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The Water, Land, and Carbon Footprints of Different Human Diets in China

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Summary

The demand for agricultural production is increasing significantly due to the growth of economic and population worldwide. The agricultural products have huge impact on water use, land use, and greenhouse gas emissions. This can be quantitatively expressed by three indicators: water footprint (WF), land footprint (LF), and land footprint (CF). While China is the most populated country in the world, the impact of the human food consumed in China is not only within the country but also in other parts of the world where food is imported.

In this research, the water, land, and carbon footprints of consumption (F_{cons}) in China are analyzed for five different diets: the current diet (REF) from the statistics of FAO; a healthy diet (CDG) based on the recommendations by Chinese Nutrition Society; a pesco-vegetarian diet (PES), which includes fish, eggs, and dairy; an ovo-lacto vegetarian diet (OLV), which includes eggs and dairy; and a vegan diet (VEG), which excludes all animal products. While REF has a higher intake of kcal and protein per day than CDG, the other three diets are chosen such that the kcal and protein intake per day equals that of CDG.

Meat has a bigger water, land, and carbon footprint per unit of weight than most other food products (with the meat consumed in China having a weighted average WF of 4778 m^3/tonne, an LF of 13.6 m^2/kg, and a CF of 8.52 kg CO_2eq/kg). Potatoes and other root products are amongst the product categories with smallest footprints.

The alternative diets in China result in substantial reductions of the water footprint (13.7% for CDG, 21% for PES, 24.7% for OLV, and 40.6% for VEG), land footprint (19.7% for CDG, 33.3% for PES, 37.4% for OLV, and 49.0% for VEG), and carbon footprint (10.9% for CDG, 23.3% for PES, 35.3% for OLV, and 68.8% for VEG). These reductions considerably contribute to mitigating the issues of water scarcity, agricultural land stress, and global warming both within China and other parts of the world.

Preface

This report is my master thesis, which is the final part and the conclusion of my study in the program of Water Engineering and Management at University of Twente. After 6 months research, my findings and results are shown in this thesis.

I would like to thank Arjen and Charlotte for their professional feedback and guidance. It is an honor to work with them together. I also want to thank my colleagues, family and friends who always support me during the entire study.

The finish of this thesis also means the finish of my study career in the Netherlands. I have spent truly great time in University of Twente, and everything I have experienced here will be the priceless memory in my lifetime.

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1. Introduction

1.1 Background

The demand for agricultural production and natural resources are continuously growing mainly due to the increasing wealth and growing population worldwide (Foley et al., 2011). It was estimated that the global population will grow from 6.9 billion people in 2011 to 9.3 billion people by 2050 who need to be fed (United Nations, 2012). The issues of malnutrition and overnutrition are always coexisted in the world, and associated with health problems (Vanham et al., 2013b). Meeting global food demands and the nutritious recommendations of humans can be solved through both physical agricultural products improvements and diet structure changes (Vanham et al., 2013a).

Agricultural products will consume water and land in the producing processes, and emit greenhouse gases (GHGs) at the same time (Chakrabarti et al., 2015; Hoekstra, 2013; Union of Concerned Scientists, 2013). The water footprint indicates the quantity of both direct and indirect green, blue and grey water use of a consumer or a product, and it differs from classical indicators that measure water withdrawals of direct blue water consumption (Hoekstra et al., 2011). The main fraction of the water footprint of households comes from food consumption which is indicated as the indirect share of the water use of households (Hurd & Lant, 2013). Water footprints of food products can vary among others depending on the water requirements of the products and the resource use efficiency of the food production systems (Hoekstra & Mekonnen, 2008; Mekonnen & Hoekstra, 2011; Mekonnen & Hoekstra, 2012). Within food categories, animal products often have larger contribution to the water footprint than non-animal products (York, 2011). For instance, the water footprint of a beef burger is around ten times more compared to a soy burger of the same weight (Ercin et al., 2012).

The land footprint of food products indicates the total domestic and foreign area of land both directly and indirectly required to satisfy the demand of domestic food supply (Giljum et al., 2013a). Over 38% of land on earth is used for agriculture (FAO, 2011). Inefficient agricultural land use in global scale brings growing stress of food waste and health issue (Union of Concerned Scientists, 2013). Due to crop consumption for feeding livestock and enormous pasture land use, meat-based product has larger land footprint than crop product (Schweizerische Vereinigung für Vegetarismus, 2011). There are a large number of areas in the world that are inefficient in their agricultural land use in different countries and different seasons, hence the yield of the land is relatively small compared to the inputs natural resources (Union of Concerned Scientists, 2013). For example, to produce beef large amounts of pasture land and quantities of grain and legumes are required to meet only a small fraction of the daily food intake of humans (Union of Concerned Scientists, 2013).

The carbon footprint refers to the amount of GHGs that produced due to related human activities, measured in units of carbon dioxide (Ramachandra & Mahapatra, 2015). The carbon footprint of food indicates the total emissions caused by all processes of the food production, manufacture, and delivering (Murphy-Bokern, 2010). The growth of GHG emissions nearly stabilized in recent years, but GHG emissions are still causing severe threats to global warming (Olivier et al., 2015). The GHG emissions in food industry mainly include three parts. The first component is carbon dioxide, which normally come from fossil fuels used to power farm machinery and transport, store and cook foods. The second component is methane, which derives mainly from enteric fermentation in ruminant livestock. The last part is nitrous oxide emitted from tilled and fertilized soil (Scarborough et al., 2014). Methane and nitrous oxide are the largest carbon footprint contributors from agriculture compared to carbon dioxide which mainly come from agricultural energy use (Audsley et al., 2009). agricultural carbon footprint is responsible for approximately one fifth of total GHG emissions of all human activities (Berners-Lee et al., 2012). Similar to the water and land footprint, animal products are the largest contributors to the carbon footprint compared to crop products (Heller & Keoleian, 2014).

Over 19.3% of people on the planet live in China by 2011 which drives huge influence of food demand and food supply in worldwide (United Nations, 2012). China is facing severe water scarcity issue due to both physical water shortage and growing huge water demand, and its total water deficit will reach approximately 80% of current annual capacity by 2050 (Jiang, 2009; Liu & Savenije, 2008; Tso, 2004). Fast and almost uncontrolled urbanization in China is threating the food security, and how to efficiently use the agricultural land is becoming a more considerable issue in China (Jiang et al., 2013; Liu et al., 2014). China has doubled its GHG emissions in last ten years and surpass United States became the largest emitter in the world (Olivier et al., 2015).

1.2 Literature review

1.2.1 Footprints of diets

According to Hoekstra et al. (2011), the water footprint of a national dietary consumption is following the bottom-up approach which is calculated by summarizing the water footprint of every single product in the certain country that has consumed in the proposed diet. There are numbers of products were imported from other countries, so the water footprints of imported products are supposed to be determined by the export countries according to the detailed trade data provided by FAO (Hoekstra et al., 2011). But in most researches regarding this issue, if country-specific values were unavailable or unpredictable, global averages were used for imported food products (Jalava et al., 2014).

Bolger et al. (2016); Gerbens-Leenes et al. (2002) and Qiang et al. (2013) applied physical accounting approach for land footprint, which is similar to the water footprint accounting approach for dietary consumption. The total land footprint of a certain diet in the certain country is determined by the sum of the land footprints of every consumed commodity in the certain country in the diets.

<u>Food losses</u>

Different study scales result in different footprint of diets due to the food losses along the supply chain (Heller & Keoleian, 2014). Figure 1 shows the scheme of determining the food losses in US by Heller & Keoleian (2014). The food products have three steps of losses: from farm to retail stage, retail to consumer availability stage, and consumer availability to consumed stage.

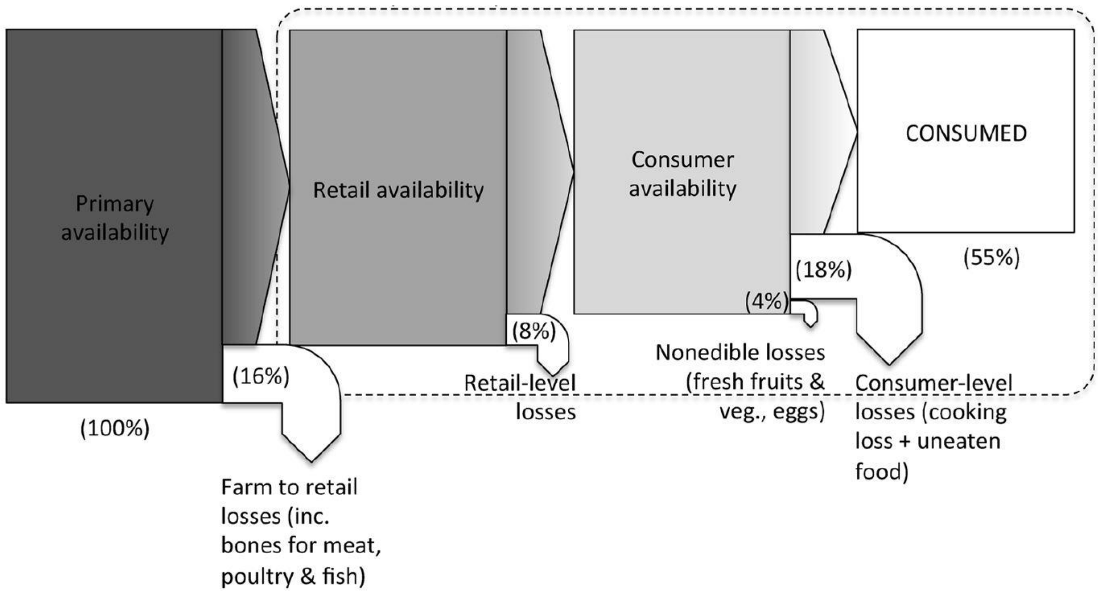

Figure 1

Representation of food flows as considered by the Loss-Adjusted Food Availability data set in the US, copied from Heller & Keoleian (2014).

