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A hybrid approach of optimization model and life cycle analysis of dietary patterns for mitigating greenhouse gas emissions

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ABSTRACT

Food production is considered as a major contributor for greenhouse gas (GHG) emissions. Unbalanced diet is regarded as a major driver to health problems. Dietary optimization presents challenges of supporting nutritional need and mitigating GHG emissions in China. In this paper, a hybrid approach of optimization model and life cycle analysis were introduced in order to obtain an environmental and healthy dietary patterns. Based on data sets of food survey and agricultural input-output, 15 types of food were incorporated with linking nutrient content and greenhouse gas emissions in the framework of life cycle analysis. The system boundary included the production of food and related materials (e.g., pesticide, fertilizers, and film). The developed approach was then demonstrated in dietary patterns of Guangdong Province, China. The target of the optimization model was minimizing greenhouse gas emissions. Residents' dietary preference and national dietary guidelines were considered in the optimization model. The desired dietary patterns was thus obtained. The results indicated that dietary patterns of residents in Guangdong Province could be optimized in order to fulfill the goal of GHG mitigation.

Keywords: Optimization model; Uncertainty analysis; Life cycle analysis; Dietary patterns; GHG emissions.

1 Introduction

The dietary pattern in China is shifting to a western style, which is characterized by excessive consumption of sugar, trans fats, red and processed meats, and insufficient consumption of vegetables, fruits, and whole grains[1]. The dietary patterns not only cause a variety of malnutrition problems, but also influence adverse environmental impacts (e.g., greenhouses gas emissions (GHGs), water, land and biodiversity, energy, and nitrogen)[2-3]. Thus, it is essential to promote the desired dietary patterns in consideration of nutrition demands and GHG mitigation of food.

A growing of previous studies focused on the environmental impacts (e.g., greenhouse gas emissions) of diets in developed countries. Many previous studies demonstrated that balanced dietary patterns would have potential for reducing greenhouse gas emissions under the framework of input-output model, and life cycle assessment (LCA)[4-5]. However, the dietary patterns in developing countries such as China are different from that in developed countries. For example, compared to many developed countries, the milk intake of Chinese is much lower, while the consumption of fruits and vegetables is higher [6]. In addition, with the rapid economic development and urbanization, the demand of livestock-based food would increase, aggravating the complications in GHG emissions of life cycle stages of food in the future[7]. As dietary patterns are undergoing tremendous changes, China is challenged by guaranteeing public health and mitigating GHG reductions. Due to the link between nutrition and environmental issues[8-10], dietary adjustment were expected to be a promising option to obtain the desired strategies under the trade-off between GHG mitigation and supporting nutrition[11]. Thus, many studies introduced optimizing models for obtaining eco-friendly dietary patterns [12-13]. However, little studies focused on conflicts between GHG reduction and nutrimental improvement.

Although many previous studies focused on the GHG emissions of food, there is a lack of research on dietary optimization in consideration of the trade-off between GHG mitigation and nutrition support. Therefore, the objective of this study is to use a hybrid approach to obtain desired dietary patterns by incorporating optimization model and life cycle analysis, considering interactions between GHG reductions and nutrition improvement. The approach will then be verified in a typical regions of China, (i.e., Guangdong Province)

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2 Methodology and data

2.1 Life Cycle Analysis

The life cycle stages of food includes food and related martial production (Fig 1). In detail, agricultural materials include chemical fertilizer, pesticide, agricultural machinery, agricultural film, and feed production. Greenhouse gas emissions from food including Related GHGs arise from N_2O emission from fertilizer, CH_4 emission from rice cultivation, and N_2O emission livestock and poultry breeding, which comes from fertilizer application and livestock and poultry manure management.

