RESEARCH ON INTERACTIVE FOOD PACKAGING DESIGN BASED ON USER EXPERIENCE UNDER THE BACKGROUND OF DUAL CARBON

Yanjun Zhao*

Department of Finance and Economics, University of Chinese Academy of Social Sciences, Beijing, 100102, China.

17801567001@163.com

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ABSTRACT

In recent years, the environmental degradation caused by carbon emissions has become more and more serious. It is particularly important to achieve the dual carbon goals of "carbon peaking" and "carbon neutral". The food packaging process accounts for a large portion of carbon emissions in the food industry and is an important concern for carbon reduction. While the task of carbon reduction is particularly important, it is also important to design food packaging with the user's experience in mind. This is the reason why interactive packaging design, which focuses on two-way communication and user experience, is used in the design of this paper. To corroborate the design scheme, the carbon footprint analysis of three packaging methods for 200g cooked peanuts was conducted in this paper. The final carbon footprints of vacuum, air, and modified atmosphere packaging methods were 36.18, 54.78, and 218.86 gCO_2eq *respectively. Subsequently, the sensitivity of different packaging methods is analyzed. It is found that vacuum packaging is more sensitive to changes in emission factors. The final carbon footprint value is changed by 16.31% under the direct influence of emission factors, while the final carbon footprint values in air and modified atmosphere packaging are 4.88% and 0.78% respectively, which are less affected by the change of factors.*

KEYWORDS

Dual Carbon; Based on user experience; Food; Interactive; Packaging Design

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1. INTRODUCTION

In 2021, the Chinese government officially included the goals of "carbon peaking" and "carbon neutrality" in the government's work report. To achieve this goal, a timeline was set for carbon emissions to reach a peak by 2030 and carbon neutrality by 2060. In response to the government's call, various industries have developed policies and strategies for energy conservation and emission reduction to achieve the "carbon neutrality" goal. In response to the government's call, the application of green packaging to food and beverage has become a major trend. Packaging has always been an important part of food products and plays an important role in ensuring the quality of food. Survey results show that in the worldwide packaging services industry, the food packaging segment accounts for 60% of the entire market and the industrial scale is a trend of expansion in recent years. In the huge industry chain, the global food system emissions of greenhouse gases accounted for about 26% of the total global emissions. Under the dual impetus of the growing food packaging industry and the implementation of carbon reduction policies, it is a huge problem to design low-carbon packaging that meets the requirements.

Scholars from different countries have different studies on how to design food packaging. Ilicic J studied a product shaking effect [1]. Consumers can moderate the anxiety effect induced by the package design by shaking the product. Anxiety-inducing product package designs with shaking product interactions were introduced and can be used as an anti-emotional eating strategy. It can also be used as an effective measure to prevent obesity. Khan A identified inefficient collaboration between design and management as a factor in the increase of packaging waste [2]. The food packaging design process and the impact of team design on packaging design were studied in his research. He categorized and analyzed the end-of-life issues of food packaging design and explored emerging opportunities. In the end, necessary design, as well as research strategies, are also proposed, which in turn promote end-of-life considerations in food packaging. Yokokawa N argued that packaging design should also try to integrate with factors such as consumers' consumption preferences and the influence of the low environment [3]. And he believes that packaging design can also be used to further influence the purchasing preferences of a particular consumer by using a particular combination of packaging or features for a particular product. In his research project, the environmental impact factors and potential consumer preference effects of over 18 design options with different packaging and functional requirements were systematically evaluated. Subsequently, he has examined quantitatively the influence relationships that exist between the options. Ma X argues that packaging waste is a major issue for both business and society [4]. However, the perception of sustainable packaging efforts in practice is less clear. To address this issue, seven interviews were conducted with providers of sustainable materials and the results were analyzed. The study by Nevala H aimed to model a reusable food packaging service using customer-centered design thinking [5]. The study was conducted using a qualitative research approach, using interviews with 11 study participants. After results such as their packaging preferences were collected, they were placed into the

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established model as elements of the value proposition. In this way, possible, new and reusable food packaging services were explored. Yu D et al. studied the application of computer graphic design color language in food packaging design at a time of rapid Internet development [6]. The study reported that the unique importance of color treatment as an integral part of the packaging design process is unquestionable. Color not only reflects people's consumption emotions but also drives consumers' psychological associations. For this reason, it is particularly important to investigate the practicality and significance of the application of computer graphic design color language in food packaging design.

