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レシピカーボンフットプリントから見た持続可能な食生活

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Recipe-specific sustainable diet analysis based on carbon footprint quantification

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食糧消費は人間に基本的なエネルギーや必要な栄養を提供するだけでなく、一連の持続可能な開発目標を達成するために不可欠である。人口の増加と生活水準の向上に伴い、食品生産及び廃棄物管理への需要の増加や、サプライチェーンの複雑化が顕著になっているからである。したがって、人間の健康と環境を保護するために、持続可能な食品システムと持続可能な食習慣の推進が極めて重要である。しかし、食事の選択が環境と健康に与える影響に関しては、評価方法が統一されておらず、消費者に標準化された方法で評価した参考情報を提示できていない。本研究では、生産から流通までの食品サプライチェーンを網羅する環境拡張投入産出を用いた分析と、調理および廃棄プロセスの複合ライフサイクル評価（LCA）を組み合わせた総合的な方法を策定し、特定のレシピのカーボンフットプリントを定量化し、レシピのカーボンフットプリントと栄養価の総合評価を含むデータセットを構築した。このデータセットは栄養価を統合し、食品業界が持続可能な選択をすることを可能にするのみならず、個人が栄養価と環境への影響とのバランスをとるのに役立ち、より多くの情報に基づいた持続可能な食生活を提供できると期待される。

Food consumption, which delivers fundamental energy and essential nutrients to human beings, is crucial for achieving a series of sustainable goals. Rising demands and supply chain complexities necessitate sustainable food systems and dietary habits. Yet, inconsistent information on dietary impacts hampers consumer understanding. This study integrates Environmentally Extended Input-Output analysis, covering the food supply chain from production to the distribution phase, complemented with a hybrid Life Cycle Assessment for cooking and disposal processes, to quantify the carbon footprint of specific recipes. The dataset spans from production to disposal, aiding the food industry and consumers in making informed, sustainable choices by balancing nutritional value with environmental impact.

1. 研究内容

1.1 Research Background and Purpose

With the rapid global population increase, food consumption demand is expected to rise. A Sustainable Food System (SFS) emphasizes balanced food production, distribution, and consumption, enhancing agricultural productivity while minimizing negative impacts on ecosystems. This system promotes eco-friendly, socially just, and economically viable methods. The sustainability of food on the table directly correlates with global poverty reduction, food security, climate change mitigation, and socio-economic growth. The 2019 Intergovernmental Panel on Climate Change (IPCC) report highlighted that transitioning to sustainable diets and reducing food waste can reduce greenhouse gas (GHG) emissions and improve human health. Moreover, achieving food

sustainability is integral to multiple Sustainable Development Goals (SDGs), as **Figure 1** shows.

The global food system has severe environmental impacts, occupying 37% of habitable land, using 70% of available freshwater resources, and contributing 19–29% of global GHG emissions. Additionally, various food products affect individual health. Global dietary imbalances, driven by uneven food supply and rapid population growth, lead to malnutrition issues, ranging from excessive sugar, trans fat, and red and processed meat consumption to deficiencies in essential nutrients like vegetables, fruits, and whole grains. Notably, dietary risks were the leading cause of global disability-adjusted life-years (DALYs) from 1990 to 2013. Therefore, promoting a net-zero and sustainable future requires stimulating demand-side changes and transitioning consumer dietary patterns from both environmental and health perspectives.