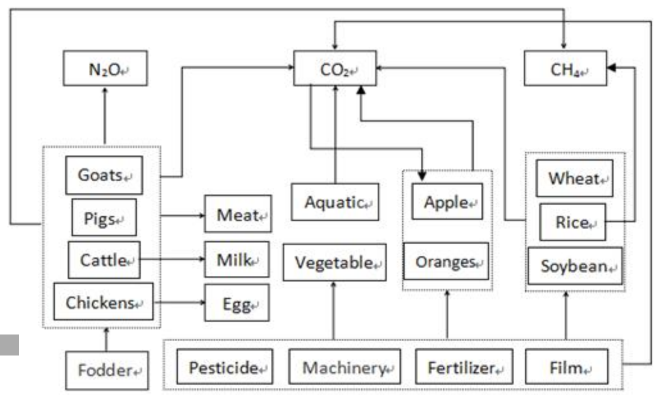

Fig.1. System boundary of food production.

2.1.1Greenhouse gas emissions from agricultural inputs

(1) The greenhouse gas emission of pesticide refers to the emission in the process of crop production[14].

(2) The production of agricultural film depends on the ethylene consumed. Greenhouse gas emissions from per kilogram of agricultural film production are estimated at 22.72kg of greenhouse gas, according to related research from Chinese Life Cycle Database(CLCD).

(3) Agricultural machinery is calculated on the basis of diesel consumption. The average emission coefficient of agricultural machinery are referred to the IPCC (2006b)[15].

(4) Fertilizer is calculated according to the nitrogen fertilizer, phosphate fertilizer and potash. Production of 1 ton P_2O_5 and 1 ton K_2O emits 0.636 tonne and 0.18 tonne CO_2 respectively[16]. According to the comprehensive estimate of energy structure, each tonne of urea and Ammonium bicarbonate(AB) fertilizer emitted 2.3 and 0.65 tonne CO_2[16].

(5) Energy consumption for feed production is calculated according to the input and output table. Mechanical inputs in feed preparation are not considered in this study. fine fodder for poultry farming in China is composed by maize (55%), soybean (25%), and wheat (15%).

2.1.2 Greenhouse gas emissions from agricultural processes

CH_4 emission from gastrointestinal fermentation of livestock and poultry (Equation 1), and CH_4 and N_2O emissions from feces management are calculated using IPCC recommended methods (Equation 2 and 3). CH_4 emission from rice is also accounted referred to the checklist recommended method in IPCC (Equation 4). GHG emissions from milk and eggs are converted to GHG emissions from ruminant feed for cows and chickens, respectively (Equation 2 and 3).

$$EF_C = \frac{GE \times \left(\frac{Y_m}{100}\right) \times 365}{55.65} \qquad (1)$$

where EF_C is methane emission factor in the gut, GE is gross energy intake, and Y_m is methane conversion factor.

$$EF_T = (VS_T \times 365) \times \left[B_T \times 0.67 \times \sum \frac{MCF_T \times MS_T}{100}\right] \qquad (2)$$

where EF_T is annual CH_4 emission factor for livestock category, VS_T is daily volatile solid excreted for livestock category, Bo_T is maximum methane producing capacity for manure produced by livestock category, MCF_T is methane conversion factors for each manure management system, and MS_T is fraction of livestock category.

$$N_2O = \left[\sum_T N_T \times NEX_T \times MS_{(T)} \times EF_{(N)}\right] \times \frac{44}{28} \qquad (3)$$

where N_2O is direct N_2O emissions from Manure Management in the country, N_T is number of head of livestock species/category, Nex_T is annual average $N_{(T)}$ excretion per head of species/category, $MS_{(T)}$ is fraction of total annual nitrogen excretion for each livestock, and $EF_{(N)}$ emission factor for direct N_2O emissions from manure management system.

$$CH_{4(s)} = EF_s \times SF_w \times SF_p \times SF_o \qquad (4)$$

where $CH_{4(S)}$ is adjusted daily emission factor for a particular harvested area, EF_s is baseline emission factor for continuously flooded fields without organic amendments, SF_w is scaling factor to account for the differences in water regime during the cultivation period, SF_p is scaling factor to account for the differences in water regime in the preseason before the cultivation, and *SFo* is scaling factor should vary for both type and amount of organic amendment applied.