From the above studies, it is easy to find that the research on food packaging design concepts and solutions is very in-depth. However, there is relatively little research on food packaging design based on the concept of carbon reduction. In addition, the integration of carbon reduction elements into interactive packaging design based on user experience is also a less studied point. Interactive packaging design integrates cultural and scientific factors into one and also applies various knowledge systems such as information media, consumer psychology, and economics. It not only meets the aesthetic requirements of contemporary people but also takes into account the dissemination of the concept of carbon reduction. One of its advantages is that it focuses more on the user's experience. How to combine the concept of carbon reduction with interactive food packaging design that focuses on user experience is the focus of this paper.

2. INTERACTIVE FOOD PACKAGING DESIGN AND USER EXPERIENCE

2.1. THE CONCEPT OF INTERACTIVE FOOD PACKAGING DESIGN

Interactive print and packaging design technology is a comprehensive applied design engineering discipline that integrates design business, culture, science, art, materials, and printing, including information media, ergonomics, economics, consumer psychology, usability engineering research, and other aspects [7-9]. The leading idea of interactive packaging design is to take digital packaging products and their supporting product systems as the carrier, a new period of two-way communication and bridge established between people and things system, to gradually enhance the effective interactive information exchange between people and things. The interactive design of food packaging places more emphasis on the interaction between packaging and consumers, with the user as the center, to meet the needs of users.

Truly excellent interactive packaging design will not only give everyone visual enjoyment but will also allow all users to experience the entire interactive process of the packaging and better understand the product characteristics and brand

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information. The process of designing various interactions in food packaging can also be dynamic and can be repeatedly changed, including the interaction designer's design logic and reasoning, accurate prediction, and grasp of the interactive use of the product and product positioning. Focusing on the user's visual experience is the correct guideline for the process of excellent interactive food packaging design. Experience psychology includes basic mental processes such as sensation, perception, feeling, thinking, and cognitive process. The experience design of interactive food packaging design is mainly based on the interaction designer's thinking about many issues such as user information and experience mode, emotional experience building structure, user behavior testing, and the way of their feedback. Food packaging design must not only focus on a variety of external product images such as product graphics, color, material texture, etc. but also first solve the problems of external visual image communication and environmental protection material use and soon.

2.2. USER EXPERIENCE

The American psychologist Maslow proposed a hierarchical model of human needs that divided the basic needs of each person into the following seven levels of needs: physiological needs, security needs, belonging and love needs, respect needs, cognitive needs, aesthetic needs, and self-actualization needs. People's needs are gradually shifting from good use needs to better levels of emotional needs. From self-worth to be recognized, and then to achieve personal social value. People began to have some higher-level design requirements for the product design and service mode of packaging design. In food packaging and design activities, designers should usually focus on the long-term usability of the product itself, and consider whether the product packaging design can fully meet the needs of its target users.

User interaction experience is concerned with the real interaction needs of users and interaction experience, and food packaging design needs to adhere to the main starting point of serving users and the center of the final design. After collecting user feedback and feedback analysis reports, we carefully check all the details in the process of product interaction to give users a comfortable and pleasant interaction experience. Think about the user's feelings when using the product, and finally get the user's consistent love and willingness to accept the interaction of the product.

As shown in Figure 1, three important aspects of user experience design in the overall food and packaging innovation design work include.