Vanham et al. (2013b) analysed from consumer level and applied two factors to converse from consumer availability to an actual consumption value. First factor accounts for non-edible food components, and the second factor represents the food waste at consumer-level. To define these factors, detailed information from the European studies of Zessner et al. (2011) and Westhoek (2011) were used.

Table 1

Food losses at retail-level in China, adapted from Liu (2014).

Food type	Percentage of loss	Volume of loss in 2011
Cereals	7%-10%	15-22.5 Mt
Vegetables	15%-20%	100 Mt
Fruits	10%-15%	14 Mt
Potatoes	15%-25%	16 Mt

Liu (2014) and Liu et al., (2013) studied the food losses in different food categories grain crops, vegetables, fruits and potatoes at retail-level in China (Table 1). The food waste rates for different food categories based on a regional survey has been reported by Xu (2005) and illustrated in Table 2.

Table 2
Food waste at consumer-level in China, adapted from Xu (2005).

Product group	Food waste rate	Product group	Food waste rate
Pig meat	11.13%	Vegetables	14.4%
Bovine meat	7.71%	Rice	11.45%
Mutton	7.18%	Cereals	11.29%
Poultry meat	9.0%	Fruits	8.33%
Seafood	10.84%	Others	10.77%
Eggs	9.57%		

1.2.2 Diet classification

Diet types

To compare the footprints among diets, it is crucial to determine the diets that will be studied in the research. There are two main possibilities to define consumption diets (Jalava et al., 2014; Vanham et al., 2013b). The first is compare the current diet with the recommended diet described by a governmental health institute, and the second is compare current diet with the diets that defined by different consumption patterns, for example vegetarian.

Current diet
The current diet is normally defined based on food consumption data of a certain period or a certain year from Food Balance Sheets (FBS) reported by Food and Agriculture Organization (FAO) (Giljum et al., 2013b; Scarborough et al., 2014; Vanham et al., 2013a; Vanham et al., 2013b).

Healthy diet
Due to the widespread overconsumption problem around the world, many countries and regions have dietary guidelines which normally describe the recommended diets of people based on available food of a country, cultural/traditional preferences, local dietary habits, and nutritional requirements. In the Dietary Guidelines of Japan, all food categories are quantitatively recommended in the unit of “serving” which is the simply countable numbers (Nakamura, 2011). In the Chinese Dietary Guidelines, all food categories are quantitatively recommended in weights of intake, and it also considers seasoning such as oil, salt and sugar (CNS, 2016). Specific weights of food products and categories are more accurate for calculating and analysing compare to countable numbers of the food products. Vanham et al. (2013b) analysed healthy diets from guidelines of different regions in Europe. West and East European recommended diets follow the guideline proposed by the German Nutrition Society. Recommended diets in Southern Europe follow studies focussing on Mediterranean countries (Aranceta & Serra-Majem, 2001; Bach-Faig et al., 2011; Willett et al., 1995). North European recommended diets follow the researches focused on Scandinavian countries (Astrup et al., 2005; Enghardt-Barbieri et al., 2005). Liu & Savenije (2008) has analysed healthy diet in China based on the recommendations made by Chinese Nutrition Society in 2003.

Vegetarian diet

The vegetarian diet comprises of little or no animal food intake (Craig, 2010). There are few different sub-types of vegetarian diets. Ovo-lacto vegetarian is the most common used type when analysing vegetarian diet (Scarborough et al., 2014; Vanham et al., 2013b). This vegetarian diet excludes the consumption of meat but does include eggs and dairy products. The Ovo-vegetarian diet is sometimes referred to as the eggetarian diet which consume eggs but no meat and dairy products. While lacto-vegetarian, in contrast to the ovo-vegetarian diet, consume dairy products but no meat and eggs. Lacto-vegetarian diet has studied by Berners-Lee et al. (2012). the vegan diet excludes all animal products, and it was studied in many researches by Berners-Lee et al. (2012), Scarborough et al. (2014) and Vanham et al. (2013b). As for pesce-vegetarian diet, only fish and seafood are included in the animal products. Scarborough et al. (2014) has taken pesce-vegetarian into account to analyse dietary GHG emissions.

Other alternative diets

in addition to common classified food consumption diets, there are other diets that focus on reducing meat consumption to a lower level. 50% meat intake has been used by Giljum et al. (2013b) to compare with current scenario from FAO. It reduces 50% of meat products equally distributed over the different animal products. A more detailed classification based on meat intake has been designed by Scarborough et al. (2014): high meat-eaters (>=100 g/d), medium meat-eaters (50 to 99 g/d), low meat-eaters (>0 and<50 g/d).

Diet modelling

Because the current European meat intake almost doubled from dietary guidelines, there is an important assumption applied by Giljum et al. (2013b) that the reduced meat products will not be replaced by any alternative food products like soy and nuts. To make the results unbiased, some studies make the contained energy are standardized to a fixed intake for each diet (Scarborough et al. (2014) used 2000 kcal/day, and Vanham et al. (2013b) used 2200 kcal/day). All meat is substituted by the pulses, nuts and oil crops in order to reach the same energy and protein intake as recommended diet in Vanham et al. (2013a) and Vanham et al. (2013b). Perignon et al. (2016) used linear programming method to model the diets with different consumption patterns and different stringent levels of nutritional constraints.

Food categories

GHG emissions of every single food products consumptive activities in UK have been studied by Berners-Lee et al. (2012); Clune et al. (2017); Scarborough et al. (2014). Most of the researches analyzing food products by classifying them into few food categories (Jalava et al., 2014; Vanham et al., 2013a; Vanham et al., 2013b). Vanham et al. (2013a) has classified 15 food categories which are shown in Table 3. Stimulants represent coffee, tea and cocoa. Meat includes all flesh except fish. When the consumption pattern has changed in different diet scenarios, the consumption of food product groups will be changed as a whole. There is an assumption has been followed by Vanham et al. (2013a) that alcoholic beverages, stimulants and spices will not change in different dietary scenarios.

Table 3
Product groups categorized by Vanham et al. (2013a)

No.	Product group	No.	Product group	No.	Product group
1	Cereals, rice, potatoes	7	Meat	13	Spices
2	Sugar and sweeteners	8	Animal fats	14	Fish, seafood
3	Crop oils	9	Milk and milk products	15	Miscellaneous
4	Vegetables	10	Eggs		
5	Fruits	11	Stimulants		
6	Pulses, nuts, oil crops	12	Alcoholic beverages		

1.2.3 Footprints of food products

Water footprint of food products

The detailed assessment approach of water footprint was summarized by Hoekstra et al. (2011), and water footprint of every food product in every countries and regions are reported in Mekonnen & Hoekstra (2011) and Mekonnen & Hoekstra (2012). The total water footprint of a certain agricultural product consists of three components: green, blue and grey water footprint. Green water refers to the precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation. The green water footprint is the volume of rainwater consumed during the production process. The blue water footprint is an indicator of consumptive use of fresh surface water or groundwater. The grey water footprint is defined as the volume of freshwater that is required to assimilate the load of pollutants based on natural background concentrations and existing ambient water quality standards (Hoekstra et al., 2011).

Land footprint of food products

Bosire et al. (2016) stated the land footprint of a crop product is the land requirements for growing the crop. The reports from FAO (2011) and Giljum et al. (2013b) are showing the total land requirements of a crop product (ha/tonne) can be calculated as the reciprocal of the yield of the product (tonne/ha) using the data from FAOSTAT (FAO, 2017).

Qiang et al. (2013) calculated land foot print taking consider the conversion factors to avoid land double counting. For most of the food related crops, the conversion factors are based on the caloric equivalents according to nutritive standard factors from FAO (Kastner et al., 2011; Kastner & Nonhebel, 2010)

The land footprint of animal products are based on feed requirements in most related studies. Nijdam et al. (2012) has summarized the result of studies regarding the land requirement of most animal products in the world

Carbon footprint of food products

For calculating carbon footprint of certain agricultural products, all involved activities must be identified. Only carbon footprint up to the farm gate was used by Cheng et al.

(2015). Muthu (2014) used three-tier approach to determine the boundary of carbon footprint accounting for agricultural products, which represents three different accounting levels. To cover the activities up to the shelf of the store, activities related to processing, packaging, and transportation need be included. For the CF of food, the home preparation for food is also counted. Clune et al. (2017) and Agri-footprint (2015) have summarized carbon footprint at retail-level of selected food products in the world from available researches.

1.3 Research objectives and questions

This research aims to increase the understanding of the amount of water and land resources used and GHGs emitted by food consumption of different diets in mainland China (excl. Hong Kong SAR, Macau SAR and Taiwan). To quantify the use of water and land resources and the amount of GHGs emitted the footprint approach will be applied. To this extent this research will contribute knowledge of the influence of human foods on the environment.

To reach the main objective of this study the following research question is defined:

How are the water, land and carbon footprint of food consumption influenced by different diets in China?

To answer the research question, the following research sub-questions are addressed:

1. *What are the main diets in China will be studied in the research and what are their food compositions?*
2. *What are the water, land, and carbon footprints of different food products in China?*
3. *What are the water footprint, land footprint, and the carbon footprint per capita for each specified diet in China?*

2. Method and data

2.1 Methodology

To answer the research sub-questions as defined in section 1.3, information is required on the type and composition of diets in china, the footprints of food products, and the footprints of food categories. These input data will be used to finalize the footprints of different diets in China. In order to answer the sub-questions and get the footprints of diets, the following stepwise research approach has been constructed (Figure 2).