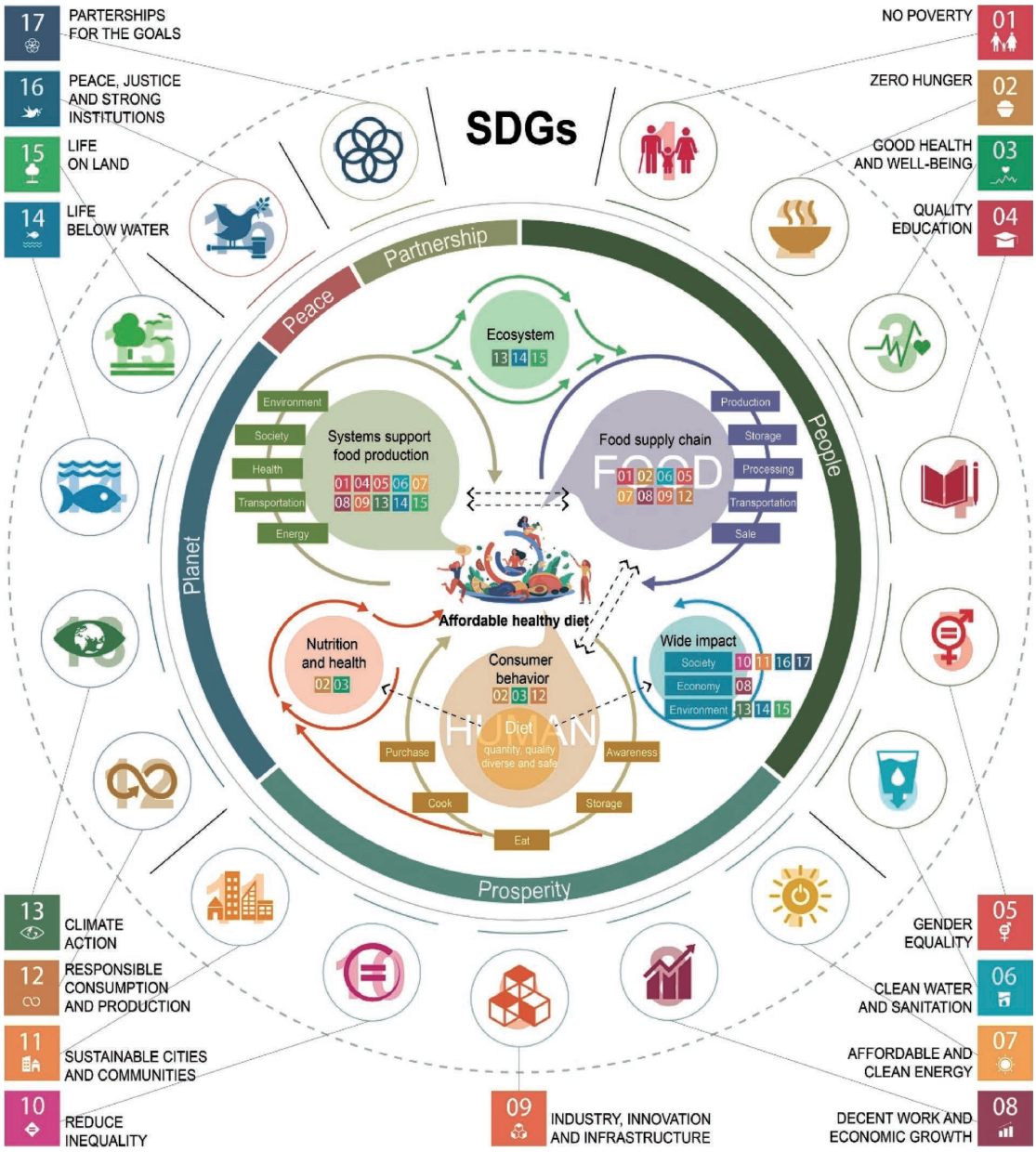

Figure 1 Schematic diagram of “human-food” coupling and the correlations with SDGs

While general principles for healthy and sustainable food consumption are established, accurate data on the environmental and nutritional impacts at the food-product level are lacking, which hinders guiding consumer behavior effectively. In fact, consumers prepare and consume dishes, necessitating dish-level evaluations to provide clear information on their environmental and nutritional impacts. This study aims to inform consumers by evaluating these impacts at the dish level to promote sustainable cooking practices. We developed a dataset covering the environmental footprint (including ingredients and cooking methods) and nutritional values of various recipes using the Environmentally Extended Input-Output (EEIO) method, capturing all supply chain stages. The study includes a broad range of recipes beyond traditional Japanese cuisine, offering insights into sustainable dietary policies globally amid dietary shifts. By providing scientific evidence through dish-level analysis, consumers can understand the impacts of their choices, aiding in sustainable dietary transformations.

1.2 Research Methodology

The dataset includes information on the environmental impact of ingredients and cooking methods, as well as detailed nutritional values. The data collection process involved using the “Recipe Encyclopedia” operated by Ajinomoto Co., Inc., which provides a comprehensive range of recipes with detailed information. We collected 10,337 non-duplicate recipes from the Recipe Encyclopedia. After filtering for popular recipes with over 1,000 saves and including rice recipes, we targeted 388 recipes for our study. Each recipe’s data included unique identifiers, names, publication dates, ingredients, cooking instructions, as **Table 1** depicts.