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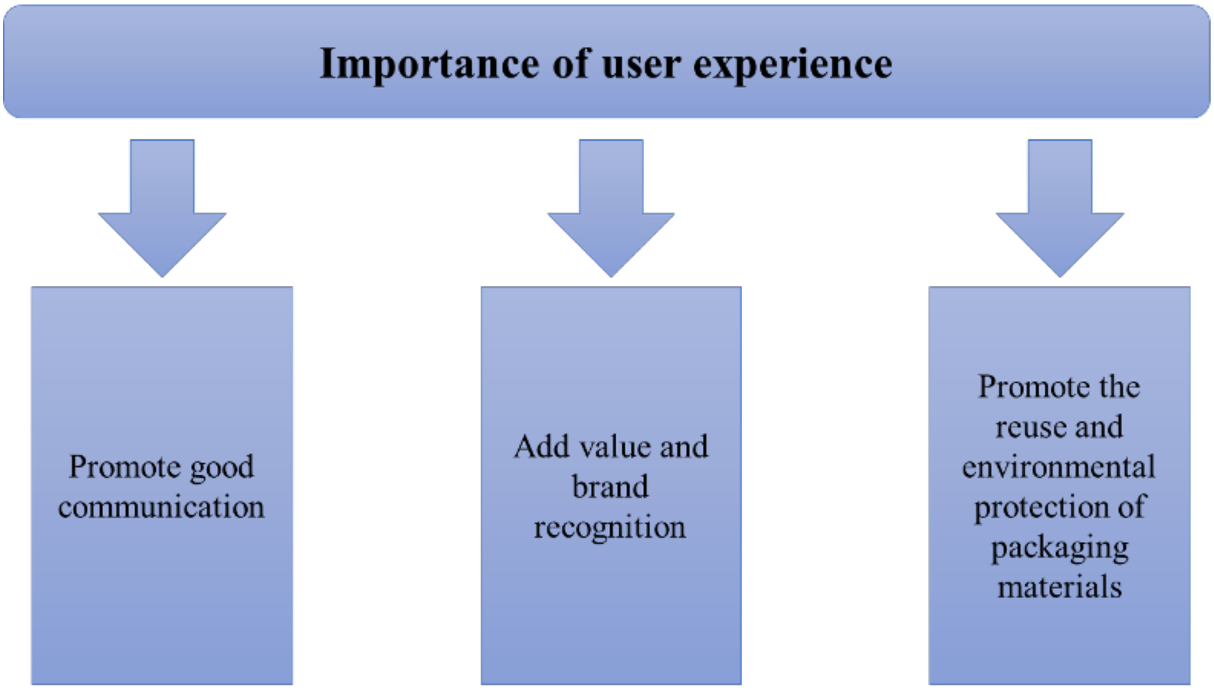

Figure 1. The importance of user experience in food packaging design

1. It often promotes better communication between users and other food manufacturers and product packaging suppliers. User experience-based food packaging design can ensure that all users can accurately receive the relevant information conveyed by the product packaging, making the use of the product clearer, simpler, and more convenient, and achieving two-way communication between the product itself and the target user group.

2. It can likewise further enhance the value and brand awareness of food production operators. Good commodity packaging and design style can ensure a good product image to the majority of user consumers. The interactive contact process between customers and food products will make the user a good and pleasant psychological experience, thus strengthening people's emotional trust, loyalty, and secondary purchase desire for their products, forming the product's word-of-mouth image and brand reputation.

3. It can actively promote the economical use of waste food packaging materials and green environmental protection.

Under the requirement of the ecological background environment of double carbon, designers should further fully consider the final use experience effect of commodity packaging products in the process of designing and manufacturing, and define the reasonable reuse process of packaging resources to increase the user's experience, which can effectively maintain the balance of the whole ecological environment.

The distinctive feature of interactive packaging design is that the interaction between the package and the user is predesigned by the designer. Before completing the package design, the package designer must anticipate the visual image of the

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package, the opening method of packaging, the using method of packaging, and the secondary use the package will bring to the user's experience.

One of the most significant technical features of interactive packaging design technology is that the designer can design in advance to control the interaction between the user and the product packaging. Before the overall package design is completed, visual designers can anticipate the overall visual image of the package, the way the package will be opened, the way the package will be used, and the experience the user will have when the package is used again.

3. COMPARISON OF THE IMPACT OF CARBON FOOTPRINT IN DIFFERENT FOOD INTERACTIVE PACKAGING METHODS

General food packaging methods are vacuum packaging, air packaging, and modified atmosphere packaging. Among them, vacuum packaging is widely used, research shows that modified atmosphere packaging has the advantage of improving the quality of food storage and extending the shelf life [10-12]. Therefore, this paper firstly takes cooked peanut bags as an example, and per 200g of cooked peanuts, three different packaging and transportation methods, such as vacuum packaging, air packaging, and air-regulated packaging, are used to study the impact of carbon footprint brought by different packaging methods.