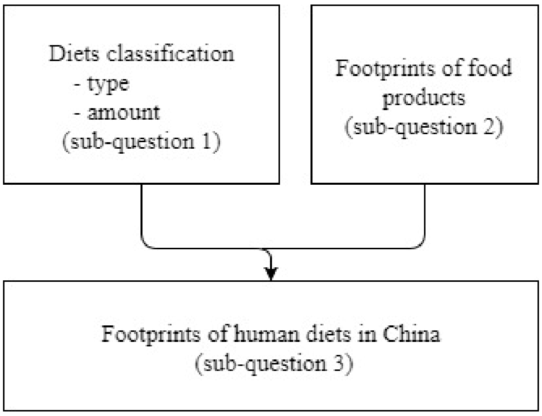

Figure 2

The stepwise approach of the thesis. Each step answers one sub-question proposed in the previous section.

The first step is to determine the food composition of the diets that will be assessed in the research. The second step is to collect the data or calculate the specific water, land, and carbon footprints of each food products and categories. The third step is to calculate the total water, land and carbon footprints of each diets based on their specific food compositions. The Last step in the end is to compare the results of the footprints of different diets. In this chapter, each of the mentioned research steps will be further explained.

The water, land and carbon footprints of different dietary scenarios vary with different quantities of each food categories. The footprints of consumption for diet d in China (for $F_{cons,d}$, for WF: m^3/capita/day; for LF: ha/capita/day; for CF: kg CO_2eq/capita/day) are defined by:

$$F_{cons,d} = \sum_c \left(C_{d,c} \times F_c^*\right) \tag{1}$$

Where $C_{d,c}$ is the consumption of food category c in diet d in China (g/capita/day). F_c^* indicates the average footprints per unit of consumed food category c in China (F_c^*, for WF: m^3/tonne; for LF: ha/kg; for CF: kg CO_2eq/kg), which are defined by:

$$F_c^* = \frac{\sum_i \left(F_{i,c}^* \times DS_{i,c}\right)}{\sum_i DS_{i,c}} \tag{2}$$

Where $F_{i,c}^{*}$ is the average footprints per unit of consumed food product or group i in China classified as food category c and their determination are explained in section 3.2. While $DS_{i,c}$ is the annual domestic supply (the determination of domestic supply can be seen in equation (12)) of food product or group i in China classified as food category c (tonne/year) from FAO (2017).

The data collections of the main input data of $C_{d,c}$ and $F_{i,c}^{*}$ will be explained in the following sections.

2.2 Input data

2.2.1 Diet classification

As illustrated in Figure 2, this research will first address the diets that will be studied. According to Jalava (2014) and York (2011), meat intake amount is crucial in diet classification and analysing diet changes effect. Thus, distinguishing animal food product consumption is the key to classify different diets. Therefore, five diets have been selected based on different animal products intake level. The diets and their specifications are illustrated in Table 4. The method of approaching these diets is briefly shown in Figure 3.

Table 4
Specifications of different diets in this research, the diets will be presented by the unit of g/capita/day.

Diets	Specifications
Current diet (REF)	Chinese food consumption data in 2013 are based on food supply data from the Food Balance Sheets of FAOSTAT (FAO, 2017) and factors to correct for the difference between supply and actual intake.
Healthy diet (CDG)	Adapted from the dietary recommendations from *Chinese Dietary Guidelines (CDG)* published by Chinese Nutrition Society (CNS, 2016).
Pescetarian diet (PES)	Pesco-vegetarian or fish-eater diet. Included are fish, other seafood, dairy, and eggs; other animal products are excluded. *
Vegetarian diet (OLV)	Ovo-lacto vegetarian. Included are dairy and eggs; other animal products are excluded. *
Vegan diet (VEG)	All animal products are excluded. *

** Precise diet composition is estimated through linear programming*

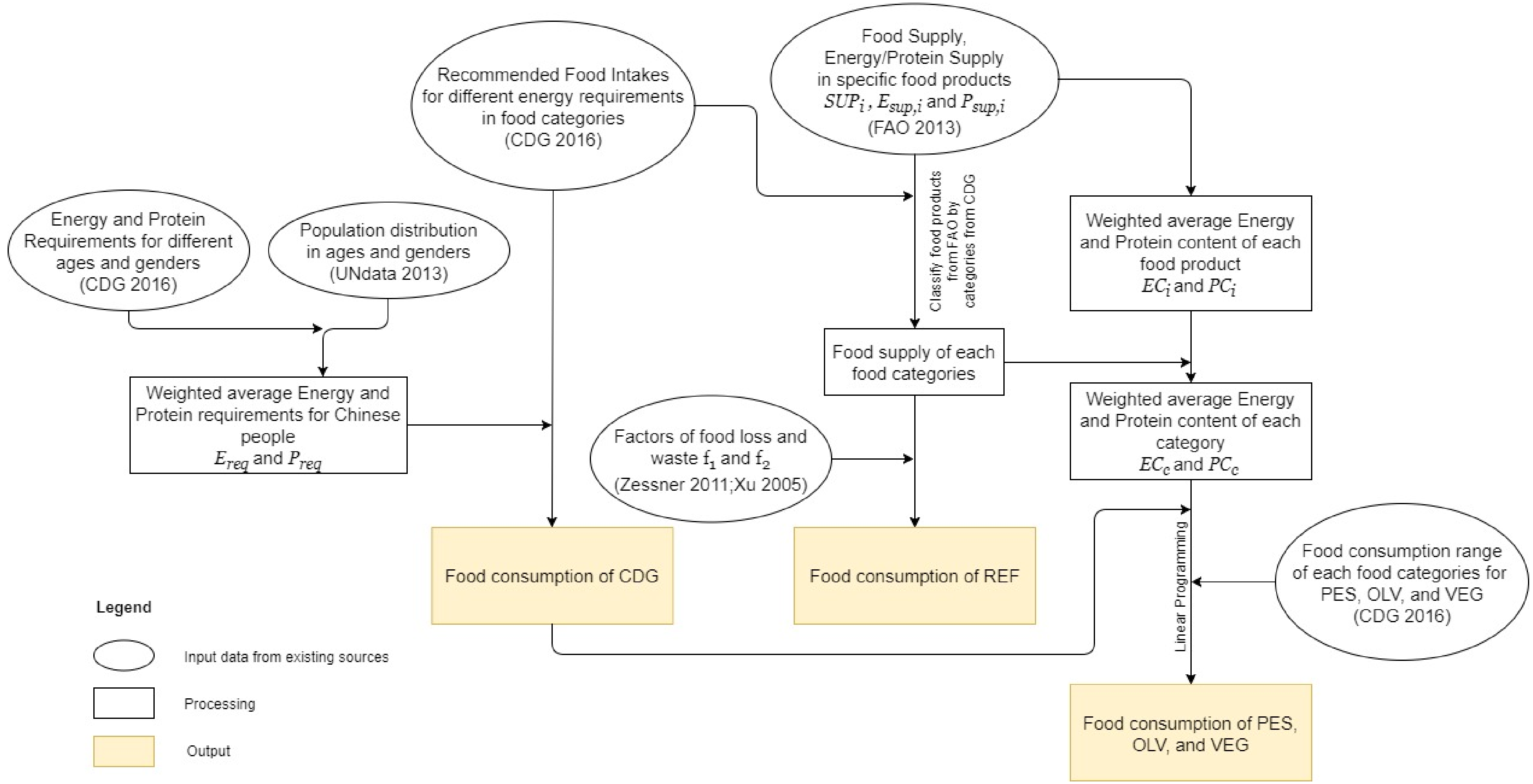

Figure 3

The diagram of approaching dietary scenarios of current diet in China (REF), healthy diet (CDG) recommended by Chinese Dietary Guidelines, pescetarian diet (PES) ovo-lacto vegetarian diet (OLV) and vegan diet (VEG) in this research.

REF

The REF scenario represents the current China's dietary consumption. The food supply data of each food products were obtained from the *Food Balance Sheet* reported by FAO (2017), and classify the 88 reported food products and groups into 12 food categories proposed by CNS (2016). Because cereals and pulses significantly differ in protein content, one of the category "*Cereals and Pulses*" is further split as "*Cereals*" and "*Pulses*". Some reported food products and groups such as beverage and flavoring seasoner are not able to be classified as any of the food category, so they are marked as "*Others*" and remain the same value in all diet scenarios. The actual food consumption of food category c in REF ($C_{REF,c}$) is determined by:

$$C_{REF,c} = SUP_c \times \left(1 - f_{1,c}\right) \times \left(1 - f_{2,c}\right) \tag{3}$$

Where SUP_c is the food supply quantity (g/capita/day) of food category c in China in 2013 from FAO (2017). $f_{1,c}$ and $f_{2,c}$ are two factors of food losses and waste. $f_{1,c}$ indicates the non-edible factor of food category c from Zessner et al. (2011) and USDA (1991), and $f_{2,c}$ is the factor of household food waste of food category c in China from Xu (2005). These correction factors are shown in Table 5.

