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Change in the carbon footprint of Iranians' food consumption from 1961 to 2019: A decomposition analysis of drivers

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Abstract. The study investigates the role of three drivers: population, energy intake per capita, and dietary change on the carbon footprint of food consumption in Iran from 1961 to 2019. Iran was chosen for this analysis because the country has experienced a noteworthy population increase in the past century, and the imposed international sanctions have changed the economic welfare of the nation. Logarithmic Mean Division Index, along with data of FAOSTAT Food balance sheets and carbon footprint per item, were utilized to decompose the impacts of the drivers. The results demonstrated that the carbon footprint of food consumption in Iran increased by 1.6 during this period. We also found that population increase, and energy intake per capita were the main drivers of the carbon footprint of food consumption in Iran while diet change contributed negatively.

Key words: carbon footprint, food consumption, diet change, Iran.

INTRODUCTION

Production of foods consumed by humans in their daily lives generate considerable amounts of greenhouse gases (GHG) (Bruno et al., 2019; Lenerts, Popluga and Naglis-Liepa, 2019; Kovacs et al., 2021; Zhang et al., 2022). Estimates show that the food system is responsible for up to 30% of global GHG emissions (Aleksandrowicz et al., 2016; Esteve-Llorens et al., 2019; Crippa et al., 2021; Lignicka et al., 2022). The food production emissions are expressed in most studies by an environmental indicator called carbon footprint (CFP). CFP captures the GHG emissions during all stages of production (Cao et al., 2020; Crippa et al., 2021). Hence there is an urgent need to reduce the CFP of food consumption (Zhang et al., 2022).

The national CFP associated with food consumption depends on population numbers, energy intake per capita, change of diet, and CFP per unit of food items (Gerbens-Leenes & Nonhebel, 2005; Kastner et al., 2012; Cao et al., 2020; Lignicka et al., 2022). These factors change over time and show spatial variation. For example, studies show that with economic development, growth rate of population decreases. Besides that, diet undergoes changes such as higher energy intake and consumption of more affluent foods for instance animal-based products, vegetable oils, and fruits. Therefore cereals and starchy roots become less important in food baskets (Garvey et al., 2021; Paris et al., 2022). Determining how these drivers place a burden on the environment is crucial to provide policymakers in designing food supply chains and people's diets to accomplish a sustainable food system(Cao et al., 2020).

Scientific literature is rich in studies that have investigated the environmental impacts of food consumption for a period in the past. For example, Cao et al. (2020) estimated the CFP of Chinese diet during 1961 to 2019 and indicated that it has been growing. Land required for food in the Philippines from 1910 to 2003 was evaluated by Kastner & Nonhebel, (2010). In a similar approach de Ruiter et al. (2017) estimated land footprint associated with the food supply in the United Kingdom during 1986–2011. There are many studies that have estimated environmental impacts of food consumption at global level as well. Crippa et al.(2021) estimated the global GHG emission from food systems for the years 1990–2015. In another study, researchers evaluated the global CFP of diet for the year 2018 and proposed dietary shifts to mitigate the climate change crisis (Kim et al., 2020).

The goal of the research was to analyze the change in carbon footprint (CFP) associated with food consumption in Iran from 1961 to 2019, and to decompose this change into three drivers: population, energy intake per capita, and diet pattern (Kastner & Nonhebel, 2010; Kastner et al., 2012; Cao et al., 2020) using the Logarithmic Mean Division Index (LMDI) method.

Iran was chosen as a case study because the country has undergone significant demographic and economic changes. Firstly, Iran experienced a noteworthy population increase in the past century, especially after the revolution of 1979 and it almost increased by two folds in the first two decades of 20th century (Madani, 2021). Secondly, Iran was targeted by international economic sanctions over the past four decades that changed the economic welfare of the nation (Madani, 2020, 2021). These characteristics could cause shift in food consumption of nation therefore make Iran a magnificent case to investigate the long-term change in the CFP of food consumption.

The research aims to provide insights into the historical transition in dietary CFP and the contribution of driving factors. This information will be valuable for experts in designing less impactful diets and making informed decisions in the future.

MATERIALS AND METHODOLOGY

Economic welfare of Iranians

The economic welfare of the nation has been fluctuating since 1961 (*World Bank Group*): increases in gross domestic product (GDP) per capita were achieved until 2012, however, after 2012 GDP per capita started to decline sharply until 2019 (Fig. 1). It is believed that intensified international sanctions and the increase in population were the main reasons for the decrease in the level of income in Iran that led the country to a sophisticated condition that drove significant changes in the people's living habits (Fu et al., 2020; Madani, 2020, 2021). Diet (energy intake per capita and diet pattern) is one of the habits that get affected by change in economic prosperity of people (Eini-Zinab, Sobhani et al., 2021; Garvey et al., 2021; Paris et al., 2022).