3.1. DEFINITION AND SCOPE OF OBJECTIVES

This study is based on the Life Cycle Assessment (LCA) methodology, which is consistent with the methodology described in PAS 2050[13-15]. Calculate the carbon footprint of different packaging methods in the packaging process and assess the impact of the packaging method on the product's carbon footprint [16,17]. The experimental objective of this study was to compare the potential carbon footprint in vacuum, air, and modified atmosphere packaging. The packaging unit process analysis method was used to calculate the potential carbon footprint in cooked peanut packaging. The project uses the vacuum cooling method to reduce the center temperature of the cooked peanut package to less than 10℃, and the cooked peanuts obtained after cooling will be packaged in different kinds of packaging methods, such as vacuum, air, and modified atmosphere packaging. The functional unit reflects the consumption behavior pattern of the end-consumer and can be regarded as a meaningful quantity of a specific product function at the same time. One of the primary objectives of this experimental design is to study the calculation of the overall carbon emissions of the product during the actual operation of the packaging storage and transportation unit. In other words, the experimental study does not cover the entire production, transportation, storage, and consumption of the product packaging [18-20]. One of the functional units in this study is a cooked peanut with a packaging mass of 200g. Determined system boundary To facilitate quantitative calculations and

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determine the carbon footprint in the production process of specific research products, the system boundary was determined to clarify the objectives of quantitative evaluation and research, to specify the scope of the experimental research process, and to clarify the carbon input and output sources in the quantitative experiment[21-23]. To further investigate the carbon emissions of cooked peanuts during packaging and processing, the scope of this study included the preparation of cooked peanuts, control equipment, and cooling and packaging processes [24-26].

The study scope process is shown in Figure 2, where the green area is the area delineated by the system boundary.

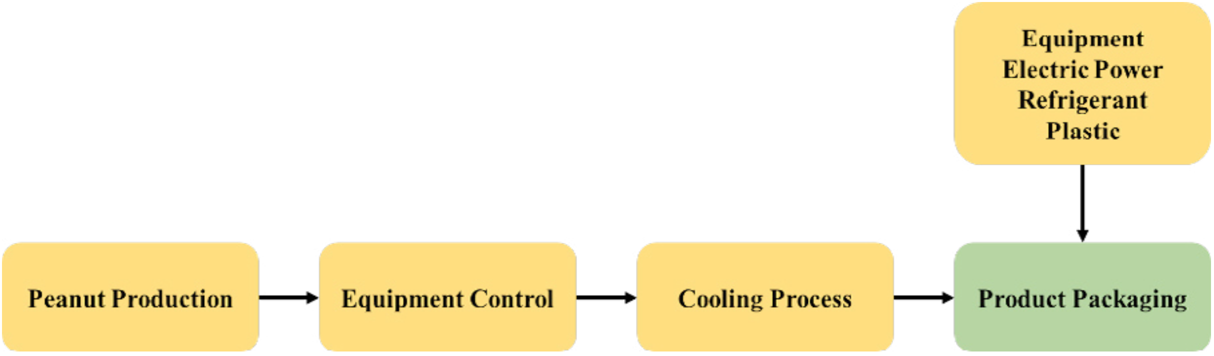

Figure 2. Experimental flow chart

3.2. INVENTORY ANALYSIS

For the inventory analysis step of the entire LCA process, sufficiently detailed input and output data about the product's carbon footprint and processes need to be collected and disaggregated [27,28]. The long phase of inventory analysis is data collection, and the accuracy and validity of the data collected have a significant impact on the accuracy of the carbon emissions calculation, which is the key to the four main steps of the carbon emissions calculation. Data sources for life cycle evaluation can be published data sources, experimental data, or even hypotheses [29-31]. There are two methods of data collection, direct and indirect. Direct collection refers to the collection of primary materials through experiments or interviews with experimenters, while indirect collection refers to the recording of carbon emissions from a process through reading literature, expert interviews, and the use of supporting software.

According to the international standard ISO 14040, the manufacture, maintenance, and disassembly of stationary equipment during the packaging process should be included in the system boundaries. In this test, the inputs used for the vacuum packaging of cooked peanuts, air packaging, and modified atmosphere packaging include equipment, electricity, gases (indirect and direct emissions), and plastic products. The equations for calculating the product carbon footprint of the packaging process are shown in Equation (1) and Equation (2).

$$EF_i = \frac{GHG_i}{t_i} \quad (1)$$

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$$CF = \sum_{i=1}^{n} (Q_i \times EF_i) \quad (2)$$

In the above equation, CF is the final carbon footprint, gCO_2eq; EF_i is the i-th input carbon emission factor, gCO_2eq/min; GHG_i is the life cycle carbon emissions for the i-th input, gCO_2eq; t_i is life cycle of the i-th input, min; Q_i is the processing time of samples, min.

