	1.6 g	2.3 g	1.8 g
Potassium	407 mg	401 mg	550 mg	328 mg
Vitamin C	9.1 mg	9.7 mg	8.3 mg	7.4 mg

4.4 Storage-cooking nutrient trade-off and uncertainty

According to the Central Analytic Lab data, the nutrient content varies significantly with the cooking method but does not vary significantly with the storage method. Additionally, the CV for the data in each category is significantly higher for the storage conditions than for the cooking methods (Figure 19). This indicates that the cooking method significantly impacts the nutrient content, while the storage condition does not drastically affect the nutrient content. However, the moisture content is higher for unstored potatoes than any other condition, indicating that storing potatoes over time causes mass loss. The researchers' observations corroborate that potatoes shrink the longer they are stored.

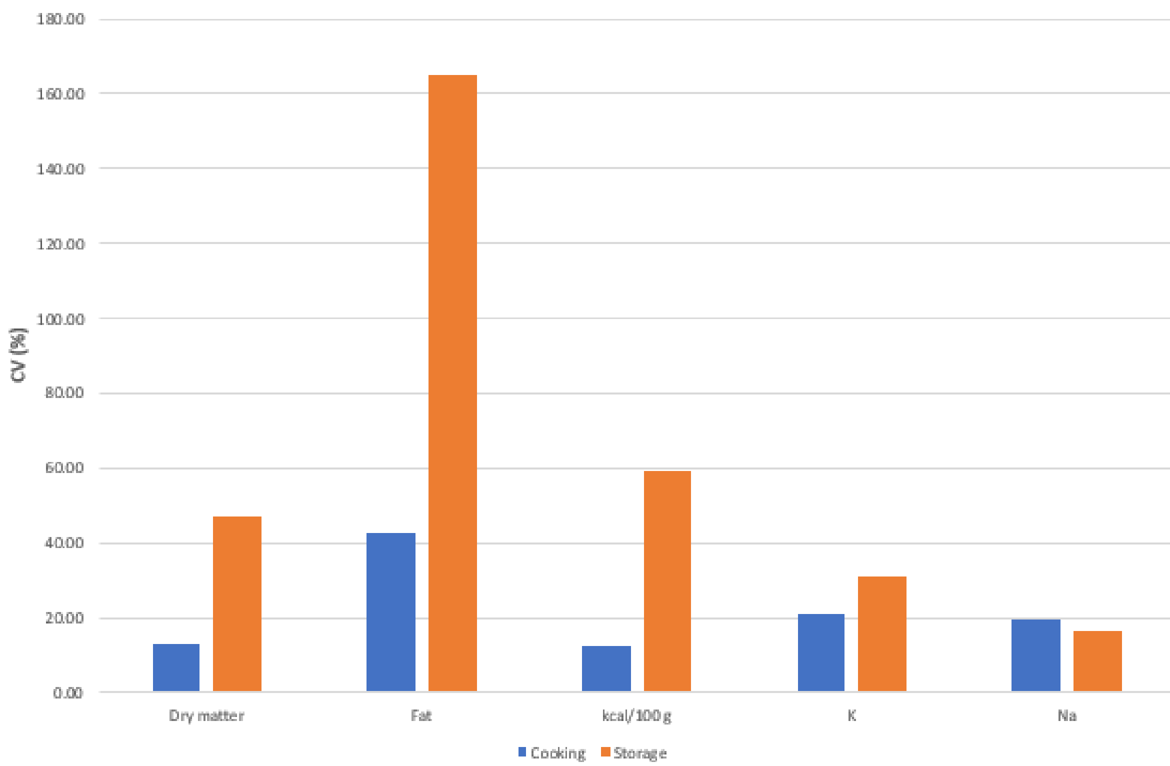

Figure 19: Comparison of the sum of CV values for each nutrient for cooking method vs. storage method

4.5 Cost analysis

The cost of performing each process for 1 kg of potatoes is detailed in Table 5. The storage conditions are indicated by the number of days (17 or 33) and the condition (ideal or fridge). All costs are expressed in US Dollars. According to the data, the lowest cost combination of processing options would be boiling potatoes that were unstored or stored in the cupboard (total processing cost: 8.65₵). The highest cost combination of processing options is frying potatoes stored for 33 days in the fridge (total processing cost: $4.14).

Table 5: Cost breakdown for potato storage and cooking methods

Treatment	Cost Of Electricity	Cost Of Water	Cost Of Oil	Total Cost
Frying	0.20	0	3.91	4.11
Baking	0.089	0	0	0.089
Boiling	0.085	0.0015	0	0.0865
17, Fridge	0.013	0	0	0.013

17, Ideal	0.01	0	0	0.01
33, Fridge	0.026	0	0	0.026
33, Ideal	0.019	0	0	0.019
Cupboard/ Unstored	0	0	0	0

4.6 Comparison to culinary service providers (Literature values)

Many people consume their potatoes in a highly processed form instead of processing them fresh at home [1]. Figure 20 and Figure 21 compare the caloric values and sodium content, respectively, of potatoes processed at home with the potatoes processed with popular potato products from several fast-food restaurants: French fries from McDonald's, baked potatoes from Wendy's, and mashed potatoes from Kentucky Fried Chicken. The data shown is for a 100-gram sample. The home processing data is taken from [8], and the fast-food caloric data was corroborated between [17] and [18].

The figures show that caloric values for home-processed and restaurant processed potatoes are similar, but the sodium content is typically higher for fast-food potato products than home-processed products. Frying yields the highest caloric content for both home and restaurant processed products. However, the sodium content is highest in mashed potatoes. While this data does not necessarily incriminate restaurant processed potato products, it is important to consider that processing at home gives consumers much more agency over the ingredients used. For example, a consumer could decrease the amount of salt used to make mashed potatoes at home but could not ask KFC to use less salt in their recipe.

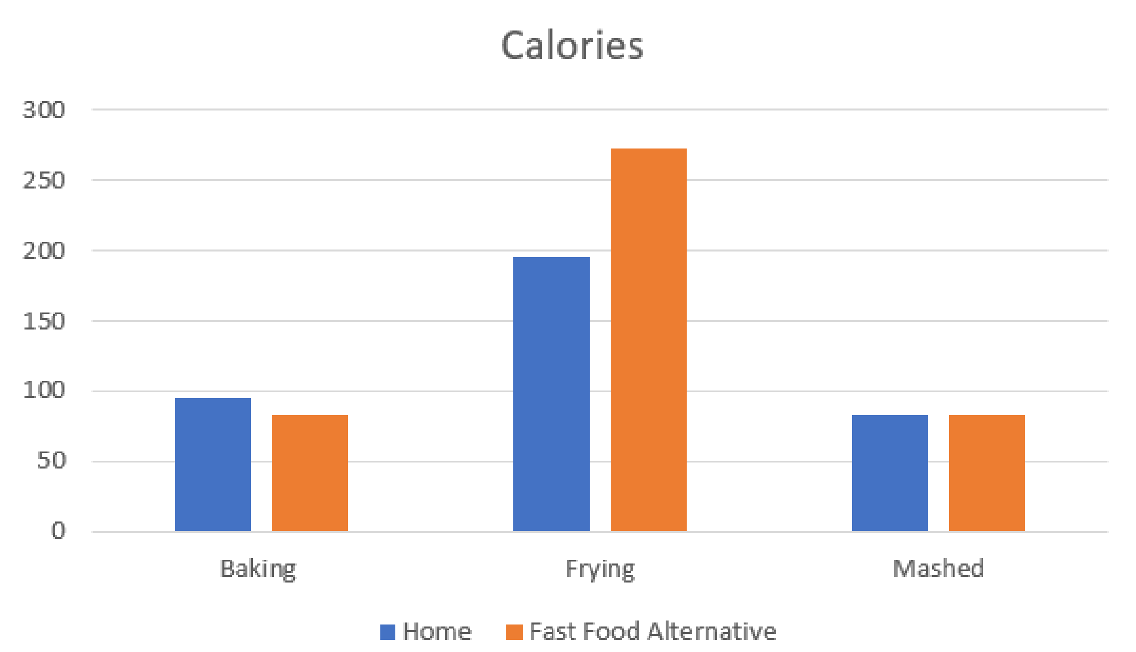

Figure 20: Comparison of calories for home cooked and restaurant processed potatoes