Table 5

Correction factors in China. ($f_{1,c}$: non-edible factor of food category c. $f_{2,c}$: household food waste of food category c)

Food Category	$f_{1,c}$	$f_{2,c}$
Oil	0	0.11
Sugar	0	0.11
Milk and dairy products	0	0.11
Soybeans	0	0.11
Nuts	0	0.11
Meat	0.32	0.10
Fish and seafood	0.33	0.11
Eggs	0.11	0.10
Vegetables	0	0.14
Fruits	0.27	0.08
Cereals and products	0	0.11
Pulses and products	0	0.11
Potato and other root products	0	0.11
Others	0	0.11

Sources: Zessner et al. (2011), USDA (1991) and Xu (2005)

CDG

CNS (2016) has provided different Chinese dietary recommendations of intake amount of food categories for multiple energy intake requirements from 1000 kcal/capita/day to 3000 kcal/capita/day, and they are shown in Table 11 in Appendix II. In order to select

CDG in this research from these recommendations, the total energy intake and protein intake of the diet CDG E_{CDG} (kcal/capita/day) and P_{CDG} (g/capita/day) are required to approach two restrictions of both China's weighted average energy and protein requirements $E_{req,CN}$ (kcal/capita/day) and $P_{req,CN}$ (g/capita/day) as close as possible, which are determined by:

$$E_{req,CN} = \frac{\sum_{age}\left(E_{req,age,m} \times Pop_{age,m}\right) + \sum_{age}\left(E_{req,age,f} \times Pop_{age,f}\right)}{Pop_{CN}} \tag{4}$$

$$P_{req,CN} = \frac{\sum_{age}\left(P_{req,age,m} \times Pop_{age,m}\right) + \sum_{age}\left(P_{req,age,f} \times Pop_{age,f}\right)}{Pop_{CN}} \tag{5}$$

Where $E_{req,age,m}$ and $E_{req,age,f}$ are energy requirements of male and female for different ages (kcal/capita/day) reported by CNS (2016), and shown in Table 9 in Appendix I. $P_{req,age,m}$ and $P_{req,age,f}$ are protein requirements of male and female for different ages (g/capita/day) also reported by CNS (2016). $Pop_{age,m}$ and $Pop_{age,f}$ are the population of male and female of different ages in China from UNSD (2010), and shown in Table 10 in Appendix I. Pop_{CN} is the total population of China also from UNSD (2010).

While E_{CDG} and P_{CDG} are determined by:

$$E_{CDG} = \sum_{c}\left(EC_c \times C_{CDG,c}\right) \tag{6}$$

$$P_{CDG} = \sum_{c}\left(PC_c \times C_{CDG,c}\right) \tag{7}$$

Where $C_{CDG,c}$ is the total consumption of food category c in diet CDG (g/capita/day). EC_c and PC_c are weighted average energy content of food category c in China (kcal/g) and weighted average protein content of food category c in China (mg/g), which are determined by:

$$EC_c = \frac{\sum_c E_{sup,i,c}}{\sum_c SUP_{i,c}} \tag{8}$$

$$PC_c = \frac{\sum_c P_{sup,i,c}}{\sum_c SUP_{i,c}} \tag{9}$$

Where $SUP_{i,c}$ is the food supply quantity (g/capita/day) of food product or group i classified as food category c in China in 2013 from FAO (2017). $E_{sup,i,c}$ and $P_{sup,i,c}$ are energy supply (kcal/capita/day) and protein supply (mg/capita/day) of food product or group i classified as food category c in China in 2013 from FAO (2017).

PES, OLV and VEG

Linear programming has been used to estimate the precise composition of the PES, OLV and VEG diets. To avoid unrealistic diet modelling, the diets will be chosen by the smallest difference in total food consumption with CDG. It leads to the objective function of linear programming:

$$\text{minimize } |C_d - C_{CDG}| = \left|\sum_c C_{d,c} - \sum_c C_{CDG,c}\right| \quad (10)$$

Where C_d indicates the total consumption amount of dietary scenario d (g/capita/day), and $C_{d,c}$ is the food consumption of food category c in dietary scenario d (g/capita/day).

Two restrictions have been applied in the linear programming process. In order to be able to fairly compare the three diets with CDG, the first restriction applied is that PES, OLV and VEG should have the same total energy and protein intakes as CDG (as were calculated in equation (6) and (7)).

The second restriction is the consumption of each food category in each diet will change with certain constraints. These constraints are defined by the recommended consumption range for Chinese ovo-lacto vegetarian (for PES and OLV) and vegan diets (for VEG) by CNS (2016), and they are shown in Table 12 in Appendix II.

2.2.2 Footprints of food products

For this research, the footprints of food products in China's market are used, which involves imported and exported quantities. However, the trade of food products changes over time and not predictable, therefore the world average footprints are applied for imported products in the research instead of the footprints of producing in other specific countries. Regardless of which category the food product or group classified as, the average footprints of consumed food product or group i in China (F_i^*) are defined by:

$$F_i^* = \frac{F_{i,CN} \times DS_{i,CN} + F_{i,WA} \times DS_{i,imp}}{DS_i} \quad (11)$$

Where $F_{i,CN}$ is the footprints of food product or group i which is produced in China, and $F_{i,WA}$ is world average footprints of the food product or group i. The footprints will be discussed in detail in the following sections. DS_i $(tons/yr)$ is the annual domestic supply of food product or group i in China in 2013 from FAO (2017). But some of the domestic supply data are not direct available from FAO dataset such as apple and banana, and they can be derived by:

$$DS_i = PROD_i + IMP_i - EXP_i \quad (12)$$

Where $PROD_i$, IMP_i and EXP_i represent annual domestic production quantity, imported quantity, and exported quantity in China of food product or group i in 2013 respectively (tonnes/yr). These data can be obtained from FAO (2017).

The domestic supply of food product or group i in China (DS_i) consists of two parts, one is come from imported products $DS_{i,imp}$, another one is come from domestic production in China $DS_{i,CN}$. Due to lack of data, an assumption has been made here in the research:

$$DS_{i,imp} = DS_i \times \frac{IMP_i}{PROD_i + IMP_i} \tag{13}$$

$$DS_{i,CN} = DS_i \times \frac{PROD_i}{PROD_i + IMP_i} \tag{14}$$

WF of food products

The water footprints in this research consist of all three components: green, blue, and grey water footprint. The data of WF of crop commodities in China and world average value were obtained from Mekonnen & Hoekstra (2011), and the data of WF of livestock commodities in China and world average value were used from Mekonnen & Hoekstra (2012).

$$WF_i = WF_{i,green} + WF_{i,blue} + WF_{i,grey} \tag{15}$$

Since the data sources distinguished green, blue and grey water footprints, the total water footprints of the commodity i (WF_i, m^3/kg) is the summation of three different water footprint types of the certain commodity ($WF_{i,green}$, $WF_{i,blue}$, $WF_{i,grey}$, m^3/kg).

LF of food products

LF for crop products

The land footprint of crop product i (LF_i, ha/ton) is derived by:

$$LF_i = \frac{vf_{i,pre}}{Y_i \times pf_i} \tag{16}$$

Where Y_i is the yield of crop product i (tonne/ha) from FAO (2017). pf_i indicates the product fraction of product i which is reported in Mekonnen & Hoekstra (2011) when it is the processed crop product for example soybean oil. $vf_{i,pre}$ is the value fraction of the premium product of product i, and it only be applied when the by-product of product i were used as feed ingredient. It will be explained in the following section and determined in equation (21).

LF for animal products

A feed-based footprint approach has been applied here. The land footprint of livestock product l (LF_l, ha/tonne) such as beef, pork, milk, and eggs are determined by:

$$LF_l = \sum_i \left(LF_{feed,i,l} \times f_{i,l}\right) \times FCE_l \tag{17}$$

Where FCE_l is the feed conversion efficiency of livestock product l from Mekonnen & Hoekstra (2011). $f_{i,l}$ is the share fraction of feed ingredient product i in the feed mix of livestock of product l, and the feed composition of different livestock can be found in Wirsenius (2000).

$LF_{feed,i,l}$ is the land footprint of feed ingredient i which consumed by the livestock product l (ha/tonne). If the ingredient i is the premium product of a crop, the land footprint results of crop products from the previous section are used. If pasture land has involved, for example beef and lamb, the land footprint of grass was derived by world average grass yield (10.5 ha/tonne) from Reckling et al. (2014) by equation (16). If the ingredient i is the by-product of a crop, the land footprint of the by-product i ($LF_{feed,i,by}$, ha/tonne) will be calculated as:

$$LF_{feed,i,by} = \frac{vf_{i,by}}{Y_{i,by}} \tag{18}$$

Where $Y_{i,by}$ indicates the Yield of by-product i (tonne/ha), and it is derived by:

$$Y_{i,by} = Y_{i,pre} \times \frac{1 - HI_{i,pre}}{HI_{i,pre}} \tag{19}$$

Due to the lack of data, an assumption has been made that all feed products are supplied by domestic producers in China. So $HI_{i,pre}$ is the harvest index of the premium product of the by-product i in China. They can be found in Xie et al. (2011a) and Xie et al. (2011b). $Y_{i,pre}$ is the Yield of the premium product of the by-product i in China which is approachable from FAO (2017).

$vf_{i,by}$ in equation (18) is the value fraction of by-product i which is determined by:

$$vf_{i,by} = \frac{P_{i,by} \times Y_{i,by}}{P_{i,pre} \times Y_{i,pre} + P_{i,by} \times Y_{i,by}} \tag{20}$$

Where $P_{i,pre}$ is the price of the premium product of the by-product i in China (CNY/tonne) which is available by FAO (2017). $P_{i,by}$ is the price of the by-product i in China (CNY/tonne). There is no official data available regarding the by-product price, so the average retail price from wholesalers on the website of Alibaba[1] are applied here.