Multiply each input emission factor by each input to obtain the input life-cycle GHG emission data. In estimating equipment lifecycle GHG emissions data, 110 $kg/million$ yuan will be used as the equipment emission factor, i.e., the equipment emission factor multiplied by the selling price of each piece of equipment to arrive at the lifecycle GHG emissions per piece of equipment. The service life of vacuum packaging machines, tabletop gasifiers, air compressors, gas mixers, gas cylinders, and buffer tanks is provided by the equipment manufacturer and distributor. In addition to the equipment, other materials should be used in the packaging process. The electricity emission factor is 1.03 $kgCO_2/kW\dot{h}$, 2.0 $kgCO_2eq$ per kg of plastic. As the emission factor of plastic products, the GaBi database of GaBi5 version, a professional carbon footprint calculation software developed by Hangzhou Green Blue Environmental Technology Co. Calculating the carbon dioxide equivalent emissions to the atmosphere for the production of 1 kg of O_2, N_2 and 1 kg of liquid CO_2 in the U.S. yields gas emission factors of 0.15 $kgCO_2eq/kg$, 0.088 $kgCO_2/kg$ and 0.45 $kgCO_2eq/kg$ for the production of O_2, N_2 and CO_2, respectively.

3.3. DATA ANALYSIS

This study investigated the life-cycle carbon emissions in the packaging process of cooked peanuts. It also investigates the three mainstream packaging methods based on the dietary style preferences of users. A 100-year time horizon global warming potential value was used for the calculation according to the Intergovernmental Panel on Climate Change (IGC). The experimental data were statistically analyzed using SPSS software, and the variance of the mean of each sample was analyzed using Tukey's method. The experimental data should be expressed as mean ± standard deviation; Origin 8.5 software was used for the drawing of pictures.

4. RESULTS AND ANALYSIS

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4.1. CARBON FOOTPRINT ANALYSIS OF DIFFERENT PACKAGING METHODS

For different user preferences, three packaging methods were studied: vacuum packaging (VP), air packaging (AP), and modified atmosphere packaging (MAP). The final carbon footprint of the packaging process of 200 g of ripe peanuts was also investigated. The calculations can be done using equations (1) and (2). The inputs of the packaging process include equipment (vacuum packaging machine, tabletop gas conditioning machine, air compressor, gas mixer, gas cylinder, buffer tank), electricity energy consumption, gases (CO_2, O_2, N_2), plastic products for packaging, etc. Inputs in the packaging process are respectively: equipment (vacuum packaging machine, tabletop gas conditioning machine, air compressor, gas mixer, gas cylinders, and buffer tanks), electricity consumption, gas (CO_2, O_2 , N_2) plastic products for packaging, etc.

Figure 3 shows the final carbon footprint of 200g of cooked peanuts packed in different packaging methods.

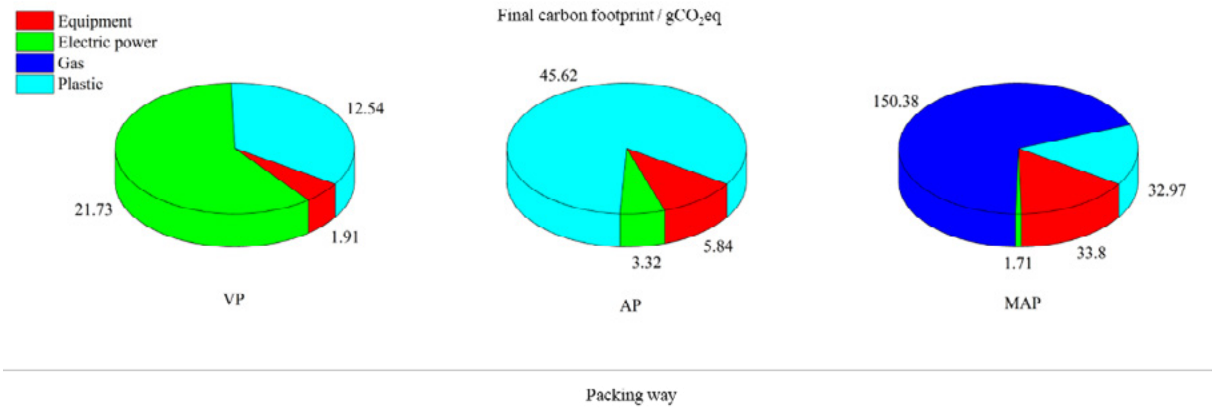

Figure 3. Final carbon footprint of 200g of cooked peanuts packed in different packaging methods