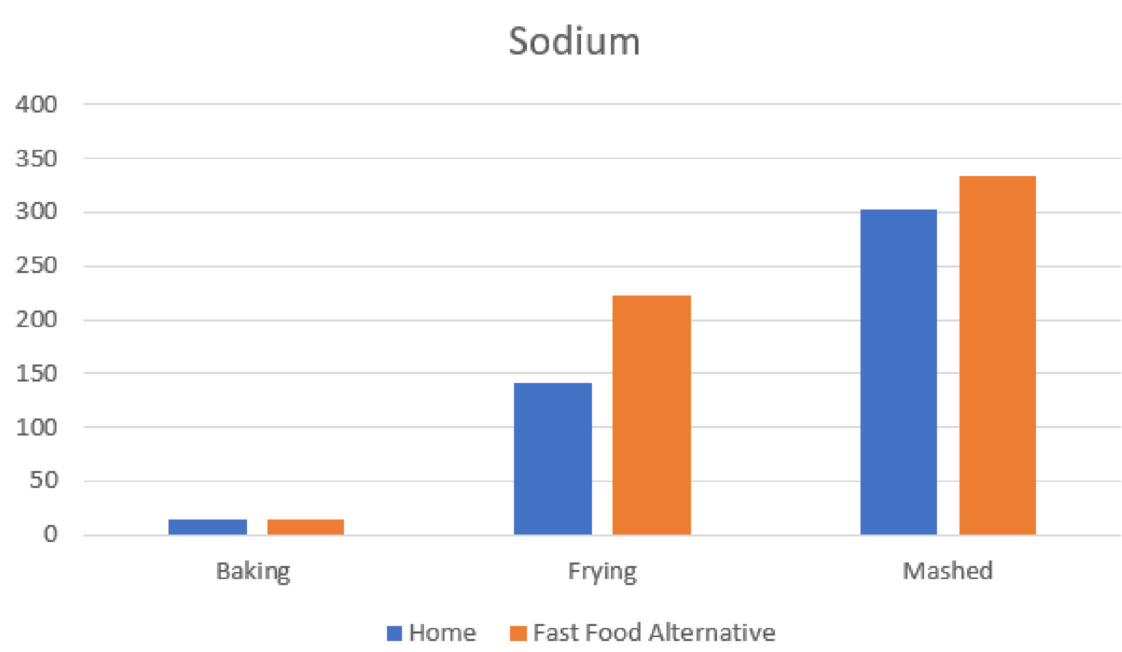

Figure 21: Comparison of sodium content for home cooked and restaurant processed potatoes

4.7 Trade-off analysis

Table 6 shows the results of the data envelopment calculation comparing cooking methods, and

Table 7 shows the results of the data envelopment calculation comparing storage methods. The results in the tables indicate that baking potatoes that are either fresh or have been stored in the cupboard is the optimal processing method at the current weighting distribution. On the cooking end, boiling is close behind, and frying performs considerably worse in all metrics. On the storage end, the data indicates an increase in both cost and environmental impact for longer storage times and more intense refrigeration requirements. However, it should be noted that potatoes germinate when stored in cupboard conditions for long periods, so there may be a negative impact on the subjective quality of potatoes in the cupboard setting despite that condition returning the best objective metrics. The calculations in this table can be redone with different weights or different evaluation criteria (*e.g.,* higher calories are favorable rather than detrimental) to achieve weighted values that correspond to consumers' differing priorities.

Table 6: Data Envelopment Analysis (DEA) table for nutrition, environmental impact, and cost for cooking methods

TREATMEN*T*	WEIGHT	BAKING	BOILING	FRYING
CALORIES	0.2	1.18	1.63	0.45
FAT	0.2	1.99	1.99	0.20
FIBER	0.2	1.44	1.18	1.06
POTASSIUM (K)	0.2	1.37	0.50	1.53
VITAMIN C	0.2	1.10	1.21	1.38
GLOBAL WARMING POTENTIAL	1	9.79	9.78	1.01
COST	1	9.81	9.81	1.00
TOTAL WEIGHTED VALUE		26.68	26.09	6.63

Table 7: DEA table for environmental impact and cost for storage methods

Treatment	Global Warming Potential	Cost	Total Weighted Value
Weight	1	1	
17, Fridge	6.67	6.76	13.43
33, Fridge	3.55	3.52	7.07
17, Ideal	7.57	7.51	15.08

33, Ideal	5.26	5.27	10.53
Unstored/ Cupboard	10	10	20

4.8 Recommendation for consumers and survey

The graphics presented (shown in Figure 22 Figure 23) utilized the total weighted values from the data envelopment analysis (Table 6 and

Table 7) to assign a score from 1-10 to each cooking and storage technique. Visual representations of these numbers were created for use in the survey. The objective data indicates that the optimal combination for consumers is to cook their potatoes fresh from the store or store them in a cupboard and then bake them.

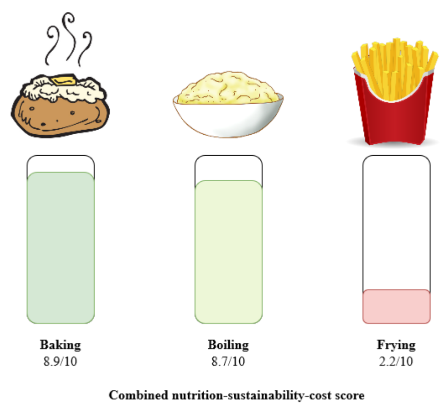

Figure 23: Consumer recommendation for cooking method

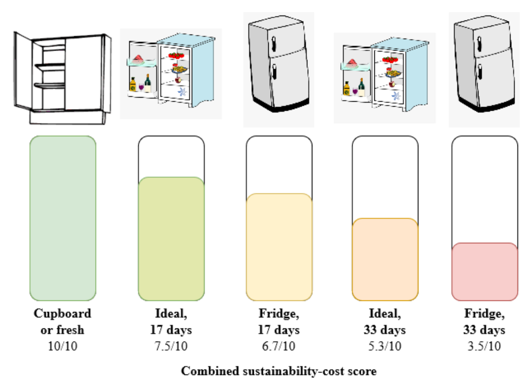

Figure 22: Consumer recommendation for storage method

4.9 Implications

The life cycle analysis and cost analysis results indicate that higher costs for processing methods often correspond to higher environmental impacts. These results are good news for consumers, who can cut down their costs and environmental impact simultaneously by choosing a cooking method such as baking or boiling, or by choosing to store their potatoes for a shorter period when possible (i.e., cook potatoes soon after purchasing instead of storing them for a long time). The latter will also help avoid food waste due to sprouting, rotting, or shrinkage, all of which occur when potatoes are stored for long periods.

4.10 Recommendation for future studies

After this research was conducted, several questions remained that warrant further exploration. Common processing methods such as drying and freezing were not explored in this research and certainly have unique effects on the shelf-life and nutritional content of the final food product. These methods could be analyzed in further research. Additionally, the cooking temperatures were monitored through this process, but a more in-depth study into the nutritional impacts of cooking with different temperatures (*e.g.,* baking at 400 °F vs. 350 °F) could return some valuable information that consumers could easily use to change their processing habits without significantly altering the final product. Additionally, the ingredients added to potatoes during the consumption process (butter, cheese, salt, ketchup, etc.) could drastically impact the overall life cycle impact of the final product, so including these products in a future life cycle analysis would return valuable information. Additionally, it would have been beneficial to measure the mass loss in the potatoes due to storage conditions to get an idea of the waste due to shrinkage or sprouting.

A plan was developed for a consumer survey as part of this research. Based on the survey results, there would be some value in determining what would convince people to change their habits to align more with their values. It is out of the area of expertise of the researchers to conduct such an experiment, but a social science study of this nature would have value beyond this application.

5 Conclusion

This project included a comprehensive study of the impacts of potato home processing in the categories of nutrition, cost, and environmental sustainability with the end goal of making a holistic recommendation for consumers and evaluating their response to the recommendation. The storage and cooking processes were simulated to indicate energy consumption and mass loss through the cooking processes. The nutritional data was measured by the University of Arkansas Central Analytics Lab and corroborated with data gathered from the USDA FoodData database, which includes nutrition-cooking dependencies but does not contain information regarding nutrition-storage dependencies. The cost data was compiled from prices of inputs as available in Fayetteville, AR, in April 2022. The environmental life cycle analysis was carried out using OpenLCA software using the Agribalyse database and the ReCiPe Midpoint (H) and Endpoint (H) analysis methods.