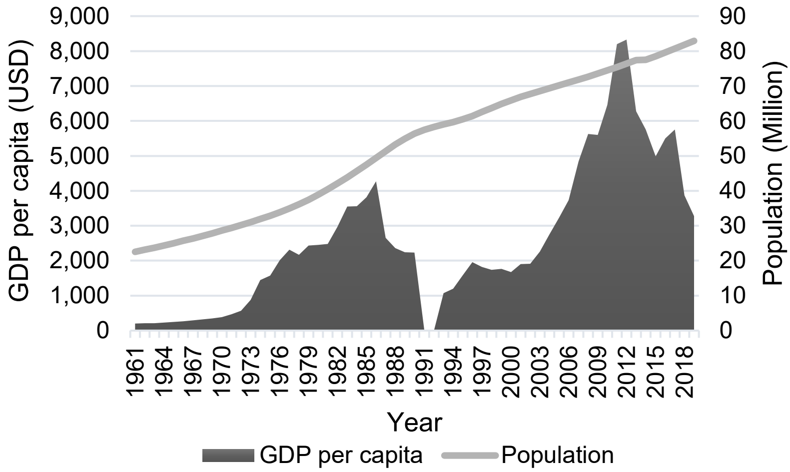

Figure 1. GDP per capita and population of Iran between 1961–2019 (based on the data from World Bank; GDP for years 1991 and 1992 were missing from database).

Food consumption data

Data on Iran's food consumption of period 1961–2019 was supplied by the Food Balance Sheets (FBSs) published by FAOSTAT (Food and Agricultural Organization of the United Nations, 2022). The FBS is claimed as one of the most detailed datasets currently available for retrieving the food supply patterns at the country level (Kastner et al., 2012; Bruno et al., 2019; Cao et al., 2020; Kim et al., 2020). The FBSs provide data on per capita food supply in a nation after accounting for import, export, losses, animal feed, and other non-food uses and the data are widely used to assess the average nutritional situation of a country. The food supply reported in the FBSs was assumed to equal consumption, not accounting for the losses at the household level. Data on the consumption of about 80 terrestrial food items were available on FBSs (Food and Agricultural Organization of the United Nations, 2022) and we categorized them into 9 categories, namely: 1 – Cereals, roots, and tubers; 2 – Pulses seeds, and nuts; 3 – Vegetables and fruits; 4 – Oils and sugar; 5 – Red meat; 6 – White meat; 7 – Eggs; 8 – Dairy products; 9 – Spices and stimulants (The food items under each category are provided in Appendix 1).

Carbon footprint of food consumption and decomposition analysis

LMDI is a method that enables us to decompose CFP of food consumption into its driving determinants to illustrate the contribution of drivers separately (Kastner et al., 2012; Tu *et* al., 2019; Cao et al., 2020). The CFP of food consumption was estimated based on four driving determinants using equation 1:

$$F = \sum(P \times E \times D_i \times I_i) \quad (1)$$

Where F is the total CFP of food consumption at the national level (kg CO_2 equivalent per year, kg CO_2-eq.yr^{-1}), P is population number, E is energy intake per capita (kilocalories per capita per day, kcal.cap^{-1}.day^{-1}), D_i is proportion of food item i to total calorie intake and I_i is CFP of food item i. The list of CFP of food items is provided in Appendix A. The CFPs of food items were derived from the literature (Bruno et al., 2019; Cao et al., 2020) in units of (kg CO_2-eq/kg) and were converted to (kg CO_2-eq/kcal) using mass-to-calories conversion factors. The latter were obtained by dividing energy-based consumption (kcal.cap^{-1}.d^{-1}) to mass based consumption (kg.cap^{-1}.d^{-1}) values, which were provided in the FBSs. As the CFP of food items (I_i) were assumed to be constant over the whole period, three driving determinants (P, E, D_i) showed changes over time. This implied that CFP have no contribution to the change in total CFP of food consumption (Cao et al., 2020). The change in the CFP (F'-F) was decomposed into three driving determinants expressed by equations 2–5 (Kastner et al., 2012; Cao et al., 2020):

$$F' - F = \Delta F = g(\Delta P) + g(\Delta E) + g(\Delta D) \tag{2}$$

$$g(\Delta P) = \sum \frac{F_i' - F_i}{\ln(F_i') - \ln(F_i)} \ln(\frac{P'}{P}) \tag{3}$$

$$g(\Delta E) = \sum \frac{F_i' - F_i}{\ln(F_i') - \ln(F_i)} \ln(\frac{E'}{E}) \tag{4}$$

$$g(\Delta D) = \sum \frac{F_i' - F_i}{\ln(F_i') - \ln(F_i)} \ln(\frac{D'}{D}) \tag{5}$$