It can be seen from Figure 3 that the final carbon footprint difference under the three packaging methods is relatively large. Overall, the final carbon footprints of vacuum, air, and modified atmosphere packaging are 36.18 , 54.78 and 218.86 respectively. The final carbon footprint of the MAP is the largest, followed by the AP, and the final carbon footprint of VP is the smallest. The size of the carbon footprint is linked to the amount of CO_2 emissions. The final carbon footprint of MAP is 6 times higher than that of VP and 4 times higher than that of AP, reflecting the significant carbon footprint of using MAP as a packaging method. MAP is a method developed to preserve the freshness of cooked food for a long time. The main working principle is to evacuate the air inside the box and fill it with a certain ratio of mixed air to achieve the effect of freshness. This is why in Figure 3(c), gas preparation accounts for 64% of the final carbon footprint. In addition, due to the complexity of the process, the amount of equipment required for MAP is also relatively large, so this part of the carbon footprint accounted for 17%. VP and AP do not require gas preparation for filling, the

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impact on the final carbon footprint is negligible. Since AP is simply compressed air for packaging, the impact on the final carbon footprint is mainly on the consumption of plastic products. As can be seen from Figure 3(b), this component accounts for 81%. Finally, VP requires vacuum preparation, so its equipment power consumption accounts for a large part of the final carbon footprint. It can be seen in Figure 3(a) as 60%. From the above description, we can find that the main influencing factors of the final carbon footprint are different due to the different processes of the three. However, since plastic packaging is used in all of them, the influence of plastic products on the final carbon footprint value accounts for a relatively high percentage in all three ways. In the three methods of VP, AP, and MAP, the percentage of this part is 34%, 81%, and 13% respectively. At a time when the concept of carbon reduction is deeply rooted in people's minds, the MAP which consumes so much carbon, should be replaced by two other methods. However, the use of MAP of goods is mostly fresh food. This packaging method allows consumers to visually observe the real appearance of the goods and find points of attraction, thus creating a desire to buy. This interactive experience between humans and food is something that the other two food packaging methods can hardly provide. Therefore, it is important to apply the interactive experience in the gas packaging method to the other two packaging methods in the subsequent research. This will reduce the carbon footprint without disrupting the user experience.

4.2. SENSITIVITY ANALYSIS OF DIFFERENT PACKAGING METHODS

Sensitivity analysis is an important component of LCA and can change the results of LCA. Therefore, this section analyzes important influencing factors that have not been considered in the previous section to consider whether changes in these factors can significantly change the carbon footprint of the packaging process. Due to the limitation of space, this section will focus on the carbon emission factors of the equipment in the carbon footprint sensitivity analysis.

In the results of this experimental study, the mass emission factor of the experimental equipment was used to simulate again the final carbon footprint of the packaging-making process. Setting the emission factor of the equipment for the second time to $3.54\ kgCO_2eq/kg$, it is expected that $2.0\ kgCO_2eq$ is generated per kilogram of plastic product. The carbon emission factors for each test equipment were multiplied by the weight of each experimental equipment itself to facilitate further data on the full life-cycle GHG mass and emissions generated by each experimental equipment itself. The final carbon footprint and emissions packaging data before and after the change in equipment emission factors can also be calculated directly from Equations 1 and 2, the results are represented in Figure 4.

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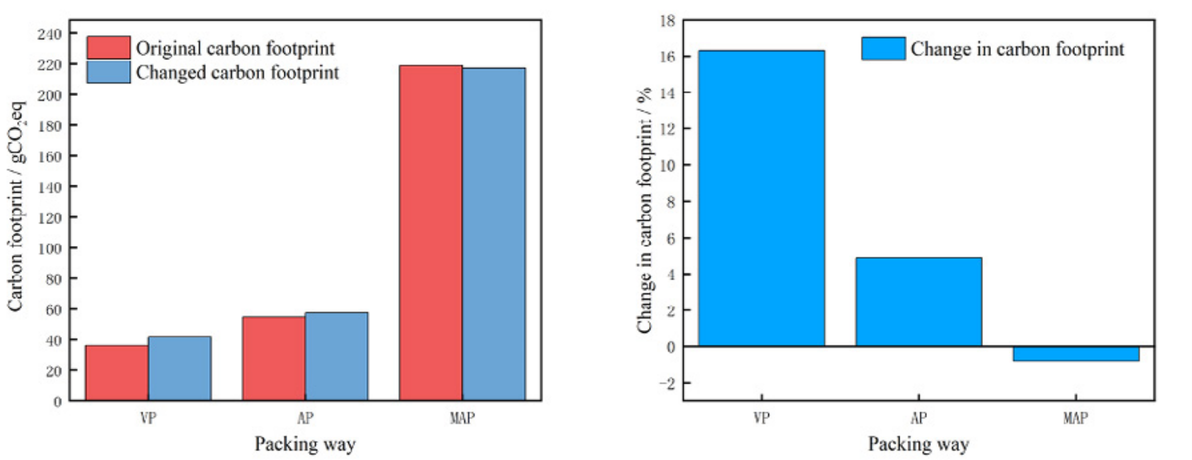

