Study on Food Life Cycle Carbon Emissions Assessment

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Abstract
Based on the Life Cycle Assessment (LCA) theory, this paper defined the accounting scope of food life cycle carbon emissions, presented an inventory analysis of carbon emissions of every food cycle phase from raw materials production, processing, consumption to waste disposal, and provided an assessment framework and methods of food life cycle carbon emissions.

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1. Introduction
Climate change becomes a global issue and a common concern to the international community\textsuperscript{[1,2]}, as well as the most serious global environmental problem facing mankind. Global scientific research shows that climate change is primarily due to human activities, excessive emissions of carbon dioxide (CO\textsubscript{2}), methane (CH\textsubscript{4}), and nitrous oxide (N\textsubscript{2}O) and other greenhouse gases to the atmosphere. Therefore, the fundamental solution to climate change is to reduce anthropogenic greenhouse gas emissions or increase the absorption of greenhouse gases in the atmosphere. The energy and resource consumption during the production and sales phases of food raw materials and solid waste disposal will result in huge greenhouse gas emissions. How to reduce carbon emissions during food raw material production, processing, packaging, transport and other processes and how to develop low-carbon food are the requirements of food industry of the times. Based on the ideas of sustainable development, this paper adopts the theory and methods of Life Cycle Assessment (LCA) to define the accounting scope of food life cycle carbon emissions, presents an inventory analysis of food life cycle carbon emissions, initially builds an assessment

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framework and methods of food life cycle carbon emissions to provide reference for the development of low-carbon food in China.

2. Food life cycle carbon emissions and low-carbon food

2.1. Food life cycle

Liu Yan, in the study of Beer Life Cycle, points that the life cycle refers to the whole process from coming from nature to coming back to nature. That is to say, the collection and other production processes of making the raw materials to products, the circulation of product storage and transportation, the use of the product, and the retirement or disposal of waste products back to the nature constitute a complete product life cycle. In the research on food life cycle assessment system, Wang Xinjie views the product life cycle as the whole process from product design, manufacturing, use / maintenance to recycling. Ren Hui and others suggest that a complete food life cycle should be the whole process from the initial production of raw materials to packaging, transportation, distribution, consumption and final disposal of waste. This paper argues that the food life cycle is the life cycle of food products, that is, the food product whole life cycle. It refers to the entire process from the beginning of food products to the disposal after eating, including food materials production, food processing, packaging, transportation, sales, use, and waste disposal. The food life cycle analysis refers to the analysis of food products system based on the biological life cycle theory, social biological organism theory and system theory.

2.2. Food life cycle carbon emissions

Food life cycle carbon emissions refer to the total carbon emissions to the outside environment of food whole life cycle, when treating as a system, due to the consumption of energy and resources. Table 1 shows sources of food life cycle carbon emissions, including food raw materials production, food processing, marketing, consumption, waste disposal and other phases. It should be noted that the food raw material production phase does not include its upstream activities (such as fertilizer production, land use change, feed production, veterinary medicine production, pesticide production, etc.), while food additives and packaging involved in food production phase does not include its upstream activities (such as additive synthesis, synthetic plastics, metal smelting, etc.).

Table 1. The sources of food life cycle carbon emissions

<table>
<thead>
<tr>
<th>Raw materials</th>
<th>Production and processing</th>
<th>Storage and transportation</th>
<th>Consumption</th>
<th>Disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon emissions from raw material production, reprocessing, storage and transportation</td>
<td>Carbon emissions from processing equipment and additives, packaging materials manufacturing</td>
<td>Carbon emissions from manufacturing, transport equipment and storage facilities</td>
<td>Carbon emissions from products reprocessing facilities and equipment</td>
<td>Carbon emissions from waste packaging, transport and disposal</td>
</tr>
</tbody>
</table>