RESULTS AND DISCUSSION

The food consumption in Iran from 1961 to 2019

Calorie intake per capita per day of Iranian residents increased from 1,724 kcal.cap^{-1}.day^{-1} in 1961 to 2,904 kcal.cap^{-1}.day^{-1} in 2019 (Fig. 2). It is worth mentioning that per capita calorie intake peaked to 3,063 kcal.cap^{-1}.day^{-1} in 1993 and after that decreased marginally. Dietary pattern also underwent the changes during this period (Fig. 3). In 1961, Iranian residents received about 62% of their calories from starchy foods such as cereals and tubers, while in 2019 the contribution of these food items to daily calorific intake decreased to 55%. There was a decrease in the consumption of red meat (i.e., beef): from 81 kcal.cap^{-1}.day^{-1} in 1961 to 65 kcal.cap^{-1}.day^{-1} in 2019. The contribution of red meat to total calorie intake had a similar trend and decreased from 4.7% to 2.2%. It is widely indicated that the consumption of red meat has a direct correlation with the purchasing power of people (Gerbens-Leenes & Nonhebel, 2005; Cao et al., 2020; Garvey et al., 2021). Hence, the collapse in the economical welfare of nation after 2010 due to the international sanctions could be the reason for less consumption of red meat. Moreover, it is expected that more sanctions would intensify such changes in food consumption generally (Madani, 2020, 2021) given the fact that food has a relatively large share in Iranian household budget (almost 24%) (Sobhani et al., 2021). There had been an appropriate increase in the consumption of white meat (i.e., poultry meat): namely, by 2019 the per capita calorie intake from white meat increased by 16 times and its contribution to total daily intake grown by 10 times. Although the calorie intake from dairy products increased from 116 kcal.cap^{-1}.day^{-1} in 1961 to 125 kcal.cap^{-1}.day^{-1} in 2019, the share of this category in total calorie intake dropped: from 6.7% to 4.3%, respectively. The calorie intake per capita from categories of ‘vegetables & fruits’, ‘oil & sugar’ and ‘pulses, seed & nuts’ experienced a light increase by 2 folds. Overall, the contribution of animal products in the total per capita calorie intake went down from 12.4% in 1961 to 11.6% in 2019 and noticeably cereals, roots and tubers remained as an important source of calories for Iranians and its proportion of daily calories intake still ranked first. Total energy intake by nation (labelled as Tera-calories per day, Tcal day^{-1}; 1 Tcal = 10^{12} cal) is also depicted on Fig. 2 (continuous black line) which incorporates the role of population increase in the consumption of food.

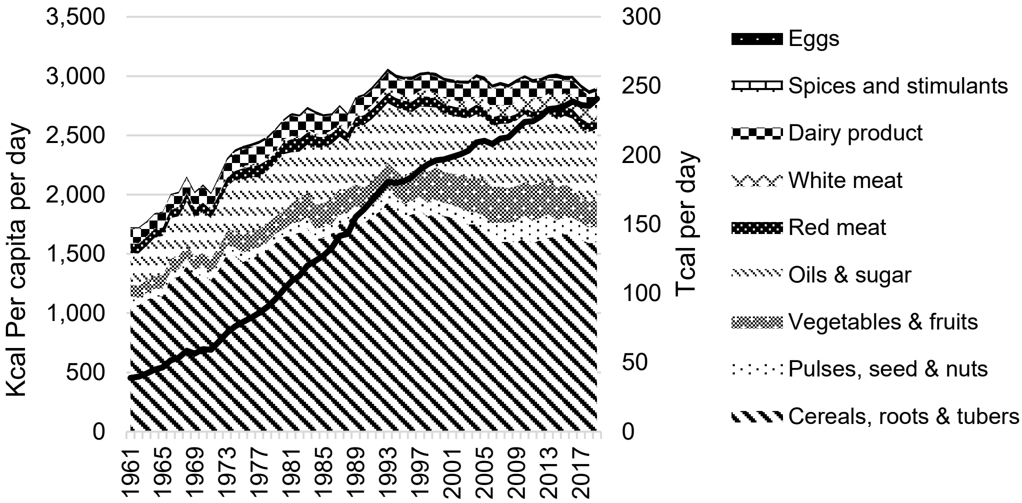

Figure 2. Energy intake per capita per day (stacked area, left axis) and total energy intake per day by nation (continuous black line, right axis) in Iran from 1961 to 2019.