Based on equation (16), for the crops whose by-products have been used for feed ingredients such as wheat, soybean, and sugarcane, the value fraction of the premium product of the product i ($vf_{i,pre}$, ha/tonne) will be determined as:

[1] Alibaba (https://www.1688.com/) is the biggest online wholesale platform in China.

$$vf_{i,pre} = 1 - vf_{i,by} \qquad (21)$$

Where $pf_{i,pre}$ indicates the product fraction of the premium product of the by-product i from FAO (2017).

CF of food products

The greenhouse gas emissions of most agricultural products have been reported by Clune et al. (2017). It has integrated as many results from other studies as possible to approach the more precise world average carbon footprint values.

In addition, to perfect the products especially processed products such as oil and sugar that haven't reported by Clune et al. (2017), another report from Agri-footprint (2015) has been used, which provides the GHG emissions of the products in only a few major countries. The world average carbon footprint of food product i ($CF_{i,WA}, kg\ CO_2eq/kg$) need to be processed by:

$$CF_{i,WA} = \frac{\sum_j (CF_{i,j} \times PROD_{i,j})}{\sum_j PROD_{i,j}} \qquad (22)$$

Where $CF_{i,j}$ is the carbon footprint of product i in country j ($kg\ CO_2eq/kg$). $PROD_{i,j}$ is the annual production quantity of product i in country j (kg/year) from FAO (2017). In order to approach a more accurate estimation, the average annual production data of recent 10 years are applied for $PROD_{i,j}$.

Exceptional cases

Aquatic Animals

Due to the lack of data, the water footprint of aquatic animals both in China and world average follow the results from the feed-based study Yuan et al. (2017), which has distinguished fresh water aquaculture, marine aquaculture and weighted average value in China.

Table 6

Production-weighted blue, green and grey water footprints of freshwater aquaculture, marine aquaculture, and the average to produce 1 tonne of product (m^3/tonne), copied from Yuan et al. (2017).

Type	Blue WF	Green WF	Grey WF	Total WF
Freshwater Aquaculture	750	1960	450	3160
Marine Aquaculture	350	960	190	1500
Average	740	1930	440	3110

The land footprints of aquatic animals are considered only come from feed in the research except freshwater fish. The land footprint of aquatic category a (demersal fish, pelagic fish, other marine fish, crustaceans, cephalopods, other mollusks, and other aquatic animals listed by FAO (2017), $LF_a, ha/ton$) is defined by:

$$LF_a = \frac{\sum_p \left(LF_{p,a} \times PROD_{p,a}\right)}{\sum_p PROD_{p,a}} \tag{23}$$

Where $PROD_{p,a}$ is the annual production quantity of aquatic product p in China classified as aquatic category a (tonne/year) from FAO (2016). $LF_{p,a}$ is the land footprint of aquatic product p classified as aquatic category a (ha/tonne), and the land footprint of aquatic product p of any category ($LF_p, ton/ha$) is defined by:

$$LF_p = \sum_i \left(LF_{feed,i,p} \times f_{i,p}\right) \times FCE_p \tag{24}$$

Where $LF_{feed,i,a}$ is the land footprint of feed ingredient product i in China which consumed by the aquatic product p (ha/tonne). $f_{i,p}$ is the share fraction of the feed ingredient product i in the feed mix of aquatic product p in China, and the data is available from the Chinese official database AgriData (2008). FCE_p is the feed conversion efficiency of aquatic product p from Tacon & Metian (2008).

The land use of fishery pond has taken into account for land footprint of freshwater aquaculture (LF_{FW}, ha/tonne) in this study, so it can be derived by:

$$LF_{FW} = \frac{\sum_f \left(LF_{f,FW} \times PROD_{f,FW}\right)}{\sum_f PROD_{f,FW}} + LF_{pond} \tag{25}$$

Where LF_{pond} is the average land footprint of fishery pond land use (ha/ton).

$$LF_{pond} = \frac{A_{pond}}{PROD_{FW}} \tag{26}$$

Where $A_{pond} = 2429479$ ha is the total area of fishery ponds in China from AgriData (2004). $PROD_{FW}$ is the annual production quantity of all fresh water fish in China from FAO (2016).

<u>Sugar</u>

There is no data available regarding the share fraction of cane sugar and beet sugar in China's market, so an assumption has been made here:

$$\frac{DS_{beet\ sugar}}{DS_{cane\ sugar}} = \frac{DS_{sugar\ beet}}{DS_{sugarcane}} \tag{27}$$

Where $DS_{beet\ sugar}$, $DS_{cane\ sugar}$, $DS_{sugar\ beet}$ and $DS_{sugarcane}$ indicate the annual domestic supply of beet sugar, cane sugar, sugar beet and sugarcane in China respectively. Thus, when approaching the weighted average footprints of sugar in China, weight the beet sugar and cane sugar by the domestic supply of sugarcane and sugar beet in China.

Lamb

Due to the lack of detail feed data of sheep and goat, the land footprint of lamb in China cannot follow the feed-based approach explained in section 3.2.2. It is assumed as the average value of few studies in other regions in the world reported by Nijdam et al. (2012).

All the other products whose footprints haven't covered in the sources above are used the weighted average value of other products in the same food category.

3. Results

3.1 Diets

Table 7 shows the energy and protein intake requirements of Chinese weighted average that calculated by equation (4) and (5). The energy intake of selected healthy diet CDG from CNS (2016) is higher than requirement with 2%, and the protein intake of the CDG is lower than requirement with 2%. Thus, the CDG is considered as approached to the both requirements of energy and protein intakes for Chinese.

Table 7

The comparisons of Chinese energy/protein requirement and energy/protein intake of CDG

	Energy intake (kcal/capita/day)	**Protein intake** (g/capita/day)
Requirement (Chinese weighted)	1914.6	57.03
CDG	1953.8	55.87
Difference	+2.0%	-2.0%

The energy content (EC_c) and protein content (PC_c) of each food category in China that calculated by equation (8) and (9) are shown in Table 8. It also gives the detail consumption quantity of current diet (REF), healthy diet (CDG), pescatarian diet (PES), ovo-lacto vegetarian diet (OLV), and vegan diet (VEG) that have been studied in this research, and the overview intake amounts of each food category are shown in Figure 4.

In diet REF, some food categories are consuming slightly less than recommendations from CDG (sugar, oil, soybeans, and eggs). Some foods lack consumption massively such as dairy products and fruits. There are also many food categories that consumed too much currently (nuts, meat, fish, vegetables, cereals, and potatoes).

Regarding the results of linear programming, the diet PES does not consume meat flesh compare to CDG, but increase the intakes of fish, soybeans, and nuts. OLV reduced intakes of meat and fish as zero, but increase soybeans, nuts, vegetables, fruits, and pulses. And the consumption of oil and potatoes decreased in OLV. For the diet VEG, no consumption of milk, eggs, meat, and fish, but increase significantly in protein-rich products such as soybeans, nuts and pulses. All three modelled diets (PES, OLV, and VEG) have the exact same energy and protein intakes as CDG ($E_{CDG} = 1953.8$ kcal/capita/day , $P_{CDG} = 55.9\ g$/capita/day).

Table 8
The energy content, protein content of each food category in China based on FAO. And the consumption amounts of each dietary scenarios proposed in this research.

Food Categories	Energy Content (EC_c kcal/g)	Protein Content (PC_c mg/g)	Consumption quantity (g/capita/day)				
			REF	**CDG**	**PES**	**OLV**	**VEG**
Oil	8.86	0.00	18	24	24	20	20
Sugar	3.58	0.00	16	24	24	24	24
Milk and dairy products	0.69	33.96	80	293	293	293	0
Soybeans	10.03	328.10	9	15	25	25	50
Nuts	4.17	159.37	16	10	15	15	20
Meat	2.78	120.03	107	49	0	0	0
Fish and seafood	0.53	87.25	58	49	59	0	0
Eggs	1.48	114.60	41	49	49	49	0
Vegetables	0.24	13.77	850	439	497	500	500
Fruits	0.41	4.69	172	293	266	308	350
Cereals and products	3.45	81.91	367	169	169	169	120
Pulses	3.04	221.21	3	1	1	26	71
Potato and other root products	0.82	14.29	168	73	73	50	69
Others			121	121	121	121	121
Total consumption quantity (g/capita/day)			2041	1625	1633	1615	1361
Total energy intake (kcal/capita/day)			2656.1	1953.8	1953.8	1953.8	1953.8
Total protein intake (g/capita/day)			77.6	55.9	55.9	55.9	55.9