These analyses found that the highest impact comes from the cooking process, with the frying process having a considerably higher impact than either the baking or boiling process, which have similar impacts in all major categories. The storage component was found to have no significant effect on the nutritional content, except for moisture content, which decreases over storage time. A small (but not insignificant) portion of the environmental impact of each processing timeline is due to the energy consumption over the storage period (see Figure 11b, Figure 11c, and Figure 11d). The data for the nutrition, sustainability, and cost analyses were used to conduct a data envelopment analysis and compiled into two data tables (one for cooking and one for storage). A combined normalized sustainability-cost-nutrition score out of 10 was calculated for each processing technique, with higher numbers being the most favorable. Assuming the impacts for storage and cooking are additive (the cost data and OpenLCA results indicate that they are), the treatment combination with the lowest combined storage and cooking score (5.7/20) was frying after 33 days of storage in the refrigerator. The treatment combination with the highest combined storage and cooking score (18.9/20) was baking potatoes that are fresh (unstored) or stored in the cupboard.

The recommendation to consumers was delivered in the form of two graphics showing the normalized sustainability-cost-nutrition scores for each processing method (Figure 22 and Figure 23). Based on this information, the consumers' reactions (whether or not they would consider changing their home processing practices) were gauged as part of a survey evaluating the overall home potato processing practices. The testing for the survey is still in progress at the time of writing.

6 Acknowledgments

Thank you to Prince Agyemang and Dr. Ebenezer Miezah Kwofie for their assistance and guidance throughout the project. Additional thanks to Dr. Jamie Baum and Dr. Ali Ubeyitogullari for sitting on the defense committee.

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Appendices:

Appendix A (Energy estimation methods):

For the refrigerator and ideal storage conditions, refrigerators were used, so the energy consumption of these refrigerators must be estimated. Data relating temperature setting to power consumption was taken from [12], which indicated that the energy consumption for a refrigerator was 1.1 kWh/day on the low setting (the setting for our ideal storage condition) and 1.5 kWh/day on the medium setting (the setting for our refrigerator storage condition). This means that over 17 days, the energy consumption was 18.7 kWh for the ideal condition, and 25.5 kWh for the refrigerator condition. However, the Bureau of Labor Statistics Food Expenditure Survey indicates that 6.4% of home food expenditure is on fresh vegetables. Making some broad assumptions that 50% of food purchased is stored in the refrigerator and that 5% of fresh vegetables purchased are potatoes, gives a generalization that 0.64% of fridge space is taken up by potatoes at any given time. The energy consumption for refrigeration is shown in Table 2.

The energy inputs for each cooking method can be calculated based on the cooking time and temperature. The equation for heat transfer is:

$$Q = mC_p\Delta T$$

Where Q is heat transferred in kJ, m is mass in kg, C_p is specific heat of the material being heated in kJ/(kg*°K) and ΔT is the temperature change in degrees K. This equation can be used to find the energy required to raise the temperature of the cooking medium (water, oil, and air for boiling, frying, and baking, respectively). From this equation, given the specific heat of water to be 4.18 kJ/(kg*°K) and the specific heat of potatoes to be 3.39 kJ/(kg*°K) [13], the energy required to raise 1.9 kg (2 quarts) of water and 0.93 kg of potatoes from 25 degrees C (ambient temperature) to 100 degrees C (boiling point) is 1427.8 kJ. At the 39% efficiency of electric burners estimated in [14], this puts the total energy requirement from the burner for the heating stage at 3660.9 kJ (1.01 kWh). Following the initial heating stage, the water temperature must be maintained for 15 minutes while heat is lost through convection to the environment. Since most recipes recommend simmering instead of boiling for the 15-minute time period, it can be assumed that minimal energy losses occur from vaporization and energy is lost exclusively through convection. The convection heat transfer equation is:

$$Q = hA(T_\infty - T_s)$$

Where h is the convection coefficient, A is the surface area of the liquid, T_∞ is the ambient temperature (25 degrees) and T_s is the surface temperature (95 degrees for simmering water). Assuming a standard pot size of a four qt saucepan to be 8 inches (0.2 m), the surface area for this application is 0.0314 m^2. Various sources place the heat transfer coefficient for ambient air between 5 and 25 W/(m^2*K), so it is assumed to be 15 W/(m^2*K) for this application. This yields a heat use of 32.97 W, or 29.7 kJ in a 15-minute time period for a total of 3690 kJ for the entire boiling process. Covering the pot with a lid negates much of the energy loss to the air [15].

Repeating these calculations for the oil in the frying process (mass = 1.74 kg + 1.89 kg potatoes, Cp = 1.67 kJ/kg*K, cooking temperature = 140°C for 7 minutes then 208°C for 2 minutes) yields an energy requirement for the total heating period of the oil, but the "frying" occurs in part due to the vaporization of water in the potato. Assuming potatoes are 80% water, frying evaporates 60% of this water (interpreted from mass loss data in Table 2), and the enthalpy of vaporization of water at 200 degrees C is 1939 kJ/kg, the total energy consumed by the frying process is 8794 kJ (2.4 kWh).

The energy consumed by the baking process is variable as the oven goes through on/off cycles. most sources estimate the average oven energy use to be around 2.4 kWh/hr on medium to high heat. This means that for the 17-minute cooking period of these potatoes, plus the 10-minute preheating period, the energy consumption will be about 1.08 kWh or 3,888 kJ.

Appendix B (OpenLCA Inputs Summary):

Table 1 shows the inputs for the different processing methods. The treatment combinations were formed by combining these processes into new OpenLCA processes.

Table 1: Summary of OpenLCA inputs

PROCESS	INPUTS
BAKING	Electricity (3888 kJ)
BOILING	Electricity (3690 kJ), water (1.9 kg)
FRYING	Electricity (8794 kJ), soy oil (1.74 kg)
17-DAY FRIDGE STORAGE	Electricity (587 kJ)
33-DAY FRIDGE STORAGE	Electricity (1140 kJ)
17-DAY IDEAL STORAGE	Electricity (430 kJ)
33-DAY IDEAL STORAGE	Electricity (836 kJ)

Appendix C (data envelopment analysis calculation):

Sample DEA calculation:

For the data envelopment analysis table, each category (nutritional value, cost, etc.), each cooking or storage method was assigned a normalized value based on the following equation:

$$\frac{X_i}{\sqrt{\sum_{j=0}^{n} X_j}}$$

For example, the values for kilocalories per 100 g of potatoes were 256.8 for frying, 135.9 for baking, and 63.1 for boiling. The square root of the sum of the squares is $\sqrt{256.8^2 + 135.9^2 + 63.1^2} = 297.3$. To get the weighted value out of 10 for frying, the following calculation was performed:

$$10 - \left(\frac{256.8}{297.3}\right) * 9 = 2.23$$

So the normalized value for baking is 2.23. This number will then be multiplied by the weight of the category (0.2 for calories) to yield the final weighted result of 0.45 for frying. Similar calculations are performed with the baking and boiling values, and since these values are normalized and weighted, they can now be added to the normalized and weighted values for the other categories to get an overall sustainability-nutrition-cost score for each processing condition.

Appendix D (Survey questions):

Demographic

Objective: The objective is to avoid making assumptions about the participants and provide context analysis of different groups' preferences.

(1) What age group are you in?

(a) Below 18 (b) 18-24, (c) 25-30, (d) 31-40, (e) above 40.

(2) How do you describe your gender?

(a) Male, (b) female, (c) non-binary/other (d) Prefer not to say

(3) Which race do you belong to?

(a) White (b) Black/African America (c) Asian (d) Hispanic

(4) Are you affiliated to the University of Arkansas?

(a) Yes (b) No

If No, Kindly state your institution of affiliation …………………..

(5) Which college are you affiliated with?

a. Dale Bumpers College of Agricultural, Food and Life Sciences
b. Fay Jones School of Architecture and Design
c. Fulbright College of Arts and Sciences
d. Sam M. Walton College of Business
e. College of Education and Health Professions,
f. College of Engineering
g. Others, kindly list below…………….

(6) Which of the following do you relate to?

(a) Undergraduate (b) Graduate (c) Staff/Faculty

Potato consumption testing

Objective: These questions will give us an idea of what percentage of people might be affected by this research

(1) Do you eat potatoes?