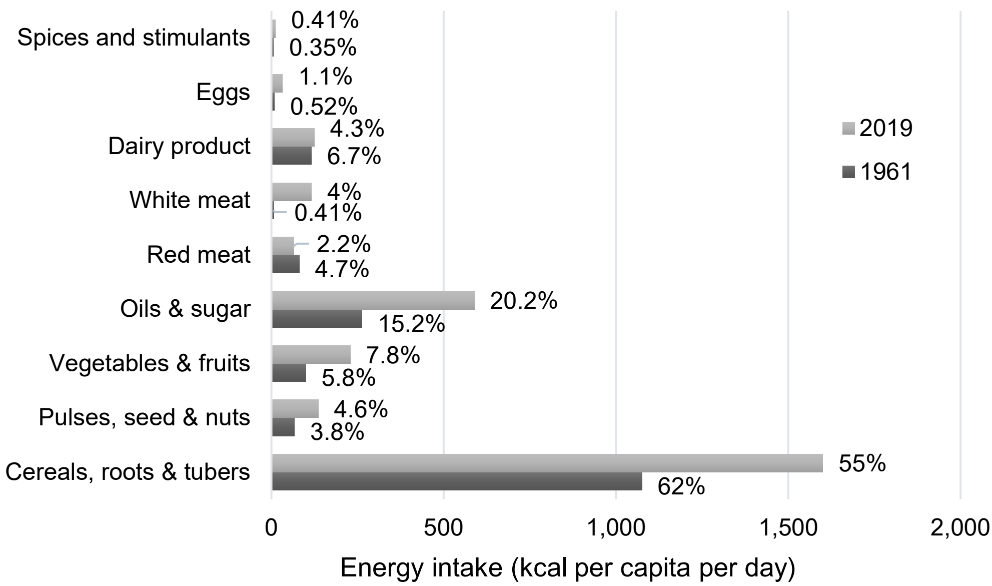

Figure 3. Absolute energy intake from food groups and their contribution in energy intake per capita in 1961 and 2019, %.

The CFP of food consumption in Iran from 1961 to 2019

The trend of the CFP of food consumption increased from 1.95 million tones (Mt) of CO_2-eq in 1961 to 2.83 Mt CO_2-eq in 2019 (Fig. 4). In 1961 the consumption of red meat had the highest contribution to CFP of food consumption (40% of the total) with 0.77 Mt CO_2-eq and category of dairy products ranked the second (24%) with 0.47 Mt CO_2-eq. In the end of period, due to the decrease in the consumption of red meat, category of dairy products became the most significant contributor to the CFP although the share of that remained almost constant (22%). The reason for this transition was that due to the decline in purchasing power, households switched from more expensive food products (e.g. red meat) to cheaper ones (e.g. dairy)(Garvey et al., 2021; Paris et al., 2022). However, from sustainability point of view less consumption of red meat is a favorable transition because in general animal products are well-known for their environmental impacts. For instance, the CFP of meats ranges from 2.43 kg CO_2eq kg^{-1} of poultry to 14.3 kg CO_2eq kg^{-1} of beef while that of cereals ranges from 0.54 kg CO_2eq kg^{-1} for barley to 1.66 kg CO_2eq kg^{-1} for rice (Treu et al., 2017; Bruno et al., 2019). Thus, although cereals were the main sources of energy intake, they were no longer the main contributors to the CFP. Emissions from the consumption of white meat increased from 0.01 to 0.24 Mt CO_2-eq over 1961–2019, whereas its contribution raised from 1% in the beginning to 9% at the end of period respectively. The CFP of vegetables and fruits went up from 0.26 in 1961 to 0.52 Mt CO_2-eq in 2019 and similarly the CFP of oils and sugar increased from 0.04 to 0.20 Mt CO_2-eq between 1961 and 2019. Although the CFP of consumption of 'cereals, roots, and tubers' and 'pulses, seed and nuts' increased during this period but their contribution to total CFP of food consumption only changed marginally.