Figure 4. Comparative sensitivity analysis of equipment carbon emission factors

As can be seen in Figure 4(a), the carbon footprints of the three initial VP, AP, and MAP methods of packaging are $36.18\ gCO_2eq$, $54.78\ gCO_2eq$, and $218.86\ gCO_2eq$, respectively. After the emission factor correction calculation, the final carbon footprint was reduced to $217.63\ gCO_2eq$ under the AP transportation method, while the final carbon footprint increases to $42.26\ gCO_2eq$ and $57.45\ gCO_2eq$ for VP and MAP methods, respectively. This is due to the high price of MAP equipment and the small quality of the equipment when the emission factors of the equipment change. The final carbon footprint of the VP and AP will increase, probably due to the larger equipment and excessive plastic usage.

From Figure 4(b), it can be seen that the carbon emissions generated in the VP process changed by 16.31% after the change of emission factors of the equipment. This is partly because the final carbon footprint of the VP production process is extremely sensitive to the influence of the carbon emission factor of the equipment. Therefore, when the influence of this factor changes significantly, the carbon footprint value of the final product tends to change dramatically as well. While the change in the final carbon emissions of AP and MAP equipment is not much different, only 4.88% and 0.78% respectively. This is because the final carbon footprint changes of AP equipment and MAP systems have better stability for the emissions of the equipment. In the subsequent selection of the packaging method, the sensitivity of the emission factor can be a more important factor to consider. Choosing a packaging method with low sensitivity to emission factors for carbon footprint analysis and improvement measures can reduce the fluctuations caused by changes. Such an improvement method can avoid the generation of errors in the investigation of carbon emission factors to a greater extent.

5. DISCUSSION

In the current context of carbon reduction, the burden of carbon reduction for the food industry is huge. As a major part of carbon emission in the food industry, it is a challenging task to make effective methodological improvements and system adjustments. When designing food packaging with the task of carbon reduction, it is

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important to retain the user's interactive experience and retain or even enhance the attractiveness of the product to consumers while achieving carbon reduction. The design of green, interactive packaging based on user experience should be human-centered and take into account the individual aesthetic needs of users as the main starting point for the product design concept. The task of carbon reduction should be taken into account when providing a better product experience to users and should be reflected. While users can enjoy the experience of food packaging, they can also appreciate the urgency of the task of carbon reduction. A good carbon reduction food packaging design should also absorb more factors of the times in order not to be easily eliminated.

6. CONCLUSION

In this paper, the final carbon footprint results of three different packaging methods were obtained by studying the carbon emission impact factors of 200g cooked peanuts. Subsequently, a sensitivity study of different packaging methods was conducted to explore the high sensitivity of the three methods to the emission factors. The specific findings are as follows.

1. Among the three completely different packaging processes, the final carbon footprint of the MAP process was the largest, at $218.86\ gCO_2eq$. This was followed by the AP process, with a size of $54.78\ gCO_2eq$, and the smallest final carbon footprint of VP, with a value of $36.18\ gCO_2eq$.

2. Among the factors influencing the final carbon footprint of the three methods, the main energy consumption of VP is the consumption of electricity, accounting for 60%. The factor affecting the size of the final carbon footprint of AP is the consumption of plastic products, accounting for 81%. In MAP, gas preparation has the largest impact on the final carbon footprint, accounting for 64%. In all three ways, the impact of plastic products on the final carbon footprint value accounted for a large part of the. For the three methods of VP, AP, and MAP, this part of the impact accounted for 34%, 81%, and 13%, respectively.

3. For the sensitivity of the emission factors, VP is the most affected. Its final carbon footprint changed by 16.31% compared to the previous one. AP and MAP are less affected, with 4.88% and 0.78% respectively.

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