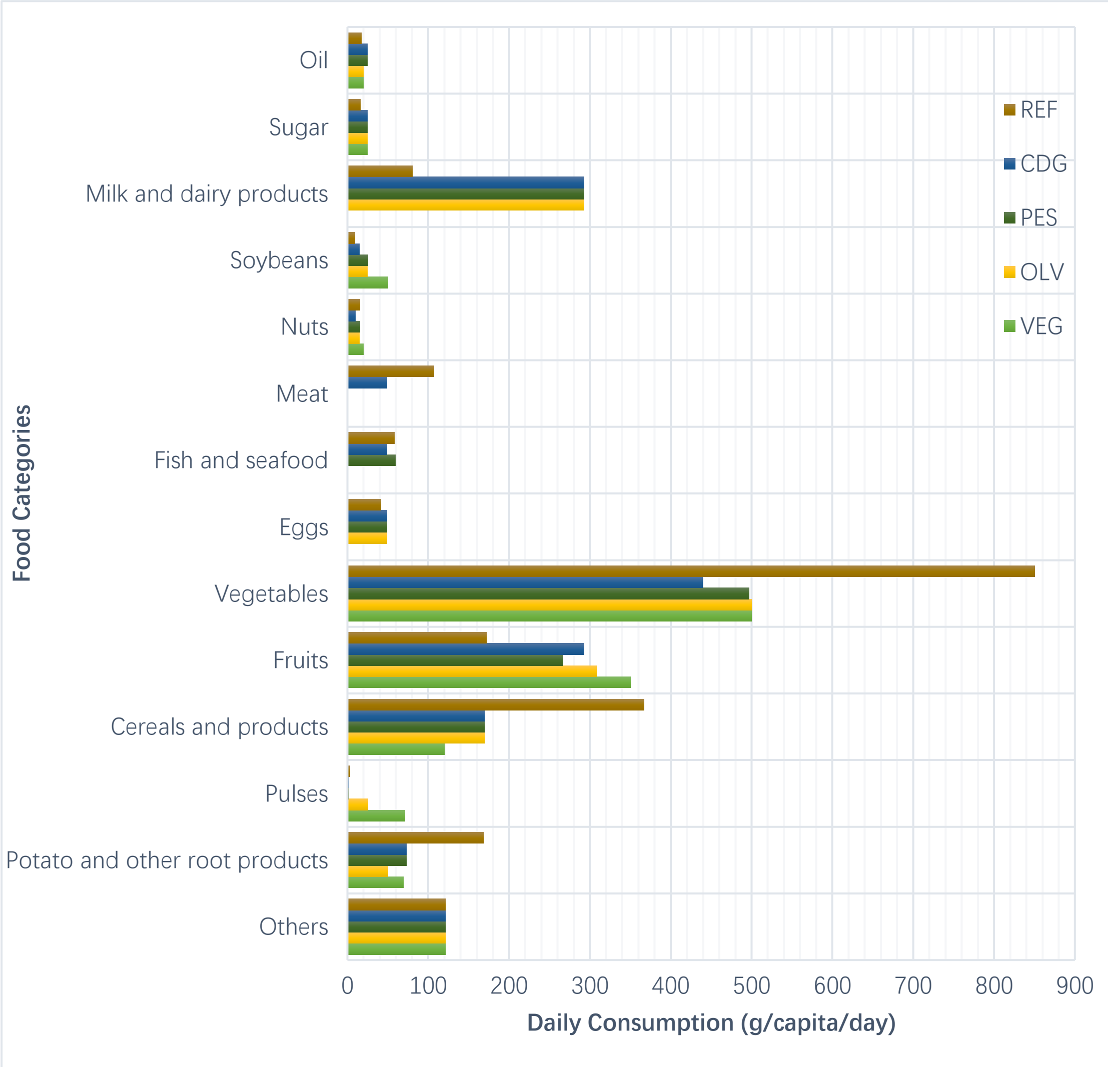

Figure 4

Intakes of food categories for the year of 2013 in China (REF), healthy diet (CDG) recommended by Chinese Dietary Guidelines, pescetarian diet (PES) ovo-lacto vegetarian diet (OLV) and vegan diet (VEG) in this research.

3.2 Footprints of food products

By following the method described in section 2.2.2, the water, land, and carbon footprints of specific food products consumed in China are shown in Table 13 in Appendix III. The land footprint of the major by-products that have involved in the feed of livestock and fish are shown in Table 14 in Appendix III.

3.3 Footprints of food categories

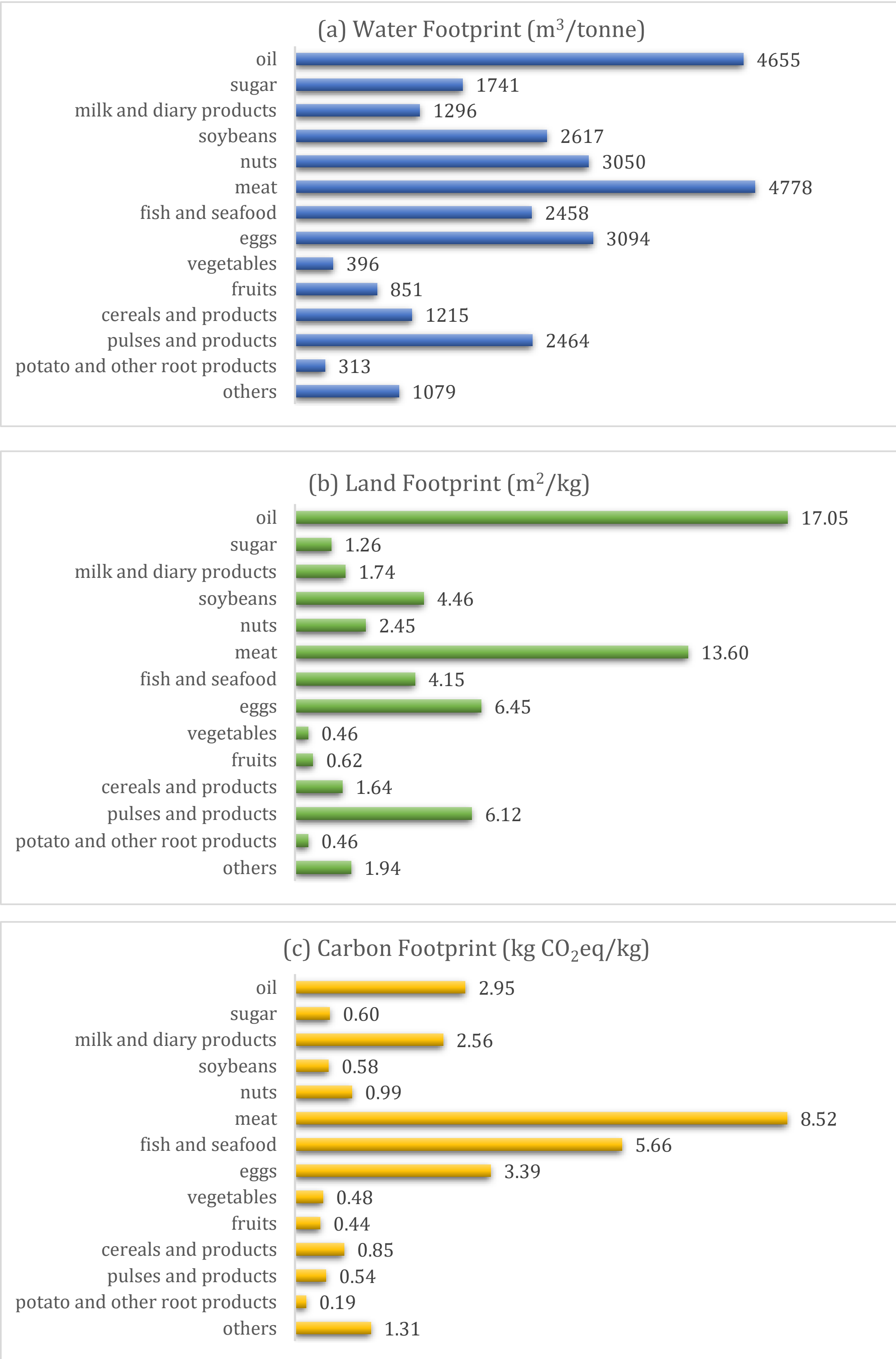

Figure 5

The water footprints (a), land footprints (b), and carbon footprints (c) of different food categories consumed in China.

By integrated the results of footprints of food products in China from section 3.2 using equation (2), the water, land, and carbon footprints of each food category are shown in Figure 5.

Regarding water footprint, meat and oil are two products that require most water (4778 m^3/tonne for meat and 4655 m^3/tonne for oil). They are around 1.5 times of water footprints of eggs and nuts which are around 3000 m^3/tonne. Potato and other root products have the lowest water footprint (313 m^3/tonne), and it is only 6.6% of the water footprint of meat.

Just like water footprint, oil and meat are still two leaders who have the largest land footprint (17.05 m^2/kg for oil and 13.60 m^2/kg for meat). The oil requires almost 35 times of land for producing vegetables and potatoes (0.46 m^2/kg), and around 30 times of fruits (0.62 m^2/kg).

As for greenhouse gas emissions, Potato and other root products have amazingly small carbon footprint with only 0.19 kg CO_2eq/kg, while meat stands out among all the others with 8.52 kg CO_2eq/kg which is over 40 times of the carbon footprints for potatoes. It can be observed that all the animal-cased products have relatively higher carbon footprint than most of the crop products because of more energy involve.

3.4 Footprints of diets

Figure 6 gives the water, land, and carbon footprints of the food products consumed in five proposed diets in China. The diet REF always has the highest footprints (WF: 2.19 m^3/capita/day, LF: 3.96 m^2/capita/day, CF: 2.66 kg CO_2eq/capita/day), which means the current food consumption pattern in China is less environmental friendly to the ecologic system comparing with other recommended diets.

In generally, due to the differentiation of animal product intake, the footprints of diets are formed like stairs. The more animal products consumed leads to the higher footprints. In vegan diet (VEG), since there are no any animal products consumed, it always has the lowest footprints (WF: 1.30 m^3/capita/day, LF: 2.02 m^2/capita/day, CF: 0.83 kg CO_2eq/capita/day).

Compared to REF, the following water savings in China are made: 13.7% for CDG, 21% for PES, 24.7% for OLV, and 40.6% for VEG. As for land savings: 19.7% for CDG, 33.3% for PES, 37.4% for OLV, and 49.0% for VEG. And for GHG emission savings: 10.9% for CDG, 23.3% for PES, 35.3% for OLV, and 68.8% for VEG.