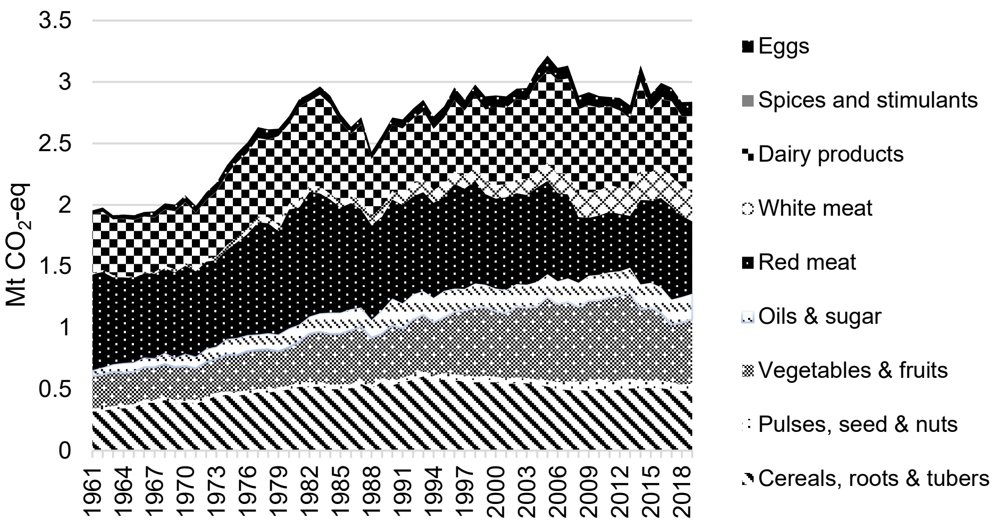

Figure 4. Carbon footprint of Iran's food consumption from 1961 to 2019 by food categories, Mt CO_2eq.

The contribution of three drivers of CFP

The contribution of three drivers (Population, Energy intake, Dietary change) to carbon footprint of food consumption in Iran during the period of 1961–2019 is illustrated in Fig. 5. The increase in population and energy intake per capita contributed positively to the CFP while the transition of the dietary pattern decelerated this trend and contributed negatively over the entire period, mainly because of the reduction in consumption of red meat. In the beginning of the period (1961–1967), the population and energy intake had almost equal contribution to the CFP. After the year 1973, the role of population became more significant, and the trend was increasing until the end of the period. The increasing rate of population growth was the main driver of CFP of food consumption during the entire period. Iran's population passed 35 million by the time of Islamic revolution in 1979, after which the population increased dramatically to about 86 million (annual growth rate = 4%) (Madani, 2021) due to socioeconomic, cultural and ideological changes among society. Iran's population is projected to reach 94–112 million by 2050 (Sobhani et al., 2022). Hence, feeding this population would impose more burden on limited resources of the country and would intensify the life cycle GHG emission by agriculture and food system.

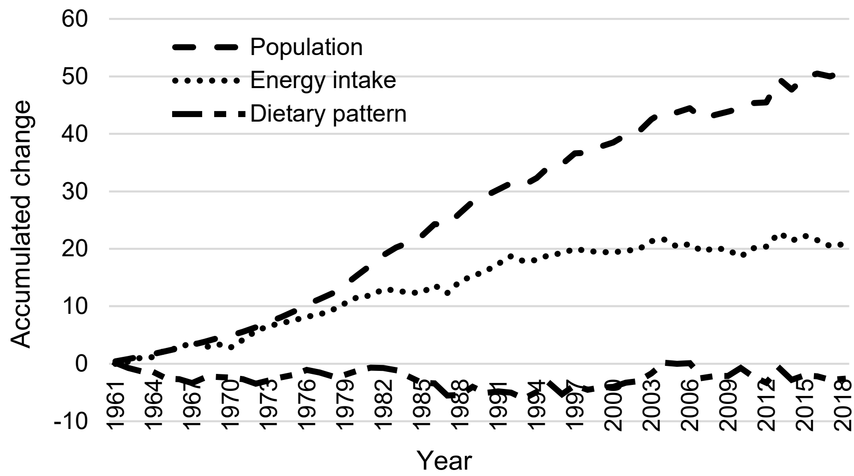

Figure 5. Drivers of carbon footprint of food consumption in Iran for the period 1961-2019 using LDMI decomposition method.