During data processing, we first standardized the names of the ingredients according to uniform criteria, resulting in 349 unique ingredients. These ingredients were then matched to similar items in the Standard Tables of Food Composition in Japan for detailed nutritional analysis. The quantities of

Table 1: Information Archive for Selected Recipes from the Recipe Encyclopedia

Information obtained from each recipe	Description
Recipe ID	A unique 6-digit number for each recipe for identification purposes
Recipe Name	Name of the recipe (used exactly as expressed on the “Recipe Encyclopedia”)
Published Datetime	Time when the recipe was posted
Modified Datetime	Time when the recipe was last updated/modified
Servings	Number of servings for the recipe
Cook Time	Preparation and cooking time for the recipe (excluding marination and similar steps)
Ingredients	Ingredients used in the recipe and their quantities
Directions	Cooking instructions, preparation steps
Cuisine Style	Type of cuisine (Japanese, Western, Chinese, Ethnic, etc.)
Cuisine Type	Classification of the dish (main dish, side dish, soup, etc.)
Number Saved	Number of times the recipe was saved

ingredients were converted into calculable forms, considering edible parts and waste rates. Finally, dishes were categorized based on the differences in environmental impacts of the ingredients used, such as meat, seafood, grains, vegetables, eggs, and legumes.

The nutritional composition of each recipe was estimated using the weights of ingredients and their nutritional content per unit weight. The calculations accounted for inedible parts and provided detailed nutritional values for each dish. Additionally, we evaluated the carbon footprint of each recipe, covering production and sales, cooking, and disposal stages. For estimating energy consumption during cooking, we considered the thermal efficiency of various cooking methods, calculating energy usage for methods such as microwaving, baking, boiling, steaming, frying, and using rice cookers. **Figure 2** provides the flowchart of the establishment of the dataset, and **Figure 3**