2.3. Low-carbon food

Various types of food we consume needs a variety of labor and human resource consumption to produce. Surveys and studies reveal that the production of high-protein and high-fat foods, such as meat, will consume more energy and cause more carbon dioxide emissions than cereal food. So low-carbon food is measured by the energy consumption and the main greenhouse emissions during production. Therefore, the low-carbon food is the food that owns a clear and detailed plan to reduce greenhouse gas emissions at the design phase and causes less or even zero greenhouse gas emissions during food life cycle phases of raw material selection, transportation, production technology, equipment selection, packaging materials selection, product storage, transportation methods, edible methods, and waste disposal methods. The goal is to reduce greenhouse gas emissions as much as possible and to
reduce the impact to climate change during the food whole life cycle. In recent years, low-carbon food has become the development trend of international market. In China, low-carbon food also draws more and more attention.

3. The food life cycle carbon emissions assessment

There are mainly two types of assessment systems for the sustainability of products, the subjective qualitative assessment system and the quantitative assessment system based on LCA theory. The subjective qualitative assessment method is simple and comprehensive. But it is difficult to ensure the objectivity and can only be used for a stage or ex-post assessment after completion of the whole process. Based on the theory of life cycle assessment, the quantitative assessment method, although need to collect large amounts of data and larger work load, excels in objectivity, quantifiability, and pre-control appliance before conducting the project, etc.[6].

3.1. Principles and methods of life cycle assessment

Life cycle assessment originated from the analysis and evaluation of packaging in the United States in about the 1970s[7]. In the development process of LCA theory, there appeared a variety of definitions, including the most authoritative ones from the International Organization for Standardization (ISO) and the International Society of Environmental Toxicology and Chemistry (SETAC).

International Society of Environmental Toxicology and Chemistry defines Life Cycle Assessment as: LCA is an environmental load assessment process identifying and quantifying the material and energy use and resulting environmental emissions of the production and activities, which is conducted by the identification and quantification of the use of energy and material and the resulting environmental waste emissions. Evaluation aims to assess the energy and material use and waste emissions on the environment, to seek opportunities to improve the environmental impact and how to use the opportunity; This assessment runs throughout the whole life cycle of the product, process and activities, including raw materials extraction and processing, product manufacturing, transportation, sales, use, reuse and maintenance, waste recycling and final disposal of waste[8]. SETAC’s LCA technical framework is divided into four parts: Determining the objectives and scope, inventory analysis, impact assessment and improvement of assessment. Among them, the inventory analysis is the most important part.

International Organization for Standardization defines LCA as the aggregate and evaluation method of all the inputs, outputs and potential impact on the environment of a product (or service) system throughout its life cycle[9]. At the same time, LCA becomes part of its ISO14000 environmental management standards. Since the 1990s, LCA studies have been undertaken in China. In 1998, China began a comprehensive introduction of ISO14000 series of standards and translated them into national standards. In the 21st century, LCA has become one of the highlights in new research fields of national sustainable development and environmental protection.

Respective definitions of LCA, given by International Society of Environmental Toxicology and Chemistry and the International Organization for Standardization, and technical framework promote the further development of LCA in an international context. Based on the theory of LCA, this paper studies the framework and methods of food life cycle carbon emissions assessment.

3.2. Scope and objects of food life cycle carbon emissions assessment

System boundaries are a set of guidelines for the process to determine which units are parts of the production system. The unit process is the smallest part of a life cycle, whose data will be analyzed during the life cycle assessment. Food life cycle system boundaries should include food raw materials production, food processing, distribution, consumption, waste disposal and other unit processes. Table 2 shows common materials and activities within the boundaries of food life cycle.

<table>
<thead>
<tr>
<th>Raw materials</th>
<th>Processing</th>
<th>Distribution / retail</th>
<th>Used by consumers</th>
<th>Disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>---All inputs at any stage</td>
<td>---All activities from raw materials collection to</td>
<td>---All steps of transport</td>
<td>---Energy required for use</td>
<td>---All disposal steps</td>
</tr>
</tbody>
</table>
The key principle of the boundary system is to include all substantive carbon emissions (through the valuation and real-time access to the data to determine whether they are substantial source of emissions), that is, the direct or indirect carbon emissions discharged in the production, use or re-use processes of the selected product. Non-substantive carbon emissions refer to any single source which accounts for less than 1% of total carbon emissions. But the non-substantive source of carbon emissions does not account for more than 5% of total carbon emissions.