(a) Yes (b) No

(2) If yes, which potato product do you eat most often?

(a) Potato chip (b) Baked Potato (c) Boiled potato (including mashed) (d) french fries

(3) How often do you eat potatoes?

(a) Every day (b) every week, (c) 3-4 times per month (e) once/twice a month

(4) Have you eaten any potatoes in the last three days?

(a) yes (b) No (c) Don't remember

(5) What percent of the potatoes you eat are cooked at home (not from a restaurant or frozen)?

(a) 0-25% (b) 25-50% (c) 50-75% (d) 75-100%

Potato storage

Objective: These questions gauge where and how people source their potatoes. This information has implications on sustainability and waste.

(1) If you cook your own potatoes, from which store do you buy them?

(a) Walmart (b) aldi (c) harps (d) organic grocer (whole foods, co-op, etc.) (e) N/A

(2) How often do you purchase potatoes?

(a) weekly (b) every two week (c) once per month (d) less than once per month

(3) How long do you store potatoes in your home after purchasing them?

(a) less than 1 week (b) 1-2 weeks (c) 2-4 weeks (d) more than 1 month

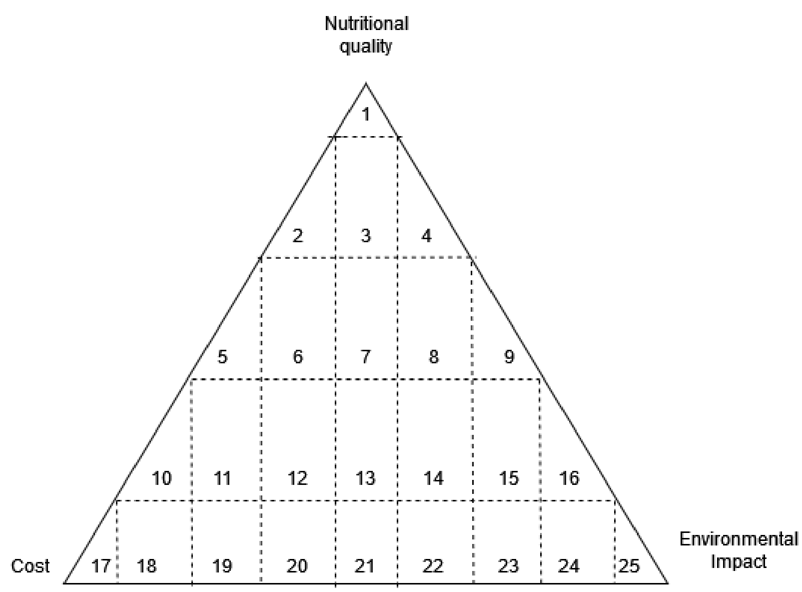
(4) Where in your home do you store your potatoes?

(a) cupboard at room temperature (b) refrigerator (d) basement or cellar

Processing importance

Objective: This section will evaluate participants' values when it comes to food consumption

USE THE FOLLOWING IMAGE TO HELP YOU ANSWER THE QUESTIONS IN THIS SECTION



(1) Please indicate a number on the triangle corresponding with the combination of factors that you find most important when purchasing and cooking potatoes (for example, if you care

equally about nutritional quality and cost, but don't care about environmental impact, enter "5."

Manual entry of number

(2) Do you feel like you are given sufficient information in a grocery store or restaurant setting to make decisions that correspond to these values?

(a) Yes (b) No

Consumer previous knowledge test

Objective: This section aims to gauge the knowledge that consumers already have on the subject

(1) Which of these methods of processing potatoes at home do you think will make more nutrients (such as vitamin C, potassium, etc.) available to you?

(a) Boiling (b) Baking (c) Frying (d) don't know

(2) Which of these home processing methods do you think adds the most calories?

(a) Boiling (b) Baking (c) Frying (d) don't know

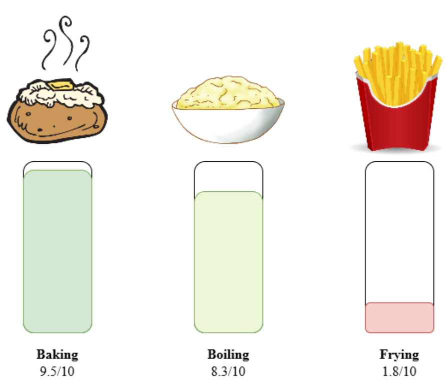
(3) Which of these home processing methods do you think has the lowest environmental impact?

(a) Boiling (b) Baking (c) Frying (d) don't know

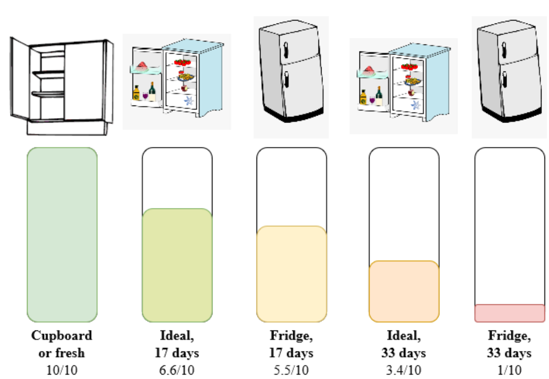
(4) Which of these home processing methods do you think has the lowest cost (considering electricity, ingredients, etc.)?

(a) Boiling (b) Baking (c) Frying (d) don't know

Recommendations for Consumers



Combined nutrition-sustainability-cost score



Combined sustainability-cost score

Based on the graphics above, does the way that you currently consume potatoes align with the values you expressed earlier in the survey (the number you selected from the triangle)?

Yes (b) no (c) the information is not clear

If you answered no to the previous question, how likely are you to change the way that you store your potatoes based on this information?

Definitely will (b) Maybe (c) Not likely (d) definitely won't (e) I did not answer "no" above

If you answered no to the first question, how likely are you to change the way that you cook your potatoes based on this information?

(a) Definitely will (b) Maybe (c) Not likely (d) definitely won't (e) I did not answer "no" above

Participants' Trusts and recommendations (Product review)

Objective: These questions gauge whether consumers would benefit from information such as this being readily available

1. Do you trust that the information presented in the graphics is accurate? (Scale

(a)Yes (b) Somewhat (c) No

(2) Would graphics such as this be useful if they were presented to you in a grocery store or restaurant setting?

(a) Yes (b) Maybe (c) No

(3) Overall, how will you rate this simulator?

(a) 5 (b) 4 (c) 3 (d) 2 (e) 1

(4) Is there any other information that you would like to see on a graphic like this that would make it more useful to you?

(5) Do you have any reviews or comments for the researchers involved in this project?

Appendix E (Impact tables for each treatment):

Table 2: 17 day Fridge Baked

Impact category	Reference unit	Mean	Standard deviation	Cv%	5% Percentile	95% Percentile
Freshwater ecotoxicity	kg 1,4-DCB	5.74E-03	3.91E-04	6.82	5.14E-03	6.44E-03
Freshwater eutrophication	kg P eq	2.06E-04	1.41E-05	6.85	1.84E-04	2.31E-04
Global warming	kg CO2 eq	1.79E-01	1.14E-02	6.34	1.62E-01	2.00E-01
Human carcinogenic toxicity	kg 1,4-DCB	1.13E-02	7.66E-04	6.78	1.01E-02	1.27E-02
Marine ecotoxicity	kg 1,4-DCB	7.93E-03	5.41E-04	6.82	7.11E-03	8.91E-03
Terrestrial ecotoxicity	kg 1,4-DCB	1.27E-01	8.43E-03	6.62	1.15E-01	1.43E-01

Table 3: 17-day fridge boiled

Impact category	Reference unit	Mean	Standard deviation	Cv%	5% Percentile	95% Percentile
Freshwater ecotoxicity	kg 1,4-DCB	8.42E-03	5.96E-04	7.09	7.52E-03	9.42E-03
Freshwater eutrophication	kg P eq	3.02E-04	2.15E-05	7.11	2.70E-04	3.38E-04
Global warming	kg CO2 eq	2.63E-01	1.73E-02	6.59	2.37E-01	2.92E-01
Human carcinogenic toxicity	kg 1,4-DCB	1.66E-02	1.17E-03	7.04	1.48E-02	1.85E-02
Marine ecotoxicity	kg 1,4-DCB	1.16E-02	8.24E-04	7.08	1.04E-02	1.30E-02
Terrestrial ecotoxicity	kg 1,4-DCB	1.87E-01	1.29E-02	6.88	1.68E-01	2.09E-01