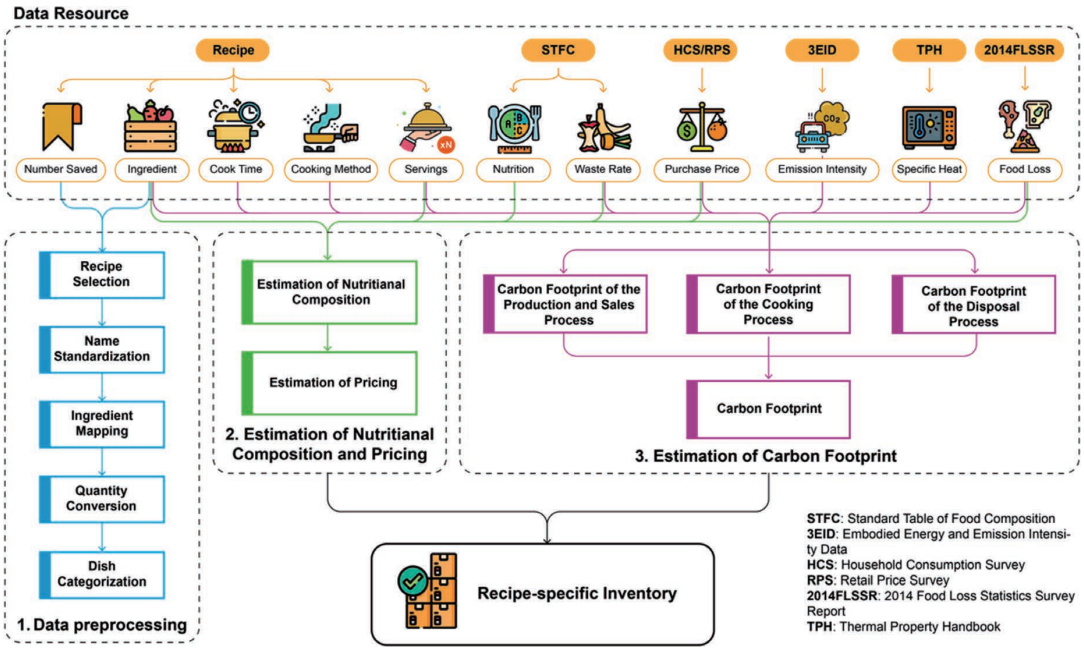

Figure 2 Flowchart of this dataset

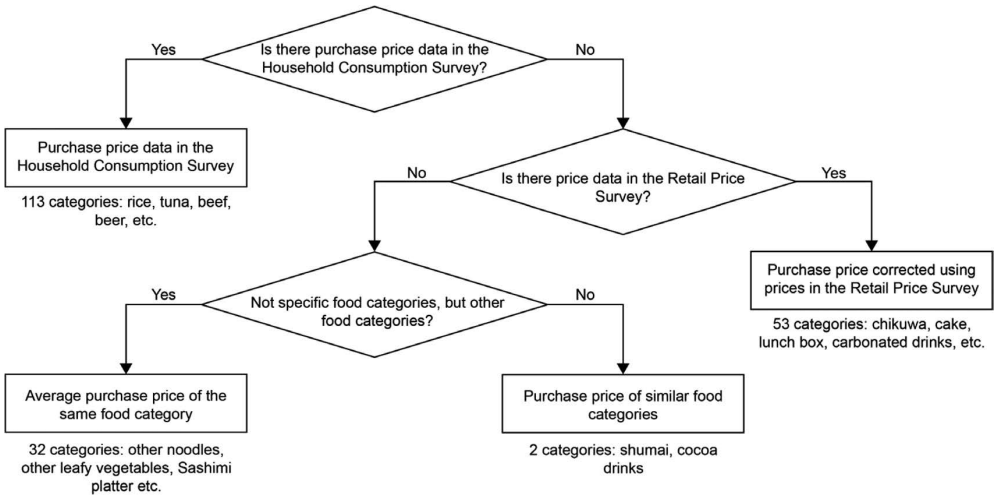

Figure 3 Flowchart of the unit price of food items purchased in this dataset

shows the flowchart for the cooking process of macaroni gratin as an example. The carbon footprint of food waste was also calculated, considering the emissions from the disposal process.

1.3 Research Results

In this study, we analyzed 388 recipes based on the calculation process of carbon footprint and nutrients, considering the detailed information on the ingredients and cooking process of the recipes. To ensure the scientific reliability of the data, we first classified all recipes according to the raw materials and major ingredients, and the specialties of countries/regions.

On the other hand, it was also found that Chinese and Japanese cuisines have relatively high carbon dioxide emissions. Specifically, for every 1 yen increase in recipe price, the average total carbon dioxide emissions for Chinese and Japanese cuisines increase by approximately 4.46 g and 4.41 g, respectively. This trend is especially noticeable in the production stage of raw materials, where carbon dioxide emissions increase by an average of 3.99 g. Japanese, Chinese, and Korean cuisines can emit up to about 100 g of carbon dioxide during the cooking process. Generally, the carbon footprint of the waste disposal stage is usually less than 10 g. In this study, among the 16 types of nutrients, all recipes contain more than 100 mg of vitamin C, calcium, and magnesium; less than 100 g of protein, fats, saturated fats, and total fiber; and less than 10 mg of zinc, iron, and vitamin E. The total GHG emissions for various nutrients in beef are significantly different from other major ingredients. Thirteen types of nutrients show a positive slope, while carbohydrates, total fiber, and vitamin A show a negative slope. This means that the more these nutrients are contained in beef, the lower the total GHG emissions. Compared to the same nutrient content, zinc in fish has the lowest total GHG emissions, while calcium and magnesium in grains have the lowest total GHG emissions. For fats, protein, vitamin E, zinc, and salt equivalent, the same nutrient content produces the highest total GHG emissions in beef, followed by pork and chicken.

To ensure the accuracy of the dataset, we conducted an analysis of the nutritional components of various recipes, comparing and analyzing with reliable data sources such as the United States Department of Agriculture (USDA), the Food and Agriculture Organization/International Network of Food Data Systems (FAO/INFOODS), and the FAO ASEAN Food Composition Database. During the validation process, the nutritional information of each recipe in the database was accurately matched, and comparisons of nutritional values were made between the three datasets.

2. 発表（研究成果の発表）

Long Yin, Huang Liqiao, Fujie Rinakira, He Pan, Chen Zhiheng, Xu Xiaoyan, and Yoshida Yoshikuni. Carbon footprint and embodied nutrition evaluation of 388 recipes. Scientific Data 10, no. 1: 794 (2023).