2.2. Optimization model

The objective of the optimization model is to minimize the GHG emissions in food consumption, considering the constraints from the nutritional requirements based on public health recommendations (Equation 5).

$$\min \text{GHG} = \sum Q_i \times \sum x_i \tag{5a}$$

s.t.

$$bi \le x_i \le ai \tag{5b}$$

$$Vi \le \sum_{i=1}^{m} x_i \le li \tag{5c}$$

$$\sum_{i=1}^{m} W_i \times x_i \ge \text{Protein}_{\min} \tag{5d}$$

$$\sum_{i=1}^{m} E_i \times x_i \ge \text{Ca}_{\min} \tag{5e}$$

$$FAT_{\min} \le \sum_{i=1}^{m} R_i \times x_i \le FAT_{\max} \tag{5f}$$

$$P_{\min} \le \sum_{i=1}^{m} T_i \times x_i \le P_{\max} \qquad \text{(5e)}$$

$$K_{\min} \le \sum_{i=1}^{m} Y_i \times x_i \le K_{\max} \tag{5g}$$

$$Mg_{\min} \le \sum_{i=1}^{m} U_i \times x_i \le Mg_{\max} \tag{5h}$$

$$Fe_{\min} \le \sum_{i=1}^{m} O_i \times x_i \le Fe_{\max} \tag{5i}$$

$$Zn_{\min} \le \sum_{i=1}^{m} S_i \times x_i \le Zn_{\max} \tag{5j}$$

$$\sum_{i=1}^{m} \text{pr}_i \times x_i \le \text{income} \times 15\% \tag{5k}$$

where, GHG represents greenhouse gas emissions, x represents food, and *i* represents the 8 total food groups (cereal, vegetables, fruits, meats, aquatic products, eggs, milk, and oil), *Q* is the greenhouse gas emission factor of each food, *W, E, R, T, Y, U* and *O* represent the contents of protein, calcium, fat, phosphorus, potassium, magnesium, iron and zinc in food, P_{ri} is the cost per unit of the i^{th} food, and *Protein, Ca, FAT, P, K, Mg, Fe,* and *Zn* represent nutrient elements of protein, calcium, fat, phosphorus, potassium, magnesium, iron, and zinc needed by the human body.

3 results

The results of GHG emission factors in life cycle stages of food were described in Table 1. The optimized dietary patterns of Guangdong Province are shown in Table 2. The results indicated that the amount of GHG emissions in food production were significantly deceased compared to 2017. Cereal and meat would be big contributors in terms of GHG emissions compared with other food. The optimized diet would reduce the intake of meat and grains, and achieved GHG reductions and nutrition improvement.

Table 1 Greenhouse gas emission factors of foods.

Types	Unit	Emission Factor
Cereal		1.185
Vegetable		0.138
Fruit		0.13
Meat		3.134
Aquatic product	g CO_2e g-1	0.67
Milk		0.53
Egg		0.87
Edible oil		0.544

Table 2 Dietary pattern and greenhouse gas emission of foods

Variable	Intake (g/day)	GHG emission (g co_{2e})
Cereal	250.00	296.25
Vegetable	500.00	69.00
Fruit	244.03	31.72
Meat	75.00	235.05
Aquatic product	100.00	67.00
Milk	417.18	221.11
Egg	100.00	87.00
Edible oil	15.00	8.16

4 Conclusions

The potential of dietary patterns for mitigating GHG emissions and improving body health by meeting the required intake of all nutrients was demonstrated in this study. A hybrid approach of optimization model and life cycle analysis was proposed to optimize diet patterns in consideration of reducing GHG emissions and maintaining nutrient intake. This approach improved conventional LCA methods for assessing GHG emissions in food production, and considering residents' dietary preference and national dietary guidelines. This represented an improvement upon conventional life cycle and optimization model. Based on the results of desired dietary patterns, meat and cereal consumption would be decreased in order to mitigate GHG emissions.

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