Table 4: 17-day Fridge Frying

Impact category	Reference unit	Mean	Standard deviation	CV (%)	5% Percentile	95% Percentile
Freshwater ecotoxicity	kg 1,4-DCB	1.38E-01	5.90E-03	4.27	1.29E-01	1.48E-01
Freshwater eutrophication	kg P eq	1.82E-03	8.56E-05	4.71	1.68E-03	1.96E-03
Global warming	kg CO2 eq	1.50E+01	2.14E+00	1.43	1.19E+01	1.87E+01
Human carcinogenic toxicity	kg 1,4-DCB	1.13E-01	4.28E-03	3.79	1.06E-01	1.20E-01
Marine ecotoxicity	kg 1,4-DCB	1.34E-01	3.03E-03	2.27	1.29E-01	1.39E-01
Terrestrial ecotoxicity	kg 1,4-DCB	8.98E+00	1.36E-01	1.52	8.77E+00	9.23E+00

Table 5: 17 Day Ideal Baking

Impact category	Reference unit	Mean	Standard deviation	CV (%)	5% Percentile	95% Percentile
Freshwater ecotoxicity	kg 1,4-DCB	1.99E-03	1.38E-04	6.92	1.78E-03	2.23E-03
Freshwater eutrophication	kg P eq	7.15E-05	4.97E-06	6.95	6.37E-05	8.00E-05
Global warming	kg CO2 eq	6.22E-02	4.00E-03	6.44	5.59E-02	6.91E-02
Human carcinogenic toxicity	kg 1,4-DCB	3.92E-03	2.70E-04	6.88	3.50E-03	4.39E-03
Marine ecotoxicity	kg 1,4-DCB	2.75E-03	1.91E-04	6.92	2.46E-03	3.08E-03
Terrestrial ecotoxicity	kg 1,4-DCB	4.43E-02	2.97E-03	6.72	3.96E-02	4.94E-02

Table 6: 17 Day Ideal Boiling

Impact category	Reference unit	Mean	Standard deviation	CV (%)	5% Percentile	95% Percentile
Freshwater ecotoxicity	kg 1,4-DCB	7.96E-03	5.34E-04	6.71	7.19E-03	8.94E-03
Freshwater eutrophication	kg P eq	2.86E-04	1.93E-05	6.74	2.58E-04	3.21E-04
Global warming	kg CO2 eq	2.49E-01	1.55E-02	6.24	2.26E-01	2.77E-01
Human carcinogenic toxicity	kg 1,4-DCB	1.57E-02	1.05E-03	6.67	1.42E-02	1.76E-02
Marine ecotoxicity	kg 1,4-DCB	1.10E-02	7.39E-04	6.71	9.94E-03	1.24E-02
Terrestrial ecotoxicity	kg 1,4-DCB	1.77E-01	1.15E-02	6.51	1.60E-01	1.98E-01

Table 7: 17 day ideal frying

Impact category	Reference unit	Mean	Standard deviation	CV (%)	5% Percentile	95% Percentile
Freshwater ecotoxicity	kg 1,4-DCB	1.37E-01	5.86E-03	4.29	1.28E-01	1.47E-01
Freshwater eutrophication	kg P eq	1.79E-03	8.68E-05	4.86	1.64E-03	1.93E-03
Global warming	kg CO2 eq	1.49E+01	2.10E+00	1.41	1.19E+01	1.89E+01
Human carcinogenic toxicity	kg 1,4-DCB	1.11E-01	4.38E-03	3.94	1.04E-01	1.19E-01
Marine ecotoxicity	kg 1,4-DCB	1.32E-01	3.18E-03	2.41	1.27E-01	1.38E-01
Terrestrial ecotoxicity	kg 1,4-DCB	8.95E+00	1.41E-01	1.58	8.74E+00	9.20E+00

Table 8: 33 day fridge baking

Impact category	Reference unit	Mean	Standard deviation	CV (%)	5% Percentile	95% Percentile
Freshwater ecotoxicity	kg 1,4-DCB	5.28E-03	3.62E-04	6.86	4.74E-03	5.93E-03
Freshwater eutrophication	kg P eq	1.89E-04	1.31E-05	6.89	1.70E-04	2.13E-04
Global warming	kg CO2 eq	1.65E-01	1.05E-02	6.38	1.49E-01	1.84E-01
Human carcinogenic toxicity	kg 1,4-DCB	1.04E-02	7.10E-04	6.82	9.35E-03	1.17E-02
Marine ecotoxicity	kg 1,4-DCB	7.30E-03	5.01E-04	6.86	6.55E-03	8.20E-03
Terrestrial ecotoxicity	kg 1,4-DCB	1.17E-01	7.81E-03	6.66	1.06E-01	1.31E-01

Table 9: 33 day fridge boiling

Impact category	Reference unit	Mean	Standard deviation	CV (%)	5% Percentile	95% Percentile
Freshwater ecotoxicity	kg 1,4-DCB	9.95E-03	6.66E-04	6.70	8.95E-03	1.12E-02
Freshwater eutrophication	kg P eq	3.57E-04	2.40E-05	6.72	3.21E-04	4.01E-04
Global warming	kg CO2 eq	3.11E-01	1.94E-02	6.23	2.82E-01	3.46E-01
Human carcinogenic toxicity	kg 1,4-DCB	1.96E-02	1.31E-03	6.66	1.76E-02	2.20E-02
Marine ecotoxicity	kg 1,4-DCB	1.38E-02	9.21E-04	6.69	1.24E-02	1.55E-02
Terrestrial ecotoxicity	kg 1,4-DCB	2.21E-01	1.44E-02	6.50	2.00E-01	2.48E-01

Table 10: 33 day fridge frying

Impact category	Reference unit	Mean	Standard deviation	CV (%)	5% Percentile	95% Percentile
Freshwater ecotoxicity	kg 1,4-DCB	1.41E-01	6.26E-03	4.44	1.31E-01	1.52E-01
Freshwater eutrophication	kg P eq	1.93E-03	9.18E-05	4.76	1.78E-03	2.09E-03
Global warming	kg CO2 eq	1.51E+01	2.18E+00	14.5	1.20E+01	1.91E+01
Human carcinogenic toxicity	kg 1,4-DCB	1.19E-01	4.78E-03	4.02	1.12E-01	1.27E-01
Marine ecotoxicity	kg 1,4-DCB	1.38E-01	3.41E-03	2.47	1.33E-01	1.44E-01
Terrestrial ecotoxicity	kg 1,4-DCB	9.04E+00	1.42E-01	1.57	8.82E+00	9.28E+00

Table 11: 33 day ideal baking

Impact category	Reference unit	Mean	Standard deviation	CV (%)	5% Percentile	95% Percentile
Freshwater ecotoxicity	kg 1,4-DCB	3.86E-03	2.66E-04	6.89	3.46E-03	4.32E-03
Freshwater eutrophication	kg P eq	1.38E-04	9.57E-06	6.92	1.24E-04	1.55E-04
Global warming	kg CO2 eq	1.20E-01	7.72E-03	6.41	1.09E-01	1.34E-01
Human carcinogenic toxicity	kg 1,4-DCB	7.60E-03	5.21E-04	6.85	6.83E-03	8.50E-03
Marine ecotoxicity	kg 1,4-DCB	5.33E-03	3.67E-04	6.89	4.79E-03	5.97E-03
Terrestrial ecotoxicity	kg 1,4-DCB	8.57E-02	5.73E-03	6.68	7.72E-02	9.56E-02

Table 12: 33 day ideal boiling

Impact category	Reference unit	Mean	Standard deviation	CV (%)	5% Percentile	95% Percentile
Freshwater ecotoxicity	kg 1,4-DCB	9.11E-03	6.47E-04	7.09	8.20E-03	1.02E-02
Freshwater eutrophication	kg P eq	3.27E-04	2.33E-05	7.12	2.94E-04	3.68E-04
Global warming	kg CO2 eq	2.85E-01	1.88E-02	6.60	2.58E-01	3.18E-01
Human carcinogenic toxicity	kg 1,4-DCB	1.80E-02	1.27E-03	7.05	1.62E-02	2.02E-02
Marine ecotoxicity	kg 1,4-DCB	1.26E-02	8.94E-04	7.09	1.13E-02	1.42E-02
Terrestrial ecotoxicity	kg 1,4-DCB	2.03E-01	1.39E-02	6.88	1.83E-01	2.27E-01