The role of energy intake had been increasing from the beginning of the period until the year 1997 and stayed almost unchanged until the end of period. Negative contribution of dietary pattern means that it has regulated the trend of the CFP by consuming more environmentally friendly food items such as cereals, vegetables, fruits, and white meat and decrease in the consumption of red meat mainly due to the collapse in purchasing power of households (decrease in GDP per capita)

In Iran, shifting towards more sustainable diets is inevitable, given the fact that there might be a continuous growth of population in the next decades and emergence of severe environmental problems such as water shortage, GHG emission and warmer climate (Madani, 2021; Sobhani et al., 2021). However, our decomposition analysis shows that there was a smooth change in the diet since 1961, and studies show that there is still scope for shifting the diet towards more sustainable eating habits.

CONCLUSION

This paper investigates the change in the CFP of food consumption in Iran in the period 1961 to 2019. The results of this study imply the role of population, energy intake and dietary pattern in the CFP of food consumption. The findings revealed that the growth in the population had the biggest contribution in the CFP of food consumption while a slight shift in the diet regulated the growing CFP of the food consumption in Iran. This happened mainly due to the decrease in the consumption of red meat which is believed to be the results of the growing price of the animal products and decrease in purchasing power of households. As the Iran's population is projected to grow in future, the demand for more food products will grow accordingly and GHG emission will be intensified consequently. This statement implies that shift in diet towards consumption of more environmentally friendly food product is a necessity in Iran and needs to be promoted by governmental bodies and requires policy and action.

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Appendix 1: Carbon footprints used in this analysis

Food groups	Food items	Carbon footprint per energy unit (kg CO_2eq.kcal^{-1})
Cereals, roots & tubers	Wheat and products	2.59E-4
	Rice and products	4.61E-4
	Barley and products	2.22E-4
	Maize and products	2.43E-4
	Rye and products	2.82E-4
	Oats	3.62E-4
	Cereals, Other	3.72E-4
	Potatoes and products	4.49E-4
Pulses, seeds & nuts	Honey	3.24E-4
	Beans	3.77E-4
	Peas	9.88E-5
	Pulses, Other and products	4.38E-4
	Nuts and products	3.83E-4
	Groundnuts	2.12E-4
Oils & sugar	Soyabean Oil	6.85E-4
	Groundnut Oil	3.24E-4
	Sunflower seed Oil	3.61E-4
	Rape and Mustard Oil	3.34E-4
	Cottonseed Oil	1.62E-4
	Palm kernel Oil	3.66E-4
	Coconut Oil	3.5E-4
	Sesame seed Oil	3.66E-4
	Olive Oil	4.31E-4
	Maize Germ Oil	3.25E-4
	Oil crops Oil, Other	4.06E-4
	Sugar (Raw Equivalent)	1.63E-4
	Sweeteners, Other	1.73E-05
Vegetables & fruits	Tomatoes and products	2.36E-3
	Coconuts - Incl Copra	3.01E-4
	Olives (including preserved)	7.65E-4
	Onions	1.46E-3
	Vegetables, other	3.1E-3
	Oranges, Mandarins	8.89E-4
	Lemons, Limes, and products	1.31E-3
	Grapefruit and products	1.08E-3
	Citrus, Other	1.04E-3
	Bananas	6.69E-4
	Apples and products	9.78E-4
	Pineapples and products	5.64E-4
	Dates	3.09E-3
	Grapes and products (excl wine)	7.05E-4
	Fruits, other	1.13E-3
Spices and stimulants	Coffee and products	8.6E-3
	Cocoa Beans and products	5.03E-05
	Tea (including mate)	6.99E-4
	Pepper	1.58E-4
	Pimento	1.64E-4
	Spices, Other	1.4E-4
	Wine	1.78E-3
	Beer	2.45E-4
	Beverages, Fermented	2.48E-3
	Beverages, Alcoholic	4.25E-4
Red meat	Bovine Meat	9.16E-3
	Mutton & Goat Meat	0.010215
	Pig meat	4.51E-3
	Meat, Other	5.75E-3
	Offal, Edible	8.62E-3

Dairy products	Butter, Ghee	7.30E-3
	Cream	7.11E-3
	Milk - Excluding Butter	2.89E-3
Eggs	Eggs	3.61E-3
White meat	Poultry Meat	1.58E-3
	Freshwater Fish	5.83E-3
	Demersal Fish	4.16E-3
	Pelagic Fish	1.9E-3
	Marine Fish, Other	5.83E-3
	Crustaceans	2.25E-2
	Cephalopods	4.22E-3
	Molluscs, Other	4.22E-3
	Aquatic Animals, Others	4.22E-3