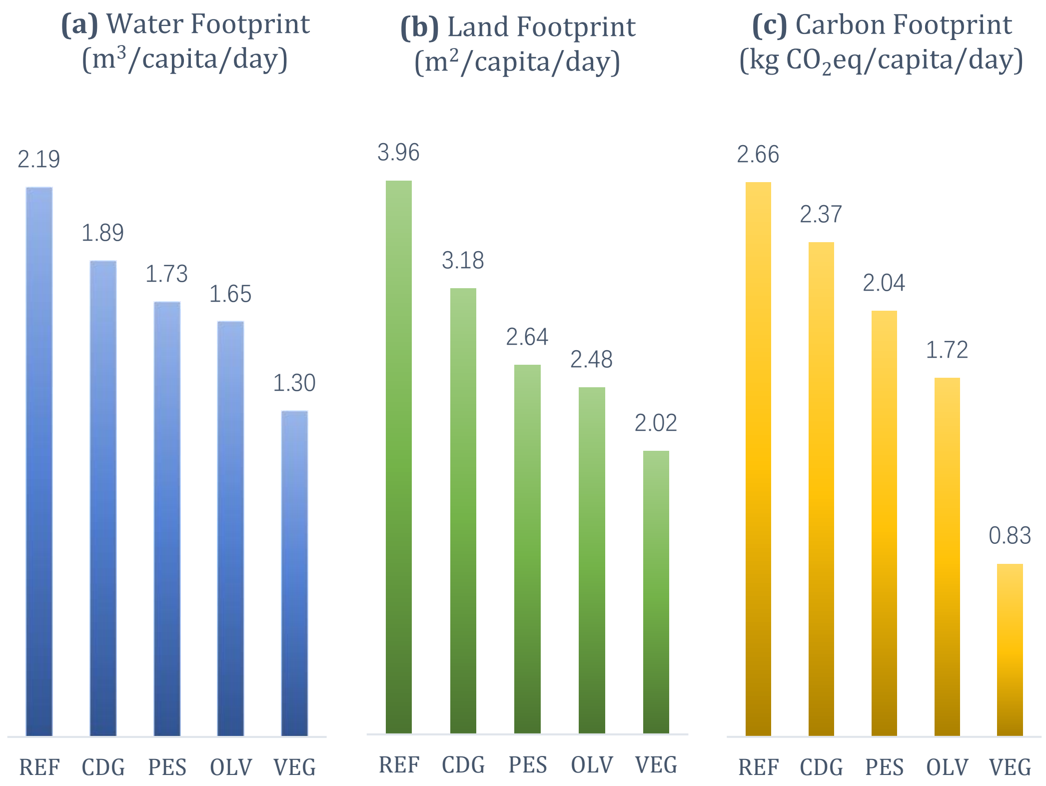

Figure 6

The water footprints (a), land footprints (b), and carbon footprints (c) of the food consumed in different diets in China: the current (2013) diet in China (REF), healthy diet (CDG) recommended by Chinese Dietary Guidelines, pescetarian diet (PES) ovo-lacto vegetarian diet (OLV) and vegan diet (VEG).

4. Discussion

This thesis shows the impact on ecological system by changing human diets in China. This impact is highly depending on regions, the result can be huge different in other regions. The healthy diet could save 13.7% water in China but only 3% in north Europe and even reach 30% in south Europe (Vanham et al., 2013a). The carbon footprint drops almost 70% from current diet to vegan diet in China, but in UK it only decrease less than a third (Berners-Lee et al., 2012).

The correction factors used in Table 5 are critical for REF determination. But due to the variety of consuming patterns, habits, and cultures among the world, the non-edible food factor f_1 and food waste factor f_2 are vary with regions and personalities. There is no precise data available regarding these factors in China, so the European and American data from Zessner et al. (2011) and USDA (1991) were used for f_1, and a regional survey result in China were used for f_2. Thus, the food consumption of REF could be revised when the more precise factors in China are available.

Figure 7 gives the protein and energy content (EC, kcal/kg and PC, mg/g) of each food category in China calculated by the method described in section 2.2.1. Animal food products are generally more efficient in protein rather than energy, so the vegetarians need to consume more protein from other food categories. Soybeans and pulses are both having high protein content, but soybean also provide high energy. If the protein compensated by soybean only, it will result in too much energy intake. It will be the other way around if the protein only come from pulses. A combination of increasing consumption of each food category to approach the same protein and energy intake is obtained by linear programming. In reality, the shortage of protein and energy from decreased animal food intake could be compensated by many combinations of other crop products. In the linear programming process, the objective function was set based on the total amount of consumption quantity, but there is no any standards or recommendations regarding the amount of food should be consumed per day. This assumption is supposed to approach the best option of PES, OLV, and VEG. But there are no official specific recommendations of these diets. Thus, the diets used in this research are only one occasion that meet the protein and energy intakes as CDG.

In this research, the consumption amount of the product that couldn't classified as any of the food category proposed by CNS (2016) are considered remain same amount as REF in all diets, and the weighted average footprints of all the others are applied for these products. These products contain 6% in REF, but it will change in other diets such as less animal fats in OLV and VEG and less alcoholic beverages in CDG. The impact of these products is supposed to be smaller in healthier diets. There is no any recommendations and guidelines available regarding the consumption of these products in China, so the actual footprints of the category "*Others*" will be smaller than the results in this research.

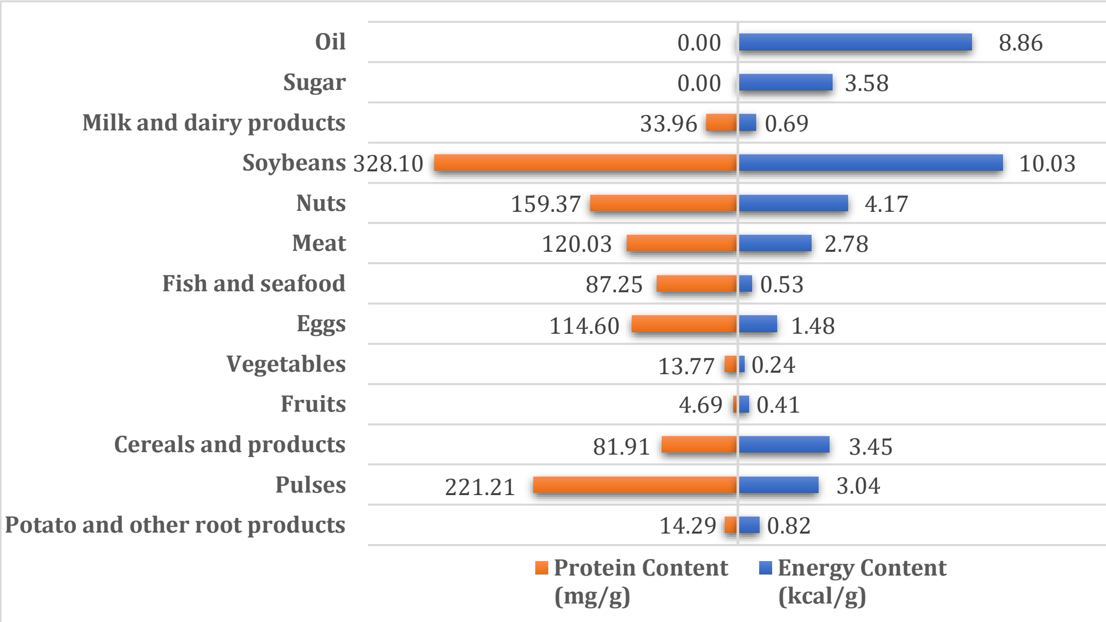

Figure 7

Average protein and energy content of each food category in China based on the food supply in 2013 from FAO (2017)

The data of footprints of the food products in China used in this research were computed with bottom-up approach which relies on the quality of trade data. While the trade circumstances change over time, only the data of year 2013 were used in the research. An assumption was made that the world average value is applied for the footprints of imported products. But the footprints of producing certain products vary with regions, it has huge difference among the world, which means it may leads to a considerable error for the footprints of some products. For example, according to Mekonnen & Hoekstra (2011), the world average water footprint of palm kernel oil is 5401 m^3/tonne which was used for imported products in China in this research. But in China, over 99% of the imported palm kernel oil was from Malaysia and Indonesia (FAO, 2017), and the weighted average water footprint of palm kernel oil in these two countries is 4208 m^3/tonne which is only 78% of the world average value. This difference of water footprint of imported palm kernel oil leads to a 15% decrease of overall water footprint of palm kernel oil consumption in China.

5. Conclusion

This study shows that different diets have a crucial effect on the water, land, and carbon footprints of Chinese consumption. This result could contribute to the potential policy options regarding protecting ecosystem and save natural resources.

The national dietary guideline (CDG) was applied for the healthy diet in China. The current diet in China is having the overconsumption issue of many products (meat, vegetables, potatoes, and cereals), and there are some products need to consume more (dairy, eggs, and fruits). Especially milk and dairy products, there is a big gap exited between the current and the healthy diet. The reduction of all water, land, and carbon footprints can be observed for the healthy, fish-eater, vegetarian and vegan diets compared to the current diet. The vegan diet always has the lowest footprints of consumption, and the reduction in animal food intake has the largest impact on the footprints reduction.

The reduction of footprints of Chinese consumption could contribute positively to sustainable of water, land, and GHG management both within China and the world. They are able to help reducing the dependency of Chinese consumption on domestic and foreign water resources, agricultural land use, and GHG emissions. In this way, it contributes significantly to the mitigation of the growing water scarcity, agricultural land shortage, and global warming issues in both within and outside China.

The results of the thesis are great support for the potential policy decisions in the future. Based on the results, government decision makers are able to realize the significance of the impact to the environment of different diets, then they could raise the eco-friendlier guidelines and recommendations take footprints issue into account. Moreover, because the Chinese diets were changed significantly in recent decades due to the economic growth, the future research could focus on the dietary changing trend in China and its potential of water, land, and carbon footprint changing trend based on the similar methodology has proposed in this research.