Table 13: 33 day ideal frying

Impact category	Reference unit	Mean	Standard deviation	CV (%)	5% Percentile	95% Percentile
Freshwater ecotoxicity	kg 1,4-DCB	1.40E-01	6.20E-03	4.45	1.30E-01	1.50E-01
Freshwater eutrophication	kg P eq	1.87E-03	8.72E-05	4.67	1.73E-03	2.01E-03
Global warming	kg CO2 eq	1.50E+01	2.13E+00	14.15	1.20E+01	1.88E+01
Human carcinogenic toxicity	kg 1,4-DCB	1.16E-01	4.54E-03	3.92	1.09E-01	1.23E-01
Marine ecotoxicity	kg 1,4-DCB	1.36E-01	3.38E-03	2.49	1.30E-01	1.41E-01
Terrestrial ecotoxicity	kg 1,4-DCB	9.00E+00	1.37E-01	1.52	8.81E+00	9.25E+00

Table 14: Baking (unstored and cupboard)

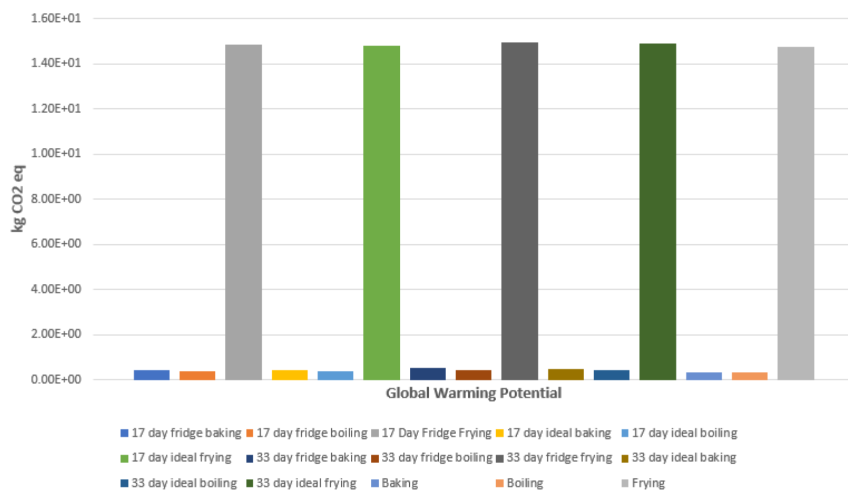
Impact category	Reference unit	Mean	Standard deviation	CV (%)	5% Percentile	95% Percentile
Freshwater ecotoxicity	kg 1,4-DCB	3.01E-06	2.07E-07	6.88	2.70E-06	3.36E-06
Freshwater eutrophication	kg P eq	1.08E-07	7.45E-09	6.91	9.68E-08	1.20E-07
Global warming	kg CO2 eq	9.38E-05	6.01E-06	6.40	8.49E-05	1.04E-04
Human carcinogenic toxicity	kg 1,4-DCB	5.92E-06	4.05E-07	6.84	5.32E-06	6.61E-06
Marine ecotoxicity	kg 1,4-DCB	4.15E-06	2.86E-07	6.88	3.73E-06	4.64E-06
Terrestrial ecotoxicity	kg 1,4-DCB	6.68E-05	4.46E-06	6.68	6.02E-05	7.43E-05

Table 15: Boiling (unstored and cupboard)

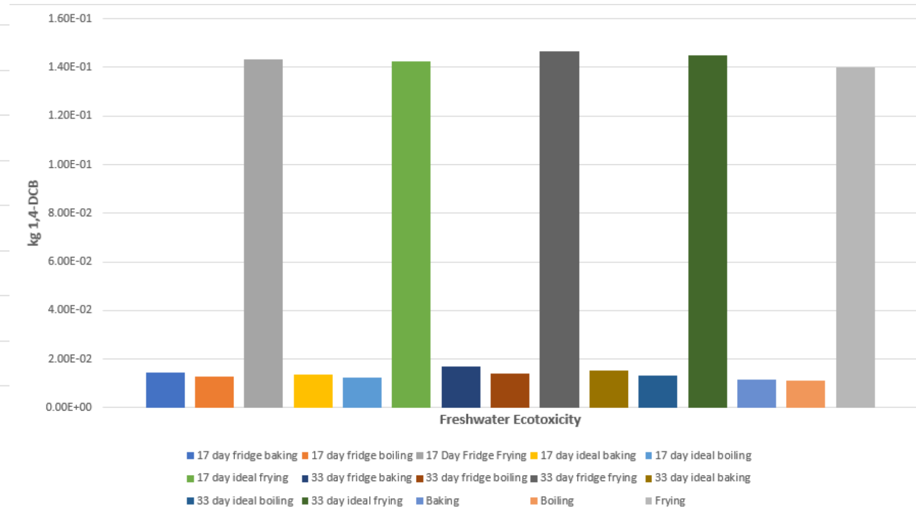
Impact category	Reference unit	Mean	Standard deviation	CV (%)	5% Percentile	95% Percentile
Freshwater ecotoxicity	kg 1,4-DCB	6.78E-03	4.50E-04	6.64	6.07E-03	7.51E-03
Freshwater eutrophication	kg P eq	2.43E-04	1.62E-05	6.66	2.18E-04	2.70E-04
Global warming	kg CO2 eq	2.12E-01	1.31E-02	6.18	1.91E-01	2.33E-01
Human carcinogenic toxicity	kg 1,4-DCB	1.34E-02	8.81E-04	6.60	1.20E-02	1.48E-02
Marine ecotoxicity	kg 1,4-DCB	9.37E-03	6.22E-04	6.64	8.39E-03	1.04E-02
Terrestrial ecotoxicity	kg 1,4-DCB	1.51E-01	9.70E-03	6.44	1.35E-01	1.67E-01

Table 16: Frying (unstored and cupboard)

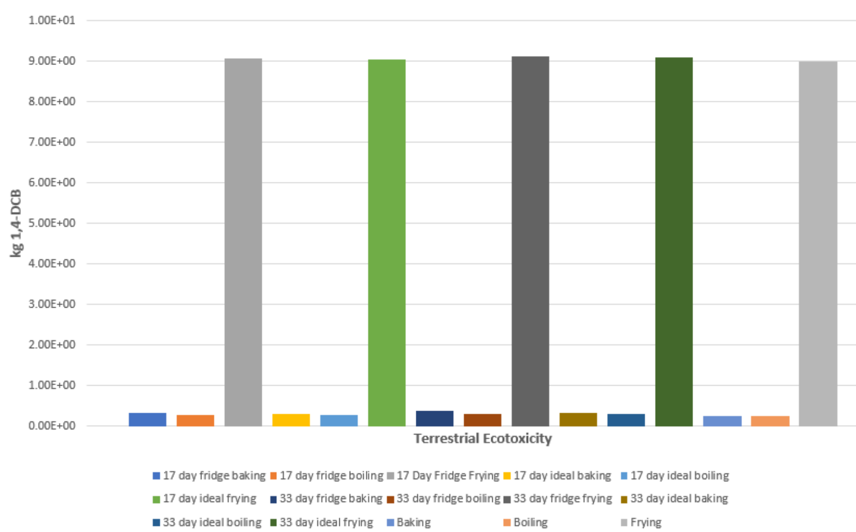
Impact category	Reference unit	Mean	Standard deviation	CV (%)	5% Percentile	95% Percentile
Freshwater ecotoxicity	kg 1,4-DCB	1.35E-01	5.97E-03	4.43	1.26E-01	1.45E-01
Freshwater eutrophication	kg P eq	1.70E-03	8.53E-05	5.02	1.57E-03	1.85E-03
Global warming	kg CO2 eq	1.49E+01	2.13E+00	14.32	1.18E+01	1.89E+01
Human carcinogenic toxicity	kg 1,4-DCB	1.07E-01	3.95E-03	3.70	1.00E-01	1.13E-01
Marine ecotoxicity	kg 1,4-DCB	1.29E-01	2.90E-03	2.25	1.25E-01	1.34E-01
Terrestrial ecotoxicity	kg 1,4-DCB	8.90E+00	1.39E-01	1.56	8.70E+00	9.14E+00