### 3.3. Functional units of food life cycle carbon emissions assessment

Varying scales of food enterprises, differences in food materials and mechanization degree sand widely various product consumption patterns directly result in the variety of carbon emissions. Usually the appropriate functional unit is driven by how the product is consumed, such as 200g French fries. Yet, a larger functional unit, such as 1 ton of potato chips, may make it easier to collect data and calculate the carbon emissions. According to the current assessment studies of domestic and foreign food [10-12], this paper defines the functional unit of food life cycle carbon emissions as the unit of packaging products carbon emissions.

### 3.4. Inventory analysis of food life cycle carbon emissions

Relevant data should include all greenhouse gas emissions within the boundaries of production systems. Calculating food life cycle carbon emissions needs two types of data, the activity level data and the emission factor. Activity level data refers to all the materials and energy sources involved in the food life cycle (input and output of materials, energy use, transportation, etc.), as shown in Table 3; The emission factor can translate the data into greenhouse gas emissions, that is, the emissions of greenhouse gases per unit of activity level data (such as kilogram of greenhouse gas per kilogram input). The activity level data and emission factor may come from primary or secondary data. Primary data refers to the direct measurement of specific product life cycle by internal departments or others in the supply chain. Secondary data refers to external general measurement, not of any specific product, which is average or common measure of similar processes or materials (such as industry report data). Under normal circumstances, the primary activity data is preferred, because such data can help better understand the actual carbon emissions and identify emission reduction opportunities.

<table>
<thead>
<tr>
<th>Table 3. General activity level data</th>
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<table>
<thead>
<tr>
<th>Input / Output</th>
<th>Energy use</th>
<th>Direct emissions</th>
<th>Distribution / Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>---Types and amount of all inputs and outputs</td>
<td>---All energy types, sources and usage: - Electricity</td>
<td>---Types and quantity of direct greenhouse gas emissions</td>
<td>---Vehicle types, average transport distance</td>
</tr>
<tr>
<td>---For each process step:</td>
<td></td>
<td></td>
<td>---Percentage of full load and co-</td>
</tr>
</tbody>
</table>
3.5. Calculation of the food life cycle carbon emissions

The total carbon emissions of food life cycle should be all materials, energy and waste of all activities throughout the product life cycle multiplied by emission factors. Carbon emissions of an activity = activity level data (mass / kWh / km) * emission factor (per unit of CO₂ equivalent). After calculating greenhouse gas emissions for each activity, you can use the Global Warming Potential (GWP) to convert it into equivalent of carbon dioxide. It should be noted that the calculation of carbon emission requires the balance of mass to ensure that all inputs, outputs and waste are included. The food carbon emissions calculation involves complex steps.

4. Summary

The assessment of food life cycle carbon emissions is a very complex task. Based on the ideas of sustainable development, this paper adopts the LCA theory and methods to analyze the carbon sources including the production of food materials, food processing and sales, use, waste disposal and other phases, clearly states the content of low-carbon food, argues the scope, objects, functional units of food life cycle carbon emissions assessment, and preliminary analyzes the collection of food life cycle carbon emissions data and calculation of carbon emissions. There being a wide range of technology of food raw material selection and re-processing in China, together with the diversity of food consumption stages and the complexity of waste recycling and disposal, makes it difficult to quantify the food life cycle carbon emissions. But with the collection and accumulation of various types of data, the food life cycle carbon emissions assessment will become increasingly standardized and routinized. We believe that food carbon emissions assessment will lead food industry to better overall efficiency and contribute to sustainable development of food industry in China.

References