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Appendix Ⅰ The energy and protein requirements for Chinese

Table 9

The energy and protein requirements for different ages in China, adapted from CNS (2016)

Age	Energy requirement (kcal/capita/day)		Protein requirement (g/capita/day)	
	Male	Female	Male	Female
0	700	650	15	15
1	900	800	25	25
2	1100	1000	25	25
3	1250	1200	25	25
4	1300	1250	30	30
5	1400	1300	30	30
6	1400	1250	30	30
7	1500	1350	40	40
8	1650	1450	40	40
9	1750	1550	45	45
10	1800	1650	50	50
11-13	2050	1800	60	55
14-17	2500	2000	75	60
18-49	2250	1800	65	55
50-64	2100	1750	65	55
65-79	2050	1700	65	55
80+	1900	1500	65	55

Table 10

Chinese population distribution, adapted from UNSD (2010)

Age	Population		Age	Population	
	Male	Female		Male	Female
0	7461199	6325235	9	7726203	6522622
1	8574973	7082982	10	7830808	6623549
2	8507697	7109678	11-13	23972545	20587760
3	8272491	6978314	14-17	38544831	34939343
4	8246206	6973835	18-49	363967556	352270233
5	7988151	6743986	50-64	111280598	107452329
6	8034452	6770018	65-79	48430783	49507029
7	7292300	6136861	80+	8774752	12214594
8	7423559	6243397			

Appendix Ⅱ Recommended intake by CNS

Table 11

Recommended food intake for healthy diets in China, adapted from CNS (2016)

Food category	**Recommended food intake** (g/capita/day) **with different energy intake level** (kcal/capita/day)										
	1000	**1200**	**1400**	**1600**	**1800**	**2000**	**2200**	**2400**	**2600**	**2800**	**3000**
Cereals and Pulses		Appropriate		50	75	100	125	150	175	200	225
Potatoes and root products		Appropriate		50	58	75	83	100	125	125	125
Vegetables	200	250	300	300	400	450	450	500	500	500	600
Fruits	150	150	150	200	200	300	300	350	350	400	400
Meat	15	25	40	40	50	50	75	75	75	100	100
Eggs	20	25	25	40	40	50	50	50	50	50	50
Fish and seafood	15	20	40	40	50	50	75	75	75	100	125
Milk and dairy products	500	500	350	300	300	300	300	300	300	300	300
Soybeans	5	15	15	15	15	15	25	25	25	25	25
Nuts	-	Appropriate		10	10	10	10	10	10	10	10
Oil	15~20		20~25		25	25	25	30	30	30	35

Table 12
Recommended food intake range for ovo-lacto vegetarian and vegan diets in China, adapted from CNS (2016)

Food category	**Recommended intake range** (g/capita/day)	
	Ovo-lacto vegetarian	**Vegan**
Cereals	100~150	120~200
Potatoes and root products	50~125	50~125
Vegetables	300~500	300~500
Fruits	200~350	200~350
Soybeans and products	25~60	50~80
Nuts	15~25	20~30
Oil	20~30	20~30
Milk	300	
Eggs	40~50	

Appendix Ⅲ The footprints of specific food products in China

Table 13

The water, land, and carbon footprints of specific food products in China

Food Product	WF (m^3/tonne)	LF (m^2/kg)	CF (kg CO_2eq/kg)
Oil			
Soybean oil	5739	31.35	1.63
Sunflowerseed oil	6401	10.94	4.84
Rape and Mustard oil	4049	11.33	2.45
Palmkernel oil	4018	2.43	6.07
Palm oil	3706	2.65	5.18
Coconut oil	2973	4.40	3.98
Maize Germ oil	2443	56.54	1.91
Groundnut oil	4784	9.67	2.95
Cottonseed oil	2298	14.35	2.95
Sesameseed oil	11782	15.86	2.95
Olive oil	9529	23.95	2.95
Other oil	4655	17.05	2.95
Sugar			
Sugar, sugarcane	1757	1.28	0.60
Sugar, sugar beet	1511	1.00	0.60
Soybeans			
Soybeans	2617	4.46	0.58
Nuts			
Groundnuts (Shelled Eq)	2468	2.62	0.87
Cashew nuts, with shell	19041	17.94	1.55
Chestnut	1599	1.78	0.43
Walnuts, with shell	4777	2.83	1.62
Pistachios	5012	4.19	1.53
Almonds shelled	8869	7.51	1.74
Kola nuts	23390	19.28	1.00
Nuts, nes	3849	2.50	1.00
Other nuts	3231	2.40	1.42
Vegetables			
Tomatoes and products	284	0.19	0.46
Onions	362	0.46	0.18
Cabbages and other brassicas	372	0.30	0.32
Artichokes	2260	1.56	0.48

Table 13 *(continued)*

Food Product	WF (m^3/tonne)	LF (m^2/kg)	CF (kg CO_2eq/kg)
Asparagus	2191	1.90	0.92
Lettuce and chicory	293	0.42	0.38
Spinach	294	0.35	0.54
Cauliflowers and broccoli	307	0.49	0.35
Pumpkins, squash and gourds	349	0.54	0.33
Cucumbers and gherkins	387	0.21	0.33
Eggplants (aubergines)	376	0.28	1.35
Chillies and peppers, green	353	0.45	0.60
Garlic	513	0.41	0.57
Beans, green	467	0.38	0.51
Carrots and turnips	290	0.24	0.22
Vegetables, fresh nes	365	0.60	0.47
Onions, shallots, green	277	0.26	0.51
Peas, green	711	1.23	0.51
Other vegetables	401	0.46	0.47
Fruits			
Oranges	1362	0.65	0.35
Tangerines, mandarins, clementines, satsumas	993	1.03	0.45
Apples	1110	0.57	0.36
Lemons and limes	804	0.48	0.30
Grapefruit (inc. pomelos)	1097	0.21	0.51
Fruit, citrus nes	667	0.38	0.35
Bananas	637	0.33	0.79
Pineapples	272	0.50	0.72
Dates	1919	0.82	0.32
Grapes	564	0.62	0.41
Coconuts	1412	1.40	0.57
Watermelons	222	0.25	0.32
Other melons (inc.cantaloupes)	228	0.30	0.88
Pears	1213	0.64	0.33
Apricots	1858	3.28	0.43
Cherries	2033	2.28	0.48
Peaches and nectarines	1123	0.61	0.54
Plums and sloes	3249	2.95	0.57
Strawberries	659	0.37	0.65
Figs	2525	2.10	0.43

Table 13 *(continued)*

Food Product	**WF** (m^3/tonne)	**LF** (m^2/kg)	**CF** (kg CO_2eq/kg)
Avocados	1050	1.51	1.30
Kiwi fruit	513	0.79	0.47
Papayas	336	1.36	0.34
Fruit, tropical fresh nes	2875	2.65	0.46
Fruit, fresh nes	3399	2.63	0.46
Other fruits	1687	1.24	0.47
Cereals and products			
Wheat	1607	1.61	0.51
Rice	1017	1.65	1.31
Barley	982	2.68	0.49
Maize	1161	1.54	0.63
Rye	2136	3.23	0.41
Oats	1003	3.43	0.44
Sorghum	1523	2.91	0.53
Millet	1862	4.10	0.53
Buckwheat	2261	11.14	0.53
Triticale	1360	4.81	0.53
Other cereal products	1215	1.64	0.53
Pulses			
Beans, dry	2876	6.37	0.62
Peas, dry	2494	6.88	0.43
Broad beans, horse beans, dry	2200	4.98	0.66
Chick peas	1192	2.66	0.67
Lentils	4498	5.01	1.03
Other pulses	2464	6.12	0.54
Potato and other root products			
Cassava	465	0.58	0.13
Potatoes	302	0.49	0.20
Sweet potatoes	301	0.39	0.19
Roots and tubers, nes	280	0.75	0.19
Other root products	313	0.46	0.19
Eggs			
Eggs, hen, in shell	3094	6.45	3.39
Meat			
Bovine meat	9729	45.01	28.73
Mutton & goat meat	4199	26.50	27.91
Pig meat	4445	9.48	5.85

Table 13 *(continued)*

Food Product	**WF** (m^3/tonne)	**LF** (m^2/kg)	**CF** (kg CO_2eq/kg)
Poultry meat	3981	10.43	3.94
Other meat and products	4778	13.60	8.52
Milk and dairy products			
Milk, whole fresh cow	1281	1.73	2.52
Butter, cow milk	6668	1.74	11.52
Cheese, whole cow milk	3588	11.50	8.86
Other milks and product	1281	1.74	2.56
Fish and seafood			
Freshwater Fish	3160	5.18	1.80
Demersal Fish	1500	1.88	11.77
Pelagic Fish	1500	0.82	4.41
Marine Fish, Other	1500	1.51	4.41
Crustaceans	3110	4.02	12.39
Cephalopods	1500	4.15	8.07
Mollusks, Other	1500	4.15	8.07
Aquatic Animals, Others	3110	4.15	5.66

Table 14
The land footprint of major by-products for feed of livestock and fish

By-product	**LF** (m^2/kg)
Pasture grass	0.952
Wheat straw	0.309
Wheat bran	0.853
Rice straw	0.180
Rice bran	0.117
Maize stover	0.174
Sorghum stover	0.230
Barley straw	0.334
Soybean stalks	0.549
Groundnut stalks	0.184
Sunflower stalks	0.183
Rape stalks	0.383
Sweet potato tops	0.174
Cassava leaves	0.427
Potato tops	0.148
Sugar cane tops	0.024
Sugar beet tops	0.102