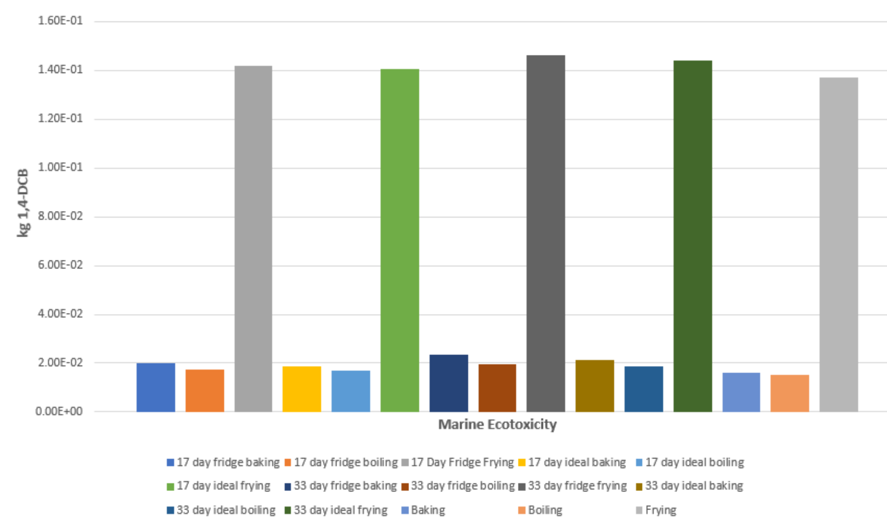
1.a) Impact results for global warming potential



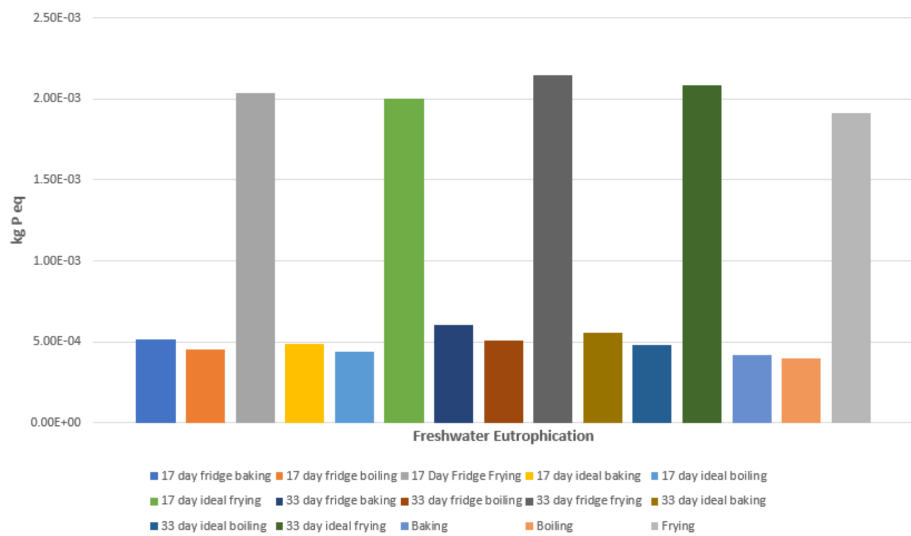
1.b) Impact results for freshwater ecotoxicity



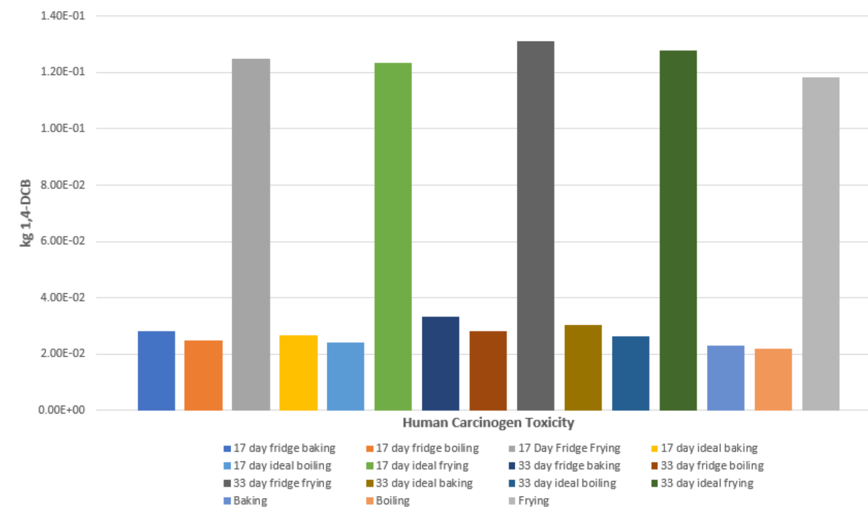
1.c) Impact results for terrestrial ecotoxicity



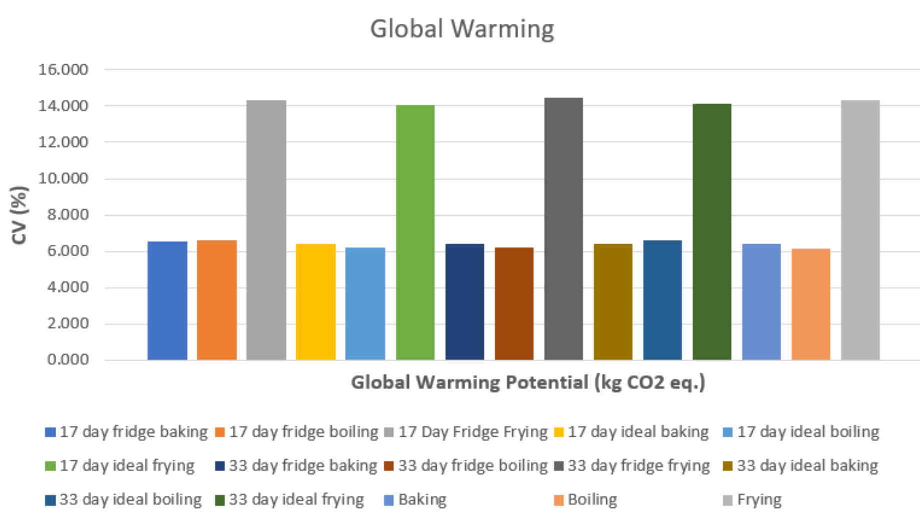
1.d) Impact results for marine ecotoxicity



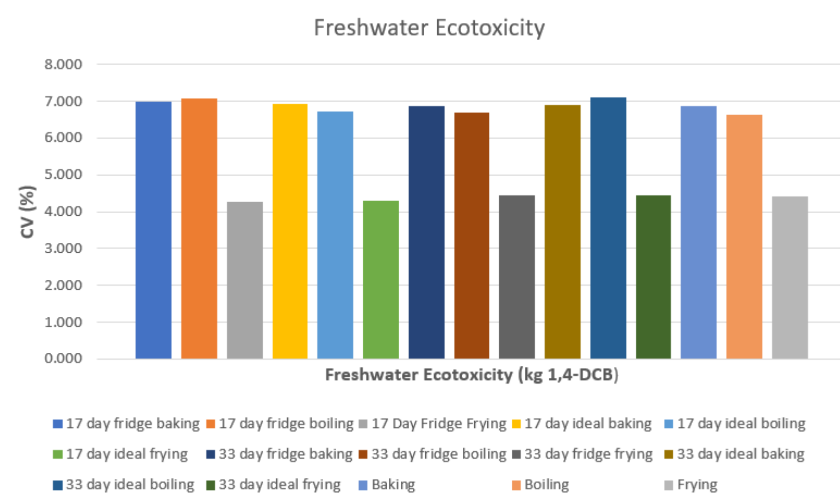
1.e) Impact results for freshwater eutrophication



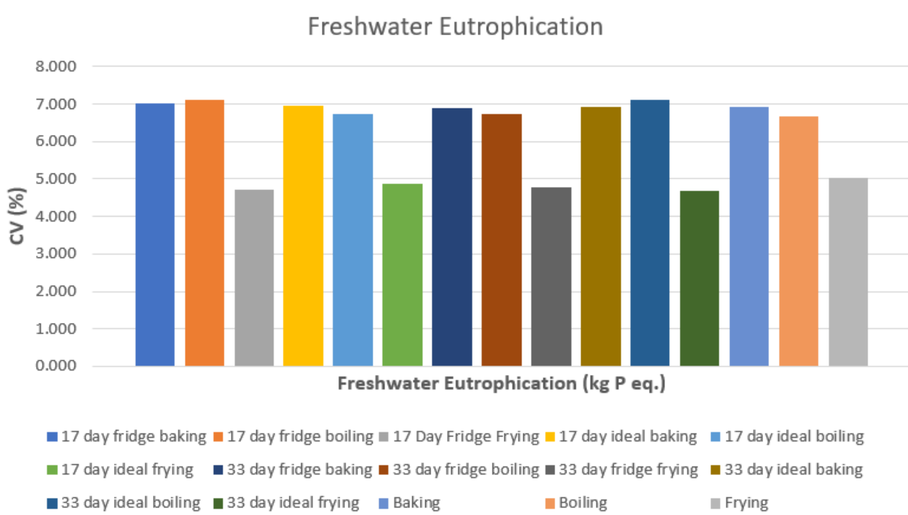
1.f) Impact results for human carcinogen toxicity



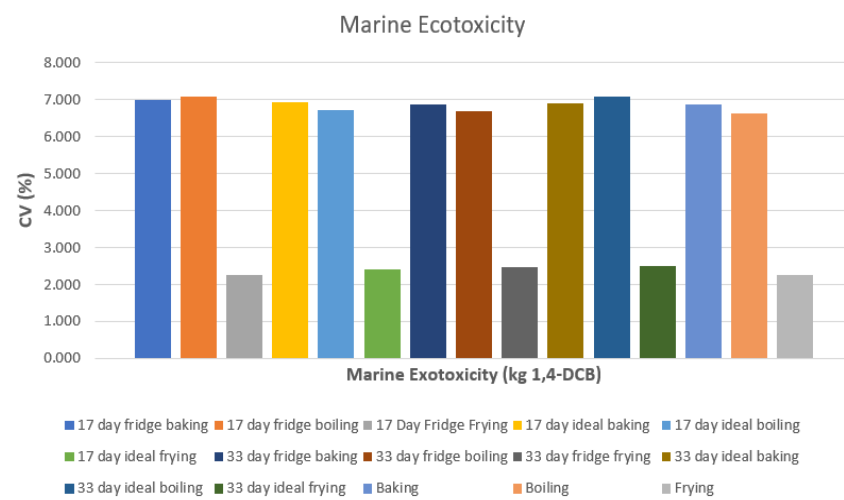
2.a) Coefficient of variation comparison for Global Warming Potential



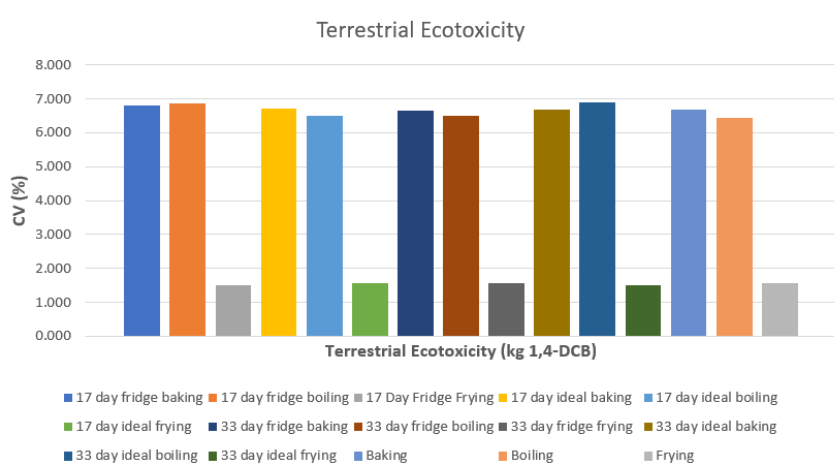
2.b) Coefficient of variation comparison for Freshwater Ecotoxicity



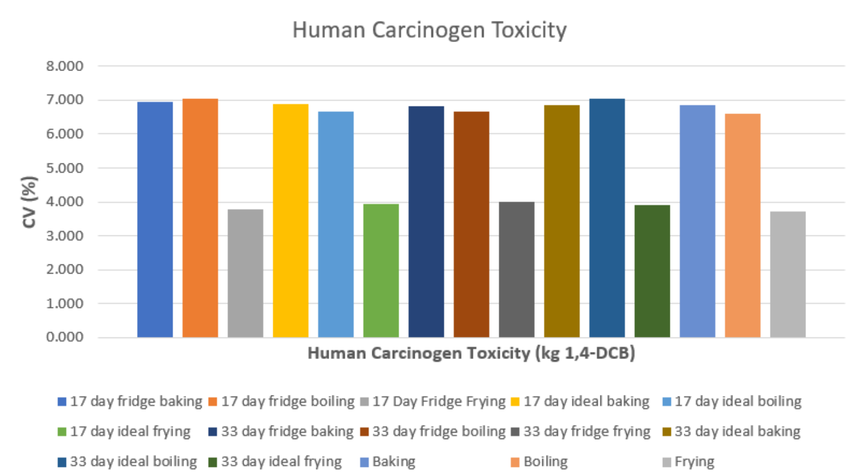
2.c) Coefficient of variation comparison for Freshwater Eutrophication



2.d) Coefficient of variation comparison for Marine Ecotoxicity



2.e) Coefficient of variation comparison for Terrestrial Ecotoxicity



2.f) Coefficient of variation comparison for Human Carcinogen Tox.

Appendix F (Sensitivity analysis for each treatment):

Boiling and frying were the only processes that contained more than one input (for most of the processes, the only input was electricity). The tables for the boiling and frying sensitivity analysis are shown below:

Table 17: Sensitivity analysis results for boiling process

Process parameters	Input value	+10% change	-10% change	Impact Category	Original Value	+10 Impact Results (% change)	%	-10 Impact Results (% change)	%
Electricity for Cooking	3690 kJ	4059 kJ	3321 kJ	Global Warming	**0.345**	0.380	10.023	0.311	9.991
				Marine Ecotox.	**0.015**	0.017	9.804	0.014	10.131
				Freshwater Ecotox.	**0.011**	0.012	10.045	0.010	9.955
				Human carcinogen	**0.022**	0.024	10.009	0.020	9.963
				Eutrophication Potential	**0.000**	0.000	10.000	0.000	10.000
				Terrestrial Ecotox.	**0.246**	0.270	10.008	0.221	9.996
Water Use	1.9 kg	2.09 kJ	1.71 kJ	Global Warming	**0.345**	0.345	0.000	0.345	0.000
				Marine Ecotox.	**0.015**	0.015	0.000	0.015	0.000
				Freshwater Ecotox.	**0.011**	0.011	0.000	0.011	0.000
				Human carcinogen	**0.022**	0.022	0.000	0.022	0.000
				Eutrophication Potential	**0.000**	0.000	0.000	0.000	0.000
				Terrestrial Ecotox.	**0.246**	0.246	0.000	0.246	0.000

Table 18: Sensitivity analysis for frying process

Process parameters	Input value	+10% change	-10% change	Impact Category	Original Value	+10 Impact Results (% change)	%	-10 Impact Results (% change)	%
Electricity for Cooking	8794 kJ	9673 kJ	7915 kJ	Global Warming	**14.731**	14.814	0.563	14.650	-0.550
				Marine Ecotox.	**0.137**	0.141	2.622	0.134	-2.695
				Freshwater Ecotox.	**0.140**	0.143	1.929	0.138	-1.786
				Human carcinogen	**0.118**	0.124	4.392	0.113	-4.307
				Eutrophication Potential	**0.002**	0.002	5.236	0.002	-4.712
				Terrestrial Ecotox.	**8.980**	9.042	0.690	8.925	-0.612
Oil Use	1.74 kg	1.91 kg	1.57 kg	Global Warming	**14.731**	16.090	9.225	13.373	-9.219
				Marine Ecotox.	**0.137**	0.147	7.138	0.127	-7.210
				Freshwater Ecotox.	**0.140**	0.151	8.000	0.129	-7.857
				Human carcinogen	**0.118**	0.125	5.490	0.112	-5.405
				Eutrophication Potential	**0.002**	0.002	5.236	0.002	-4.712
				Terrestrial Ecotox.	**8.980**	9.803	9.165	8.163	-9.098